7.3.72 Read Flow Control Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Flow_Control_Mode	0x0066		Status, Flow_Control_Mode

Description:

This command reads the value for the Flow_Control_Mode configuration parameter. See Section 6.33.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Flow_Control_Mode command succeeded.
0x01-0xFF	Read_Flow_Control_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Flow_Control_Mode: See Section 6.33.

Event(s) generated (unless masked away):

When the Read_Flow_Control_Mode command has completed, a Command Complete event shall be generated.

7.3.73 Write Flow Control Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Flow_Control_Mode	0x0067	Flow_Control_Mode	Status

Description:

This command writes the value for the Flow_Control_Mode configuration parameter. See Section 6.33.

Command Parameters:

Flow_Control_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	Packet based data flow control mode (**default for a BR/EDR Controller**)
0x01	Data block based data flow control mode (**default for an AMP Controller**)
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Flow_Control_Mode command succeeded.
0x01-0xFF	Write_Flow_Control_Mode command failed. See [Vol 2] Part D, Error Codesfor a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Flow_Control_Mode command has completed, a Command Complete event shall be generated. If the set fails then the Controller continues using its current mode.

7.3.74 Read Enhanced Transmit Power Level Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_ Enhanced_ Transmit_Power_ Level	0x0068	Connection_Handle, Type	Status, Connection_Handle, Transmit_Power_Level_GFSK, Transmit_Power_Level_DQPSK, Transmit_Power_Level_8DPSK

Description:

This command reads the values for the Enhanced_Transmit_Power_Level parameters for the specified Connection_Handle. The Connection_Handle must be a Connection_Handle for an ACL connection.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 - 0x0EFF (all other values reserved for future use).

Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Read Current Transmit Power Level
0x01	Read Maximum Transmit Power Level
All other values	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Enhanced_Transmit_Power_Level command succeeded.
0x01-0xFF	Read_Enhanced_Transmit_Power_Level command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 - 0x0EFF (all other values reserved for future use)

Transmit_Power_Level_GFSK: *Size: 1 Octet*

Value	Parameter Description
0xXX	Size: 1 Octet (signed integer) Range: -100 ≤ N ≤ 20 Units: dBm

Transmit_Power_Level_DQPSK: *Size: 1 Octet*

Value	Parameter Description
0xXX	Size: 1 Octet (signed integer) Range: -100 ≤ N ≤ 20 Units: dBm

Transmit_Power_Level_8DPSK: *Size: 1 Octet*

Value	Parameter Description
0x00	Size: 1 Octet (signed integer) Range: -100 ≤ N ≤ 20 Units: dBm

Event(s) generated (unless masked away):

When the Read_Enhanced_Transmit_Power_Level command has completed, a Command Complete event shall be generated.

7.3.75 Read Best Effort Flush Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Best_Ef-fort_Flush_Timeout	0x0069	Logical_Link_Handle	Status, Best_Effort_Flush_Timeout

Description:

This command reads the value of the Best Effort Flush Timeout from the AMP Controller.

Command Parameters:

Logical_Link_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Logical_Link_Handle to which the Write_Best_Effort_Flush_Time-out command applies. Range: 0x0000-0xEFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Best_Effort_Flush_Timeout command succeeded.
0x01-0xFF	Read_Best_Effort_Flush_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Best_Effort_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	0x00000000 - 0xFFFFFFFE: Best Effort Flush Timeout value in microseconds 0xFFFFFFFF: No Best Effort Flush Timeout used (default)

Event(s) generated (unless masked away):

When the Read_Best_Effort_Flush_Timeout command has completed, a Command Complete event shall be generated.

7.3.76 Write Best Effort Flush Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Write_Best_Effort_Flush_-Timeout	0x006A	Logical_Link_Handle, Best_Effort_Flush_Timeout	Status

Description:

This command writes the value of the Best_Effort_Flush_Timeout into the AMP Controller. The Best_Effort_Flush_Timeout shall be associated with the given logical link, and that Logical_Link_Handle must specify a Best Effort logical link.

Command Parameters:

Logical_Link_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Logica_Link_Handle to which the Write_Best_Effort_Flush_Time-out command applies. Range: 0x0000-0xEFF (all other values reserved for future use)

Best_Effort_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	0x00000000 - 0xFFFFFFFE: Best_Effort_Flush_Timeout value in microseconds 0xFFFFFFFF: No Best Effort Flush Timeout used (default)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Best_Effort_Flush_Timeout command succeeded.
0x01-0xFF	Write_Best_Effort_Flush_Timeout command failed. See " [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Best_Effort_Flush_Timeout command has completed, a Command Complete event shall be generated.

7.3.77 Short Range Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Short_Range_Mode	0x006B	Physical_Link_Handle, Short_Range_Mode	

Description:

This command will configure the value of Short_Range_Mode to the AMP Controller and is AMP type specific (see Volume 5, Core System Package [AMP Controller volume]).

Command Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle to which the Short Range Mode command applies.

Short_Range_Mode: *Size: 1 Octet*

Value	Parameter Description
0xXX	Configuration setting of Short Range Mode 0x00 - Short Range Mode disabled (default) 0x01 - Short Range Mode enabled 0x02 - 0xFF - Reserved for Future Use

Return Parameters:

None.

Event(s) generated (unless masked away):

A Command Status event is sent from the AMP Controller to the Host when the AMP Controller has received the Short_Range_Mode command. When the Short_Range_Mode command has completed, a Short Range Mode Change Complete event shall be generated.

Note: No Command Complete event will be sent by the AMP Controller to indicate that this command has been completed. Instead, the Short Range Mode Change Complete event will indicate that this command has been completed.

7.3.78 Read LE Host Support Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_LE_Host_ Support	0x006C		Status, LE_Supported_Host, Simultaneous_LE_Host

Description:

The Read_LE_Host_Support command is used to read the LE Supported (Host) and Simultaneous LE and BR/EDR to Same Device Capable (Host) Link Manager Protocol feature bits. These Link Manager Protocol feature bits are used by the local Host and a remote device (Controller and Host). See [Vol 2] Part C, Section 3.2.

The Simultaneous_LE_Host parameter shall be ignored upon receipt.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_LE_Host_Support command succeeded.
0x01 - 0xFF	Read_LE_Host_Support command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

LE_Supported_Host: *Size: 1 Octet*

Value	Parameter Description
0xXX	LE_Supported_Host parameter, see Section 6.34.

Simultaneous_LE_Host: *Size: 1 Octet*

Value	Parameter Description
0xXX	Simultaneous_LE_Host parameter, see Section 6.35.

Event(s) Generated (unless masked away):

When the Read_LE_Host_Support command has completed, a Command Complete event shall be generated.

7.3.79 Write LE Host Support Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_LE_Host_Support	0x006D	LE_Supported_Host, Simultaneous_LE_Host	Status

Description:

The Write_LE_Host_Support command is used to set the LE Supported (Host) and Simultaneous LE and BR/EDR to Same Device Capable (Host) Link Manager Protocol feature bits. These Link Manager Protocol feature bits are used by a remote Host. See [Vol 2] Part C, Section 3.2.

The default value for these feature bits shall be disabled. When LE_Supported_Host is set to enabled the bit in LMP features mask indicating support for LE Support (Host) shall be set. The Simultaneous_LE_Host parameter shall be set to disabled.

Command Parameters:

LE_Supported_Host: *Size: 1 Octet*

Value	Parameter Description
0xXX	LE_Supported_Host parameter. See Section 6.34

Simultaneous_LE_Host: *Size: 1 Octet*

Value	Parameter Description
0xXX	Simultaneous_LE_Host parameter. See Section 6.35

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_LE_Host_Support command succeeded.
0x01 - 0xFF	Write_LE_Host_Support command failed. See "[Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the Write_LE_Host_Support command has completed, a Command Complete event shall be generated.

7.3.80 Set MWS Channel Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_MWS_Channel_Parameters	0x006E	MWS_Channel_Enable, MWS_RX_Center_Frequency, MWS_TX_Center_Frequency, MWS_RX_Channel_Bandwidth, MWS_TX_Channel_Bandwidth, MWS_Channel_Type	Status

Description:

The Set_MWS_Channel_Parameters command is used to inform the Controller of the MWS channel parameters.

The MWS_Channel_Enable parameter is used to enable or disable the MWS channel.

The MWS_RX_Center_Frequency and MWS_TX_Center_Frequency parameters are used to indicate the center frequency of the MWS device's uplink (TX) and downlink (RX) channels. Note that the uplink and downlink channel centers may be the same value or different values.

The MWS_RX_Channel_Bandwidth and MWS_TX_Channel_Bandwidth parameters are used to indicate the bandwidth, in kHz, of the MWS device's uplink and downlink channels.

The MWS_Channel_Type parameter describes the type of channel. The types are defined in the Bluetooth Assigned Numbers.

Command Parameters:

MWS_Channel_Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	MWS channel is disabled.
0x01	MWS channel is enabled.
0x02 – 0xFF	Reserved for Future Use.

MWS_RX_Center_Frequency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS RX center frequency in MHz.

MWS_TX_Center_Frequency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS TX center frequency in MHz

MWS_RX_Channel_Bandwidth: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS RX channel bandwidth in kHz.

MWS_TX_Channel_Bandwidth: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS TX channel bandwidth in kHz.

MWS_Channel_Type: *Size: 1 Octet*

Value	Parameter Description
0xXX	See Bluetooth Assigned numbers.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_MWS_Channel_Parameters command succeeded.
0x01-0xFF	Set_MWS_Channel_Parameters command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

Event(s) generated (unless masked away):

When the Set_MWS_Channel_Parameters command has completed, a Command Complete event shall be generated.

7.3.81 Set External Frame Configuration Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Set_ External_ Frame_Configuration	0x006F	Ext_Frame_Duration, Ext_Frame_Sync_Assert_Offset, Ext_Frame_Sync_Assert_Jitter, Ext_Num_Periods, Period_Duration[i], Period_Type[i]	Status

Description:

The Set_External_Frame_Configuration command allows the Host to specify a frame configuration for an external collocated MWS system. This frame configuration persists until overwritten with a subsequent Set_External_Frame_Configuration or until the Primary Controller is reset.

This command may be supported by a device that declares support for the Coarse Clock Adjustment feature. It may be used to allow the Controller to align the piconet clock with an external frame structure.

When the external frame structure is a multiple of 1.25 ms, it can be aligned in a stable manner with the piconet clock.

The start of the external frame structure is defined as an offset from an external frame synchronization signal. This offset is defined by the Ext_Frame_Sync_Assert_Offset parameter. The offset is represented as the time (in microseconds) from the start of the next MWS frame to the FRAME_SYNC signal.

An external frame consists of downlink periods, uplink periods and guard periods. Downlink means the collocated MWS system is receiving, thus may be interfered with by Bluetooth transmissions. Uplink means the collocated MWS system is transmitting, thus may cause interference to Bluetooth receptions. A guard period may be used by the MWS system to compensate for propagation delays; in this case it should be regarded as split equally between downlink and uplink durations.

The number of specified periods is given by Ext_Num_Periods.

The duration in microseconds of each period is defined by the Period_Duration[i] parameters.

The Period_Type[i] parameter indicates if the specified period is an uplink, downlink, bi-directional or guard period.

The sum of all Period_Duration[i] parameters shall be equal to the Ext_Frame_Duration parameter.

Upon reception of a Set_External_Frame_Configuration command and a FRAME_SYNC signal from the MWS Coexistence Logical Interface, the Controller may compute the type 0 submap for local SAM slot maps. The Controller may then initiate the SAM set type 0 and SAM define map LMP sequences with the remote device.

Command Parameters:

Ext_Frame_Duration: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	External frame duration in microseconds (unsigned integer)

Ext_Frame_Sync_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	External frame offset in microseconds (signed integer)

Ext_Frame_Sync_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	External frame sync jitter in microseconds (unsigned integer)

Ext_Num_Periods: *Size: 1 Octet*

Value	Parameter Description
N	Number of specified periods in an external frame. Valid range: 1 to 32 (unsigned integer)

Period_Duration[i]: *Size: Ext_Num_Periods * 2 Octets*

Value	Parameter Description
0xXXXX	Duration of the [i] period in microseconds (unsigned integer)

Period_Type[i]: *Size: Ext_Num_Periods * 1 Octet*

Value	Parameter Description
0x00	Downlink
0x01	Uplink
0x02	Bi-Directional
0x03	Guard Period
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_External_Frame_Configuration command succeeded.
0x01-0xFF	Set_External_Frame_Configuration command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

Event(s) generated (unless masked away):

When the Set_External_Frame_Configuration command has completed, a Command Complete event shall be generated.

7.3.82 Set MWS Signaling Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_ MWS_Signaling	0x0070	MWS_RX_Assert_Offset, MWS_RX_Assert_Jitter, MWS_RX_Deassert_Offset, MWS_RX_Deassert_Jitter, MWS_TX_Assert_Offset, MWS_TX_Assert_Jitter, MWS_TX_Deassert_Offset, MWS_TX_Deassert_Jitter, MWS_Pattern_Assert_Offset, MWS_Pattern_Assert_Jitter, MWS_Inactivity_Duration_ Assert_Offset, MWS_Inactivity_Duration_ Assert_Jitter, MWS_Scan_Frequency_ Assert_Offset, MWS_Scan_Frequency_ Assert_Jitter, MWS_Priority_Assert_ Offset_Request	Status, Bluetooth_Rx_Priority_ Assert_Offset, Bluetooth_Rx_Priority_ Assert_Jitter, Bluetooth_Rx_Priority_ Deassert_Offset, Bluetooth_Rx_Priority_ Deassert_Jitter, 802_Rx_Priority_Assert_ Offset, 802_Rx_Priority_Assert_ Jitter, 802_Rx_Priority_Deassert_ Offset, 802_Rx_Priority_Deassert_ Jitter, Bluetooth_Tx_On_Assert_ Offset, Bluetooth_Tx_On_Assert_ Jitter, Bluetooth_Tx_On_Deassert_ Offset, Bluetooth_Tx_On_Deassert_ Jitter, 802_Tx_On_Assert_Offset, 802_Tx_On_Assert_Jitter, 802_Tx_On_Deassert_Offset, 802_Tx_On_Deassert_Jitter

Description:

The Set_MWS_Signaling command is used to inform the Bluetooth Controller of the MWS signaling interface logical layer parameters.

All signals are defined in [Vol 7] Part A.

Command Parameters:

MWS_RX_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_RX signal assert offset in microseconds (signed integer).

MWS_RX_Assert_Jitter: Size: 2 Octets

Value	Parameter Description
0xXXXX	MWS_RX signal assert jitter in microseconds (unsigned integer).

MWS_RX_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_RX signal de-assert offset in microseconds (signed integer).

MWS_RX_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_RX signal de-assert jitter in microseconds (unsigned integer).

MWS_TX_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_TX signal assert offset in microseconds (signed integer).

MWS_TX_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_TX signal assert jitter in microseconds (unsigned integer).

MWS_TX_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_TX signal de-assert offset in microseconds (signed integer).

MWS_TX_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_TX signal de-assert jitter in microseconds (unsigned integer).

MWS_Pattern_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_PATTERN signal assert offset in microseconds (signed integer).

MWS_Pattern_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_PATTERN signal assert jitter in microseconds (unsigned integer).

MWS_Inactivity_Duration_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_INACTIVITY_DURATION signal assert offset in microseconds (signed integer).

MWS_Inactivity_Duration_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_INACTIVITY_DURATION signal assert jitter in microseconds (unsigned integer).

MWS_Scan_Frequency_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_SCAN_FREQUENCY signal assert offset in microseconds (signed integer).

MWS_Scan_Frequency_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	MWS_SCAN_FREQUENCY signal assert jitter in microseconds (unsigned integer).

MWS_Priority_Assert_Offset_Request: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Minimum advance notification from the beginning of an MWS Uplink period in microseconds (unsigned integer) before which the BLUETOOTH_RX_PRI or 802_RX_PRI signal shall be asserted to be recognized by the MWS.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_MWS_Signaling command succeeded.
0x01-0xFF	Set_MWS_Signaling command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

Bluetooth_RX_Priority_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_RX_PRI signal assert offset in microseconds (signed integer).

Bluetooth_RX_Priority_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_RX_PRI signal assert jitter in microseconds (unsigned integer).

Bluetooth_RX_Priority_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_RX_PRI signal de-assert offset in microseconds (signed integer).

802_RX_Bluetooth_RX_Priority_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_RX_PRI signal de-assert jitter in microseconds (unsigned integer).

Priority_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_RX_PRI signal assert offset in microseconds (signed integer).

802_RX_Priority_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_RX_PRI signal assert jitter in microseconds (unsigned integer).

802_RX_Priority_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_RX_PRI signal de-assert offset in microseconds (signed integer).

802_RX_Priority_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_RX_PRI signal de-assert jitter in microseconds (unsigned integer).

Bluetooth_TX_On_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_TX_ON signal assert offset in microseconds (signed integer).

Bluetooth_TX_On_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_TX_ON signal assert jitter in microseconds (unsigned integer).

Bluetooth_TX_On_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_TX_ON signal de-assert offset in microseconds (signed integer).

Bluetooth_TX_On_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	BLUETOOTH_TX_ON signal de-assert jitter in microseconds (unsigned integer).

802_TX_On_Assert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_TX_ON signal assert offset in microseconds (signed integer).

802_TX_On_Assert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_TX_ON signal assert jitter in microseconds (unsigned integer).

802_TX_On_Deassert_Offset: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_TX_ON signal de-assert offset in microseconds (signed integer).

802_TX_On_Deassert_Jitter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	802_TX_ON signal de-assert jitter in microseconds (unsigned integer).

Event(s) generated (unless masked away):

When the Set_MWS_Signaling command has completed, a Command Complete event shall be generated.

7.3.83 Set MWS Transport Layer Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_MWS_Transport_Layer	0x0071	Transport_Layer, To_MWS_Baud_Rate, From_MWS_Baud_Rate	Status

Description:

The Set_MWS_Transport_Layer command configures the transport layer between the Bluetooth Controller and MWS device.

Command Parameters:

Transport_Layer: *Size: 1 Octet*

Value	Parameter Description
0xXX	See Bluetooth Assigned numbers.

To_MWS_Baud_Rate: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Baud rate in the Bluetooth to MWS direction in Baud.

From_MWS_Baud_Rate: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Baud rate in the MWS to Bluetooth direction in Baud.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_MWS_Transport_Layer command succeeded.
0x01-0xFF	Set_MWS_Transport_Layer command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

Event(s) generated (unless masked away):

When the Set_MWS_Transport_Layer command has completed, a Command Complete event shall be generated.

7.3.84 Set MWS Scan Frequency Table Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_MWS_Scan_ Frequency_Table	0x0072	Num_Scan_Frequencies, Scan_Frequency_Low[i], Scan_Frequency_High[i]	Status

Description:

The Set_MWS_Scan_Frequency_Table command configures the MWS scan frequency table in the Controller.

The Num_Scan_Frequencies parameter indicates the number of MWS scan frequencies to be set. A Controller shall support at least 8 table entries.

The Scan_Frequency_Low[i] and Scan_Frequency_High[i] parameters indicate the lower and upper edges for each scan frequency.

Command Parameters:

Num_Scan_Frequencies: *Size: 1 Octet*

Value	Parameter Description
N	Number of MWS scan frequencies to be set in the table.

Scan_Frequency_Low[i]: *Size: Num_Scan_Frequencies * 2 Octets*

Value	Parameter Description
0xXXXX	Lower edge of the MWS scan frequency in MHz (unsigned integer).

Scan_Frequency_High[i]: *Size: Num_Scan_Frequencies * 2 Octets*

Value	Parameter Description
0xXXXX	Upper edge of the MWS scan frequency in MHz (unsigned integer).

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_MWS_Scan_Frequency_Table command succeeded.
0x01-0xFF	Set_MWS_Scan_Frequency_Table command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

Event(s) generated (unless masked away):

When the Set_MWS_Scan_Frequency_Table command has completed, a Command Complete event shall be generated.

7.3.85 Set MWS_PATTERN Configuration Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_MWS_ PATTERN_Configuration	0x0073	MWS_PATTERN_Index, MWS_PATTERN_NumIntervals, MWS_PATTERN_IntervalDuration[i], MWS_PATTERN_IntervalType[i]	Status

Description:

The Set_MWS_PATTERN_Configuration command is used by the Host to specify, in conjunction with the Set_External_Frame_Configuration command, local MWS_PATTERN parameters for an external collocated system.

An MWS_PATTERN configuration shall persist until overwritten by a subsequent Set_MWS_PATTERN_Configuration. All MWS_PATTERN configurations are deleted when a Set_External_Frame_Configuration command is received or when the Primary Controller is reset.

The sum of the MWS_PATTERN_IntervalDuration parameters shall be an integral multiple of the length of a frame as defined by the most recent Set_External_Frame_Configuration command.

If any interval with type 4 either has a MWS_PATTERN_IntervalDuration greater than the length of a frame or the sum of the MWS_PATTERN_IntervalDuration parameters for the previous intervals is not a multiple of the length of the frame, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Upon reception of a Set_MWS_PATTERN_Configuration command, the Controller may compute the local SAM slot map with SAM_Index equal to MWS_PATTERN_Index. If the SAM slot map does not exist, it should be created; if the SAM slot map already exists, its parameters should be replaced. The Controller may then initiate the SAM define map LMP sequence with the remote device.

Upon reception of a MWS_PATTERN signal, with a value other than 3, from the MWS Coexistence Logical Interface (see [Vol 7] Part A), the Controller should check the MWS_PATTERN value against the SAM_Index of those SAM slot maps that have been configured by previous Set_MWS_PATTERN_Configuration commands. It should then take the following course of action:

1. If MWS_PATTERN does not match any configured SAM slot map, it should take no further action.
2. If MWS_PATTERN matches an available SAM slot map that is already active or is being activated, it should take no further action (i.e. let the current or pending active SAM slot map continue).

3. If MWS_PATTERN matches an available SAM slot map that is neither active nor is being activated, then:

    a) If the SAM slot map has been activated previously using the LMP_SAM_set_type0 (if relevant) and LMP_SAM_define_map LMP sequences, the Controller should start the SAM switch LMP sequence to activate the matched SAM slot map;

    b) Otherwise the Controller should start or complete the SAM set type 0 (if relevant), SAM define map, and SAM switch LMP sequences to activate the matched SAM slot map.

Command Parameters:

MWS_PATTERN_Index: *Size: 1 Octet*

Value	Parameter Description
0xXX	Index of the MWS_PATTERN instance to be configured. Range is 0-2.

MWS_PATTERN_NumIntervals: *Size: 1 Octet*

Value	Parameter Description
0xXX	The number of intervals in the following array.

MWS_PATTERN_IntervalDuration[i]:
*Size: MWS_PATTERN_NumInterval * 2 Octets*

Value	Parameter Description
0xXXXX	An array specifying the duration of Bluetooth activity intervals in microseconds.

MWS_PATTERN_IntervalType[i]:
*Size: MWS_PATTERN_NumInterval * 1 Octet*

Value	Parameter Description
0xXX	An array specifying the types of permitted Bluetooth activities in each interval: 0. Neither transmission nor reception is allowed. 1. Transmission is allowed. 2. Reception is allowed. 3. Both transmission and reception are allowed. 4. Interval for the MWS frame as defined by the Set_External_Frame_Configuration command.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_MWS_PATTERN_Configuration command succeeded
0x01-0xFF	Set_MWS_PATTERN_Configuration command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Set_MWS_PATTERN_Configuration command has completed, a Command Complete event shall be generated.

7.3.86 Set Reserved LT_ADDR Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_ Reserved_LT_ADDR	0x0074	LT_ADDR	Status, LT_ADDR

Description:

The Set_Reserved_LT_ADDR command allows the Host to request that the BR/EDR Controller reserve a specific LT_ADDR for Connectionless Slave Broadcast.

If the LT_ADDR indicated in the LT_ADDR parameter is already in use by the BR/EDR Controller, it shall return the *Connection Already Exists* (0x0B) error code. If the LT_ADDR indicated in the LT_ADDR parameter is out of range, the Controller shall return the *Invalid HCI Command Parameters* (0x12) error code. If the command succeeds, then the reserved LT_ADDR shall be used when issuing subsequent Set Connectionless Slave Broadcast Data and Set Connectionless Slave Broadcast commands.

To ensure that the reserved LT_ADDR is not already allocated, it is recommended that this command be issued at some point after HCI_Reset is issued but before page scanning is enabled or paging is initiated.

Command Parameters:

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR to reserve for Connectionless Slave Broadcast
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_Reserved_LT_ADDR command succeeded.
0x01-0xFF	Set_Reserved_LT_ADDR command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR reserved for Connectionless Slave Broadcast. This parameter shall have the same value as the Command Parameter LT_ADDR.
All other values	Reserved for future use

Event(s) generated (unless masked away):

When the Set_Reserved_LT_ADDR command has completed, a Command Complete event shall be generated.

7.3.87 Delete Reserved LT_ADDR Command

Command	OCF	Command Parameters	Return Parameters
HCI_Delete_ Reserved_LT_ADDR	0x0075	LT_ADDR	Status, LT_ADDR

Description:

The Delete_Reserved_LT_ADDR command requests that the BR/EDR Controller cancel the reservation for a specific LT_ADDR reserved for the purposes of Connectionless Slave Broadcast.

If the LT_ADDR indicated in the LT_ADDR parameter is not reserved by the BR/EDR Controller, it shall return the *Unknown Connection Identifier* (0x02) error code.

If connectionless slave broadcast mode is still active, then the Controller shall return the *Command Disallowed* (0x0C) error code.

Command Parameters:

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR currently reserved for Connectionless Slave Broadcast and for which reservation is to be cancelled
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Delete_Reserved_LT_ADDR command succeeded.
0x01-0xFF	Delete_Reserved_LT_ADDR command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR whose reservation the Host has requested to cancel.
All other values	Reserved for future use

Event(s) generated (unless masked away):

When the Delete_Reserved_LT_ADDR command has completed, a Command Complete event shall be generated.

7.3.88 Set Connectionless Slave Broadcast Data Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_Connectionless_ Slave_Broadcast_Data	0x0076	LT_ADDR, Fragment, Data_Length, Data	Status, LT_ADDR

Description:

The Set_Connectionless_Slave_Broadcast_Data command provides the ability for the Host to set Connectionless Slave Broadcast data in the BR/EDR Controller. This command may be issued at any time after an LT_ADDR has been reserved regardless of whether connectionless slave broadcast mode has been enabled or disabled by the Enable parameter in the Set_Connectionless_Slave_Broadcast command. If the command is issued without the LT_ADDR reserved, the *Unknown Connection Identifier* (0x02) error code shall be returned.

If connectionless slave broadcast mode is disabled, this data shall be kept by the BR/EDR Controller and used once connectionless slave broadcast mode is enabled. If connectionless slave broadcast mode is enabled, and this command is successful, this data will be sent starting with the next Connectionless Slave Broadcast instant.

The Data_Length field may be zero, in which case no data needs to be provided.

The Host may fragment the data using the Fragment field in the command. If the combined length of the fragments exceeds the capacity of the largest allowed packet size specified in the Set Connectionless Slave Broadcast command, all fragments associated with the data being assembled shall be discarded and the Invalid HCI Command Parameters error (0x12) shall be returned.

Command Parameters:

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR on which to send Connectionless Slave Broadcast data
All other values	Reserved for future use

Fragment: *Size: 1 Octet*

Value	Parameter Description
0x00	Continuation fragment
0x01	Starting fragment
0x02	Ending fragment
0x03	No fragmentation (single fragment)
All other values	Reserved for future use

Data_Length: *Size: 1 Octet*

Value	Parameter Description
0xXX	Length of the Data field

Data: *Size: Data_Length Octets*

Value	Parameter Description
Variable	Data to send in future Connectionless Slave Broadcast packets. This data will be repeated in future Connectionless Slave Broadcast instants until new data is provided

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_Connectionless_Slave_Broadcast_Data command succeeded.
0x01-0xFF	Set_Connectionless_Slave_Broadcast_Data command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR on which Connectionless Slave Broadcast data will be sent
All other values	Reserved for future use

Event(s) generated (unless masked away):

When the Set_Connectionless_Slave_Broadcast_Data command has completed, a Command Complete event shall be generated.

7.3.89 Read Synchronization Train Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Synchroniza-tion_ Train_Parameters	0x0077	None	Status, Sync_Train_Interval, synchroniza-tion_trainTO, Service_Data

Description:

The Read_Synchronization_Train_Parameters command returns the currently configured values for the Synchronization Train functionality in the master's BR/EDR Controller. This command may be issued at any time.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Synchronization_Train_Parameters command succeeded.
0x01-0xFF	Read_Synchronization_Train_Parameters command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

Sync_Train_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Interval in slots between consecutive Synchronization Train events on the same channel. Range: 0x0020-0xFFFE; only even values are valid

synchronization_trainTO: *Size: 4 Octets*

Value	Parameter Description
N = 0xXXXXXXXX	Duration in slots to continue sending the synchronization train Range: 0x00000002 - 0x07FFFFFE; only even values are valid

Service_Data: *Size: 1 Octet*

Value	Parameter Description
0xXX	Host provided value included in Synchronization Train packet, octet 27; see [Vol 2] Part B, Table 8.10.

Event(s) generated (unless masked away):

When the BR/EDR Controller receives the Read_Synchronization_Train_Parameters command, it shall send a Command Complete event to the Host.

7.3.90 Write Synchronization Train Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Synchroniza-tion _Train_Parameters	0x0078	Interval_Min, Interval_Max, synchroniza-tion_trainTO, Service_Data	Status, Sync_Train_Interval

Description:

The Write_Synchronization_Train_Parameters command configures the Synchronization Train functionality in the BR/EDR Controller. This command may be issued at any time.

Note: The AFH_Channel_Map used in the Synchronization Train packets is configured by the Set_AFH_Channel_Classification command and the local channel classification in the BR/EDR Controller.

Interval_Min and Interval_Max specify the allowed range of Sync_Train_Interval. Refer to [Vol 2] Part B, Section 2.7.2 for a detailed description of Sync_Train_Interval. The BR/EDR Controller shall select an interval from this range and return it in Sync_Train_Interval. If the Controller is unable to select a value from this range, it shall return the *Invalid HCI Command Parameters* (0x12) error code.

Once started (via the Start_Synchronization_Train Command) the Synchronization Train will continue until *synchronization_trainTO* slots have passed or Connectionless Slave Broadcast has been disabled.

Command Parameters:

Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum value allowed for the interval Sync_Train _Interval in slots. Range: 0x0020-0xFFFE; only even values are valid

Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum value allowed for the interval Sync_Train _Interval in slots. Range: 0x0020-0xFFFE; only even values are valid

synchronization_trainTO : *Size: 4 Octets*

Value	Parameter Description
N = 0xXXXXXXXX	Duration in slots to continue sending the synchronization train Range: 0x0000 0002-0x07FF FFFE; only even values are valid

Service_Data: *Size: 1 Octet*

Value	Parameter Description
0xXX	Host provided value to be included in octet 27 of the Synchronization Train packet payload body; see [Vol 2] Part B, Table 8.10.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Synchronization_Train_Parameters command succeeded.
0x01-0xFF	Write_Synchronization_Train_Parameters command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

Sync_Train_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Interval in slots between consecutive Synchronization Train packets on the same channel. Range: 0x0020-0xFFFE; only even values are valid

Event(s) generated (unless masked away):

When the BR/EDR Controller receives the Write_Synchronization_Train_Parameters command, it shall send a Command Complete event to the Host.

7.3.91 Read Secure Connections Host Support Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Secure_Connections_Host_Support	0x0079		Status, Secure_Connections_Host_Support

Description:

This command reads the Secure_Connections_Host_Support parameter in the BR/EDR Controller. When Secure Connections Host Support is set to 'enabled' the Controller uses the enhanced reporting mechanisms for the Encryption_Enabled parameter in the Encryption Change event (see Section 7.7.8) and the Key_Type parameter in the Link Key Notification event (see Section 7.7.24).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Secure_Connections_Host_Support command succeeded.
0x01-0xFF	Read_Secure_Connections_Host_Support command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Secure_Connections_Host_Support: *Size: 1 Octet*

Value	Parameter Description
0x00	Secure_Connections_Host_Support is ‘disabled’. Host does not support Secure Connections (default)
0x01	Secure_Connections_Host_Support is ‘enabled’. Host supports Secure Connections
All other values	Reserved for future use

Event(s) generated (unless masked away):

When the Read_Secure_Connections_Host_Support command has completed, a Command Complete event shall be generated.

7.3.92 Write Secure Connections Host Support Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Secure_ Connections_Host_Support	0x007A	Secure_Connections_ Host_Support	Status

Description:

This command writes the Secure_Connections_Host_Support parameter in the BR/EDR Controller. When Secure Connections Host Support is set to 'enabled' the Controller shall use the enhanced reporting mechanisms for the Encryption_Enabled parameter in the Encryption Change event (see Section 7.7.8) and the Key_Type parameter in the Link Key Notification event (see Section 7.7.24). If the Host has not written this parameter before initiating page scan or paging procedures, the Controller shall return the error code *Command Disallowed* (0x0C).

The Link Manager Secure Connections (Host Support) feature bit shall be set to the Secure_Connections_Host_Support parameter. The default value for Secure_Connections_Host_Support shall be 'disabled.' When Secure_Connections_Host_Support is set to 'enabled,' the bit in the LMP features mask indicating support for Secure Connections (Host Support) shall be set to enabled in subsequent responses to an LMP_features_req from a remote device.

Command Parameters:

Secure_Connections_Host_Support: *Size: 1 Octet*

Value	Parameter Description
0x00	Secure_Connections_Host_Support is ‘disabled’. Host does not support Secure Connections (default)
0x01	Secure_Connections_Host_Support is ‘enabled’. Host supports Secure Connections
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Secure_Connections_Host_Support command succeeded.
0x01-0xFF	Write_Secure_Connections_Host_Support command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Secure_Connections_Host_Support command has completed, a Command Complete event shall be generated.

7.3.93 Read Authenticated Payload Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Authenticated_Payload_Timeout	0x007B	Connection_Handle	Status, Connection_Handle, Authenticated_Payload_Timeout

Description:

This command reads the Authenticated_Payload_Timeout (*authenticatedPayloadTO*, see [Vol 2] Part B, Section Appendix B for BR/EDR connections and [Vol 6] Part B, Section 5.4 for LE connections) parameter in the Primary Controller on the specified Connection_Handle.

When the Connection_Handle identifies a BR/EDR synchronous connection, the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Authenticated_Payload_Timeout command succeeded.
0x01-0xFF	Read_Authenticated_Payload_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Authenticated_Payload_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum amount of time specified between packets authenticated by a MIC. Default = 0x0BB8 (30 s) Range: 0x0001 to 0xFFFF Time = N * 10 ms Time Range: 10 ms to 655,350 ms

Event(s) generated (unless masked away):

When the Read_Authenticated_Payload_Timeout command has completed, a Command Complete event shall be generated.

7.3.94 Write Authenticated Payload Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Authenticated_ Payload_Timeout	0x007C	Connection_Handle, Authenticated_ Payload_Timeout	Status, Connection_Handle

Description:

This command writes the Authenticated_Payload_Timeout (*authenticatedPayloadTO*, see [Vol 2] Part B, Section Appendix B and [Vol 6] Part B, Section 5.4 for the LE connection) parameter in the Primary Controller for the specified Connection_Handle.

When the Connection_Handle identifies a BR/EDR ACL connection:

- If the connection is in sniff mode, the Authenticated_Payload_Timeout shall be equal to or greater than T_{sniff}.
- If the connection is in sniff subrating mode, the Authenticated_Payload_Timeout shall be equal to or greater than (max subrate)xT_{sniff}.
- If the connection is in hold mode, the Authenticated_Payload_Timeout shall be equal to or greater than the *holdTO* value.

When the Connection_Handle identifies a BR/EDR synchronous connection, this command shall be rejected with the error code *Command Disallowed* (0x0C).

When the Connection_Handle identifies an LE connection, the Authenticated_Payload_Timeout shall be equal to or greater than *connInterval* * (1 + *connSlaveLatency*).

When the Connection_Handle is associated with an ACL connection, the Link Manager will use this parameter to determine when to use the LMP ping sequence.

When the Connection_Handle is associated with an LE connection, the Link Layer will use this parameter to determine when to use the LE ping sequence.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Authenticated_Payload_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum amount of time specified between packets authenticated by a valid MIC. Range: 0x0001 to 0xFFFF Time = N * 10 ms Time Range: 10 ms to 655,350 ms

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Authenticated_Payload_Timeout command succeeded.
0x01-0xFF	Write_Authenticated_Payload_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Event(s) generated (unless masked away):

When the Write_Authenticated_Payload_Timeout command has completed, a Command Complete event shall be generated.

7.3.95 Read Local OOB Extended Data Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_OOB_Extended_Data	0x007D		Status, C_192, R_192, C_256, R_256

Description:

This command obtains Simple Pairing Hash C_192, Simple Pairing Randomizer R_192, Simple Pairing Hash C_256, and Simple Pairing Randomizer R_256, which are intended to be transferred to a remote device using an OOB mechanism. The BR/EDR Controller shall create new values for C_192, R_192, C_256, and R_256 for each invocation of this command. Each random number (R_192 and R_256) shall be created according to [Vol 2] Part H, Section 2.

Note: Each OOB transfer will have unique C_192, R_192, C_256, and R_256 values so after each OOB transfer this command shall be used to obtain a new set of values for the next OOB transfer.

Note: The Controller keeps information used to generate these values for later use in the simple pairing process. If the BR/EDR Controller is powered off or reset then this information is lost and the values obtained before the power off or reset are invalid.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_OOB_Extended_Data command succeeded.
0x01-0xFF	Read_Local_OOB_Extended_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

C_192: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXX XXXXXXXXXXX XXXXXXXXX	Simple Pairing Hash C derived from the P-192 public key.

R_192: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXX XXXXXXXXXXX XXXXXXXXX	Simple Pairing Randomizer associated with the P-192 public key.

C_256: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXX XXXXXXXXXXX XXXXXXXXX	Simple Pairing Hash C derived from the P-256 public key.

R_256: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXX XXXXXXXXXXX XXXXXXXXX	Simple Pairing Randomizer associated with the P-256 public key.

Event(s) generated (unless masked away):

When the Read_Local_OOB_Extended_Data command has completed, a Command Complete event shall be generated.

7.3.96 Read Extended Page Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Extended_ Page_Timeout	0x007E		Status, Extended_Page_Timeout

Description:

The Read_Extended_Page_Timeout command will read the value for the Extended_Page_Timeout configuration parameter. See Section 6.41.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Extended_Page_Timeout command succeeded.
0x01-0x0F	Read_Extended_Page_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Extended_Page_Timeout: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Extended Page Timeout measured in Number of Baseband slots. Interval Length = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 (default) – 0xFFFF Time Range: 0 - 40.9 s

Event(s) generated (unless masked away):

When the Read_Extended_Page_Timeout command has completed, a Command Complete event shall be generated.

7.3.97 Write Extended Page Timeout Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Extended_ Page_Timeout	0x007F	Extended_Page_Timeout	Status

Description:

The Write_Extended_Page_Timeout command will write the value for the Extended_Page_Timeout configuration parameter.
The Extended_Page_Timeout configuration parameter defines the maximum time after the Page_Timeout expires that the local Link Manager may wait for a baseband page response from the remote device at a locally initiated connection attempt. If this time expires and the remote device has not responded to the page at baseband level, the connection attempt will be considered to have failed.

Command Parameters:

Extended_Page_Timeout: *Size: 2 Octets*

Value	Parameter Description
0	Default
N = 0xXXXX	Extended Page Timeout measured in Number of Baseband slots. Interval Length = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFF Time Range: 0 - 40.9 s Mandatory Range for Controller: 0x0000 to 0xFFFF

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Extended_Page_Timeout command succeeded.
0x01-0x0F	Write_Extended_Page_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Extended_Page_Timeout command has completed, a Command Complete event shall be generated.

7.3.98 Read Extended Inquiry Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Extended_ Inquiry_Length	0x0080		Status, Extended_Inquiry_Length

Description:

The Read_Extended_Inquiry_Length command will read the value for the Extended_Inquiry_Length configuration parameter. See Section 6.42.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Extended_Inquiry_Length command succeeded.
0x01-0x0F	Read_Extended_Inquiry_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Extended_Inquiry_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Extended_Inquiry_Length measured in Number of Baseband slots. Interval Length = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 (default) – 0xFFFF Time Range: 0 - 40.9 s

Event(s) generated (unless masked away):

When the Read_Extended_Inquiry_Length command has completed, a Command Complete event shall be generated.

7.3.99 Write Extended Inquiry Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Extended_ Inquiry_Length	0x0081	Extended_Inquiry_Length	Status

Description:

The Write_Extended_Inquiry_Length command will write the value for the Extended_Inquiry_Length configuration parameter.
The Extended_ Inquiry_Length configuration parameter defines the maximum time after the Inquiry_Length expires that the local Link Manager may wait for a baseband inquiry response from the remote device at a locally initiated connection attempt. If this time expires and the remote device has not responded to the inquiry at baseband level, the inquiry will be considered to have failed.

Command Parameters:

Extended_Inquiry_Length: *Size: 2 Octets*

Value	Parameter Description
0	Default
0xXXXX	Extended_Inquiry_Length measured in Number of Baseband slots. Interval Length = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFF Time Range: 0 - 40.9 s

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Extended_Inquiry_Length command succeeded.
0x01-0x0F	Write_Extended_Inquiry_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Extended_Inquiry_Length command has completed, a Command Complete event shall be generated.

7.4 INFORMATIONAL PARAMETERS

The Informational Parameters are fixed by the manufacturer of the Bluetooth hardware. These parameters provide information about the BR/EDR Controller and the capabilities of the Link Manager and Baseband in the BR/EDR Controller and PAL in the AMP Controller. The Host device cannot modify any of these parameters.

For Informational Parameters Commands, the OGF is defined as 0x04.

7.4.1 Read Local Version Information Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_Version_ Information	0x0001		Status, HCI Version, HCI Revision, LMP Version, Manufacturer_Name, LMP Subversion

Description:

This command reads the values for the version information for the local Controller.

The HCI Version information defines the version information of the HCI layer. The LMP/PAL Version information defines the version of the LMP or PAL. The Manufacturer_Name information indicates the manufacturer of the local device.

The HCI Revision and LMP/PAL Subversion are implementation dependent.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_Version_Information command succeeded.
0x01-0xFF	Read_Local_Version_Information command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

HCI_Version: *Size: 1 Octet*

Value	Parameter Description
See Bluetooth Assigned Numbers	

HCI_Revision: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Revision of the Current HCI in the BR/EDR Controller.

LMP/PAL_Version: *Size: 1 Octet*

Value	Parameter Description
0xXX	Version of the Current LMP or PAL in the Controller. See Bluetooth Assigned Numbers

Manufacturer_Name: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Manufacturer Name of the BR/EDR Controller. See Bluetooth Assigned Numbers

LMP/PAL_Subversion: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Subversion of the Current LMP or PAL in the Controller. This value is implementation dependent.

Event(s) generated (unless masked away):

When the Read_Local_Version_Information command has completed, a Command Complete event shall be generated.

7.4.2 Read Local Supported Commands Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Local_Supported_Commands	0x0002		Status, Supported_Commands

Description:

This command reads the list of HCI commands supported for the local Controller.

This command shall return the Supported_Commands configuration parameter. It is implied that if a command is listed as supported, the feature underlying that command is also supported.

See Section 6.27 for more information.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0	Read_Local_Supported_Commands command succeeded
0x01-0xff	Read_Local_Supported_Commands command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Supported Commands: *Size: 64 Octets*

Value	Parameter Description
	Bit mask for each HCI Command. If a bit is 1, the Controller supports the corresponding command and the features required for the command. Unsupported or undefined commands shall be set to 0. See Section 6.27.

Event(s) generated (unless masked away):

When the Read_Local_Supported_Commands command has completed, a Command Complete event shall be generated.

7.4.3 Read Local Supported Features Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_Supported_Features	0x0003		Status, LMP_Features

Description:

This command requests a list of the supported features for the local BR/EDR Controller. This command will return a list of the LMP features. For details see [Vol 2] Part C, Link Manager Protocol Specification.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_Supported_Features command succeeded.
0x01-0xFF	Read_Local_Supported_Features command failed. See [Vol 2] Part D, Error Codes.

LMP_Features: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXX XXXXXXXX	Bit Mask List of LMP features. For details see [Vol 2] Part C, Link Manager Protocol Specification.

Event(s) generated (unless masked away):

When the Read_Local_Supported_Features command has completed, a Command Complete event shall be generated.

7.4.4 Read Local Extended Features Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_ Extended_Features	0x0004	Page number	Status, Page number, Maximum Page Number, Extended_LMP_Features

Description:

The Read_Local_Extended_Features command returns the requested page of the extended LMP features.

Command Parameters:

Page Number: *Size: 1 Octet*

Value	Parameter Description
0x00	Requests the normal LMP features as returned by Read_Local_Supported_Features.
0x01-0xFF	Return the corresponding page of features.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_Extended_Features command succeeded
0x01-0xFF	Read_Local_Extended_Features command failed. See [Vol 2] Part D, Error Codes for list of error codes.

Page Number: *Size: 1 Octet*

Value	Parameter Description
0x00	The normal LMP features as returned by Read_Local_Supported_Features.
0x01-0xFF	The page number of the features returned.

Maximum Page Number: *Size: 1 Octet*

Value	Parameter Description
0x00-0xFF	The highest features page number which contains non-zero bits for the local device.

Extended_LMP_Features: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX	Bit map of requested page of LMP features. See LMP specification for details.

Event(s) generated (unless masked away):

When the Read_Local_Extended_Features command has completed, a Command Complete event shall be generated.

7.4.5 Read Buffer Size Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Buffer_Size	0x0005		Status, HC_ACL_Data_Packet_Length, HC_Synchronous_Data_Packet_Length, HC_Total_Num_ACL_Data_Packets, HC_Total_Num_Synchronous_Data_Packets

Description:

The Read_Buffer_Size command is used to read the maximum size of the data portion of HCI ACL and synchronous Data Packets sent from the Host to the Controller. The Host will segment the data to be transmitted from the Host to the Controller according to these sizes, so that the HCI Data Packets will contain data with up to these sizes. The Read_Buffer_Size command also returns the total number of HCI ACL and synchronous Data Packets that can be stored in the data buffers of the Controller. The Read_Buffer_Size command must be issued by the Host before it sends any data to the Controller.

For a device supporting BR/EDR and LE, if the LE_Read_Buffer_Size command returned zero for the number of buffers, then buffers returned by Read_Buffer_Size are shared between BR/EDR and LE.

On an Primary Controller that supports LE only, the Read_Buffer_Size command shall not be supported (the LE_Read_Buffer_Size command is to be used in this case).

The HC_ACL_Data_Packet_Length return parameter will be used to determine the size of the L2CAP segments contained in ACL Data Packets, which are transferred from the Host to the Controller to be broken up into baseband packets by the Link Manager. The HC_Synchronous_Data_Packet_Length return parameter is used to determine the maximum size of HCI synchronous Data Packets. The HC_Total_Num_ACL_Data_Packets return parameter contains the total number of HCI ACL Data Packets that can be stored in the data buffers of the Controller. The Host will determine how the buffers are to be divided between different Connection_Handles. The HC_Total_Num_Synchronous_Data_Packets return parameter gives the same information but for HCI synchronous Data Packets.

Note: The HC_ACL_Data_Packet_Length and HC_Synchronous_Data_Packet_Length return parameters do not include the length of the HCI Data Packet header.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Buffer_Size command succeeded.
0x01-0xFF	Read_Buffer_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

HC_ACL_Data_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Maximum length (in octets) of the data portion of each HCI ACL Data Packet that the Controller is able to accept.

HC_Synchronous_Data_Packet_Length: *Size: 1 Octet*

Value	Parameter Description
0xXX	Maximum length (in octets) of the data portion of each HCI Synchronous Data Packet that the Controller is able to accept.

HC_Total_Num_ACL_Data_Packets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Total number of HCI ACL Data Packets that can be stored in the data buffers of the Controller.

HC_Total_Num_Synchronous_Data_Packets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Total number of HCI Synchronous Data Packets that can be stored in the data buffers of the Controller.

Event(s) generated (unless masked away):

When the Read_Buffer_Size command has completed, a Command Complete event shall be generated.

7.4.6 Read BD_ADDR Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_BD_ADDR	0x0009		Status, BD_ADDR

Description:

On a BR/EDR Controller, this command reads the Bluetooth Controller address (BD_ADDR). See the [Vol 2] Part B, Baseband Specification for details of how BD_ADDR is used (see [Vol 3] Part C, Section 3.2.1).

On an LE Controller, this command shall read the Public Device Address as defined in [Vol 6] Part B, Section 1.3. If this Controller does not have a Public Device Address, the value 0x000000000000 shall be returned.

On a BR/EDR/LE Controller, the public address shall be the same as the BD_ADDR.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_BD_ADDR command succeeded.
0x01-0xFF	Read_BD_ADDR command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Device

Event(s) generated (unless masked away):

When the Read_BD_ADDR command has completed, a Command Complete event shall be generated.

7.4.7 Read Data Block Size Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Data_ Block_Size	0x000A		Status, Max_ACL_Data_Packet_Length, Data_Block_Length, Total_Num_Data_Blocks

Description:

The Read_Data_Block_Size command is used to read values regarding the maximum permitted data transfers over the Controller and the data buffering available in the Controller.

The Host uses this information when fragmenting data for transmission, and when performing block-based flow control, based on the Number Of Completed Data Blocks event. The Read_Data_Block_Size command shall be issued by the Host before it sends any data to the Controller.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Data_Block_Size command succeeded.
0x01-0xFF	Read_Data_Block_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Max_ACL_Data_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Maximum length (in octets) of the data portion of an HCI ACL Data Packet that the Controller is able to accept for transmission. For AMP Controllers this always equals to Max_PDU_Size.

Data_Block_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Maximum length (in octets) of the data portion of each HCI ACL Data Packet that the Controller is able to hold in each of its data block buffers.

Total_Num_Data_Blocks: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Total number of data block buffers available in the Controller for the storage of data packets scheduled for transmission.

Event(s) generated (unless masked away):

When the Read_Data_Block_Size command has completed, a Command Complete event shall be generated.

7.4.8 Read Local Supported Codecs Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_ Supported_Codecs	0x000B		Status, Number_of_Supported_Codecs, Supported_Codecs[i], Number_of_Supported_ Vendor_Specific_Codecs, Vendor_Specific_Codecs[k]

The order of the return parameters in an HCI event packet is:

Status
Number_of_Supported_Codecs
Supported_Codecs[0]
. . .
Supported_Codecs[n]
Number_of_Supported_Vendor_Specific_Codecs
Vendor_Specific_Codecs[0]
. . .
Vendor_Specific_Codecs[m]

Description:

This command reads a list of the Bluetooth SIG approved codecs supported by the Controller, as well as vendor specific codecs, which are defined by an individual manufacturer.

Command Parameters:

None

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_Supported_Codecs command succeeded.
0x01 – 0xFF	Read_Local_Supported_Codecs command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Number_of_Supported_Codecs: *Size: 1 Octet*

Value	Parameter Description
0xXX	Total number of codecs supported

Supported_Codecs[i]: *Size: 1 * Number_of_Supported_Codecs Octets*

Value	Parameter Description
0xXX, 0xXX, …	An array of codec identifiers. See Assigned Numbers for Codec ID

Number_of_Supported_Vendor_Specific_Codecs: *Size: 1 Octet*

Value	Parameter Description
0xXX	Total number of vendor specific codecs supported

Vendor_Specific_Codecs[k]:
*Size: 4 * Number_of_Supported_Vendor_Specific_Codecs*

Value	Parameter Description
0xXXXXXXXX	Octets 0 and 1: Company ID, see Assigned Numbers for Company Identifier Octets 2 and 3: Vendor defined codec ID

Event(s) generated (unless masked away):

When the Read_Local_Supported_Codecs command has completed, a Command Complete event shall be generated.

7.5 STATUS PARAMETERS

The Controller modifies all status parameters. These parameters provide information about the current state of the Link Manager and Baseband in the BR/EDR Controller and the PAL in an AMP Controller. The Host device cannot modify any of these parameters other than to reset certain specific parameters.

For the Status Parameters Commands, the OGF is defined as 0x05.

7.5.1 Read Failed Contact Counter Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Failed_ Contact_Counter	0x0001	Handle	Status, Handle, Failed_Contact_Counter

Description:

This command reads the value for the Failed_Contact_Counter parameter for a particular connection to another device. The Handle shall be a Handle for an ACL connection. See Section 6.15.

Command Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the Connection for which the Failed Contact Counter should be read. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Failed_Contact_Counter command succeeded.
0x01-0xFF	Read_Failed_Contact_Counter command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the Failed Contact Counter has been read. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Failed_Contact_Counter: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Number of consecutive failed contacts for a connection corresponding to the Handle.

Event(s) generated (unless masked away):

When the Read_Failed_Contact_Counter command has completed, a Command Complete event shall be generated.

7.5.2 Reset Failed Contact Counter Command

Command	OCF	Command Parameters	Return Parameters
HCI_Reset_Failed_ Contact_Counter	0x0002	Handle	Status, Handle

Description:

This command resets the value for the Failed_Contact_Counter parameter for a particular connection to another device. The Handle shall be a Handle for an ACL connection. See Section 6.15.

Command Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the Failed Contact Counter should be reset. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical Link Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Reset_Failed_Contact_Counter command succeeded.
0x01-0xFF	Reset_Failed_Contact_Counter command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the Failed Contact Counter has been reset. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Event(s) generated (unless masked away):

When the Reset_Failed_Contact_Counter command has completed, a Command Complete event shall be generated.

7.5.3 Read Link Quality Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Link_Quality	0x0003	Handle	Status, Handle, Link_Quality

Description:

This command returns the value for the Link_Quality for the specified Handle. The Handle shall be a Handle for an ACL connection. This command shall return a Link_Quality value from 0-255, which represents the quality of the link between two BR/EDR Controllers. The higher the value, the better the link quality is. Each Bluetooth module vendor will determine how to measure the link quality.

The Read_Link_Quality command is provided by AMPs. The meaning of the link quality metric is AMP type specific and defined in the AMP PALs (see Volume 5, Core System Package [AMP Controller volume].

Command Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which link quality parameters are to be read. The Handle is a Connection_Handle for a BR/EDR Controller and a Physical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Link_Quality command succeeded.
0x01-0xFF	Read_Link_Quality command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the link quality parameter has been read. The Handle is a Connection_Handle for a BR/EDR Controller and a Physical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Link_Quality: *Size: 1 Octet*

Value	Parameter Description
0xXX	The current quality of the Link connection between the local device and the remote device specified by the Handle. Range: 0x00 – 0xFF The higher the value, the better the link quality is.

Event(s) generated (unless masked away):

When the Read_Link_Quality command has completed, a Command Complete event shall be generated.

7.5.4 Read RSSI Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_RSSI	0x0005	Handle	Status, Handle, RSSI

Description:

This command reads the Received Signal Strength Indication (RSSI) value from a Controller.

For a BR/EDR Controller, a Connection_Handle is used as the Handle command parameter and return parameter. The RSSI parameter returns the difference between the measured Received Signal Strength Indication (RSSI) and the limits of the Golden Receive Power Range for a Connection_Handle to another BR/EDR Controller. The Connection_Handle must be a Connection_Handle for an ACL connection. Any positive RSSI value returned by the Controller indicates how many dB the RSSI is above the upper limit, any negative value indicates how many dB the RSSI is below the lower limit. The value zero indicates that the RSSI is inside the Golden Receive Power Range.

Note: How accurate the dB values will be depends on the Bluetooth hardware. The only requirements for the hardware are that the BR/EDR Controller is able to tell whether the RSSI is inside, above or below the Golden Device Power Range.

The RSSI measurement compares the received signal power with two threshold levels, which define the Golden Receive Power Range. The lower threshold level corresponds to a received power between -56 dBm and 6 dB above the actual sensitivity of the receiver. The upper threshold level is 20 dB above the lower threshold level to an accuracy of +/- 6 dB.

For an AMP Controller, a Physical_Link_Handle is used for the Handle command parameter and return parameter. The meaning of the RSSI metric is AMP type specific and defined in the AMP PALs (see Volume 5, Core System Package [AMP Controller volume].

For an LE transport, a Connection_Handle is used as the Handle command parameter and return parameter. The meaning of the RSSI metric is an absolute receiver signal strength value in dBm to ± 6 dB accuracy. If the RSSI cannot be read, the RSSI metric shall be set to 127.

Command Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the RSSI is to be read. The Handle is a Connection_Handle for a BR/EDR Controller and a Physical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_RSSI command succeeded.
0x01-0xFF	Read_RSSI command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Handle for the connection for which the RSSI has been read. The Handle is a Connection_Handle for a BR/EDR Controller and a Physical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

RSSI: *Size: 1 Octet*

Value	Parameter Description
	BR/EDR Range: -128 ≤ N ≤ 127 (signed integer) Units: dB AMP: Range: AMP type specific (signed integer) Units: dBm LE: Range: -127 to 20, 127 (signed integer) Units: dBm

Event(s) generated (unless masked away):

When the Read_RSSI command has completed, a Command Complete event shall be generated.

7.5.5 Read AFH Channel Map Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_AFH_Channel_Map	0x0006	Connection_Handle	Status, Connection_Handle, AFH_Mode, AFH_Channel_Map

Description:

This command returns the values for the AFH_Mode and AFH_Channel_Map for the specified Connection_Handle. The Connection_Handle shall be a Connection_Handle for an ACL connection.

The returned values indicate the state of the hop sequence specified by the most recent LMP_Set_AFH message for the specified Connection_Handle, regardless of whether the master has received the baseband ACK or whether the AFH_Instant has passed.

This command shall be supported by a device that declares support for either the AFH_capable_slave or AFH_capable_master feature.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_AFH_Channel_Map command succeeded.
0x01-0xFF	Read_AFH_Channel_Map command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

AFH_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	AFH disabled.
0x01	AFH enabled.
All other values	Reserved for future use.

AFH_Channel_Map: *Size: 10 Octets (79 Bits meaningful)*

Value	Parameter Description
0xXXXXXXXX XXXXXXXX XXX	If AFH_Mode is not AFH enabled then the contents of this parameter are reserved for future use. Otherwise: This parameter contains 80 1-bit fields. The n^{th} such field (in the range 0 to 78) contains the value for channel *n*: 0: channel *n* is unused 1: channel *n* is used The most significant bit (bit 79) is reserved for future use

Event(s) generated (unless masked away):

When the Read_AFH_Channel_Map command has completed, a Command Complete event shall be generated.

7.5.6 Read Clock Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Clock	0x0007	Connection_Handle, Which_Clock	Status, Connection_Handle, Clock, Accuracy

Description:

This command reads the estimate of the value of the Bluetooth Clock from the BR/EDR Controller.

If the Which_Clock value is 0, then the Connection_Handle shall be ignored, the local Bluetooth Clock value shall be returned and the accuracy parameter shall be set to 0.

If the Which_Clock value is 1, then the Connection_Handle shall be a valid ACL Connection_Handle. If the current role of this ACL connection is Master, then the Bluetooth Clock of this device shall be returned. If the current role is Slave, then an estimate of the Bluetooth Clock of the remote master and the accuracy of this value shall be returned.

The accuracy reflects the clock drift that might have occurred since the slave last received a valid transmission from the master.

Note: The Bluetooth Clock has a minimum accuracy of 250ppm, or about 22 seconds drift in one day.

Note: See [Vol 2] Part B, Section 1.1 for more information about the Bluetooth Clock.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Which_Clock: *Size 1 Octet)*

Value	Parameter Description
0xXX	0x00 = Local Clock (Connection_Handle does not have to be valid) 0x01 = Piconet Clock (Connection_Handle shall be valid) 0x02 to 0xFF = Reserved for Future Use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Clock command succeeded.
0x01 – 0xFF	Read_Clock command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Connection_Handle for the connection for which the master clock has been read. If the Which_Clock parameter was 0, then the Connection_Handle is reserved for future use. Range: 0x0000-0x0EFF (all other values reserved for future use)

Clock: *Size: 4 Octets (28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	Bluetooth Clock of the device requested.

Accuracy: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	+/- maximum Bluetooth Clock error. Value of 0xFFFF means Unknown. Accuracy = +/- N * 0.3125 ms (1 Bluetooth Clock) Range for N: 0x0000 - 0xFFFE Time Range for N: 0 - 20479.375 ms

Event(s) generated (unless masked away):

When the Read_Clock command has completed, a Command Complete event shall be generated.

7.5.7 Read Encryption Key Size Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Encryption_ Key_Size	0x0008	Connection_Handle	Status, Connection_Handle, Key_Size

Description:

This command reads the current encryption key size associated with the Connection_Handle. The Connection_Handle shall be a Connection_Handle for an active ACL connection.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use).

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Encryption_Key_Size succeeded
0x01 - 0xFF	Read_Encryption_Key_Size failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use).

Key_Size: *Size: 1 Octet*

Value	Parameter Description
0xXX	Encryption key size. See [Vol 2] Part C, Section 5.2.

Event(s) generated (unless masked away):

When the Read_Encryption_Key_Size command has completed, a Command_Complete event shall be generated.

If the ACL connection associated with the Connection_Handle is not encrypted, the Controller shall return a Command Complete event with the error code *Insufficient Security* (0x2F).

7.5.8 Read Local AMP Info Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Local_AMP_Info	0x0009		Status, AMP_Status, Total_Bandwidth, Max_Guaranteed_Bandwidth, Min_Latency, Max_PDU_Size, Controller_Type, PAL_Capabilities, Max_AMP_ASSOC_Length, Max_Flush_Timeout, Best_Effort_Flush_Timeout

Description:

This command returns information about the AMP Controller.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_AMP_Info command succeeded
0x01-0xFF	Read_Local_AMP_Info command failed. See [Vol 2] Part D, Error Codes

AMP_Status: *Size: 1 Octet*

Value	Parameter Description
0x00	The Controller is available but is currently physically powered down. This value shall be used if the AMP Controller is present and can be powered up by the AMP Manager. This value indicates that there may be a cost of time and power to use this AMP Controller (i.e., the time taken and power required to power up the AMP Controller). These costs are AMP type and AMP implementation dependent.

Value	Parameter Description
0x01	This value indicates that the AMP Controller is only used by Bluetooth technology and will not be shared with other non-Bluetooth technologies. This value shall only be used if the AMP Controller is powered up. This value does not indicate how much bandwidth is currently free on the AMP Controller.
0x02	The AMP Controller has no capacity available for Bluetooth operation This value indicates that all of the AMP Controller's bandwidth is currently allocated to servicing a non Bluetooth technology. A device is permitted to create a Physical Link to an AMP Controller that has this status. This value shall only be used if the AMP Controller is powered up.
0x03	The AMP Controller has low capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controller's bandwidth is currently allocated to servicing a non Bluetooth technology. An AMP Controller with capacity in the approximate range of 0% to 30% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.
0x04	The AMP Controller has medium capacity available for Bluetooth operation. An AMP Controller with capacity in the approximate range of 30% to 70% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.
0x05	The AMP Controller has high capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controller's bandwidth is currently allocated to servicing the Bluetooth technology. An AMP Controller with capacity in the approximate range of 70% to 100% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.

Value	Parameter Description
0x06	The AMP Controller has full capacity available for Bluetooth operation. This value indicates that while currently the AMP is only being used by Bluetooth the device allows a different technology to share the radio. This value shall be used by devices that are not capable of determining the current available capacity of an AMP that is shared by a different technology. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.
All other values	Reserved for future use

The AMP Controller to generate AMP_Status_Change event if this parameter changes after initial Read_Local_AMP_Info request. See [Vol 3] Part E, Section 3.4.

Total_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
	An upper bound on the total data rate that can be achieved by the AMP over HCI. It accounts for the total bandwidth provided by the HCI transport. No sustained combination of transmit and receive operations shall exceed this value. This can be used to help in AMP selection and admission control. Expressed in kb/s.

Max_Guaranteed_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
	An upper bound on the maximum data the AMP can guarantee for a single logical link over HCI. Any request made by an application above this threshold would be rejected. It accounts for any bandwidth limitations of the HCI transport. No sustained combination of transmit and receive operations shall exceed this value. This can be used to help in AMP selection and admission control. Expressed in kb/s.

Min_Latency: *Size: 4 Octets*

Value	Parameter Description
	A lower bound on the latency in microseconds that the AMP can guarantee for a logical channel. It accounts for the minimum latency of the HCI transport. This can be used to help in AMP selection and admission control.

Max_PDU_Size: *Size: 2 Octets*

Value	Parameter Description
	An upper bound on the size of L2CAP PDU which may be provided for transmission or reception on this AMP. The Host shall not require the AMP to transport L2CAP PDUs larger than this value. Expressed in octets. The Maximum PDU Size parameter described in [Vol 3] Part A, Section 5.4 for any connection over this AMP should not exceed this value.

Controller_Type: *Size: 1 Octet*

Value	Parameter Description
See Bluetooth Assigned Numbers.	

PAL_Capabilities: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Bit 0: "Service Type = Guaranteed" is supported by PAL = 1 Bits 15-1: Reserved for future use (See [Vol 3] Part A, Section 5.6.)

Max_AMP_ASSOC_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	AMP_ASSOC maximum length for this local AMP Controller. For use with Read and Write AMP_ASSOC commands [Section 7.5.8 and Section 7.5.9]. This value is sent to the remote AMP Manager in the AMP Get Info Response (see "[Vol 3] Part E, Section 3.8).

Max_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Maximum time period, in microseconds, which the AMP device uses to attempt to transmit a frame on a Guaranteed Logical Link. If the Controller is configured to retry frames for an unbounded time (i.e. there is no flushing at all), then it shall set this value to 0xFFFFFFFF.

Best_Effort_Flush_Timeout *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	The typical time period, in microseconds, which the AMP device may use to attempt to transmit a frame on a Best Effort Logical Link. The value shall not exceed the value given in Max_Flush_-Timeout. If the Controller is configured to retry frames for an unbounded time (i.e. there is no flushing at all), then it shall set this value to 0xFFFFFFFF.

Event(s) generated (unless masked away):

When the Read_Local_AMP_Info command has completed, a Command Complete event shall be generated.

7.5.9 Read Local AMP ASSOC Command

Command	OCF	Command Parameters	Return Parameters
HCI_ Read_Local_AMP_ASSOC	0x000A	Physical_Link_Handle, Length_So_Far, Max_Remote_ AMP_ASSOC_Length	Status, Physical_Link_Handle, AMP_ASSOC_ Remaining_Length, AMP_ASSOC_fragment

Description:

This command returns a fragment of the AMP_ASSOC structure. The AMP_ASSOC contains information in an AMP type specific format and is defined in the AMP PALs (see Volume 5, Core System Package [AMP Controller volume]). This may include a combination of address, capabilities and status information. This command can be used when creating an AMP physical link as given by the Physical_Link_Handle parameter, see the Create Physical Link command for more details. If the command is being executed outside of the context of any physical link creation, then the Physical_Link_Handle shall be 0x00.

The Controller shall limit the returned AMP_ASSOC to Max_AMP_ASSOC_Length octets. The Host shall set this parameter to the "AMP_ASSOC_Size" value returned from the remote device in the AMP Get Info Response (see AMP Manager Protocol Specification, [Vol 3] Part E, Section 3.8).

The AMP_ASSOC length may be larger than can fit in a single HCI event. Each time the Read_Local_AMP_ASSOC command is called, the remaining length of the AMP_ASSOC (including the data returned in the Command Complete event) is included in the AMP_ASSOC_Remaining_Length parameter and data from the AMP_ASSOC is contained in the AMP_ASSOC_fragment parameter. In order to obtain the entire AMP_ASSOC, a Host shall continue calling Read_Local_AMP_ASSOC until the AMP_ASSOC_Remaining_Length parameter returned is equal to the size of the AMP_ASSOC_fragment in that event.

The Length_So_Far parameter shall be set to 0 to obtain the first AMP_ASSOC_fragment. Subsequent fragments are obtained by incrementing the Length_So_Far parameter by the length of the previous fragment.

Once the Host begins reading an AMP_ASSOC, all fragments returned in a sequence of Read_Local_AMP_ASSOC commands shall be from one, static AMP_ASSOC.

Command Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00	Used to indicate invalid Physical_Link_Handle
0xXX	Physical_Link_Handle which describes the link to which the AMP_ASSOC belongs.

Length_So_Far: *Size: 2 Octets*

Value
Set Length_So_Far to 0 for the first fragment. Increment parameter by the length of the previous fragment, for each subsequent call

AMP_ASSOC_Length : *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The maximum length, in octets, allowed by the Host for the AMP_ASSOC maximum length for the remote returned by the AMP Controller. For use with Read command to prevent interoperability issues.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Local_AMP_ASSOC command succeeded
0x01-0xFF	Read_Local_AMP_ASSOC command failed. See [Vol 2] Part D, Error Codes for list of Error Codes.

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle identifying the physical link to be created with the associated AMP_ASSOC.

AMP_ASSOC_Remaining_Length: *Size: 2 Octets*

Value	Parameter Description
1-size of variable	Length, in octets, of the remainder of the AMP_ASSOC including this fragment.
0	Reserved for Future Use

AMP_ASSOC_fragment: *Size: 1 to 248 Octets*

Value
A fragment of the local AMP_ASSOC structure created by a remote AMP of the same Controller type. A fragment, other than the final one, shall be exactly 248 bytes in length.

Event(s) generated (unless masked away):

When the Read_Local_AMP_ASSOC command has completed, a Command Complete event shall be generated.

7.5.10 Write Remote AMP ASSOC Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Remote_ AMP_ASSOC	0x000B	Physical_Link_Handle, Length_So_Far, AMP_ASSOC_ Remaining_Length, AMP_ASSOC_fragment	Status, Physical_Link_Handle

Description:

This command writes an AMP_ASSOC fragment to the AMP Controller. The AMP_ASSOC contains information in an AMP type specific format and is defined in the AMP PALs (see Volume 5, Core System Package [AMP Controller volume]). This may include a combination of address, capabilities and status information. This command may be used when creating an AMP physical link. See the Create_Physical_Link command for more details. See Section 7.1.37.

The AMP_ASSOC length may be larger than can fit in a single HCI command. Each time the Write_Remote_AMP_ASSOC command is called, the remaining length of the AMP_ASSOC (including the data provided in the command) is included in the AMP_ASSOC_Remaining_Length parameter and data from the AMP_ASSOC is contained in the AMP_ASSOC_fragment parameter. In order to write the entire AMP_ASSOC to the Controller, a Host shall continue calling Write_Remote_AMP_ASSOC until the AMP_ASSOC_Remaining_Length parameter returned is equal to the size of the AMP_ASSOC_fragment in that command.

The Write_Local_AMP_ASSOC command shall be called immediately after the Command Status event (with result of success) for either the Create_Physical_Link or Accept_Physical_Link commands.

The Length_So_Far parameter shall be set to 0 to write the first AMP_ASSOC_fragment. Subsequent fragments are written by incrementing the Length_So_Far parameter by the length of the previous fragment.

Command Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle identifying the physical link to be created with the associated AMP_ASSOC.

Length_So_Far: *Size: 2 Octets*

Value
Set Length_So_Far to 0 for the first fragment. Increment it by the length of the previous fragment, for each subsequent call.

AMP_ASSOC_Remaining_Length: *Size: 2 Octets*

Value	Parameter Description
0x0001- Max-_AMP_AS-SOC_Length	Length, in octets, of the remainder of the AMP_ASSOC, including this fragment. Max_AMP_ASSOC_Length as reported in Read_Local_AMP_Info command.
0x0000	Reserved for Future Use

AMP_ASSOC_fragment: *Size: 1 to 248 Octets*

Value
A fragment of the AMP_ASSOC structure created by a remote AMP of the same Controller type.
The fragment length shall be 248 bytes for all but the last fragment.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Remote_AMP_ASSOC command succeeded
0x01-0xFF	Write_Remote_AMP_ASSOC command failed. See "[Vol 2] Part D, Error Codes for list of Error Codes.

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle identifying the physical link to be created with the associated AMP_ASSOC.

Event(s) generated (unless masked away):

When the Write_Remote_AMP_ASSOC command has completed, a Command Complete event shall be generated.

7.5.11 Get MWS Transport Layer Configuration Command

Command	OCF	Command Parameters	Return Parameters
HCI_Get_MWS_Transport_Layer_Configuration	0x000C		Status, Num_Transports, Transport_Layer[i], Num_Baud_Rates[i], To_MWS_Baud_Rate[k], From_MWS_Baud_Rate[k]

The order of the return parameters in an HCI event packet is:

Status
Num_Transports
Transport_Layer[0]
Num_Baud_Rates[0]
. . .
Transport_Layer[n]
Num_Baud_Rates[n]
To_MWS_Baud_Rate[0]
From_MWS_Baud_Rate[0]
. . .
To_MWS_Baud_Rate[m]
From_MWS_Baud_Rate[m]

Description:

The Get_MWS_Transport_Layer_Configuration command is used to inform the Host of the Baud rates supported by the Controller for the transport layer.

The Num_Transports parameter is used to indicate the number of MWS coexistence transport interfaces supported by the Controller.
The Num_Baud_Rates parameter indicates the number of supported baud rates for each transport.

The To_MWS_Baud_Rate parameters indicate the supported baud rates in the direction from Bluetooth to MWS for each transport.

The From_MWS_Baud_Rate parameters indicate the supported baud rates in the direction from MWS to Bluetooth for each transport.

If one direction has more supported rates than the other direction, the Controller shall - in the direction with less supported rates - fill with sufficient

zeros to produce the same number of values. The rates for the two directions are not necessarily paired.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Get_MWS_Transport_Layer_Configuration command succeeded.
0x01-0xFF	Get_MWS_Transport_Layer_Configuration command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

Num_Transports: *Size: 1 Octet*

Value	Parameter Description
0xXX	Number of supported MWS coexistence transport layers.

Transport_Layer[i]: *Size: Num_Transports * 1 Octet*

Value	Parameter Description
0xXX	See Bluetooth Assigned numbers.

Num_Baud_Rates[i]: *Size: Num_Transports * 1 Octet*

Value	Parameter Description
0xXX	Number of different baud rates supported for one transport.

To_MWS_Baud_Rate[k]: *Size: SUM (Num_Baud_Rates [i])* 4 Octets*

Value	Parameter Description
0xXXXXXXXX	List of supported Baud rates in the Bluetooth Controller to MWS Device direction in Baud. Each element of the list shall have the format 0xXXXXXXXX. The list shall start with the first baud rate for the first transport, followed by the remaining baud rates for the first transport, followed by the baud rates for the second transport (if any), followed by baud rates for subsequent transports (if any).

*From_MWS_Baud_Rate[k]: Size: SUM (Num_Baud_Rates[i]) * 4 Octets*

Value	Parameter Description
0xXXXXXXXX	List of supported Baud rates in the Bluetooth Controller for signals in the MWS to Bluetooth Controller Device direction in Baud. Each element of the list shall have the format 0xXXXXXXXX. The list shall start with the first baud rate for the first transport, followed by the remaining baud rates for the first transport, followed by the baud rates for the second transport (if any), followed by baud rates for subsequent transports (if any).

Event(s) generated (unless masked away):

When the Get_MWS_Transport Layer_Configuration command has completed, a Command Complete event shall be generated.

7.5.12 Set Triggered Clock Capture Command

Command	OCF	Command Parameters	Return Parameters
HCI_Set_Triggered_ Clock_Capture	0x000D	Connection_Handle, Enable, Which_Clock, LPO_Allowed, Num_Clock_ Captures_To_Filter	Status

Description:

The Set_Triggered_Clock_Capture command configures the BR/EDR Controller for triggered clock capturing.

Triggered clock capturing is enabled or disabled by the Enable parameter.

If the Which_Clock value is 0, then the Connection_Handle shall be ignored. If the Which_Clock value is 1, then the Connection_Handle shall be a valid ACL Connection _Handle.

The LPO_Allowed parameter informs the BR/EDR Controller whether it may use a lower accuracy clock or not.

The Num_Clock_Captures_To_Filter parameter is used to filter triggered clock captures between sending Triggered Clock Capture events to the Host. When set to zero, all triggered clock captures shall result in a Triggered Clock Capture event sent to the Host. When set to a non-zero value, after every Triggered Clock Capture event, Num_Clock_Captures_To_Filter triggered clock captures in a row shall not trigger an event to be sent to the Host.

Note: An implementation should ensure that the rate of triggered clock captures does not overwhelm the HCI event queue and processing.

Note: See [Vol 2] Part B, Section 1.1 for more information about the Bluetooth Clock.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 – 0x0EFF (all other values reserved for future use)

Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Disable triggered clock capturing on the specified Connection_Handle (Default)
0x01	Enable triggered clock capturing on the specified Connection_Handle
All other values	Reserved for future use

Which_Clock: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x00 = Local Clock (Connection_Handle does not have to be valid) 0x01 = Piconet Clock (Connection_Handle shall be valid) 0x02-0xFF = Reserved for Future Use

LPO_Allowed: *Size: 1 Octet*

Value	Parameter Description
0x00	Controller shall not sleep (that is, clock accuracy shall be equal to or better than ± 20 ppm)
0x01	Controller may sleep (that is, clock accuracy shall be equal to or better than ± 250 ppm)
All other values	Reserved for future use

Num_Clock_Captures_To_Filter: *Size: 1 Octet*

Value	Parameter Description
0x00	All triggered clock captures result in a Triggered Clock Capture event sent to the Host
0x01-0xFF	Number of triggered clock captures filtered between sending a Triggered Clock Capture event to the Host.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Set_Triggered_Clock_Capture command succeeded.
0x01-0xFF	Set_Triggered_Clock_Capture command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

Event(s) generated (unless masked away):

When the Set_Triggered_Clock_Capture command has completed, a Command Complete event shall be sent to the Host.

When Triggered Clock Capturing is enabled, Triggered Clock Capture events are returned until Triggered Clock Capturing is disabled.

7.6 TESTING COMMANDS

The Testing commands are used to provide the ability to test various functional capabilities of the Bluetooth hardware. These commands provide the ability to arrange various conditions for testing.

For the Testing Commands, the OGF is defined as 0x06.

7.6.1 Read Loopback Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Read_Loopback_Mode	0x0001		Status, Loopback_Mode

Description:

This command reads the value for the setting of the Controller's Loopback_Mode. The setting of the Loopback_Mode parameter shall determine the path of information. In Non-testing Mode operation, the Loopback_Mode parameter is set to Non-testing Mode and the path of the information is as specified by the Bluetooth specifications. In Local Loopback Mode, every Data Packet (ACL, SCO and eSCO) and Command Packet that is sent from the Host to the Controller is sent back with no modifications by the Controller, as shown in Figure 7.1. For details of loopback modes see Section 7.6.2.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Loopback_Mode command succeeded.
0x01-0xFF	Read_Loopback_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Loopback_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	No Loopback mode enabled (default).
0x01	Enable Local Loopback.
0x02	Enable Remote Loopback. (Not supported by AMPs)
All other values	Reserved for future use.

Event(s) generated (unless masked away):

When the Read_Loopback_Mode command has completed, a Command Complete event shall be generated.

7.6.2 Write Loopback Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Loopback_Mode	0x0002	Loopback_Mode	Status

Description:

This command writes the value for the setting of the BR/EDR Controller's Loopback Mode. The setting of the Loopback_Mode parameter shall determine the path of information. In Non-testing Mode operation, the Loopback_Mode parameter is set to Non-testing Mode and the path of the information as specified by the Bluetooth specifications. In Local Loopback Mode, every Data Packet (ACL, SCO and eSCO) and Command Packet that is sent from the Host to the BR/EDR Controller is sent back with no modifications by the BR/EDR Controller, as shown in Figure 7.1.

When the BR/EDR Controller enters Local Loopback Mode, it shall respond with one to four Connection_Handles, one for an ACL connection and zero to three for synchronous connections. The Host should use these Connection_Handles when sending data in Local Loopback Mode. The number of Connection_Handles returned for synchronous connections (between zero and three) is implementation specific. When in Local Loopback Mode, the BR/EDR Controller loops back commands and data to the Host. The Loopback Command event is used to loop back commands that the Host sends to the Controller.

When an AMP enters Local Loopback Mode, all data transmission will be looped back with the received Logical_Link_Handle value, without checking the validity of the Logical Link Handle. This allows local loopback of data without any link creation, and without any data transmission over the air.

There are some commands that are not looped back in Local Loopback Mode: Reset, Set_Controller_To_Host_Flow_Control, Host_Buffer_Size, Host_Number_Of_Completed_Packets, Read_Buffer_Size, Read_Loopback_Mode and Write_Loopback_Mode. These commands should be executed in the way they are normally executed. The commands Reset and Write_Loopback_Mode can be used to exit local loopback mode.

If Write_Loopback_Mode is used to exit Local Loopback Mode on a BR/EDR Controller, Disconnection Complete events corresponding to the Connection Complete events that were sent when entering Local Loopback Mode should be sent to the Host. Furthermore, no connections are allowed in Local Loopback mode. If there is a connection, and there is an attempt to set the device to Local Loopback Mode, the attempt will be refused. When the device is in Local Loopback Mode, the Controller will refuse incoming connection attempts. This allows the Host BR/EDR Controller Transport Layer to be tested without any other variables.

If a BR/EDR Controller is set to Remote Loopback Mode, it will send back all data (ACL, SCO and eSCO) that comes over the air. It will only allow a maximum of one ACL connection and three synchronous connections, and these shall all be to the same remote device. If there are existing connections to a remote device and there is an attempt to set the local device to Remote Loopback Mode, the attempt shall be refused.

If a Host sets Loopback Mode to “Remote Loopback” on an AMP Controller, the Controller shall reject the command with the error code *Invalid HCI command parameter* (0x12).

See Figure 7.2, where the rightmost device is set to Remote Loopback Mode and the leftmost device is set to Non-testing Mode. This allows the BR/EDR Air link to be tested without any other variables.

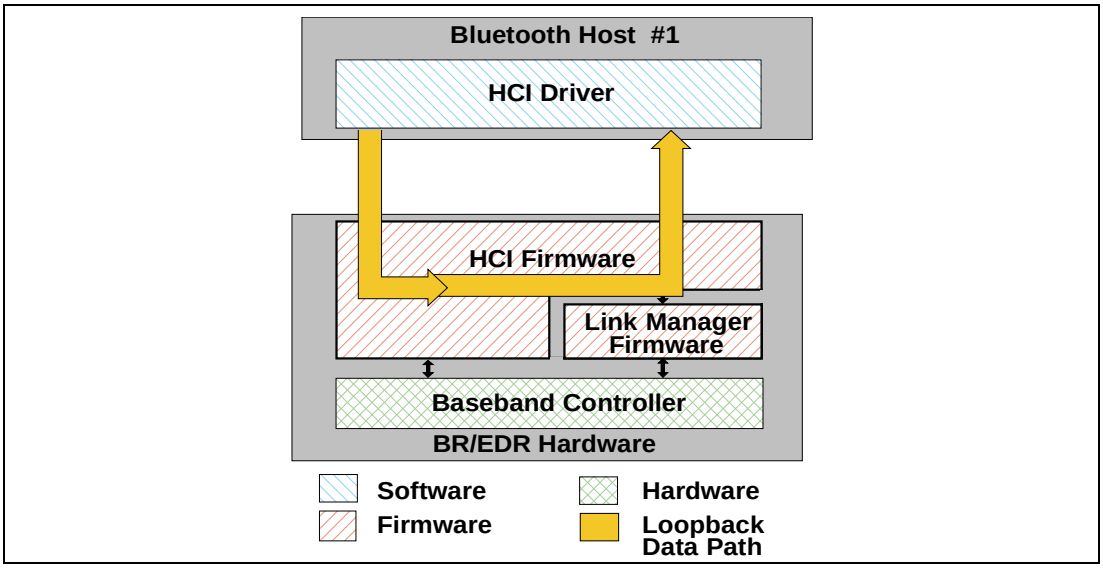

Figure 7.1: Local Loopback Mode

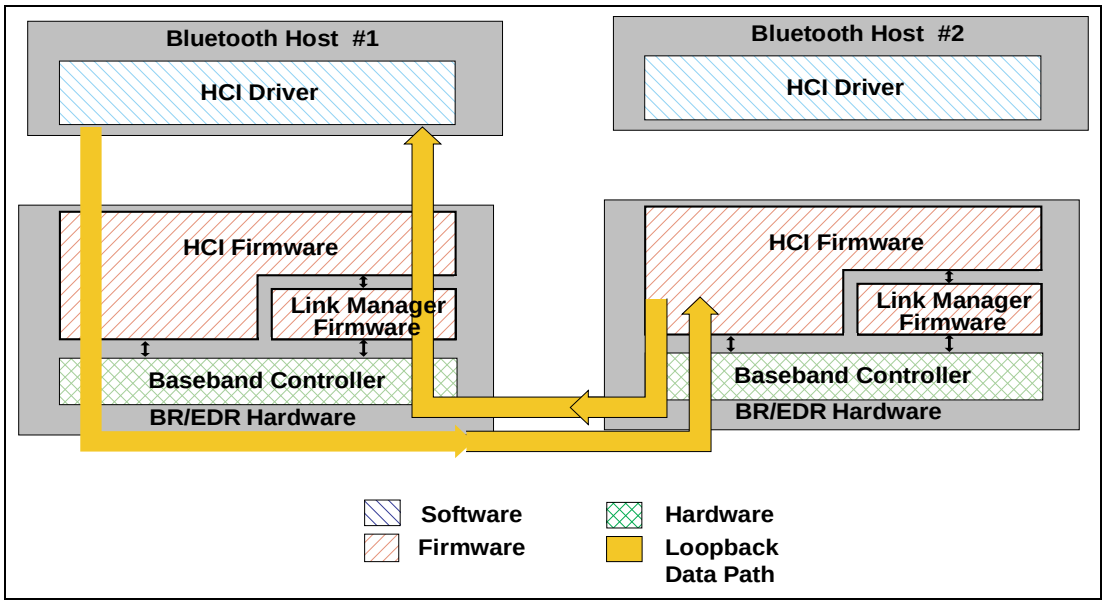

Figure 7.2: Remote Loopback Mode

Command Parameters:

Loopback_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	No Loopback mode enabled (default).
0x01	Enable Local Loopback.
0x02	Enable Remote Loopback. (Not Supported by AMPs)
All other values	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Loopback_Mode command succeeded.
0x01-0xFF	Write_Loopback_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Loopback_Mode command has completed, a Command Complete event shall be generated.

7.6.3 Enable Device Under Test Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Enable_Device_Under_ Test_Mode	0x0003		Status

Description:

The Enable_Device_Under_Test_Mode command allows the local BR/EDR Controller to enter test mode via LMP test commands for BR/EDR Controllers or via the AMP Test Command for AMP Controllers. For details see [Vol 2] Part C, Link Manager Protocol Specification for BR/EDR Controllers or Section 7.6.7 for AMP Controllers. The Host issues this command when it wants the local device to be the DUT for the Testing scenarios as described in the [Vol 3] Part D, Section 1. When the BR/EDR Controller receives this command, it shall complete the command with a Command Complete event. The BR/EDR Controller functions as normal until the remote tester issues the LMP test command or for AMPs the AMP Test Command to place the local device into Device Under Test mode. To disable and exit the Device Under Test Mode, the Host may issue the Reset command. This command prevents remote BR/EDR Controllers from causing the local BR/EDR Controller to enter test mode without first issuing this command.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Enter_Device_Under_Test_Mode command succeeded.
0x01-0xFF	Enter_Device_Under_Test_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Enter_Device_Under_Test_Mode command has completed, a Command Complete event shall be generated.

7.6.4 Write Simple Pairing Debug Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Simple_Pairing_Debug_Mode	0x0004	Simple_Pairing_Debug_-Mode	Status

Description:

This command configures the BR/EDR Controller to use a predefined Diffie Hellman private key for Simple Pairing to enable debug equipment to monitor the encrypted connection.

Note: Only one side (initiator or responder) needs to set simple pairing debug mode in order for debug equipment to be able to determine the link key and, therefore, be able to monitor the encrypted connection.

When the Simple_Pairing_Debug_Mode parameter is set to enabled the BR/EDR Controller shall use the predefined Diffie Hellman private key. The BR/EDR Controller shall also set the resulting Link_Key type to "Debug Combination Key."

When in Simple Pairing debug mode, the Link Manager shall use the following Diffie Hellman private / public key pairs:

For P-192:

Private key: `07915f86918ddc27005df1d6cf0c142b625ed2eff4a518ff`

Public key (X): `15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed`

Public key (Y): `b09d42b81bc5bd009f79e4b59dbbaa857fca856fb9f7ea25`

For P-256:

Private key: `3f49f6d4 a3c55f38 74c9b3e3 d2103f50 4aff607b eb40b799 5899b8a6 cd3c1abd`

Public key (X): `20b003d2 f297be2c 5e2c83a7 e9f9a5b9 eff49111 acf4fddb cc030148 0e359de6`

Public key (Y): `dc809c49 652aeb6d 63329abf 5a52155c 766345c2 8fed3024 741c8ed0 1589d28b`

Command Parameters:

Simple_Pairing_Debug_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	Simple Pairing debug mode disabled (default)
0x01	Simple pairing debug mode enabled
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Simple_Pairing_Mode command succeeded.
0x01 - 0xFF	Write_Simple_Pairing_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Simple_Pairing_Debug_Mode command has completed, a Command Complete event shall be generated.

7.6.5 Enable AMP Receiver Reports Command

Command	OCF	Command Parameters	Return Parameters
HCI_Enable_AMP_Receiver_Reports	0x0007	Enable, Interval	Status

Description:

This command enables and disables the reporting of frames received. This command shall only be valid in AMP Test Mode. After multiples of the specified Interval, a report of frames that have been received/not received by the DUT shall be sent to the tester. Optionally, the sums of bits in error are also reported. The values returned are the cumulative totals since the mode was last initiated or reset. The totals are reset by sending the Enable_AMP_Receiver_Reports, the HCI_AMP_Test command or the AMP_Test_End command. This event is also generated after an AMP Test End event.

Command Parameters:

Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Disable
0x01	Enable
All other values	Reserved for future use

Interval: *Size: 1 Octet*

Value	Parameter Description
0x00	Reserved for Future Use
0x01-0xFF	Number of s between event reporting

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Enable_AMP_Receiver_Reports command succeeded
0x01-0xFF	Enable_AMP_Receiver_Reports command failed. [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the Enable_AMP_Receiver_Reports command has completed, a Command Complete event shall be generated.

7.6.6 AMP Test End Command

Command	OCF	Command Parameters	Return Parameters
HCI_AMP_Test_End	0x0008		Status

Description:

This command is used to stop any test scenario in progress. This command shall only be used in AMP Test Mode when a test is in progress. This command shall not exit an AMP Controller from AMP Test mode.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP_Test_End command succeeded
0x01-0xFF	AMP_Test_End command failed. [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the AMP_Test_End command has completed an AMP Test End event shall be generated and the AMP Receiver Report event shall be generated if the AMP receiver reports are enabled.

7.6.7 AMP Test Command

Command	OCF	Command Parameters	Return Parameters
HCI_AMP_Test	0x0009	Test_Parameters	Status

Description:

This command is used to configure and start a test. This command shall be only valid in AMP Test Mode.

When a test scenario has completed or on receiving a AMP_Test_End command the AMP shall send a AMP Test End event and the AMP returns to an idle state with the RX and TX off.

The details of the Test_Parameters for each Controller Type are detailed in the AMP PAL specification.

Command Parameters:

Test_Parameters: *Size: 1 Octet*

Value	Parameter Description
0xXX	Controller Type. See Assigned Numbers

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP_Test command succeeded
0x01-0xFF	AMP_Test command failed. See [Vol 2] Part D, Error Codes

Event(s) generated (unless masked away):

When the AMP Controller receives the AMP_Test command, the AMP Controller shall send the Command Status event to the AMP Test Manager which shall be routed to the tester.

The AMP Start Test event shall be generated when the AMP_Test command has completed and the first data is ready to be sent or received.

Command Complete event shall not be sent by the AMP to indicate that this command has been completed. Instead, the AMP Start Test event shall indicate that this command has been completed.

When in a transmitter test scenario and the frames/bursts count have been transmitted the AMP Test End event shall be sent.

7.6.8 Write Secure Connections Test Mode Command

Command	OCF	Command Parameters	Return Parameters
HCI_Write_Secure_ Connections_Test_Mode	0x000A	Connection_Handle, DM1_ACL-U_Mode, eSCO_Loopback_Mode	Status, Connection_Handle

Description:

This command configures the BR/EDR Controller to enable and disable the two test modes used for verifying the Secure Connections feature during qualification. The DM1_ACL-U_Mode parameter enables and disables the use of DM1 packets for transmitting ACL-U data. When DM1 ACL-U Mode is disabled, ACL-U traffic may use DM1 packets. When DM1 ACL-U Mode is enabled, ACL-U traffic shall not use DM1 packets unless the Packet_Type parameter only allows DM1 packets (e.g. set to 0x3306 or 0x330E).

The command is used during testing to help make transmit ACL packet selection predictable.

The eSCO_Loopback_Mode parameter enables and disables the loopback of received eSCO payloads. When the eSCO_Loopback_Mode parameter is set to Enabled, the BR/EDR Controller will send back all eSCO data that comes over the air irrespective of whether the CRC check in the received eSCO packet passes or fails. It will only allow one synchronous connection. If there is more than one synchronous connection and there is an attempt to set the local device to eSCO_Loopback_Mode, the attempt shall be refused.

See Figure 7.3, where the rightmost device has the eSCO_Loopback_Mode parameter set to enabled and the leftmost device is in a normal mode of operation. This allows the encryption and decryption of eSCO packets to be tested without any other variables.

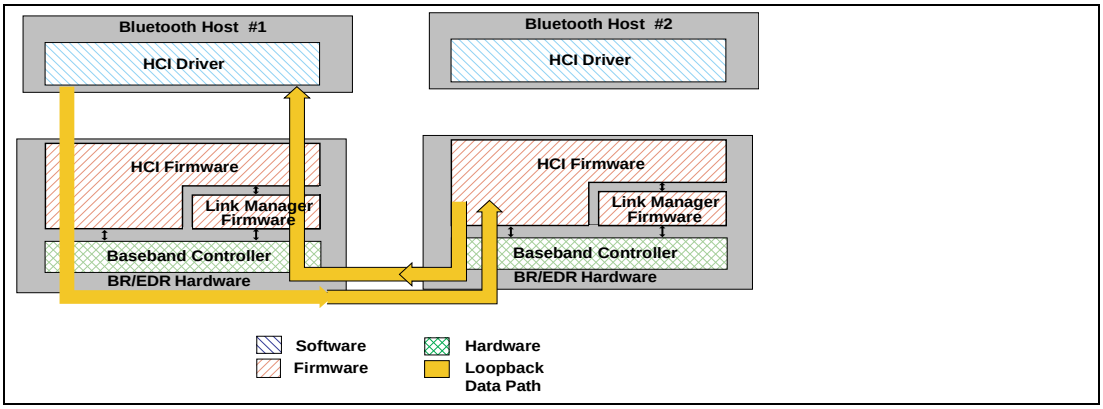

Figure 7.3: Secure Connections eSCO Loopback

The Connection_Handle shall be for an ACL connection.

When the eSCO_Loopback_Mode parameter is set to enabled, received eSCO payloads are looped back as subsequent transmitted eSCO payloads. There may be a delay of 0 or more eSCO intervals before the Controller loops back the payload. This is illustrated in the following three figures.

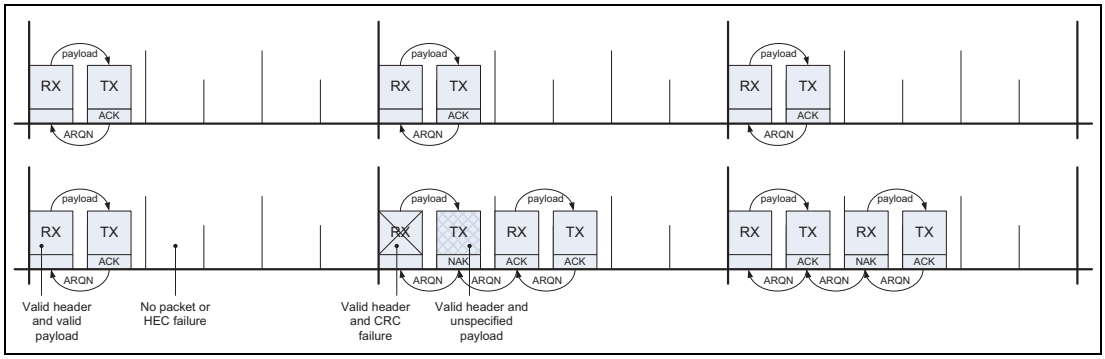

Figure 7.4: Secure Connections eSCO loopback immediate

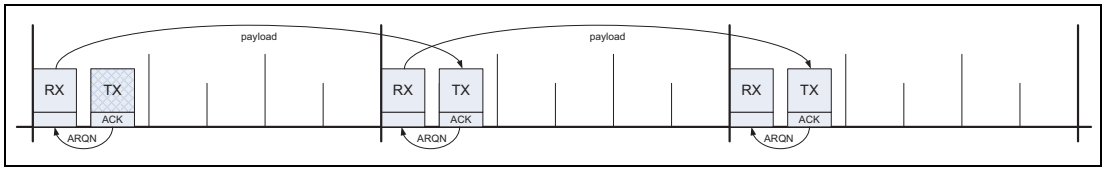

Figure 7.5: Secure Connections eSCO loopback delayed

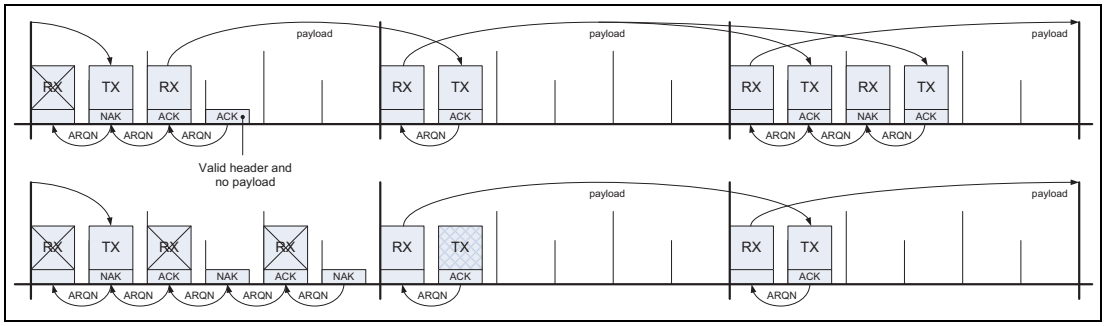

Figure 7.6: Secure Connections eSCO loopback delayed with retransmissions

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

DM1_ACL-U_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	DM1 ACL-U mode disabled (default)
0x01	DM1 ACL-U mode enabled
All other values	Reserved for future use

eSCO_Loopback_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	eSCO loopback mode disabled (default)
0x01	eSCO loopback mode enabled
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Secure_Connections_Test_Mode command succeeded.
0x01-0xFF	Write_Secure_Connections_Test_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Events(s) generated (unless masked away):

When the Write_Secure_Connections_Test_Mode command has completed, a Command_Complete event shall be generated.

7.7 EVENTS

7.7.1 Inquiry Complete Event

Event	Event Code	Event Parameters
Inquiry Complete	0x01	Status

Description:

The Inquiry Complete event indicates that the Inquiry is finished. This event contains a Status parameter, which is used to indicate if the Inquiry completed successfully or if the Inquiry was not completed.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Inquiry command completed successfully.
0x01-0xFF	Inquiry command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

7.7.2 Inquiry Result Event

Event	Event Code	Event Parameters
Inquiry Result	0x02	Num_Responses, BD_ADDR[i], Page_Scan_Repetition_Mode[i], Reserved[i], Reserved[i], Class_of_Device[i] Clock_Offset[i]

Description:

The Inquiry Result event indicates that a BR/EDR Controller or multiple BR/EDR Controllers have responded so far during the current Inquiry process. This event will be sent from the BR/EDR Controller to the Host as soon as an Inquiry Response from a remote device is received if the remote device supports only mandatory paging scheme. The BR/EDR Controller may queue these Inquiry Responses and send multiple BR/EDR Controllers information in one Inquiry Result event. The event can be used to return one or more Inquiry responses in one event.

This event is only generated if the Inquiry_Mode parameter of the last Write_Inquiry_Mode command was set to 0x00 (Standard Inquiry Result event format) or if the Write_Inquiry_Mode command has not been used.

Event Parameters:

Num_Responses: *Size: 1 Octet*

Value	Parameter Description
0xXX	Number of responses from the Inquiry.

BD_ADDR[i]: *Size: 6 Octets * Num_Responses*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR for each device which responded.

Page_Scan_Repetition_Mode[i]: *Size: 1 Octet * Num_Responses*

Value	Parameter Description
0x00	R0
0x01	R1
0x02	R2

Value	Parameter Description
0x03 – 0xFF	Reserved for Future Use

Reserved[i]: [1] *Size: 1 Octet * Num_Responses*

Value	Parameter Description
0xXX	Reserved for Future Use.

Reserved[i]: [2] *Size: 1 Octet * Num_Responses*

Value	Parameter Description
0xXX	Reserved for Future Use.

Class_of_Device[i]: *Size: 3 Octets * Num_Responses*

Value	Parameter Description
0xXXXXXX	Class of Device for the device

Clock_Offset[i]: *Size: 2 Octets * Num_Responses*

Bit format	Parameter Description
Bits 14-0	Bits 16-2 of CLKNslave-CLK
Bit 15	Reserved for Future Use

1. This was the Page_Scan_Period_Mode parameter in the v1.1 specification. This parameter has no meaning in v1.2 or later and no default value.
2. This was the Page_Scan_Mode parameter in the v1.1 specification.

7.7.3 Connection Complete Event

Event	Event Code	Event Parameters
Connection Complete	0x03	Status, Connection_Handle, BD_ADDR, Link_Type, Encryption_Enabled

Description:

The Connection Complete event indicates to both of the Hosts forming the connection that a new connection has been established. This event also indicates to the Host, which issued the Create_Connection, or Accept_Connection_Request or Reject_Connection_Request command and then received a Command Status event, if the issued command failed or was successful.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01-0xFF	Connection failed to Complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the other connected Device forming the connection.

Link_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	SCO connection.
0x01	ACL connection (Data Channels).
All other values	Reserved for future use.

Encryption_Enabled: *Size: 1 Octet*

Value	Parameter Description
0x00	Link level encryption disabled.
0x01	Link level encryption enabled.
All other values	Reserved for future use.

7.7.4 Connection Request Event

Event	Event Code	Event Parameters
Connection Request	0x04	BD_ADDR, Class_of_Device, Link_Type

Description:

The Connection Request event is used to indicate that a new incoming connection is trying to be established. The connection may either be accepted or rejected. If this event is masked away and there is an incoming connection attempt and the BR/EDR Controller is not set to auto-accept this connection attempt, the BR/EDR Controller shall automatically refuse the connection attempt. When the Host receives this event and the link type parameter is ACL, it should respond with either an Accept_Connection_Request or Reject_Connection_Request command before the timer Conn_Accept_Timeout expires. If the link type is SCO or eSCO, the Host should reply with the Accept_Synchronous_Connection_Request or the Reject_Synchronous_Connection_Request command. If the link type is SCO, the Host may respond with Accept_Connection_Request command. If the event is responded to with Accept_Connection_Request command, then the default parameter settings of the Accept_Synchronous_Connection_Request command (see Section 7.1.27) should be used by the local Link Manager when negotiating the SCO link parameters. In that case, the Connection Complete event and not the Synchronous Connection Complete event, shall be returned on completion of the connection.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the device that requests the connection.

Class_of_Device: *Size: 3 Octets*

Value	Parameter Description
0xXXXXXX	Class of Device for the device, which requests the connection.
0x000000	Unknown Class of Device

Link_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	SCO Connection requested
0x01	ACL Connection requested
0x02	eSCO Connection requested
All other values	Reserved for future use.

7.7.5 Disconnection Complete Event

Event	Event Code	Event Parameters
Disconnection Complete	0x05	Status, Connection_Handle, Reason

Description:

The Disconnection Complete event occurs when a connection is terminated. The status parameter indicates if the disconnection was successful or not. The reason parameter indicates the reason for the disconnection if the disconnection was successful. If the disconnection was not successful, the value of the reason parameter can be ignored by the Host. For example, this can be the case if the Host has issued the Disconnect command and there was a parameter error, or the command was not presently allowed, or a Connection_Handle that didn't correspond to a connection was given.

Note: When a physical link fails, one Disconnection Complete event will be returned for each logical channel on the physical link with the corresponding Connection_Handle as a parameter.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Disconnection has occurred.
0x01-0xFF	Disconnection failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle which was disconnected. Range: 0x0000-0x0EFF (all other values reserved for future use)

Reason: *Size: 1 Octet*

Value	Parameter Description
0xXX	Reason for disconnection. See [Vol 2] Part D, Error Codes for error codes and descriptions.

7.7.6 Authentication Complete Event

Event	Event Code	Event Parameters
Authentication Complete	0x06	Status, Connection_Handle

Description:

The Authentication Complete event occurs when authentication has been completed for the specified connection. The Connection_Handle must be a Connection_Handle for an ACL connection.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Authentication Request successfully completed.
0x01-0xFF	Authentication Request failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle for which Authentication has been performed. Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.7 Remote Name Request Complete Event

Event	Event Code	Event Parameters
Remote Name Request Complete	0x07	Status, BD_ADDR, Remote_Name

Description:

The Remote Name Request Complete event is used to indicate that a remote name request has been completed. The Remote_Name event parameter is a UTF-8 encoded string with up to 248 octets in length. The Remote_Name event parameter will be null-terminated (0x00) if the UTF-8 encoded string is less than 248 octets. The BD_ADDR event parameter is used to identify which device the user-friendly name was obtained from.

Note: The Remote_Name parameter is a string parameter. Endian-ness does therefore not apply to the Remote_Name parameter. The first octet of the name is received first.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Remote_Name_Request command succeeded.
0x01-0xFF	Remote_Name_Request command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR for the device whose name was requested.

Remote_Name: *Size: 248 Octets*

Value	Parameter Description
Name[248]	A UTF-8 encoded user-friendly descriptive name for the remote device. If the name contained in the parameter is shorter than 248 octets, the end of the name is indicated by a NULL octet (0x00), and the following octets (to fill up 248 octets, which is the length of the parameter) do not have valid values.

7.7.8 Encryption Change Event

Event	Event Code	Event Parameters
Encryption Change	0x08	Status, Connection_Handle, Encryption_Enabled

Description:

The Encryption Change event is used to indicate that the change of the encryption mode has been completed. The Connection_Handle will be a Connection_Handle for an ACL connection and is used to identify the remote device. The Encryption_Enabled event parameter specifies the new Encryption_Enabled parameter for the Connection_Handle specified by the Connection_Handle event parameter. This event will occur on both devices to notify the Hosts when Encryption has changed for all connections between the two devices. Note: This event shall not be generated if encryption is paused or resumed; during a role switch, for example.

The meaning of the Encryption_Enabled parameter depends on whether the Host has indicated support for Secure Connections in the Secure_Connections_Host_Support parameter. When Secure_Connections_Host_Support is ‘disabled’ or the Connection_Handle refers to an LE link, the Controller shall only use Encryption_Enabled values 0x00 (OFF) and 0x01 (ON). When Secure_Connections_Host_Support is ‘enabled’ and the Connection_Handle refers to a BR/EDR link, the Controller shall set Encryption_Enabled to 0x00 when encryption is off, to 0x01 when encryption is on and using E0 and to 0x02 when encryption is on and using AES-CCM.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Encryption Change has occurred.
0x01-0xFF	Encryption Change failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Encryption_Enabled: *Size: 1 Octet*

Value	Parameter Description
0x00	Link Level Encryption is OFF.
0x01	Link Level Encryption is ON with E0 for BR/EDR. Link Level Encryption is ON with AES-CCM for LE.
0x02	Link Level Encryption is ON with AES-CCM for BR/EDR.
All other values	Reserved for future use.

7.7.9 Change Connection Link Key Complete Event

Event	Event Code	Event Parameters
Change Connection Link Key Complete	0x09	Status, Connection_Handle

Description:

The Change Connection Link Key Complete event is used to indicate that the change in the Link Key for all connections to a given remote BR/EDR Controller has been completed.

The Connection_Handle will be a Connection_Handle for an ACL connection to the remote Controller. The Change Connection Link Key Complete event is sent only to the Host which issued the Change_Connection_Link_Key command.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Change_Connection_Link_Key command succeeded.
0x01-0xFF	Change_Connection_Link_Key command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.10 Master Link Key Complete Event

Event	Event Code	Event Parameters
Master Link Key Complete	0x0A	Status, Connection_Handle, Key_Flag

Description:

The Master Link Key Complete event is used to indicate that the Link Key managed by the master of the piconet has been changed. The Connection_Handle will be a Connection_Handle for an ACL connection within that piconet. The link key used for the connection will be the temporary link key of the master device or the semi-permanent link key indicated by the Key_Flag. The Key_Flag event parameter is used to indicate which Link Key (temporary link key of the Master, or the semi-permanent link keys) is now being used in the piconet.

Note: For a master, the change from a semi-permanent Link Key to temporary Link Key will affect all Connection_Handles related to the piconet. For a slave, this change affects only this particular Connection_Handle. A temporary link key must be used when both broadcast and point-to-point traffic shall be encrypted.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Master_Link_Key command succeeded.
0x01-0xFF	Master_Link_Key command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Key_Flag: *Size: 1 Octet*

Value	Parameter Description
0x00	Using Semi-permanent Link Key.
0x01	Using Temporary Link Key.

7.7.11 Read Remote Supported Features Complete Event

Event	Event Code	Event Parameters
Read Remote Supported Features Complete	0x0B	Status, Connection_Handle, LMP_Features

Description:

The Read Remote Supported Features Complete event is used to indicate the completion of the process of the Link Manager obtaining the supported features of the remote BR/EDR Controller specified by the Connection_Handle event parameter. The Connection_Handle will be a Connection_Handle for an ACL connection. The event parameters include a list of LMP features. For details see [Vol 2] Part C, Link Manager Protocol Specification.

Note: If the features are requested more than once while a connection exists between the two devices, the second and subsequent requests may report a cached copy of the features rather than fetching the feature mask again.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Remote_Supported_Features command succeeded.
0x01-0xFF	Read_Remote_Supported_Features command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

LMP_Features: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXX XXXXXXXX	Bit Mask List of LMP features. See [Vol 2] Part C, Link Manager Protocol Specification.

7.7.12 Read Remote Version Information Complete Event

Event	Event Code	Event Parameters
Read Remote Version Information Complete	0x0C	Status, Connection_Handle, Version, Manufacturer_Name, Subversion

Description:

The Read Remote Version Information Complete event is used to indicate the completion of the process obtaining the version information of the remote Controller specified by the Connection_Handle event parameter. The Connection_Handle shall be for an ACL connection.

The Version event parameter defines the specification version of the BR/EDR or LE Controller. The Manufacturer_Name event parameter indicates the manufacturer of the remote Controller. The Subversion event parameter is controlled by the manufacturer and is implementation dependent. The Subversion event parameter defines the various revisions that each version of the Bluetooth hardware will go through as design processes change and errors are fixed. This allows the software to determine what Bluetooth hardware is being used and, if necessary, to work around various bugs in the hardware.

When the Connection_Handle is associated with a BR/EDR ACL-U logical link, the Version event parameter shall be LMP VersNr parameter, the Manufacturer_Name event parameter shall be the CompId parameter, and the Subversion event parameter shall be the LMP SubVersNr parameter.

When the Connection_Handle is associated with an LE-U logical link, the Version event parameter shall be Link Layer VersNr parameter, the Manufacturer_Name event parameter shall be the CompId parameter, and the Subversion event parameter shall be the SubVersNr parameter.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Remote_Version_Information command succeeded.
0x01-0xFF	Read_Remote_Version_Information command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Version: *Size: 1 Octet*

Value	Parameter Description
0xXX	Version of the Current LMP in the remote Controller. See LMP VersNr and Link LayerVersNr in the Bluetooth Assigned Numbers.

Manufacturer_Name: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Manufacturer Name of the remote Controller. See CompId in the Bluetooth Assigned Numbers.

Subversion: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Subversion of the LMP in the remote Controller. See [Vol 2] Part C, Table 5.2 and [Vol 6] Part B, Section 2.4.2.13(SubVersNr).

7.7.13 QoS Setup Complete Event

Event	Event Code	Event Parameters
QoS Setup Complete	0x0D	Status, Connection_Handle, Flags, Service_Type, Token_Rate, Peak_Bandwidth, Latency, Delay_Variation

Description:

The QoS Setup Complete event is used to indicate the completion of the process of the Link Manager setting up QoS with the remote BR/EDR Controller specified by the Connection_Handle event parameter. The Connection_Handle will be a Connection_Handle for an ACL connection. For more detail see [Vol 3] Part A, Logical Link Control and Adaptation Protocol Specification.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	QoS_Setup command succeeded.
0x01-0xFF	QoS_Setup command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Flags: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xFF	Reserved for future use.

Service_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	No Traffic Available.
0x01	Best Effort Available.
0x02	Guaranteed Available.
All other values	Reserved for future use.

Token_Rate: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Available Token Rate, in octets per s.

Peak_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Available Peak Bandwidth, in octets per s.

Latency: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Available Latency, in microseconds.

Delay_Variation: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Available Delay Variation, in microseconds.

7.7.14 Command Complete Event

Event	Event Code	Event Parameters
Command Complete	0x0E	Num_HCI_Command_Packets, Command_Opcode, Return_Parameters

Description:

The Command Complete event is used by the Controller for most commands to transmit return status of a command and the other event parameters that are specified for the issued HCI command.

The Num_HCI_Command_Packets event parameter allows the Controller to indicate the number of HCI command packets the Host can send to the Controller. If the Controller requires the Host to stop sending commands, the Num_HCI_Command_Packets event parameter will be set to zero. To indicate to the Host that the Controller is ready to receive HCI command packets, the Controller generates a Command Complete event with the Command_Opcode set to 0x0000 and the Num_HCI_Command_Packets event parameter set to 1 or more. Command_Opcode 0x0000 is a special value indicating that this event is not associated with a command sent by the Host. The Controller can send a Command Complete event with Command Opcode 0x0000 at any time to change the number of outstanding HCI command packets that the Host can send before waiting. See each command for the parameters that are returned by this event.

Event Parameters:

Num_HCI_Command_Packets: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	The Number of HCI command packets which are allowed to be sent to the Controller from the Host. Range for N: 0 – 255

Command_Opcode: *Size: 2 Octets*

Value	Parameter Description
0x0000	No associated command
0xXXXX	(non-zero) Opcode of the command which caused this event.

Return_Parameter(s): *Size: Depends on Command*

Value	Parameter Description
0xXX	This is the return parameter(s) for the command specified in the Command_Opcode event parameter. See each command's definition for the list of return parameters associated with that command.

7.7.15 Command Status Event

Event	Event Code	Event Parameters
Command Status	0x0F	Status, Num_HCI_Command_Packets, Command_Opcode

Description:

The Command Status event is used to indicate that the command described by the Command_Opcode parameter has been received, and that the Controller is currently performing the task for this command. This event is needed to provide mechanisms for asynchronous operation, which makes it possible to prevent the Host from waiting for a command to finish. If the command cannot begin to execute (a parameter error may have occurred, or the command may currently not be allowed), the Status event parameter will contain the corresponding error code, and no complete event will follow since the command was not started. The Num_HCI_Command_Packets event parameter allows the Controller to indicate the number of HCI command packets the Host can send to the Controller. If the Controller requires the Host to stop sending commands, the Num_HCI_Command_Packets event parameter will be set to zero. To indicate to the Host that the Controller is ready to receive HCI command packets, the Controller generates a Command Status event with Status 0x00 and Command_Opcode 0x0000 and the Num_HCI_Command_Packets event parameter set to 1 or more. Command_Opcode 0x0000 is a special value indicating that this event is not associated with a command sent by the Host. The Controller can send a Command Status event with Command Opcode 0x0000 at any time to change the number of outstanding HCI command packets that the Host can send before waiting.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Command currently in pending.
0x01-0xFF	Command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Num_HCI_Command_Packets: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	The Number of HCI command packets which are allowed to be sent to the Controller from the Host. Range for N: 0 – 255

Command_Opcode: *Size: 2 Octets*

Value	Parameter Description
0x0000	No associated command
0xXXXX	(non-zero) Opcode of the command which caused this event and is pending completion.

7.7.16 Hardware Error Event

Event	Event Code	Event Parameters
Hardware Error	0x10	Hardware_Code

Description:

The Hardware Error event is used to notify the Host that a hardware failure has occurred in the Controller.

Event Parameters:

Hardware_Code: *Size: 1 Octet*

Value	Parameter Description
0x00-0xFF	These Hardware_Codes will be implementation-specific, and can be assigned to indicate various hardware problems.

7.7.17 Flush Occurred Event

Event	Event Code	Event Parameters
Flush Occurred	0x11	Handle

Description:

The Flush Occurred event is used to indicate that, for the specified Handle, the current user data to be transmitted has been removed. The Handle shall be a Connection_Handle for a BR/EDR LE ACL connection or a Logical_Link_Handle for an AMP ACL connection. This could result from the Flush command, or be due to the automatic flush. Multiple blocks of an L2CAP packet could have been pending in the Controller. If one baseband packet part of an L2CAP PDU is flushed, then the rest of the HCI data packets for the L2CAP PDU must also be flushed.

Event Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Handle that was flushed. The Handle is a Connection_Handle for a Primary Controller or a Logical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.18 Role Change Event

Event	Event Code	Event Parameters
Role Change	0x12	Status, BD_ADDR, New_Role

Description:

The Role Change event is used to indicate that the current role of the BR/EDR Controller related to the particular connection has changed. This event only occurs when both the remote and local BR/EDR Controllers have completed their role change for the BR/EDR Controller associated with the BD_ADDR event parameter. This event allows both affected Hosts to be notified when the Role has been changed.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Role change has occurred.
0x01-0xFF	Role change failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Device for which a role change has completed.

New_Role: *Size: 1 Octet*

Value	Parameter Description
0x00	Currently the Master for specified BD_ADDR.
0x01	Currently the Slave for specified BD_ADDR.

7.7.19 Number Of Completed Packets Event

Event	Event Code	Event Parameters
Number Of Completed Packets	0x13	Number_of_Handles, Connection_Handle[i], HC_Num_Of_Completed_Packets[i]

Description:

The Number Of Completed Packets event is used by the Controller to indicate to the Host how many HCI Data Packets have been completed (transmitted or flushed) for each Connection_Handle since the previous Number Of Completed Packets event was sent to the Host. This means that the corresponding buffer space has been freed in the Controller. Based on this information, and the HC_Total_Num_ACL_Data_Packets and HC_Total_Num_Synchronous_Data_Packets return parameter of the Read_Buffer_Size command, the Host can determine for which Connection_Handles the following HCI Data Packets should be sent to the Controller. The Number Of Completed Packets event shall not specify a given Connection_Handle before the Connection Complete event for the corresponding connection or after an event indicating disconnection of the corresponding connection. While the Controller has HCI data packets in its buffer, it must keep sending the Number Of Completed Packets event to the Host at least periodically, until it finally reports that all the pending ACL Data Packets have been transmitted or flushed. The rate with which this event is sent is manufacturer specific.

Note: Number Of Completed Packets events will not report on synchronous Connection_Handles if synchronous Flow Control is disabled. (See Section 7.3.36 and Section 7.3.37.)

Event Parameters:

Number_of_Handles: *Size: 1 Octet*

Value	Parameter Description
0xXX	The number of Connection_Handles and Num_HCI_Data_Packets parameters pairs contained in this event. Range: 0-255

*Connection_Handle[i]: Size: Number_of_Handles * 2 Octets(12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle. Range: 0x0000-0x0EFF (all other values reserved for future use)

*HC_Num_Of_Completed_Packets [i]: Size: Number_of_Handles * 2 Octets*

Value	Parameter Description
N = 0xXXXX	The number of HCI Data Packets that have been completed (transmitted or flushed) for the associated Connection_Handle since the previous time the event was returned. Range for N: 0x0000-0xFFFF

7.7.20 Mode Change Event

Event	Event Code	Event Parameters
Mode Change	0x14	Status, Connection_Handle, Current_Mode, Interval

Description:

The Mode Change event is used to indicate when the device associated with the Connection_Handle changes between Active mode, Hold mode, and Sniff mode. The Connection_Handle will be a Connection_Handle for an ACL connection. The Connection_Handle event parameter is used to indicate which connection the Mode Change event is for. The Current_Mode event parameter is used to indicate which state the connection is currently in. The Interval parameter is used to specify a time amount specific to each state. Each Controller that is associated with the Connection_Handle which has changed Modes shall send the Mode Change event to its Host.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	A Mode Change has occurred.
0x01-0xFF	Hold_Mode, Sniff_Mode, or Exit_Sniff_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets(12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle. Range: 0x0000-0x0EFF (all other values reserved for future use)

Current_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	Active Mode.
0x01	Hold Mode.
0x02	Sniff Mode.
All other values	Reserved for future use.

Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Hold: Number of Baseband slots to wait in Hold Mode. Hold Interval = N * 0.625 ms (1 Baseband slot) Range for N: 0x0002-0xFFFE Time Range: 1.25 ms-40.9 s Sniff: Number of Baseband slots between sniff anchor points. Time between sniff anchor points = N * 0.625 ms (1 Baseband slot)Range for N: 0x0002-0xFFFE Time Range: 1.25 ms-40.9 s

7.7.21 Return Link Keys Event

Event	Event Code	Event Parameters
Return Link Keys	0x15	Num_Keys, BD_ADDR [i], Link_Key[i]

Description:

The Return Link Keys event is used by the BR/EDR Controller to send the Host the BD_ADDRs associated with one or more stored Link Keys. Zero or more instances of this event will occur after the Read_Stored_Link_Key command. When there are no link keys stored, no Return Link Keys events shall be returned. When there are link keys stored, the number of link keys returned in each Return Link Keys event is implementation specific. This event shall never return the value of the link keys. The link keys value parameter shall always contain the value of zero.

Event Parameters:

Num_Keys: *Size: 1 Octet*

Value	Parameter Description
0xXX	Number of Link Keys contained in this event. Range: 0x01 – 0x0B

BD_ADDR [i]: *Size: 6 Octets * Num_Keys*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR for the associated Link Key.

Link_Key[i]: *Size:16 Octets * Num_Keys*

Value	Parameter Description
0x00000000000000000000000000000000	Shall be zero.

7.7.22 PIN Code Request Event

Event	Event Code	Event Parameters
PIN Code Request	0x16	BD_ADDR

Description:

The PIN Code Request event is used to indicate that a PIN code is required to create a new link key. The Host shall respond using either the PIN_Code_Request_Reply or the PIN_Code_Request_Negative_Reply command, depending on whether the Host can provide the Controller with a PIN code or not.

Note: If the PIN Code Request event is masked away, then the BR/EDR Controller will assume that the Host has no PIN Code.

When the BR/EDR Controller generates a PIN Code Request event in order for the local Link Manager to respond to the request from the remote Link Manager (as a result of a Create_Connection or Authentication_Requested command from the remote Host), the local Host must respond with either a PIN_Code_Request_Reply or PIN_Code_Request_Negative_Reply command before the remote Link Manager detects LMP response timeout. (See [Vol 2] Part C, Link Manager Protocol Specification.)

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Device which a new link key is being created for.

7.7.23 Link Key Request Event

Event	Event Code	Event Parameters
Link Key Request	0x17	BD_ADDR

Description:

The Link Key Request event is used to indicate that a Link Key is required for the connection with the device specified in BD_ADDR. If the Host has the requested stored Link Key, then the Host shall pass the requested Key to the Controller using the Link_Key_Request_Reply command. If the Host does not have the requested stored Link Key, or the stored Link Key does not meet the security requirements for the requested service, then the Host shall use the Link_Key_Request_Negative_Reply command to indicate to the Controller that the Host does not have the requested key.

Note: If the Link Key Request event is masked away, then the BR/EDR Controller will assume that the Host has no additional link keys.

If the Host uses the Link_Key_Request_Negative_Reply command when the requested service requires an authenticated Link Key and the current Link Key is unauthenticated, the Host should set the Authentication_Requirements parameter one of the MITM Protection Required options.

When the Controller generates a Link Key Request event in order for the local Link Manager to respond to the request from the remote Link Manager (as a result of a Create_Connection or Authentication_Requested command from the remote Host), the local Host must respond with either a Link_Key_Request_Reply or Link_Key_Request_Negative_Reply command before the remote Link Manager detects LMP response timeout. (See [Vol 2] Part C, Link Manager Protocol Specification.)

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Device which a stored link key is being requested.

7.7.24 Link Key Notification Event

Event	Event Code	Event Parameters
Link Key Notification	0x18	BD_ADDR, Link_Key, Key_Type

Description:

The Link Key Notification event is used to indicate to the Host that a new Link Key has been created for the connection with the device specified in BD_ADDR. The Host can save this new Link Key in its own storage for future use. Also, the Host can decided to store the Link Key in the BR/EDR Controller's Link Key Storage by using the Write_Stored_Link_Key command. The Key_Type event parameter informs the Host about which key type (combination key, local unit key, or remote unit key, debug combination key, unauthenticated combination key, authenticated combination key or changed combination key) that was used during pairing. If pairing with unit key is not supported, the Host can for instance discard the key or disconnect the link.

The combination key Key_Type is used when standard pairing was used. The debug combination key Key_Type is used when Simple Pairing was used and the debug public key is sent or received. The unauthenticated combination key Key_Type is used when the Just Works Simple Pairing association model was used. The authenticated combination key Key_Type is used when Simple Pairing was used and the Just Works association mode was not used. The changed combination key Key_Type is used when the link key has been changed using the Change Connection Link Key procedure and Simple Pairing Mode is set to enabled. Note: It is the responsibility of the Host to remember the Key_Type (combination, debug combination, unauthenticated combination, or authenticated combination) prior to changing the link key.

When the unauthenticated or authenticated combination key Key_Type is used, the Controller shall use values 0x04 and 0x05 to indicate keys created with the P-192 elliptic curve and values 0x07 through 0x08 to indicate keys created with the P-256 elliptic curve. The values 0x07 and 0x08 shall only be used when the Host has indicated support for Secure Connections in the Secure_Connections_Host_Support parameter.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Device for which the new link key has been generated.

Link_Key: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	Link Key for the associated BD_ADDR.

Key_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Combination Key
0x01	Local Unit Key
0x02	Remote Unit Key
0x03	Debug Combination Key
0x04	Unauthenticated Combination Key generated from P-192
0x05	Authenticated Combination Key generated from P-192
0x06	Changed Combination Key
0x07	Unauthenticated Combination Key generated from P-256
0x08	Authenticated Combination Key generated from P-256
All other values	Reserved for future use

7.7.25 Loopback Command Event

Event	Event Code	Event Parameters
Loopback Command	0x19	HCI_Command_Packet

Description:

When in Local Loopback mode, the BR/EDR Controller loops back commands and data to the Host. The Loopback Command event is used to loop back all commands that the Host sends to the Controller with some exceptions. See Section 7.6.1 for a description of which commands that are not looped back. The HCI_Command_Packet event parameter contains the entire HCI Command Packet including the header.

Note: The event packet is limited to a maximum of 255 octets in the payload; since an HCI Command Packet has 3 octets of header data, only the first 252 octets of the command parameters will be returned.

Event Parameters:

HCI_Command_Packet: *Size: Depends on Command*

Value	Parameter Description
0xXXXXXX	HCI Command Packet, including header.

7.7.26 Data Buffer Overflow Event

Event	Event Code	Event Parameters
Data Buffer Overflow	0x1A	Link_Type

Description:

This event is used to indicate that the Controller's data buffers have been overflowed. This can occur if the Host has sent more packets than allowed. The Link_Type parameter is used to indicate that the overflow was caused by ACL or synchronous data.

Event Parameters:

Link_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Synchronous Buffer Overflow (Voice Channels).
0x01	ACL Buffer Overflow (Data Channels).
All other values	Reserved for future use.

7.7.27 Max Slots Change Event

Event	Event Code	Event Parameters
Max Slots Change	0x1B	Connection_Handle, LMP_Max_Slots

Description:

This event is used to notify the Host about the LMP_Max_Slots parameter when the value of this parameter changes. It shall be sent each time the maximum allowed length, in number of slots, for baseband packets transmitted by the local device, changes. The Connection_Handle will be a Connection_Handle for an ACL connection.

Event Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle. Range: 0x0000-0x0EFF (all other values reserved for future use)

LMP_Max_Slots: *Size: 1 octet*

Value	Parameter Description
0x01, 0x03, 0x05	Maximum number of slots allowed to use for baseband packets, see [Vol 2] Part C, Section 4.1.10 and Section 5.2.

7.7.28 Read Clock Offset Complete Event

Event	Event Code	Event Parameters
Read Clock Offset Complete	0x1C	Status, Connection_Handle, Clock_Offset

Description:

The Read Clock Offset Complete event is used to indicate the completion of the process of the Link Manager obtaining the Clock Offset information of the BR/EDR Controller specified by the Connection_Handle event parameter. The Connection_Handle will be a Connection_Handle for an ACL connection.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Clock_Offset command succeeded.
0x01-0xFF	Read_Clock_Offset command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Clock_Offset: *Size: 2 Octets*

Bit format	Parameter Description
Bits 14-0	Bits 16-2 of CLKNslave-CLK
Bit 15	Reserved for Future Use.

7.7.29 Connection Packet Type Changed Event

Event	Event Code	Event Parameters
Connection Packet Type Changed	0x1D	Status, Connection_Handle, Packet_Type

Description:

The Connection Packet Type Changed event is used to indicate that the process has completed of the Link Manager changing which packet types can be used for the connection. This allows current connections to be dynamically modified to support different types of user data. The Packet_Type event parameter specifies which packet types the Link Manager can use for the connection identified by the Connection_Handle event parameter for sending L2CAP data or voice. The Packet_Type event parameter does not decide which packet types the LM is allowed to use for sending LMP PDUs.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection Packet Type changed successfully.
0x01-0xFF	Connection Packet Type Changed failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle. Range: 0x0000-0x0EFF (all other values reserved for future use)

Packet_Type: *Size: 2 Octets*

For ACL_Link_Type

Value	Parameter Description
0x0001	Reserved for future use.
0x0002	2-DH1 shall not be used.
0x0004	3-DH1 shall not be used.
0x0008[1]	DM1 may be used.
0x0010	DH1 may be used.
0x0020	Reserved for future use.
0x0040	Reserved for future use.

Value	Parameter Description
0x0080	Reserved for future use.
0x0100	2-DH3 shall not be used.
0x0200	3-DH3 shall not be used.
0x0400	DM3 may be used.
0x0800	DH3 may be used.
0x1000	2-DH5 shall not be used.
0x2000	3-DH5 shall not be used.
0x4000	DM5 may be used.
0x8000	DH5 may be used.

1. This bit will be interpreted as set to 1 by Bluetooth V1.2 or later Controllers.

For SCO_Link_Type

Value	Parameter Description
0x0001	Reserved for future use.
0x0002	Reserved for future use.
0x0004	Reserved for future use.
0x0008	Reserved for future use.
0x0010	Reserved for future use.
0x0020	HV1
0x0040	HV2
0x0080	HV3
0x0100	Reserved for future use.
0x0200	Reserved for future use.
0x0400	Reserved for future use.
0x0800	Reserved for future use.
0x1000	Reserved for future use.
0x2000	Reserved for future use.
0x4000	Reserved for future use.
0x8000	Reserved for future use.

7.7.30 QoS Violation Event

Event	Event Code	Event Parameters
QoS Violation	0x1E	Handle

Description:

The QoS Violation event is used to indicate the Controller is unable to provide the current QoS requirement for the Connection or Logical Link Handle. This event indicates that the Controller is unable to provide one or more of the agreed QoS parameters.

The Host chooses what action should be done. With a BR/EDR Controller the Host can reissue the QoS_Setup command to renegotiate the QoS setting for Connection_Handle. With an AMP Controller the Host can reissue the Flow_Spec_Modify command.

Event Parameters:

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Handle for the link that the Controller cannot provide the current QoS requested. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical_Link_Handle for an AMP Controller. Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.31 Page Scan Repetition Mode Change Event

Event	Event Code	Event Parameters
Page Scan Repetition Mode Change	0x20	BD_ADDR, Page_Scan_Repetition_Mode

Description:

The Page Scan Repetition Mode Change event indicates that the remote BR/EDR Controller with the specified BD_ADDR has successfully changed the Page_Scan_Repetition_Mode (SR).

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the remote device.

Page_Scan_Repetition_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	R0
0x01	R1
0x02	R2
0x03 – 0xFF	Reserved for Future Use.

7.7.32 Flow Specification Complete Event

Event	Event Code	Event Parameters
Flow Specification Complete	0x21	Status, Connection_Handle, Flags, Flow_direction, Service_Type, Token_Rate, Token_Bucket_Size, Peak_Bandwidth, Access Latency

Description:

The Flow Specification Complete event is used to inform the Host about the Quality of Service for the ACL connection the Controller is able to support. The Connection_Handle will be a Connection_Handle for an ACL connection. The flow parameters refer to the outgoing or incoming traffic of the ACL link, as indicated by the Flow_direction field. The flow parameters are defined in the L2CAP specification [Vol 3] Part A, Section 5.3. When the Status parameter indicates a successful completion, the flow parameters specify the agreed values by the Controller. When the Status parameter indicates a failed completion with the error code *QoS Unacceptable Parameters* (0x2C), the flow parameters specify the acceptable values of the Controller. This enables the Host to continue the 'QoS negotiation' with a new HCI Flow_Specification command with flow parameter values that are acceptable for the Controller. When the Status parameter indicates a failed completion with the error code *QoS Rejected* (0x2D), this indicates a request of the Controller to discontinue the 'QoS negotiation'. When the Status parameter indicates a failed completion, the flow parameter values of the most recently successful completion must be assumed (or the default values when there was no success completion).

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Flow_Specification command succeeded
0x01 – 0xFF	Flow_Specification command failed. See [Vol 2] Part D, Error Codes for list of Error Codes

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 - 0x0EFF (all other values reserved for future use)

Flags: *Size: 1 Octet)*

Value	Parameter Description
0x00 – 0xFF	Reserved for future use.

Flow_direction: *Size: 1 Octet*

Value	Parameter Description
0x00	Outgoing Flow i.e. traffic send over the ACL connection
0x01	Incoming Flow i.e. traffic received over the ACL connection
0x02 – 0xFF	Reserved for future use.

Service_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	No Traffic
0x01	Best Effort
0x02	Guaranteed
0x03 – 0xFF	Reserved for future use

Token Rate: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Token Rate in octets per s

Token Bucket Size: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Token Bucket Size in octets

Peak_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Peak Bandwidth in octets per s

Access Latency: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Access Latency in microseconds

7.7.33 Inquiry Result with RSSI Event

Event	Event Code	Event Parameters
Inquiry Result with RSSI	0x22	Num_responses, BD_ADDR[i], Page_Scan_Repetition_Mode[i], Reserved[i], Class_of_Device[i], Clock_Offset[i], RSSI[i]

Description:

The Inquiry Result with RSSI event indicates that a BR/EDR Controller or multiple BR/EDR Controllers have responded so far during the current Inquiry process. This event will be sent from the BR/EDR Controller to the Host as soon as an Inquiry Response from a remote device is received if the remote device supports only mandatory paging scheme. This BR/EDR Controller may queue these Inquiry Responses and send multiple BR/EDR Controllers information in one Inquiry Result event. The event can be used to return one or more Inquiry responses in one event. The RSSI parameter is measured during the FHS packet returned by each responding slave.

This event shall only be generated if the Inquiry Mode parameter of the last Write_Inquiry_Mode command was set to 0x01 (Inquiry Result format with RSSI), or was set to 0x02 (Inquiry Result with RSSI format or Extended Inquiry Result format) and the inquiry response packet had the EIR field set to 0.

Event Parameters:

Num_Responses: *Size: 1 Octet*

Value	Parameter Description
0xXX	Number of responses from the Inquiry.

BD_ADDR[i]: *Size: 6 Octets * Num_Responses*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR for each device which responded.

Page_Scan_Repetition_Mode[i]: *Size: 1 Octet* Num_Responses*

Value	Parameter Description
0x00	R0
0x01	R1
0x02	R2
0x03 – 0xFF	Reserved for Future Use

Reserved[i]:[1] *Size: 1 Octet* Num_Responses*

Value	Parameter Description
0xXX	Reserved for Future Use.

Class_of_Device[i]: *Size: 3 Octets * Num_Responses*

Value	Parameter Description
0xXXXXXX	Class of Device for the device

Clock_Offset[i]: *Size: 2 Octets * Num_Responses*

Bit format	Parameter Description
Bits 14-0	Bits 16-2 of CLKNslave-CLK
Bit 15	Reserved for Future Use

RSSI[i]: *Size: 1 Octet * Num_Responses*

Value	Parameter Description
0xXX	Range: -127 to +20 Units: dBm

1. This was the Page_Scan_Period_Mode parameter in the v1.1 specification. This parameter has no meaning in v1.2 or later and no default value.

7.7.34 Read Remote Extended Features Complete Event

Event	Event Code	Event Parameters
Read Remote Extended Features Complete	0x23	Status, Connection_Handle, Page_Number, Maximum page number, Extended_LMP_Features

Description:

The Read Remote Extended Features Complete event is used to indicate the completion of the process of the Link Manager obtaining the remote extended LMP features of the remote device specified by the Connection_Handle event parameter. The Connection_Handle will be a Connection_Handle for an ACL connection. The event parameters include a page of the remote devices extended LMP features. For details see [Vol 2] Part C, Link Manager Protocol Specification.

Note: If a feature page is requested more than once while a connection exists between the two devices, the second and subsequent requests may report a cached copy of that page rather than fetching it again.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Request for remote extended features succeeded
0x01-0xFF	Request for remote extended features failed. See [Vol 2] Part D, Error Codes for error codes.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	The Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Page Number: *Size: 1Octet*

Value	Parameter Description
0x00	The normal LMP features as returned by Read_Remote_Supported_Features command
0x01-0xFF	The page number of the features returned

Maximum Page Number: *Size: 1Octet*

Value	Parameter Description
0x00-0xFF	The highest features page number which contains non-zero bits for the remote device

Extended_LMP_Features: *Size: 8 Octets*

Value	Parameter Description
0xFFFFFFFFFFFFFFFF	Bit map of requested page of LMP features. See LMP [Vol 2] Part C, Section 3.3 for details.

7.7.35 Synchronous Connection Complete Event

Event	Event Code	Event Parameters
Synchronous Connection Complete	0x2C	Status, Connection_Handle, BD_ADDR, Link Type, Transmission_Interval, Retransmission Window, Rx_Packet_Length, Tx_Packet_Length Air Mode

Description:

The Synchronous Connection Complete event is sent to indicate completion of any of the following commands:

- Setup_Synchronous_Connection
- Accept_Synchronous_Connection_Request
- Reject_Synchronous_Connection_Request
- Enhanced_Setup_Synchronous_Connection
- Enhanced_Accept_Synchronous_Connection_Request

This event returns the completion status for the command.

When the Synchronous Connection Complete event was triggered by the Enhanced_Setup_Synchronous_Connection or Enhanced_Accept_Synchronous_Connection_Request commands, the Controller shall set the Air Mode parameter to the Transmit Air Coding Format parameter of the original command.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01 –0xFF	Connection failed to complete. See [Vol 2] Part D, Error Codes for error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the other connected device forming the connection.

Link_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	SCO Connection
0x01	Reserved for Future Use
0x02	eSCO Connection
0x03 – 0xFF	Reserved for Future Use

Transmission_Interval: *Size: 1 Octet*

Value	Parameter Description
0xXX	Time between two consecutive eSCO instants measured in slots. Must be zero for SCO links.

Retransmission window: *Size: 1 Octet*

Value	Parameter Description
0xXX	The size of the retransmission window measured in slots. Must be zero for SCO links.

Rx_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length in bytes of the eSCO payload in the receive direction. Must be zero for SCO links.

Tx_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length in bytes of the eSCO payload in the transmit direction. Must be zero for SCO links.

Air Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	μ-law log
0x01	A-law log
0x02	CVSD
0x03	Transparent Data
0x04 – 0xFF	Reserved for Future Use

7.7.36 Synchronous Connection Changed Event

Event	Event Code	Event Parameters
Synchronous Connection Changed	0x2D	Status, Connection_Handle, Transmission_Interval, Retransmission Window, Rx_Packet_Length, Tx_Packet_Length

Description:

The Synchronous Connection Changed event indicates to the Host that an existing synchronous connection has been reconfigured. This event also indicates to the initiating Host (if the change was Host initiated) if the issued command failed or was successful.

Command Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully reconfigured.
0x01 –0xFF	Reconfiguration failed to complete. See [Vol 2] Part D, Error Codes for error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Transmission_Interval: *Size: 1 Octet*

Value	Parameter Description
0xXX	Time between two consecutive SCO/eSCO instants measured in slots.

Retransmission window: *Size: 1 Octet*

Value	Parameter Description
0xXX	The size of the retransmission window measured in slots. Must be zero for SCO links.

Rx_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length in bytes of the SCO/eSCO payload in the receive direction.

Tx_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length in bytes of the SCO/eSCO payload in the transmit direction.

7.7.37 Sniff Subrating Event

Event	Event Code	Event Parameters
Sniff Subrating	0x2E	Status Connection_Handle Maximum_Transmit_Latency Maximum_Receive_Latency Minimum_Remote_Timeout Minimum_Local_Timeout

Description:

The Sniff Subrating event indicates that the device associated with the Connection_Handle has either enabled sniff subrating or the sniff subrating parameters have been renegotiated by the link manager. The Connection_Handle will be a Connection_Handle for an ACL connection. The Connection_Handle event parameter indicates which connection the Sniff Subrating event is for.

Each BR/EDR Controller that is associated with the Connection_Handle that has changed its subrating parameters will send the Sniff Subrating event to its Host.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Sniff_Subrating command succeeded
0x01 – 0xFF	Subrating command failed to complete. See [Vol 2] Part D, Error Codes for error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle. Range: 0x0000 – 0x0EFF (all other values reserved for future use)

Maximum_Transmit_Latency: *Size: 2 Octet*

Value	Parameter Description
N = 0xXXXX	Maximum latency for data being transmitted from the local device to the remote device. Latency = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFE Time Range: 0 s - 40.9 s

Maximum_Receive_Latency: *Size: 2 Octet*

Value	Parameter Description
N = 0xXXXX	Maximum latency for data being received by the local device from the remote device. Latency = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFE Time Range: 0 s - 40.9 s

Minimum_Remote_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	The base sniff subrate timeout in baseband slots that the remote device shall use. Timeout = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFE Time Range: 0 s – 40.9 s

Minimum_Local_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	The base sniff subrate timeout in baseband slots that the local device will use. Timeout = N * 0.625 ms (1 Baseband slot) Range for N: 0x0000 – 0xFFFE Time Range: 0 s – 40.9 s

7.7.38 Extended Inquiry Result Event

Event	Event Code	Event Parameters
Extended Inquiry Result	0x2F	Num_Responses, BD_ADDR, Page_Scan_Repetition_Mode, Reserved, Class_of_Device, Clock_Offset, RSSI, Extended_Inquiry_Response

Description:

The Extended Inquiry Result event indicates that a BR/EDR Controller has responded during the current inquiry process with extended inquiry response data. This event will be sent from the BR/EDR Controller to the Host upon reception of an Extended Inquiry Response from a remote device. One single Extended Inquiry Response is returned per event. This event contains RSSI and inquiry response data for the BR/EDR Controller that responded to the latest inquiry. The RSSI parameter is measured during the FHS packet returned by each responding slave. The Num_Responses parameter shall be set to one.

This event is only generated if the Inquiry_Mode parameter of the last Write_Inquiry_Mode command was set to 0x02 (Inquiry Result with RSSI format or Extended Inquiry Result format).

Note: This ensures that a Host that does not support Extended Inquiry Results will never receive the Extended Inquiry Result event.

If an inquiry response packet with the EIR field set to zero is received, the Inquiry Result with RSSI event format shall be used. If the EIR bit is set to one the Extended Inquiry Result event format shall be used. If the EIR bit is set to one but the Controller failed to receive the extended inquiry response packet, the Extended_Inquiry_Response parameter is set to zeros. If an extended inquiry response packet from the same device is correctly received in a later response, another event shall be generated.

Note: The only difference between the Extended Inquiry Result event and the Inquiry Result with RSSI event is the additional Extended_Inquiry_Response parameter.

Note: The Extended_Inquiry_Response parameter is not interpreted by the Controller. The tagged data set by the other Host should be passed unaltered if it has been correctly received.

Event Parameters:

Num_Responses: *Size: 1 Octet*

Value	Parameter Description
0x01	Number of responses from the inquiry. The Extended Inquiry Result event always contains a single response.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR for the device that responded.

Page_Scan_Repetition_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	R0
0x01	R1
0x02	R2
All other values	Reserved for future use

Reserved: *Size: 1 Octet*

Value	Parameter Description
0xXX	Reserved for Future Use.

Class_of_Device: *Size: 3 Octets*

Value	Parameter Description
0xXXXXXX	Class of Device for the device that responded.

Clock_Offset *Size: 2 Octets*

Value	Parameter Description
Bits 14-0	Bits 16-2 of CLKNslave-CLK
Bit 15	Reserved for Future Use.

RSSI: *Size: 1 Octet*

Value	Parameter Description
0xXX	Range: -127 to +20
	Units: dBm

Extended_Inquiry_Response: *Size: 240 Octets*

Value	Parameter Description
	Extended Inquiry Response data as defined in [Vol 3] Part C, Section 8

7.7.39 Encryption Key Refresh Complete Event

Command	Event Code	Event Parameters
Encryption Key Refresh Complete	0x30	Status, Connection_Handle

Description:

The Encryption Key Refresh Complete event is used to indicate to the Host that the encryption key was refreshed on the given Connection_Handle any time encryption is paused and then resumed. The BR/EDR Controller shall send this event when the encryption key has been refreshed due to encryption being started or resumed.

If the Encryption Key Refresh Complete event was generated due to an encryption pause and resume operation embedded within a change connection link key procedure, the Encryption Key Refresh Complete event shall be sent prior to the Change Connection Link Key Complete event.

If the Encryption Key Refresh Complete event was generated due to an encryption pause and resume operation embedded within a role switch procedure, the Encryption Key Refresh Complete event shall be sent prior to the Role Change event.

Event parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Encryption Key Refresh completed successfully
0x01 - 0xFF	Encryption Key Refresh failed. See [Vol 2] Part D, Error Codes for list of Error Codes

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use).

7.7.40 IO Capability Request Event

Event	Event Code	Event Parameters
IO Capability Request	0x31	BD_ADDR

Description:

The IO Capability Request event is used to indicate that the IO capabilities of the Host are required for a simple pairing process. The Host shall respond with an IO_Capability_Request_Reply command. This event shall only be generated if simple pairing has been enabled with the Write_Simple_Pairing_Mode command.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of remote device involved in simple pairing process

7.7.41 IO Capability Response Event

Event	Event Code	Event Parameters
IO Capability Response	0x32	BD_ADDR, IO_Capability, OOB_Data_Present, Authentication_Requirements

Description:

The IO Capability Response event is used to indicate to the Host that IO capabilities from a remote device specified by BD_ADDR have been received during a simple pairing process. This event will only be generated if simple pairing has been enabled with the Write_Simple_Pairing_Mode command.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR identifying the device to which the IO capabilities apply.

IO_Capability: *Size: 1 Octet*

Value	Parameter Description
0x00	DisplayOnly
0x01	DisplayYesNo
0x02	KeyboardOnly
0x03	NoInputNoOutput
0x04 – 0xFF	Reserved for future use

OOB_Data_Present: *Size: 1 Octet*

Value	Parameter Description
0x00	OOB authentication data not present
0x01	OOB authentication data from remote device present
0x02 – 0xFF	Reserved for future use

Authentication_Requirements: *Size: 1 Octet*

Value	Parameter Description
0x00	MITM Protection Not Required – No Bonding. Numeric comparison with automatic accept allowed.

Value	Parameter Description
0x01	MITM Protection Required – No Bonding. Use IO Capabilities to determine authentication procedure
0x02	MITM Protection Not Required – Dedicated Bonding. Numeric comparison with automatic accept allowed.
0x03	MITM Protection Required – Dedicated Bonding. Use IO Capabilities to determine authentication procedure
0x04	MITM Protection Not Required – General Bonding. Numeric Comparison with automatic accept allowed.
0x05	MITM Protection Required – General Bonding. Use IO capabilities to determine authentication procedure.
All other values	Reserved for future use

7.7.42 User Confirmation Request Event

Event	Event Code	Event Parameters
User Confirmation Request	0x33	BD_ADDR, Numeric_Value

Description:

The User Confirmation Request event is used to indicate that user confirmation of a numeric value is required. The Host shall reply with either the User_Confirmation_Request_Reply or the User_Confirmation_Request_Negative_Reply command. If the Host has output capability (DisplayYesNo or KeyboardOnly), it shall display the Numeric_Value until the Simple Pairing Complete event is received. It shall reply based on the yes/no response from the user. If the Host has no input and no output it shall reply with the User Confirmation Request Reply command. When the Controller generates a User Confirmation Request event, in order for the local Link Manager to respond to the request from the remote Link Manager, the local Host must respond with either a User_Confirmation_Request_Reply or a User_Confirmation_Request_Negative_Reply command before the remote Link Manager detects LMP response timeout. (See [Vol 2] Part C, Link Manager Protocol Specification.)

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of device involved in Simple Pairing process.

Numeric_Value: *Size: 4 Octets*

Value	Parameter Description
0x00000000 – 0x000F423F	Numeric value to be displayed. Valid values are decimal 000000 – 999999.

7.7.43 User Passkey Request Event

Event	Event Code	Event Parameters
User Passkey Request	0x34	BD_ADDR

Description:

The User Passkey Request event is used to indicate that a passkey is required as part of a Simple Pairing process. The Host shall respond with either a User_Passkey_Request_Reply or User_Passkey_Request_Negative_Reply command. This event will only be generated if simple pairing has been enabled with the Write_Simple_Pairing_Mode command. When the Controller generates a User Passkey Request event, in order for the local Link Manager to respond to the request from the remote Link Manager, the local Host must respond with either a User_Passkey_Request_Reply or User_Passkey_Request_Negative_Reply command before the remote Link Manager detects LMP response timeout. (See [Vol 2] Part C, Link Manager Protocol Specification.)

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the device involved in simple pairing process.

7.7.44 Remote OOB Data Request Event

Event	Event Code	Event Parameters
Remote OOB Data Request	0x35	BD_ADDR

Description:

The Remote OOB Data Request event is used to indicate that the Simple Pairing Hash C and the Simple Pairing Randomizer R is required for the Secure Simple Pairing process involving the device identified by BD_ADDR. The C and R values were transferred to the Host from the remote device via an OOB mechanism. This event is sent by the Controller because the Host previously set the OOB Data Present parameter to "OOB authentication data from remote device present" in an IO Capability Request Reply command. If both the Host and Controller support Secure Connections the Host shall respond with the Remote OOB Extended Data Request Reply command. Otherwise, the Host shall respond with the Remote OOB Data Request Reply command.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the device from which the C and R values were received.

7.7.45 Simple Pairing Complete Event

Event	Event Code	Event Parameters
Simple Pairing Complete	0x36	Status, BD_ADDR

Description:

The Simple Pairing Complete event is used to indicate that the simple pairing process has completed. A Host that is displaying a numeric value can use this event to change its UI.

When the LMP simple pairing sequences fail for any reason, the Simple Pairing Complete event shall be sent to the Host. When Simple Pairing Complete event is sent in response to the IO capability exchange failing, the Status parameter shall be set to the error code received from the remote device. Otherwise, the Status shall be set to the error code *Authentication Failure* (0x05).

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Simple Pairing succeeded
0x01 - 0xFF	Simple Pairing failed. See [Vol 2] Part D, Error Codes for a list of Error Codes.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the device involved in simple pairing process.

7.7.46 Link Supervision Timeout Changed Event

Event	Event Code	Event Parameters
Link Supervision Timeout Changed	0x38	Connection_Handle, Link_Supervision_Timeout

Description:

The Link Supervision Timeout Changed event is used to notify the slave's Host when the Link_Supervision_Timeout parameter is changed in the slave Controller. This event shall only be sent to the Host by the slave Controller upon receiving an LMP_supervision_timeout PDU from the master.

Note: The Connection_Handle used for this command shall be the ACL connection of the appropriate device.

Event Parameters:

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Link_Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Measured in Number of Baseband slots Link_Supervision_Timeout = N*0.625 ms (1 Baseband slot) Range for N: 0x0001 - 0xFFFF Time Range: 0.625ms - 40.9 s (0 means infinite timeout)

7.7.47 Enhanced Flush Complete Event

Event	Event Code	Event parameter
Enhanced Flush Complete	0x39	Handle

Description:

The Enhanced Flush Complete event is used to indicate that an Enhanced Flush is complete for the specified Handle.

Event Parameters:

Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Handle of the link for which Controller cannot provide the requested QoS. The Handle is a Connection_Handle for a BR/EDR Controller and a Logical_Link_Handle for an AMP Controller. Range: 0x0000 - 0x0EFF (all other values reserved for future use)

7.7.48 User Passkey Notification Event

Event	Event Code	Event Parameters
User Passkey Notification	0x3B	BD_ADDR, Passkey

Description:

The User Passkey Notification event is used to provide a passkey for the Host to display to the user as required as part of a Simple Pairing process. The Passkey parameter shall be a randomly generated number (see [Vol 2] Part H, Section 2) generated by the Controller modulo 1,000,000.

This event will be generated if the IO capabilities of the local device are DisplayOnly or DisplayYesNo and the IO capabilities of the remote device are KeyboardOnly.

This event shall only be generated if simple pairing has been enabled with the Write_Simple_Pairing_Mode command.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the device involved in simple pairing process.

Passkey: *Size: 4 Octets*

Value	Parameter Description
0x00000000 - 0x000F423F	Passkey to be displayed. Valid values are decimal 000000 - 999999.

7.7.49 Keypress Notification Event

Command	Event Code	Event Parameters
Keypress Notification	0x3C	BD_ADDR, Notification_Type

Description:

The Keypress Notification event is sent to the Host after a passkey notification has been received by the Link Manager on the given BD_ADDR. The Notification_Type parameter may be used by the Host's user interface.

Event parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of remote device involved in simple pairing process

Notification_Type: *Size: 1 Octet*

Value	Parameter Description
0	Passkey entry started
1	Passkey digit entered
2	Passkey digit erased
3	Passkey cleared
4	Passkey entry completed
5-255	Reserved for future use

7.7.50 Remote Host Supported Features Notification Event

Command	Event Code	Event Parameters
Remote Host Supported Features Notification	0x3D	BD_ADDR, Host_Supported_Features

Description:

The Remote Host Supported Features Notification event is used to return the LMP extended features page containing the Host features. The BD_ADDR shall be the address of the remote device.

This event shall only be generated after the LMP extended features are read from the remote device during a connection initiated by a Remote Name Request command.

Note: This event is not generated during a connection initiated by the Create_Connection command.

Event parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of remote device.

Host_Supported_Features: *Size: 8 Octets*

Value	Parameter Description
0xFFFFFFFFFFFFFFFF	Bit map of Host Supported Features page of LMP extended features. For more information, see [Vol 2] Part C, Link Manager Protocol Specification.

7.7.51 Physical Link Complete Event

Event	Event Code	Event Parameters
Physical Link Complete	0x40	Status, Physical_Link_Handle

Description:

The Physical Link Complete event indicates to the Host that a new AMP physical link has been established. This event is used as a response for either Create_Physical_Link or Accept_Physical_Link commands and is preceded by a Command Status event.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01-0xFF	Connection failed to Complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle identifying the physical link which has been created.

7.7.52 Channel Selected Event

Event	Event Code	Event Parameters
Channel Selected	0x41	Physical_Link_Handle

Description:

The Channel Selected event indicates to the Host originating the physical link that the link information data is available to be read using the Read Local AMP Assoc command. This allows the originating device to determine link implementation parameters such as an underlying physical channel choice. This structure shall be sent in the AMP Create Physical Link Request (see [Vol 3] Part E, Section 3.11]) and be used at the remote end in the Accept_Physical_Link command.

Event Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle to the established physical link.

7.7.53 Disconnection Physical Link Complete Event

Event	Event Code	Event Parameters
Disconnection Physical Link Complete	0x42	Status, Physical_Link_Handle, Reason

Description:

The Disconnection Physical Link Complete event occurs when a physical link is terminated. The status parameter indicates if the disconnection was successful or not.

When a physical link fails, one Disconnection Logical Link Complete event will be returned for each logical channel on the physical link with the corresponding Logical_Link_Handle as a parameter.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Disconnection has occurred.
0x01-0xFF	Disconnection failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle which was disconnected.

Reason: *Size: 1 Octet*

Value	Parameter Description
0xXX	Reason for disconnection. See [Vol 2] Part D, Error Codes for error codes and descriptions.

7.7.54 Physical Link Loss Early Warning Event

Event	Event Code	Event Parameters
Physical Link Loss Early Warning	0x43	Physical_Link_Handle, Link_Loss_Reason

Description:

The Physical Link Loss Early Warning event occurs when a physical link has early indication that the link may be disrupted. Data transmission and reception may suffer impairment on this link. The Host may use this to indicate to the user that traffic may be disrupted.

The exact low level meaning is dependent on the AMP type. Some AMP types may never generate this event.

Event Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle to which the warning refers.

Link_Loss_Reason: *Size: 1 Octet*

Value	Parameter Description
0	Unknown
1	Range related
2	Bandwidth related
3	Resolving conflict
4	Interference
5-255	Reserved for Future Use

7.7.55 Physical Link Recovery Event

Event	Event Code	Event Parameters
Physical Link Recovery	0x44	Physical_Link_Handle

Description:

The Physical Link Recovery event indicates that whatever interruption caused an earlier Physical Link Loss Early Warning event has now been cleared. The normal data transmission and reception service can be expected. The exact low level meaning is dependent on the AMP type. The Host may use this event to cancel any indication to the user caused by the Physical Link Loss Early Warning event.

Event Parameters:

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle to which the warning referred.

7.7.56 Logical Link Complete Event

Event	Event Code	Event Parameters
Logical Link Complete	0x45	Status, Logical_Link_Handle, Physical_Link_Handle, TX_Flow_Spec_ID

Description:

The Logical Link Complete event indicates to both of the Hosts forming the connection whether a new connection has been established successfully.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01-0xFF	Connection failed to Complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Logical_Link_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Logical_Link_Handle to be used to identify a connection between two BR/EDR Controllers with communicating AMPs. The Logical_Link_Handle is used as an identifier for transmitting and receiving data. Range: 0x0000-0x0EFF (all other values reserved for future use)

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link identifying the physical link over which the logical link has been created.

TX_Flow_Spec_ID: *Size: 1 Octet*

Value	Parameter Description
0xXX	Flow Spec ID identifying the logical link creation that completed. This matches the ID field of the TX_Flow_Spec

7.7.57 Disconnection Logical Link Complete Event

Event	Event Code	Event Parameters
Disconnection Logical Link Complete	0x46	Status, Logical_Link_Handle, Reason

Description:

The Disconnection Logical Link Complete event occurs when a logical link is terminated on the local Controller. The status parameter indicates if the disconnection was successful or not.

Note: When the local Controller disconnects a logical link, the remote Controller will not be notified.

Note: When a physical link fails, one Disconnection Logical Link Complete event will be returned for each logical channel on the physical link with the corresponding Logical_Link_Handle as a parameter.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Disconnection has occurred.
0x01-0xFF	Disconnection failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Logical_Link_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Logical_Link_Handle which was disconnected. Range: 0x0000-0x0EFF (all other values reserved for future use)

Reason: *Size: 1 Octet*

Value	Parameter Description
0xXX	Reason for disconnection. See [Vol 2] Part D, Error Codes for error codes and descriptions.

7.7.58 Flow Spec Modify Complete Event

Event	Event Code	Event Parameters
Flow Spec Modify Complete	0x47	Status, Handle

Description:

The Flow Spec Modify Complete event indicates to the Host that a Flow Spec Modify command has been completed. This event also indicates to the Host which issued the Flow_Spec_Modify command and then received a Command Status event if the issued command failed or was successful.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Flow_Spec_Modify command successfully completed.
0x01-0xFF	Flow_Spec_Modify command failed to Complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle if the receiving Controller is a BR/EDR Controller. Logical_Link_Handle, if the receiving Controller is an AMP Controller, identifying the logical link to be changed. Logical_Link_Handle to be used to identify a connection between two BR/EDR Controllers with communicating AMPs. Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.59 Number Of Completed Data Blocks Event

Event	Event Code	Event Parameters
Number Of Completed Data Blocks	0x48	Total_Num_Data_Blocks, Number_of_Handles, Handle[i], Num_Of_Completed_Packets[i], Num_Of_Completed_Blocks[i]

Description:

The Number Of Completed Data Blocks event is used by the Controller to indicate to the Host how many HCI ACL Data Packets have been completed (transmitted or flushed), and how many data block buffers have been freed, for each Handle (a Connection_Handle if the Controller is a BR/EDR Controller or a Logical_Link_Handle if the Controller is an AMP Controller) since the previous Number Of Completed Data Blocks event was sent to the Host. This means that the corresponding buffer space has been freed in the Controller. Based on this information, and the Total_Num_Data_Blocks parameter, the Host can determine for which Handles the following HCI ACL Data Packets should be sent to the Controller.

The Host should determine the number of blocks occupied by each ACL data packet by dividing the ACL data packet size by the Data_Block_Length parameter of the Read_Data_Block_Size command.

The Total_Num_Data_Blocks parameter indicates the total number of buffer blocks available in the Controller. Before any Number of Complete Data Blocks event is received, the value of Total_Num_Data_Blocks from the Read_Data_Block_Size command is used. This allows the value to be updated at any time, which provides the Controller with some flexibility on its buffer allocation.

If the Controller were permitted to reduce its buffer pool in an arbitrary way then there is a potential race condition, in the case where the Host has just started to transmit a new packet. In order to prevent this race condition, the Total_Num_Data_Blocks parameter shall not indicate a reduction in the pool of blocks greater than the sum of the Num_Of_Completed_Blocks values in this event. If a greater reduction in the block pool is required then the value 0 shall be indicated here. The value 0 has a special meaning and indicates that the Host shall re-issue the Read Data Block Size command in order to find the new buffer pool size. The Host shall wait for any outstanding TX to complete and shall defer further TX until the Read_Data_Block_Size command has been issued and completed. The Controller shall reduce its allocation only after the Read_Data_Block_Size command has been issued and completed. This ensures that the race condition described above is avoided.

Event Parameters:

Total_Num_Data_Blocks: *Size: 2 Octets*

Value	Parameter Description
0x0000	The size of the buffer pool may have changed. The Host is requested to issue a Read Data Block Size command in order to determine the new value of Total_Num_Data_Blocks.
0xXXXX	Total number of data block buffers available in the Controller for the storage of data packets scheduled for transmission. This indicates the existing value is unchanged, or increased, or reduced by up to the sum of the Num_Of_Completed_Blocks values in this command.

Number_of_Handles: *Size: 1 Octet*

Value	Parameter Description
0xXX	The number of Handles and Num_Of_Completed_Packets and Num_Of_Completed_Blocks parameter triples contained in this event.
Range: 0-255	

Handle[i]: *Size: Number_of_Handles * 2 Octets(12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Handle (Connection_Handle for a BR/EDR Controller or a Logical_Link_Handle for an AMP Controller). Range: 0x0000-0x0EFF (all other values reserved for future use)

Num_Of_Completed_Packets [i]: *Size: Number_of_Handles * 2 Octets*

Value	Parameter Description
N = 0xXXXX	The number of HCI ACL Data Packets that have been completed (transmitted or flushed) for the associated Handle since the previous time that a Number Of Completed Data Blocks event provided information about this Handle. Range for N: 0x0000-0xFFFF

Num_Of_Completed_Blocks [i]: *Size: Number_of_Handles * 2 Octets*

Value	Parameter Description
N = 0xXXXX	The number of data blocks that have been freed for the associated Handle since the previous time that a Number Of Completed Data Blocks event provided information about this Handle. Range for N: 0x0000-0xFFFF

7.7.60 Short Range Mode Change Complete Event

Event	Event Code	Event Parameters
Short_ Range_ Mode_ Change_-Complete	0x4C	Status, Physical_Link_Handle, Short_Range_Mode_State

Description:

The Short Range Mode Change Complete event occurs after the AMP Controller has been notified to enable or disable Short Range Mode for a given physical link. The status parameter indicates if the configuration change was successful or not.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Short Range Mode configuration has occurred.
0x01-0xFF	Short Range Mode configuration failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Physical_Link_Handle: *Size: 1 Octet*

Value	Parameter Description
0xXX	Physical_Link_Handle to which the configuration applies.

Short_Range_Mode_State: *Size: 1 Octet*

Value	Parameter Description
0xXX	State of Short Range Mode in Controller. 0 - Short Range Mode disabled 1 - Short Range Mode enabled 0x02 - 0xFF - Reserved for Future Use

7.7.61 AMP Status Change Event

Event	Event Code	Event Parameters
AMP_ Status_ Change	0x4D	Status, AMP_Status

Description:

The AMP Status Change event can occur at any time, after initial Read_Local_AMP_Info_Request command, and when the AMP Controller detects a change has occurred regarding status and is based on availability thresholds.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP_Status_Change has occurred.
0x01-0xFF	AMP_Status_Change failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

AMP_Status: *Size: 1 Octet*

Value	Parameter Description
0x00	The Controller radio is available but is currently physically powered down. This value should be used if the AMP Controller is present and can be powered up by the AMP Manager. This value indicates that there may be a cost of time and power to use this AMP Controller (i.e., the time taken and power required to power up the AMP Controller). These costs are AMP type and AMP implementation dependent.
0x01	This value indicates that the AMP Controller is only used by Bluetooth technology and will not be shared with other non-Bluetooth technologies. This value shall only be used if the AMP Controller is powered up. This value does not indicate how much bandwidth is currently free on the AMP Controller.
0x02	The AMP Controller has no capacity available for Bluetooth operation. This value indicates that all of the AMP Controllers bandwidth is currently allocated to servicing a non Bluetooth technology. A device is permitted to create a Physical Link to an AMP Controller that has this status. This value shall only be used if the AMP Controller is powered up.

Value	Parameter Description
0x03	The AMP Controller has low capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controllers bandwidth is currently allocated to servicing a non Bluetooth technology. An AMP Controller that with capacity in the approximate range of 0 < capacity < 30% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.
0x04	The AMP Controller has medium capacity available for Bluetooth operation. An AMP Controller that with capacity in the approximate range of 30% < capacity < 70% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up
0x05	The AMP Controller has high capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controllers bandwidth is currently allocated to servicing the Bluetooth technology. An AMP Controller that with capacity in the approximate range of 70% < capacity < 100% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up
0x06	The AMP Controller has full capacity available for Bluetooth operation. This value indicates that while currently the AMP is only being used by Bluetooth the device allows a different technology to share the radio. This value shall be used by devices that are not capable of determining the current available capacity of an AMP that is shared by a different technology. This value does not indicate how much of the capacity available for Bluetooth operation is currently available. This value shall only be used if the AMP Controller is powered up.
All other values	Reserved for future use

7.7.62 AMP Start Test Event

Event	Event Code	Event Parameters
AMP Start Test	0x49	Status, Test Scenario

Description:

The AMP Start Test event shall be generated when the AMP_Test command has completed and the first data is ready to be sent or received .

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Test command succeeded
0x01-0xFF	Test command failed. See [Vol 2] Part D, Error Codes

Test Scenario: *Size: 1 Octet*

Value	Parameter Description
0xXX	See the Test Commands section of the Protocol Adaptation Layer Functional Specification for the Controller type

7.7.63 AMP Test End Event

Event	Event Code	Event Parameters
AMP Test End	0x4A	Status, Test Scenario

Description:

The AMP Test End event shall be generated to indicate that the AMP has transmitted or received the number of frames/bursts configured.

If the Receiver reports are enabled an AMP Receiver Report Event shall be generated.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP_Test_End command succeeded
0x01-0xFF	AMP_Test_End command failed. See [Vol 2] Part D, Error Codes

Test Scenario: *Size: 1 Octet*

Value	Parameter Description
0xXX	See the Test Commands section of the Protocol Adaptation Layer Functional Specification for the Controller type

7.7.64 AMP Receiver Report Event

Event	Event Code	Event Parameters
AMP Receiver Report	0x4B	Controller_Type, Reason, Event_Type, Number_Of_Frames, Number_Of_Error_Frames, Number_Of_Bits, Number_Of_Error_Bits

Description:

The AMP Receiver Report event shall be sent from the AMP to the tester via the AMP Test Manager at the interval configured by the Enable_AMP_Receiver_Reports command.

The AMP Receiver Report event is generated to indicate the number of frames received and optionally the number of bits in error detected.

Event Parameters:

Controller_Type: *Size: 1 Octet*

Value	Parameter Description
0xXX	See Bluetooth Assigned Numbers

Reason: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x00 Configured Interval report 0x01 Test Ended report 0x02 – 0xFF Reserved for Future Use

Event_type: *Size: 4 Bytes*

Value	Parameter Description
0xXX	0x00 Frames received report 0x01 Frames received and bits in error report (optional) 0x02 – 0xFF Reserved for Future Use

Number_Of_Frames: *Size: 2 Bytes*

Value	Parameter Description
0xXXXX	Number of frames received so far

Number_Of_Error_Frames: *Size: 2 Bytes*

Value	Parameter Description
0xXXXX	Number of frames with errors received so far

Number_Of_Bits: *Size: 4 Bytes*

Value	Parameter Description
0xXXXXXXXX	Number of bits received so far. Shall be set to 0x00000000 if the Event_type is not equal to 0x01.

Number_Of_Error_Bits: *Size: 4 Bytes*

Value	Parameter Description
0xXXXXXXXX	Number of bit errors received so far. Shall be set to 0x00000000 if the Event_type is not equal to 0x01.

7.7.65 LE Meta Event

Description:

The LE Meta Event is used to encapsulate all LE Controller specific events. The Event Code of all LE Meta Events shall be 0x3E. The Subevent_Code is the first octet of the event parameters. The Subevent_Code shall be set to one of the valid Subevent_Codes from an LE specific event. All other Subevent_Parameters are defined in the LE Controller specific events.

7.7.65.1 LE Connection Complete Event

Event	Event Code	Event parameters
LE Connection Complete	0x3E	Subevent_Code, Status, Connection_Handle, Role, Peer_Address_Type, Peer_Address, Conn_Interval, Conn_Latency, Supervision_Timeout, Master_Clock_Accuracy

Description:

The LE Connection Complete event indicates to both of the Hosts forming the connection that a new connection has been created. Upon the creation of the connection a Connection_Handle shall be assigned by the Controller, and passed to the Host in this event. If the connection creation fails this event shall be provided to the Host that had issued the LE_Create_Connection command.

This event indicates to the Host which issued a LE_Create_Connection command and received a Command Status event if the connection creation failed or was successful.

The Master_Clock_Accuracy parameter is only valid for a slave. On a master, this parameter shall be set to 0x00.

Note: This event is not sent if the LE Enhanced Connection Complete event (see Section 7.7.65.10) is unmasked.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x01	Subevent code for the LE Connection Complete event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01 – 0xFF	Connection failed to complete. [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Role: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection is master
0x01	Connection is slave
All other values	Reserved for future use

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Peer is using a Public Device Address
0x01	Peer is using a Random Device Address
All other values	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address or Random Device Address of the peer device

Conn_Interval: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Connection interval used on this connection. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4000 ms.

Conn_Latency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3

Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Connection supervision timeout. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s

Master_Clock_Accuracy: *Size: 1 Octet*

Value	Parameter Description
0x00	500 ppm
0x01	250 ppm
0x02	150 ppm
0x03	100 ppm
0x04	75 ppm
0x05	50 ppm
0x06	30 ppm
0x07	20 ppm
All other values	Reserved for future use

7.7.65.2 LE Advertising Report Event

Event	Event Code	Event parameters
LE Advertising Report	0x3E	Subevent_Code, Num_Reports, Event_Type[i], Address_Type[i], Address[i], Length[i], Data[i], RSSI[i]

Description:

The LE Advertising Report event indicates that one or more Bluetooth devices have responded to an active scan or have broadcast advertisements that were received during a passive scan. The Controller may queue these advertising reports and send information from multiple devices in one LE Advertising Report event.

This event shall only be generated if scanning was enabled using the LE Set Scan Enable command. It only reports advertising events that used legacy advertising PDUs.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x02	Subevent code for the LE Advertising Report event

Num_Reports: *Size: 1 Octet*

Value	Parameter Description
0x01 - 0x19	Number of responses in event.
All other values	Reserved for future use

Event_Type[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00	Connectable and scannable undirected advertising (ADV_IND)
0x01	Connectable directed advertising (ADV_DIRECT_IND)
0x02	Scannable undirected advertising (ADV_SCAN_IND)
0x03	Non connectable undirected advertising (ADV_NONCONN_IND)

Value	Parameter Description
0x04	Scan Response (SCAN_RSP)
All other values	Reserved for future use

Address_Type[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Public Identity Address (Corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (Corresponds to Resolved Private Address)
All other values	Reserved for future use

Address[i]: *Size: 6 Octets * Num_Reports*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address or Random (static) Identity Address of the advertising device.

Length_Data[i]: *Size: 1 Octets * Num_Reports*

Value	Parameter Description
0x00 - 0x1F	Length of the Data[i] field for each device which responded.
All other values	Reserved for future use.

Data[i]: *Size: SUM (Length_Data[i]) Octets*

Value	Parameter Description
	Length_Data[i] octets of advertising or scan response data formatted as defined in [Vol 3] Part C, Section 11. Note: Each element of this array has a variable length.

RSSI[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
N	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +20 Units: dBm
127	RSSI is not available
21 to 126	Reserved for future use

7.7.65.3 LE Connection Update Complete Event

Event	Event Code	Event parameters
LE Connection Update Complete	0x3E	Subevent_Code, Status, Connection_Handle, Conn_Interval, Conn_Latency, Supervision_Timeout

Description:

The LE Connection Update Complete event is used to indicate that the Controller process to update the connection has completed.

This event shall be issued if the LE Connection Update command was issued by the Host or if the connection parameters are updated following a request from the peer device. If no parameters are updated following a request from the peer device then this event shall not be issued.

Note: This event can be issued autonomously by the Master's Controller if it decides to change the connection interval based on the range of allowable connection intervals for that connection.

Note: The parameter values returned in this event may be different from the parameter values provided by the Host through the LE Connection Update command (Section 7.8.18) or the LE Remote Connection Parameter Request Reply command (Section 7.8.31).

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x03	Subevent code for the LE Connection Update Complete event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection_Update command successfully completed.
0x01 – 0xFF	Connection_Update command failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Conn_Interval: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Connection interval used on this connection. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4000 ms.

Conn_Latency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3

Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Supervision timeout for this connection. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32000 ms

7.7.65.4 LE Read Remote Features Complete Event

Event	Event Code	Event parameters
LE Read Remote Features Complete	0x3E	Subevent_Code, Status, Connection_Handle, LE_Features

Description:

The LE Read Remote Features Complete event is used to indicate the completion of the process of the Controller obtaining the features used on the connection and the features supported by the remote Bluetooth device specified by the Connection_Handle event parameter.

Note: If the features are requested more than once while a connection exists between the two devices, the second and subsequent requests may report a cached copy of the features rather than fetching the feature mask again.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x04	Subevent code for the LE Read Remote Features Complete event.

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Remote_Features command successfully completed.
0x01 – 0xFF	LE_Read_Remote_Features command failed to complete. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

LE_Features: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX	Bit Mask List of LE features. See [Vol 6] Part B, Section 4.6.

7.7.65.5 LE Long Term Key Request Event

Event	Event Code	Event parameters
LE Long Term Key Request	0x3E	Subevent_Code, Connection_Handle, Random_Number, Encryption_Diversifier

Description:

The LE Long Term Key Request event indicates that the master device is attempting to encrypt or re-encrypt the link and is requesting the Long Term Key from the Host. (See [Vol 6] Part B, Section 5.1.3).

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x05	Subevent code for the LE Long Term Key Request event

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Random_Number: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXX	64-bit random number.

Encrypted_Diversifier: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	16-bit encrypted diversifier.

7.7.65.6 LE Remote Connection Parameter Request Event

Event	Event Code	Event parameters
LE Remote Connection Parameter Request	0x3E	Subevent_Code, Connection_Handle, Interval_Min, Interval_Max, Latency, Timeout

Description:

This event indicates to the master's Host or the slave's Host that the remote device is requesting a change in the connection parameters. The Host replies either with the HCI LE Remote Connection Parameter Request Reply command or the HCI LE Remote Connection Parameter Request Negative Reply command.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x06	Subevent code for the LE Remote Connection Parameter Request event.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum value of the connection interval requested by the remote device. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s

Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum value of the connection interval requested by the remote device. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s

Latency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Maximum allowed slave latency for the connection specified as the number of connection events requested by the remote device. Range: 0x0000 to 0x01F3 (499)

Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Supervision timeout for the connection requested by the remote device. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s

7.7.65.7 LE Data Length Change Event

Event	Event Code	Event parameters
LE Data Length Change	0x3E	Subevent_Code, Connection_Handle, MaxTxOctets, MaxTxTime, MaxRxOctets, MaxRxTime

Description:

The LE Data Length Change event notifies the Host of a change to either the maximum Payload length or the maximum transmission time of packets in either direction. The values reported are the maximum that will actually be used on the connection following the change, except that on the LE Coded PHY a packet taking up to 2704 µs to transmit may be sent even though the corresponding parameter has a lower value.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x07	Subevent code for the LE Data Length Change event

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

MaxTxOctets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The maximum number of payload octets in a Link Layer packet that the local Controller will send on this connection (*connEffectiveMaxTxOctets* defined in [Vol 6] Part B, Section 4.5.10). Range 0x001B-0x00FB (all other values reserved for future use)

MaxTxTime: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The maximum time that the local Controller will take to send a Link Layer packet on this connection (*connEffectiveMaxTxTime* defined in [Vol 6] Part B, Section 4.5.10). Range 0x0148-0x4290 (all other values reserved for future use)

MaxRxOctets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The maximum number of payload octets in a Link Layer packet that the local Controller expects to receive on this connection (*connEffectiveMaxRxOctets* defined in [Vol 6] Part B, Section 4.5.10). Range 0x001B-0x00FB (all other values reserved for future use)

MaxRxTime: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The maximum time that the local Controller expects to take to receive a Link Layer packet on this connection *(connEffectiveMaxRxTime* defined in [Vol 6] Part B, Section 4.5.10). Range 0x0148-0x4290 all other values reserved for future use)

7.7.65.8 LE Read Local P-256 Public Key Complete Event

Event	Event Code	Event Parameters
LE Read Local P-256 Public Key Complete	0x3E	Subevent_Code, Status, Local_P-256_Public_Key

Description:

This event is generated when local P-256 key generation is complete.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x08	Subevent code for the LE Read Local P-256 Public Key Complete event.

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE Read Local P-256 Public Key command completed successfully.
0x01-0xFF	LE Read Local P-256 Public Key command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Local_P-256_Public_Key: *Size: 64 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX	Local P-256 public key.

7.7.65.9 LE Generate DHKey Complete Event

Event	Event Code	Event Parameters
LE Generate DHKey Complete	0x3E	Subevent_Code, Status, DHKey

Description:

This event indicates that LE Diffie Hellman key generation has been completed by the Controller.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x09	Subevent code for the LE Generate DHKey Complete event.

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Generate_DHKey command completed successfully.
0x01-0xFF	LE_Generate_DHKey command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

DHKey: *Size: 32 Octets*

Value	Parameter Description
0xXXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX	Diffie Hellman Key.

7.7.65.10 LE Enhanced Connection Complete Event

Event	Event Code	Event parameters
LE Enhanced Connection Complete	0x3E	Subevent_Code, Status, Connection_Handle, Role, Peer_Address_Type, Peer_Address, Local_Resolvable_Private_Address, Peer_Resolvable_Private_Address Conn_Interval, Conn_Latency, Supervision_Timeout, Master_Clock_Accuracy

Description:

The LE Enhanced Connection Complete event indicates to both of the Hosts forming the connection that a new connection has been created. Upon the creation of the connection a Connection_Handle shall be assigned by the Controller, and passed to the Host in this event. If the connection creation fails, this event shall be provided to the Host that had issued the LE_Create_Connection or LE_Extended_Create_Connection command.

If this event is unmasked and LE Connection Complete event is unmasked, only the LE Enhanced Connection Complete event is sent when a new connection has been created.

This event indicates to the Host that issued an LE_Create_Connection or LE_Extended_Create_Connection command and received a Command Status event if the connection creation failed or was successful.

The Master_Clock_Accuracy parameter is only valid for a slave. On a master, this parameter shall be set to 0x00.

Event Parameters:

Subevent Code: *Size: 1 Octet*

Value	Parameter Description
0x0A	Subevent code for the LE Enhanced Connection Complete event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection successfully completed.
0x01 – 0xFF	Connection failed to complete. See Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Role: *Size: 1 Octet*

Value	Parameter Description
0x00	Connection is master
0x01	Connection is slave
All other values	Reserved for future use

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address (default)
0x01	Random Device Address
0x02	Public Identity Address (Corresponds to Resolved Private Address)
0x03	Random (Static) Identity Address (Corresponds to Resolved Private Address)
All other values	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, or Random Device Address, Public Identity Address or Random (static) Identity Address of the device to be connected.

Local_Resolvable_Private_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Resolvable Private Address being used by the local device for this connection. This is only valid when the Own_Address_Type (from the HCI_LE_Create_Connection, HCI_LE_Set_Advertising_Parameters, HCI_LE_Set_Extended_Advertising_Parameters, or HCI_LE_Extended_Create_Connection commands) is set to 0x02 or 0x03, and the Controller generated a resolvable private address for the local device using a non-zero local IRK. For other Own_Address_Type values, the Controller shall return all zeros.

Peer_Resolvable_Private_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Resolvable Private Address being used by the peer device for this connection. This is only valid for Peer_Address_Type 0x02 and 0x03. For other Peer_Address_Type values, the Controller shall return all zeros.

Conn_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Connection interval used on this connection. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4000 ms.

Conn_Latency: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3

Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Connection supervision timeout. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s

Master_Clock_Accuracy: *Size: 1 Octet*

Value	Parameter Description
0x00	500 ppm
0x01	250 ppm

Value	Parameter Description
0x02	150 ppm
0x03	100 ppm
0x04	75 ppm
0x05	50 ppm
0x06	30 ppm
0x07	20 ppm
0x08 – 0xFF	Reserved for future use

7.7.65.11 LE Directed Advertising Report Event

Event	Event Code	Event parameters
LE Directed Advertising Report	0x3E	Subevent_Code, Num_Reports, Event_Type[i], Address_Type[i], Address[i], Direct_Address_Type[i], Direct_Address[i], RSSI[i]

Description:

The LE Directed Advertising Report event indicates that directed advertisements have been received where the advertiser is using a resolvable private address for the TargetA field of the advertising PDU which the Controller is unable to resolve and the Scanning_Filter_Policy is equal to 0x02 or 0x03, see Section 7.8.10. Direct_Address_Type and Direct_Address specify the address the directed advertisements are being directed to. Address_Type and Address specify the address of the advertiser sending the directed advertisements. The Controller may queue these advertising reports and send information from multiple advertisers in one LE Directed Advertising Report event.

This event shall only be generated if scanning was enabled using the LE Set Scan Enable command. It only reports advertising events that used legacy advertising PDUs.

Event Parameters:

Subevent Code: *Size: 1 Octet*

Value	Parameter Description
0x0B	Subevent code for the LE Directed Advertising Report event

Num_reports: *Size: 1 Octet*

Value	Parameter Description
0x01 – 0x19	Number of responses in event
All other values	Reserved for future use

Event_Type[i]: *Size: 1 Octet*

Value	Parameter Description
0x01	Connectable directed legacy advertising (ADV_DIRECT_IND)
All other values	Reserved for future use

Address_Type[i]: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address (default)
0x01	Random Device Address
0x02	Public Identity Address (Corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (Corresponds to Resolved Private Address)
0xFF	No address provided (anonymous advertisement)
All other values	Reserved for future use

Address[i]: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address or Random (static) Identity Address of the advertising device.

Direct_Address_Type[i]: *Size: 1 Octet*

Value	Parameter Description
0x01	Random Device Address (default)
All other values	Reserved for future use

Direct_Address[i]: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Random Device Address

RSSI[i]: *Size: 1 Octet*

Value	Parameter Description
N	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +20 Units: dBm
127	RSSI is not available
21 to 126	Reserved for future use

7.7.65.12 LE PHY Update Complete Event

Event	Event Code	Event Parameter
LE PHY Update Complete	0x3E	Subevent_Code, Status, Connection_Handle, TX_PHY, RX_PHY

Description:

The LE PHY Update Complete Event is used to indicate that the Controller has changed the transmitter PHY or receiver PHY in use.

If the Controller changes the transmitter PHY, the receiver PHY, or both PHYs, this event shall be issued.

If an LE_Set_PHY command was sent and the Controller determines that neither PHY will change as a result, it issues this event immediately.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x0C	Subevent code for the LE PHY Update Complete event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_PHY command succeeded or autonomous PHY update made by the Controller.
0x01 – 0xFF	LE_Set_PHY command failed. See Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

TX_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	The transmitter PHY for the connection is LE 1M
0x02	The transmitter PHY for the connection is LE 2M

Value	Parameter Description
0x03	The transmitter PHY for the connection is LE Coded
All other values	Reserved for future use

RX_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	The receiver PHY for the connection is LE 1M
0x02	The receiver PHY for the connection is LE 2M
0x03	The receiver PHY for the connection is LE Coded
All other values	Reserved for future use

7.7.65.13 LE Extended Advertising Report Event

Event	Event Code	Event Parameters
LE Extended Advertising Report	0x3E	Subevent_Code, Num_Reports, Event_Type[i], Address_Type[i], Address[i], Primary_PHY[i], Secondary_PHY[i], Advertising_SID[i], Tx_Power[i], RSSI[i], Periodic_Advertising_Interval[i], Direct_Address_Type[i], Direct_Address[i], Data_Length[i], Data[i]

Description:

The LE Extended Advertising Report event indicates that one or more Bluetooth devices have responded to an active scan or have broadcast advertisements that were received during a passive scan. The Controller may coalesce multiple advertising reports from the same or different advertisers into a single LE Extended Advertising Report event, provided all the parameters from all the advertising reports fit in a single HCI event.

This event shall only be generated if scanning was enabled using the LE Set Extended Scan Enable command. It reports advertising events using either legacy or extended advertising PDUs.

The Controller may split the data from a single advertisement (whether one PDU or several) into several reports. If so, each report except the last shall have an Event_Type with a data status field of "incomplete, more data to come", while the last shall have the value "complete"; the Address_Type, Address, Advertising_SID, Primary_PHY, and Secondary_PHY fields shall be the same in all the reports.

When a scan response is received, bits 0-2 and 4 of the event type shall indicate the properties of the original advertising event.

An Event_Type with a data status field of "incomplete, data truncated" indicates that the Controller attempted to receive an AUX_CHAIN_IND PDU but was not successful.

Where the event being reported used a legacy advertising PDU, the Controller shall set the Event_Type to the value specified in Table 7.1.

PDU Type	Event_Type
ADV_IND	0010011b
ADV_DIRECT_IND	0010101b
ADV_SCAN_IND	0010010b
ADV_NONCONN_IND	0010000b
SCAN_RSP to an ADV_IND	0011011b
SCAN_RSP to an ADV_SCAN_IND	0011010b

Table 7.1: Event_Type values for legacy PDUs

If the Event_Type indicates a legacy PDU (bit 4 = 1), the Primary_PHY parameter shall indicate the LE 1M PHY and the Secondary_PHY parameter shall be set to 0x00. Otherwise, the Primary_PHY parameter indicates the PHY used to send the advertising PDU on the primary advertising channel and the Secondary_PHY parameter indicates the PHY used to send the advertising PDU(s), if any, on the secondary advertising channel.

The Periodic_Advertising_Interval event parameter is set to zero when no periodic advertising exists as part of the advertising set.

The Direct_Address_Type and Direct_Address parameters indicate the TargetA address in the advertising PDU for directed advertising event types (bit 2 = 1). These parameters shall be ignored for undirected advertising event types (bit 2 = 0).

When multiple advertising packets are used to complete a single advertising report (e.g., a packet containing an ADV_EXT_IND PDU combined with one containing an AUX_ADV_IND PDU), the RSSI and TxPower event parameters shall be set based on the last packet received.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x0D	Subevent code for the LE Extended Advertising Report event

Num_Reports: *Size: 1 Octet*

Value	Parameter Description
0x01 – 0x0A	Number of separate reports in the event
All other values	Reserved for future use

Event_Type[i]: *Size: 2 Octets * Num_Reports*

Bit Number	Parameter Description
0	Connectable advertising
1	Scannable advertising
2	Directed advertising
3	Scan response
4	Legacy advertising PDUs used
5-6	Data status: 00b = Complete 01b = Incomplete, more data to come 10b = Incomplete, data truncated, no more to come 11b = Reserved for future use
All other bits	Reserved for future use

Address_Type[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Public Identity Address (corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (corresponds to Resolved Private Address)
0xFF	No address provided (anonymous advertisement)
All other values	Reserved for future use

Address[i]: *Size: 6 Octets * Num_Reports*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address or Random (static) Identity Address of the advertising device.

Primary_PHY[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x01	Advertiser PHY is LE 1M
0x03	Advertiser PHY is LE Coded
All other values	Reserved for future use

Secondary_PHY[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00	No packets on the secondary advertising channel
0x01	Advertiser PHY is LE 1M
0x02	Advertiser PHY is LE 2M
0x03	Advertiser PHY is LE Coded
All other values	Reserved for future use

Advertising_SID[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00 – 0x0F	Value of the Advertising SID subfield in the ADI field of the PDU
0xFF	No ADI field in the PDU
All other values	Reserved for future use

Tx_Power[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm
127	Tx Power information not available

RSSI[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
N	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +20 Units: dBm
127	RSSI is not available
All other values	Reserved for future use

Periodic_Advertising_Interval[i]: *Size:* 2 Octets * Num_Reports

Value	Parameter Description
0	No periodic advertising
N = 0xXXXX	Interval of the periodic advertising Range: 0x0006 to 0xFFFF Time = N * 1.25 ms Time Range: 7.5 ms to 81,918.75 s

Direct_Address_Type[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Public Identity Address (Corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (Corresponds to Resolved Private Address)
0xFE	Random Device Address (Controller unable to resolve)
All other values	Reserved for future use

Direct_Address[i]: *Size: 6 Octets * Num_Reports*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address or Random (static) Identity Address of the target device

Data_Length[i]: *Size: 1 Octet * Num_Reports*

Value	Parameter Description
0-229	Length of the Data[i] field for each device which responded
All other values	Reserved for future use

Data[i]Size: *SUM (Data_Length[i]) Octets*

Value	Parameter Description
	Data_Length[i] octets of advertising or scan response data formatted as defined in [Vol 3] Part C, Section 11. Note: Each element of this array has a variable length.

7.7.65.14 LE Periodic Advertising Sync Established Event

Event	Event Code	Event Parameters
LE Periodic Advertising Sync Established	0x3E	Subevent_Code, Status, Sync_Handle, Advertising_SID, Advertiser_Address_Type, Advertiser_Address, Advertiser_PHY, Periodic_Advertising_Interval, Advertiser_Clock_Accuracy

Description:

The LE Periodic Advertising Sync Established event indicates that the Controller has received the first periodic advertising packet from an advertiser after the LE_Periodic_Advertising_Create_Sync Command has been sent to the Controller.

The Sync_Handle shall be assigned by the Controller.

This event indicates to the Host which issued an LE_Periodic_Advertising_Create_Sync command and received a Command Status event if the periodic advertising reception failed or was successful.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x0E	Subevent code for the LE Periodic Advertising Sync Established event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Periodic advertising sync successful
0x01 - 0xFF	Periodic advertising sync failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions

Sync_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Sync_Handle to be used to identify the periodic advertiser Range: 0x0000-0x0EFF

Value	Parameter Description
All other values	Reserved for future use

Advertising_SID: *Size: 1 Octet*

Value	Parameter Description
0x00 - 0x0F	Value of the Advertising SID subfield in the ADI field of the PDU
All other values	Reserved for future use

Advertiser_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
0x02	Public Identity Address (corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (corresponds to Resolved Private Address)
All other values	Reserved for future use

Advertiser_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the advertiser

Advertiser_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	Advertiser PHY is LE 1M
0x02	Advertiser PHY is LE 2M
0x03	Advertiser PHY is LE Coded
All other values	Reserved for future use

Periodic_Advertising_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Periodic_advertising interval Range: 0x0006 to 0xFFFF Time = N * 1.25 ms Time Range: 7.5 ms to 81.91875 s

Advertiser_Clock_Accuracy: *Size: 1 Octet*

Value	Parameter Description
0x00	500 ppm
0x01	250 ppm
0x02	150 ppm
0x03	100 ppm
0x04	75 ppm
0x05	50 ppm
0x06	30 ppm
0x07	20 ppm
All other values	Reserved for future use

7.7.65.15 LE Periodic Advertising Report Event

Event	Event Code	Event Parameters
LE Periodic Advertising Report	0x3E	Subevent_Code, Sync_Handle, Tx_Power, RSSI, Unused Data_Status, Data_Length, Data

Description:

The LE Periodic Advertising Report event indicates that the Controller has received a Periodic Advertising packet.

The Sync_Handle parameter indicates the identifier for the periodic advertisements specified by the Advertising SID subfield of the ADI field in the ADV_EXT_IND PDU.

The Controller may split the data from a single periodic advertisement (whether one PDU or several) into several reports. If so, each report except the last shall have a Data_Status of "incomplete, more data to come", while the last shall have the value "complete".

A Data_Status of "incomplete, data truncated" indicates that the Controller attempted to receive an AUX_CHAIN_IND PDU but was not successful.

The Unused parameter shall be set to 0xFF by the Controller and ignored by the Host.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x0F	Subevent code for the LE Periodic Advertising Report event

Sync_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Sync_Handle to be used to identify the periodic advertiser from which data has been received. Range: 0x0000-0x0EFF
All other values	Reserved for future use

Tx_Power: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm
127	Tx Power information not available

RSSI: *Size: 1 Octet*

Value	Parameter Description
N	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +20 Units: dBm
127	RSSI is not available
All other values	Reserved for future use

Unused:[1] *Size: 1 Octet*

Value	Parameter Description
0xFF	This value must be used by the Controller
All other values	Reserved for future use

1. This parameter is intended to be used in a future feature.

Data_Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Data complete
0x01	Data incomplete, more data to come
0x02	Data incomplete, data truncated, no more to come
All other values	Reserved for future use

Data_Length: *Size: 1 Octet*

Value	Parameter Description
0 - 248	Length of the Data field
All other values	Reserved for future use

Data: *Size: Data_Length Octets*

Value	Parameter Description
Variable	Data received from a Periodic Advertising packet

7.7.65.16 LE Periodic Advertising Sync Lost Event

Event	Event Code	Event Parameters
LE Periodic Advertising Sync Lost	0x3E	Subevent_Code, Sync_Handle

Description:

The LE Periodic Advertising Sync Lost event indicates that the Controller has not received a Periodic Advertising packet identified by Sync_Handle within the timeout period.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x10	Subevent code for the LE Periodic Advertising Sync Lost event

Sync_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Sync_Handle to be used to identify the periodic advertiser. Range: 0x0000-0x0EFF
All other values	Reserved for future use

7.7.65.17 LE Scan Timeout Event

Event	Event Code	Event Parameters
LE Scan Timeout	0x3E	Subevent_Code

Description:

The LE Scan Timeout event indicates that scanning has ended because the duration has expired.

This event shall only be generated if scanning was enabled using the LE Set Extended Scan Enable command.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x11	Subevent code for the LE Scan Timeout event

7.7.65.18 LE Advertising Set Terminated Event

Event	Event Code	Event Parameters
LE Advertising Set Terminated	0x3E	Subevent_Code, Status, Advertising_Handle, Connection_Handle, Num_Completed_Extended_Advertising_Events

Description:

The LE Advertising Set Terminated event indicates that the Controller has terminated advertising in the advertising sets specified by the Advertising_Handle parameter.

This event shall be generated every time connectable advertising in an advertising set results in a connection being created.

This event shall only be generated if advertising was enabled using the LE Set Extended Advertising Enable command.

The Connection_Handle parameter is only valid when advertising ends because a connection was created.

If the Max_Extended_Advertising_Events parameter in the LE_Set_Extended_Advertising_Enable command was non-zero, the Num_Completed_Extended_Advertising_Events parameter shall be set to the number of completed extended advertising events the Controller had transmitted when either the duration elapsed or the maximum number of extended advertising events was reached; otherwise it shall be set to zero.

If advertising has terminated as a result of the advertising duration elapsing, the Status parameter shall be set to the error code *Advertising Timeout* (0x3C).

If advertising has terminated because the Max_Extended_Advertising_Events was reached, the Status parameter shall be set to the error code *Limit Reached* (0x43).

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x12	Subevent code for the LE Advertising Set Terminated event

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Advertising successfully ended with a connection being created
0x01 – 0xFF	Advertising ended for another reason. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Advertising_Handle in which advertising has ended
All other values	Reserved for future use

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle of the connection whose creation ended the advertising Range: 0x0000 – 0x0EFF (all other values reserved for future use)

Num_Completed_Extended_Advertising_Events: *Size: 1 Octet*

Value	Parameter Description
0xXX	Number of completed extended advertising events transmitted by the Controller

7.7.65.19 LE Scan Request Received Event

Event	Event Code	Event Parameters
LE Scan Request Received	0x3E	Subevent_Code, Advertising_Handle, Scanner_Address_Type, Scanner_Address

Description:

The LE Scan Request Received event indicates that a SCAN_REQ PDU or an AUX_SCAN_REQ PDU has been received by the advertiser. The request contains a device address from a scanner that is allowed by the advertising filter policy. The advertising set is identified by Advertising_Handle.

This event shall only be generated if advertising was enabled using the LE Set Extended Advertising Enable command.

The Scanner_Address_Type and Scanner_Address indicates the type of the address and the address of the scanner device.

Event Parameters:

Subevent_Code: *Size: 1 Octet*

Value	Parameter Description
0x13	Subevent code for the LE Scan Request Received event

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Scanner_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Public Identity Address (corresponds to Resolved Private Address)
0x03	Random (static) Identity Address (corresponds to Resolved Private Address)
All other values	Reserved for future use

Scanner_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXX X	Public Device Address, Random Device Address, Public Identity Address or Random (static) Identity Address of the advertising device

7.7.65.20 LE Channel Selection Algorithm Event

Event	Event Code	Event Parameters
LE Channel Selection Algorithm Event	0x3E	Subevent_Code, Connection_Handle, Channel_Selection_Algorithm

Description:

The LE Channel Selection Algorithm Event indicates which channel selection algorithm is used on a data channel connection (see [Vol 6] Part B, Section 4.5.8).

Event Parameters:

Subevent_Code: *Size: 1Octet*

Value	Parameter Description
0x14	Subevent code for the LE Channel Selection Algorithm event

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 – 0x0EFF (all other values reserved for future use)

Channel_Selection_Algorithm: *Size: 1Octet*

Value	Parameter Description
0x00	LE Channel Selection Algorithm #1 is used
0x01	LE Channel Selection Algorithm #2 is used
0x02 – 0xFF	Reserved for future use

7.7.66 Triggered Clock Capture Event

Event	Event Code	Event Parameters
Triggered Clock Capture	0x4E	Connection_Handle, Which_Clock, Clock, Slot_Offset

Description:

The Triggered Clock Capture event is sent to indicate that a triggering event has occurred at the specified clock and offset value. The Which_Clock parameter indicates whether the clock is local or a piconet clock. The Connection_Handle parameter is used when the clock is a piconet clock to indicate which piconet's clock was reported.

The Clock parameter indicates the value of the selected clock at the instant of the triggering event, with bits 1 and 0 set to 0b.

The Slot_Offset parameter indicates the number of microseconds (from 0 to 1249) from the instant at which the selected clock took the value Clock until the triggering event.

Note: What constitutes a triggering event is defined by the Controller implementation. For example, it could be an interrupt signal received by the Controller hardware.

Event Parameters:

Connection_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000 – 0x0EFF (all other values reserved for future use)

Which_Clock: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x00 = Local Clock (Connection_Handle does not have to be valid) 0x01 = Piconet Clock (Connection_Handle shall be valid) 0x02-0xFF = Reserved for Future Use

Clock: *Size: 4 Octets (28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	Bluetooth clock of the device requested with bits 1 and 0 set to 0b.

Slot_Offset: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Number of microseconds from the selected clock attaining the value Clock until the triggering event. Range: 0 to 1249.

7.7.67 Synchronization Train Complete Event

Event	Event Code	Event Parameters
Synchronization Train Complete	0x4F	Status

Description:

The Synchronization Train Complete event indicates that the Start Synchronization Train command has completed.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Start Synchronization Train command completed successfully.
0x01-0xFF	Start Synchronization Train command failed. See [Vol 2] Part D, Error Codes, for error codes and descriptions.

7.7.68 Synchronization Train Received Event

Event	Event Code	Event Parameters
Synchronization Train Received	0x50	Status, BD_ADDR, Clock_Offset, AFH_Channel_Map, LT_ADDR, Next_Broadcast_Instant, Connectionless_Slave_ Broadcast_Interval, Service_Data

Description:

The Synchronization Train Received event provides information received from a synchronization train packet transmitted by a Connectionless Slave Broadcast transmitter with the given BD_ADDR. If synchronization was successful, it provides the clock offset, AFH channel map, LT_ADDR, next broadcast instant, broadcast interval, and service data as received from the synchronization train payload. If the command returns a status of 0x01-0xFF, then all other parameters are undefined and shall be ignored.

A packet with the Connectionless Slave Broadcast LT_ADDR field in the payload set to zero shall be ignored for the purposes of this event.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Received Synchronization Train command completed successfully.
0x01-0xFF	Received Synchronization Train command failed. See Part D, Error Codes, for error codes and descriptions.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the Connectionless Slave Broadcast transmitter.

Clock_Offset: *Size: 4 Octets(28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	(CLKNslave - CLK) modulo 2^{28}

AFH_Channel_Map: *Size: 10 Octets (79 Bits Meaningful)*

Value	Parameter Description
0xXXXXXXXX XXXXXXXXXX XX	This parameter contains 80 1-bit fields. The n^{th} such field (in the range 0 to 78) contains the value for channel *n*: 0: channel n is unused 1: channel n is used The most significant bit (bit 79) is reserved for future use

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR of Connectionless Slave Broadcast channel.
All other values	Reserved for future use

Next_Broadcast_Instant: *Size: 4 Octets (28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	CLK of a future broadcast on this channel

Connectionless_Slave_Broadcast_Interval: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Interval between Connectionless Slave Broadcast instants in slots. Range: 0x0002-0xFFFE; only even values are valid

Service_Data: *Size: 1 Octet*

Value	Parameter Description
0xXX	Value from octet 27 of the Synchronization Train packet; see [Vol 2] Part B, Table 8.10.

7.7.69 Connectionless Slave Broadcast Receive Event

Event	Event Code	Event Parameters
Connectionless Slave Broadcast Receive	0x51	BD_ADDR, LT_ADDR, CLK, Offset, Receive_Status, Fragment, Data_Length, Data

Description:

The Connectionless Slave Broadcast Receive event shall be sent by the BR/EDR Controller every Connectionless Slave Broadcast Instant on which the BR/EDR Controller is scheduled to receive a Connectionless Slave Broadcast packet. If the packet is not received successfully, the event returns a Receive_Status of 0x01. Otherwise, the event returns the payload Data along with the Piconet Clock and the offset from the local CLKN when the packet was received.

The BR/EDR Controller shall send multiple Connectionless Slave Broadcast Receive events if the length of the received data exceeds the capacity of a single Connectionless Slave Broadcast Receive event. The fragments shall be marked as starting, continuation, or ending to allow the Host to reassemble the received packet. Only a single event shall be generated for a Connectionless Slave Broadcast instant on which a Connectionless Slave Broadcast packet was scheduled for reception but the BR/EDR Controller failed to successfully receive it.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the broadcasting master device

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR of the Connectionless Slave Broadcast
All other values	Reserved for future use

CLK: *Size: 4 Octets (28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	CLK when Connectionless Slave Broadcast data was received

Offset: *Size: 4 Octets (28 bits meaningful)*

Value	Parameter Description
0xXXXXXXXX	(CLKNslave – CLK) modulo 2^{28}

Receive Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Packet received successfully
0x01	Packet not received successfully (Fragment, Data_Length, and Data fields invalid)
All other values	Reserved for future use

Fragment: *Size: 1 Octet*

Value	Parameter Description
0x00	Continuation fragment
0x01	Starting fragment
0x02	Ending fragment
0x03	No fragmentation (single fragment)
All other values	Reserved for future use

Data_Length: *Size: 1 Octet*

Value	Parameter Description
0xXX	Length of Data field

Data: *Size: Data_Length Octets*

Value	Parameter Description
Variable	Data received from a Connectionless Slave Broadcast packet.

7.7.70 Connectionless Slave Broadcast Timeout Event

Event	Event Code	Event Parameters
Connectionless Slave Broadcast Timeout	0x52	BD_ADDR, LT_ADDR

Description:

On the Connectionless Slave Broadcast Receiver, the Connectionless Slave Broadcast Timeout event indicates to the Host that the BR/EDR Controller has lost synchronization with the Connectionless Slave Broadcast because no Connectionless Slave Broadcast packets have been received for the timeout interval, *CSB_supervisionTO*, specified in the Set Connectionless Slave Broadcast Receive command.

On the Connectionless Slave Broadcast Transmitter, the Connectionless Slave Broadcast Timeout event indicates to the Host that the BR/EDR Controller has been unable to transmit a Connectionless Slave Broadcast packet for the timeout interval, *CSB_supervisionTO*, specified in the Set Connectionless Slave Broadcast command.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the broadcasting master device

LT_ADDR: *Size: 1 Octet*

Value	Parameter Description
0x01-0x07	LT_ADDR of the Connectionless Slave Broadcast
All other values	Reserved for future use

7.7.71 Truncated Page Complete Event

Event	Event Code	Event Parameters
Truncated Page Complete	0x53	Status, BD_ADDR

Description:

The Truncated Page Complete event indicates to the Host that a Truncated Page command completed. Truncated Paging is considered to be successful when a slave page response ID packet has been received by the local BR/EDR Controller. See [Vol 2] Part B, Section 8.3.3 for more information.

A Truncated Page Complete event shall always be sent for each Truncated Page Command. If the Host issues a Truncated Page Cancel command before the Controller returns the Truncated Page Complete event, then the Truncated Page Complete event shall be sent after the Command Complete event for the Truncated Page Cancel command. If the cancellation was successful, the Truncated Page Complete event shall be generated with the error code *Unknown Connection Identifier* (0x02).

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Truncated_Page command completed successfully.
0x01-0xFF	Truncated_Page command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the paged (slave) device

7.7.72 Slave Page Response Timeout Event

Event	Event Code	Event Parameters
Slave Page Response Timeout	0x54	

Description:

The Slave Page Response Timeout event indicates to the Host that a slave page response timeout has occurred in the BR/EDR Controller. Note: This event will be generated if the slave BR/EDR Controller responds to a page but does not receive the master FHS packet (see [Vol 2] Part B, Section 8.3.3) within *pagerespTO*.

Event Parameters:

None

7.7.73 Connectionless Slave Broadcast Channel Map Change Event

Event	Event Code	Event Parameters
Connectionless Slave Broadcast Channel Map Change	0x55	Channel_Map

Description:

The Connectionless Slave Broadcast Channel Map Change event is sent by the master's BR/EDR Controller to the master's Host to indicate that the master's BR/EDR Controller has moved to a new AFH channel map for the PBD logical link.

After an AFH channel map change takes effect for the PBD logical link, the Connectionless Slave Broadcast Transmitter BR/EDR Controller shall send this event to the Host. Upon reception of this event, the Host may restart the synchronization train to allow receivers to obtain the updated AFH channel map.

This event shall also be sent if the Host issues a Set_AFH_Channel_Classification command which causes the Connectionless Slave Broadcast Channel Map to change.

Event Parameters:

Channel_Map: *Size: 10 Octets (79 Bits Meaningful)*

Value	Parameter Description
0xXXXXXXXX XXXXXXXXXX XX	This parameter contains 80 1-bit fields. The n^{th} such field (in the range 0 to 78) contains the value for channel *n*: 0: channel *n* is unused 1: channel *n* is used The most significant bit (bit 79) is reserved for future use

7.7.74 Inquiry Response Notification Event

Event	Event Code	Event Parameters
Inquiry Response Notification	0x56	LAP, RSSI

Description:

The Inquiry Response Notification event indicates to the Host that the BR/EDR Controller responded to an Inquiry message. The LAP parameter in the event indicates the LAP used to create the access code received. The parameter may be used by the Host to determine which access code was used in cases where the BR/EDR Controller is performing inquiry scan on multiple inquiry access codes using parallel scanning or sequential scanning. See [Vol 3] Part C, Section 4.1.2.1 for details on sequential and parallel scanning.

The LAP parameter returned by the BR/EDR Controller shall be one of the LAPs currently enabled. LAPs are enabled via the Write_Current_IAC_LAP command.

The RSSI parameter indicates the signal strength of the received ID packet.

Event Parameters:

LAP: *Size: 3 Octets*

Value	Parameter Description
0x9E8B00– 0x9E8B3F	LAP from which the IAC was derived; see Bluetooth Assigned Numbers.

RSSI: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX Signed Integer	Size: 1 Octet (signed integer) Range: -100 ≤ N ≤ 20, +127 indicates unknown RSSI Units: dBm

7.7.75 Authenticated Payload Timeout Expired Event

Event	Event Code	Event Parameters
Authenticated Payload Timeout Expired	0x57	Connection_Handle

Description:

The Authenticated Payload Timeout Expired event is used to indicate that a packet containing a valid MIC on the Connection_Handle was not received within the *authenticatedPayloadTO* (see [Vol 2] Part B, Section Appendix B for the BR/EDR and [Vol 6] Part B, Section 5.4 for the LE connection). Note: A Host may choose to disconnect the link when this occurs.

Event Parameters:

Connection_Handle: *Size: 2 Octet (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

7.7.76 SAM Status Change Event

Event	Event Code	Event Parameters
SAMStatusChange	0x58	Connection_Handle, Local_SAM_Index, Local_SAM_TX_Availability, Local_SAM_RX_Availability, Remote_SAM_Index, Remote_SAM_TX_Availability, Remote_SAM_RX_Availability

Description:

The SAM Status Change event indicates that the Controller has changed the SAM status for the connection identified by the Connection_Handle; i.e., a new SAM slot map has been enabled or the existing one disabled. Note: A change from one SAM slot map to another only generates one event, not two.

Event Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Local_SAM_Index: *Size: 1 Octet*

Value	Parameter Description
0xXX	The index of the current SAM slot map used by the local device.0xFF means SAM is disabled (i.e. all slots are available)

Local_SAM_TX_Availability: *Size: 1 Octet*

Value	Parameter Description
0xXX	The proportion of slots available for the local device to transmit. 0 represents "less than 1 in 255" and 255 represents "all"; other proportions shall be linearly scaled. That is, Local_SAM_TX_Availability = (total_available_TX_slots / local_T_{SAM}) * 255, rounded to the integer below, where total_available_TX_slots is the total number of slots available for transmission in the current local SAM slot map and local_TSAM is T_{SAM} for the current local SAM slot map.

Local_SAM_RX_Availability: *Size: 1 Octet*

Value	Parameter Description
0xXX	The proportion of slots available for the local device to receive. 0 represents "less than 1 in 255" and 255 represents "all"; other proportions shall be linearly scaled. That is, Local_SAM_RX_Availability = (total_available_RX_slots / local_T_{SAM}) * 255, rounded to the integer below, where total_available_RX_slots is the total number of slots available for reception in the current local SAM slot map and local_ T_{SAM} is T_{SAM} for the current local SAM slot map.

Remote_SAM_Index: *Size: 1 Octet*

Value	Parameter Description
0xXX	The index of the current SAM slot map used by the remote device.0xFF means SAM is disabled (i.e. all slots are available)

Remote_SAM_TX_Availability: *Size: 1 Octet*

Value	Parameter Description
0xXX	The proportion of slots available for the remote device to transmit. 0 represents "less than 1 in 255" and 255 represents "all"; other proportions shall be linearly scaled. That is, Remote_SAM_TX_Availability = (total_available_TX_slots / remote_T_{SAM}) * 255, rounded to the integer below, where total_available_TX_slots is the total number of slots available for transmission in the current remote SAM slot map and remote_T_{SAM} is T_{SAM} for the current remote SAM slot map.

Remote_SAM_RX_Availability: *Size: 1 Octet*

Value	Parameter Description
0xXX	The proportion of slots available for the remote device to receive. 0 represents "less than 1 in 255" and 255 represents "all"; other proportions shall be linearly scaled. That is, Remote_SAM_RX_Availability = (total_available_RX_slots / remote_T_{SAM}) * 255, rounded to the integer below, where total_available_RX_slots is the total number of slots available for reception in the current remote SAM slot map and remote_T_{SAM} is T_{SAM} for the current remote SAM slot map.

7.8 LE CONTROLLER COMMANDS

The LE Controller Commands provide access and control to various capabilities of the Bluetooth hardware, as well as methods for the Host to affect how the Link Layer manages the piconet, and controls connections.

For the LE Controller Commands, the OGF code is defined as 0x08.

7.8.1 LE Set Event Mask Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Event_Mask	0x0001	LE_Event_Mask	Status

Description:

The LE_Set_Event_Mask command is used to control which LE events are generated by the HCI for the Host. If the bit in the LE_Event_Mask is set to a one, then the event associated with that bit will be enabled. The Host has to deal with each event that is generated by an LE Controller. The event mask allows the Host to control which events will interrupt it.

For LE events to be generated, the LE Meta Event bit in the Event_Mask shall also be set. If that bit is not set, then LE events shall not be generated, regardless of how the LE_Event_Mask is set.

Command Parameters:

LE_Event_Mask: *Size: 8 Octets*

Bit	LE Subevent Types
0	LE Connection Complete Event
1	LE Advertising Report Event
2	LE Connection Update Complete Event
3	LE Read Remote Features Complete Event
4	LE Long Term Key Request Event
5	LE Remote Connection Parameter Request Event
6	LE Data Length Change Event
7	LE Read Local P-256 Public Key Complete Event
8	LE Generate DHKey Complete Event
9	LE Enhanced Connection Complete Event
10	LE Directed Advertising Report Event

Bit	LE Subevent Types
11	LE PHY Update Complete Event
12	LE Extended Advertising Report Event
13	LE Periodic Advertising Sync Established Event
14	LE Periodic Advertising Report Event
15	LE Periodic Advertising Sync Lost Event
16	LE Extended Scan Timeout Event
17	LE Extended Advertising Set Terminated Event
18	LE Scan Request Received Event
19	LE Channel Selection Algorithm Event

The value with all bits set to 0 indicates that no events are specified. The default is for bits 0 to 4 inclusive (the value 0x0000 0000 0000 001F) to be set.

All bits not listed in this table are reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Event_Mask command succeeded.
0x01 – 0xFF	LE_Set_Event_Mask command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Event_Mask command has completed, a Command Complete event shall be generated.

7.8.2 LE Read Buffer Size Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read _Buffer_Size	0x0002		Status, HC_LE_ACL_Data_Packet_Length, HC_Total_Num_LE_ACL_Data_Packets

Description:

The LE_Read_Buffer_Size command is used to read the maximum size of the data portion of HCI LE ACL Data Packets sent from the Host to the Controller. The Host will segment the data transmitted to the Controller according to these values, so that the HCI Data Packets will contain data with up to this size. The LE_Read_Buffer_Size command also returns the total number of HCI LE ACL Data Packets that can be stored in the data buffers of the Controller. The LE_Read_Buffer_Size command must be issued by the Host before it sends any data to an LE Controller (see Section 4.1.1).

If the Controller returns a length value of zero, the Host shall use the Read_Buffer_Size command to determine the size of the data buffers (shared between BR/EDR and LE transports).

Note: Both the Read_Buffer_Size and LE_Read_Buffer_Size commands may return buffer length and number of packets parameter values that are non-zero. This allows a Controller to offer different buffers and number of buffers for BR/EDR data packets and LE data packets.

The HC_LE_ACL_Data_Packet_Length return parameter shall be used to determine the size of the L2CAP PDU segments contained in ACL Data Packets, which are transferred from the Host to the Controller to be broken up into packets by the Link Layer. The HC_Total_Num_LE_ACL_Data_Packets return parameter contains the total number of HCI ACL Data Packets that can be stored in the data buffers of the Controller. The Host determines how the buffers are to be divided between different Connection_Handles.

Note: The HC_LE_ACL_Data_Packet_Length return parameter does not include the length of the HCI Data Packet header.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Buffer_Size command succeeded.
0x01 – 0xFF	LE_Read_Buffer_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

HC_LE_Data_Packet_Length: *Size: 2 Octets*

Value	Parameter Description
0x0000	No dedicated LE Buffer – use Read_Buffer_Size command.
0x0001 – 0x001A	Reserved for Future Use
0x001B – 0xFFFF	Maximum length (in octets) of the data portion of each HCI ACL Data Packet that the Controller is able to accept.

HC_Total_Num_LE_Data_Packets: *Size: 1 Octet*

Value	Parameter Description
0x00	No dedicated LE Buffer – use Read_Buffer_Size command.
0x01 – 0xFF	Total number of HCI ACL Data Packets that can be stored in the data buffers of the Controller.

Event(s) Generated (unless masked away):

When the LE_Read_Buffer_Size command has completed, a Command Complete event shall be generated.

7.8.3 LE Read Local Supported Features Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_Local_Supported_-Features	0x0003		Status, LE_Features

Description:

This command requests the list of the supported LE features for the Controller.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Local_Supported_Features command succeeded.
0x01 – 0xFF	LE_Read_Local_Supported_Features command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

LE_Features: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX	Bit Mask List of supported LE features. See [Vol 6] Part B, Section 4.6.

Event(s) Generated (unless masked away):

When the LE_Read_Local_Supported_Features command has completed, a Command Complete event shall be generated.

7.8.4 LE Set Random Address Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_Random_Address	0x0005	Random_Address	Status

Description:

The LE_Set_Random_Address command is used by the Host to set the LE Random Device Address in the Controller (see [Vol 6] Part B, Section 1.3).

If this command is used to change the address, the new random address shall take effect for advertising no later than the next successful LE Set Advertising Enable Command, for scanning no later than the next successful LE Set Scan Enable Command or LE Set Extended Scan Enable Command, and for initiating no later than the next successful LE Create Connection Command or LE Extended Create Connection Command.

Note: If Extended Advertising is in use, this command only affects the address used for scanning and initiating. The addresses used for advertising are set by the LE_Set_Advertising_Set_Random_Address command (see Section 7.8.52).

If the Host issues this command when scanning or legacy advertising is enabled, the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

Random_Addess: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Random Device Address as defined by [Vol 6] Part B, Section 1.3.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Random_Address command succeeded.
0x01 – 0xFF	LE_Set_Random_Address command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Random_Address command has completed, a Command Complete event shall be generated.

7.8.5 LE Set Advertising Parameters Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_ Advertising_ Parameters	0x0006	Advertising_Interval_Min, Advertising_Interval_Max, Advertising_Type, Own_Address_Type, Peer_Address_Type, Peer_Address, Advertising_Channel_Map, Advertising_Filter_Policy	Status

Description:

The LE_Set_Advertising_Parameters command is used by the Host to set the advertising parameters.

The Advertising_Interval_Min shall be less than or equal to the Advertising_Interval_Max. The Advertising_Interval_Min and Advertising_Interval_Max should not be the same value to enable the Controller to determine the best advertising interval given other activities.

For high duty cycle directed advertising, i.e. when Advertising_Type is 0x01 (ADV_DIRECT_IND, high duty cycle), the Advertising_Interval_Min and Advertising_Interval_Max parameters are not used and shall be ignored.

The Advertising_Type is used to determine the packet type that is used for advertising when advertising is enabled.

Own_Address_Type parameter indicates the type of address being used in the advertising packets.

If Own_Address_Type equals 0x02 or 0x03, the Peer_Address parameter contains the peer's Identity Address and the Peer_Address_Type parameter contains the Peer's Identity Type (i.e. 0x00 or 0x01). These parameters are used to locate the corresponding local IRK in the resolving list; this IRK is used to generate the own address used in the advertisement.

If directed advertising is performed, i.e. when Advertising_Type is set to 0x01 (ADV_DIRECT_IND, high duty cycle) or 0x04 (ADV_DIRECT_IND, low duty cycle mode), then the Peer_Address_Type and Peer_Address shall be valid.

If Own_Address_Type equals 0x02 or 0x03, the Controller generates the peer's Resolvable Private Address using the peer's IRK corresponding to the peer's Identity Address contained in the Peer_Address parameter and peer's Identity Address Type (i.e. 0x00 or 0x01) contained in the Peer_Address_Type parameter.

The Advertising_Channel_Map is a bit field that indicates the advertising channels that shall be used when transmitting advertising packets. At least one channel bit shall be set in the Advertising_Channel_Map parameter.

The Advertising_Filter_Policy parameter shall be ignored when directed advertising is enabled.

The Host shall not issue this command when advertising is enabled in the Controller; if it is the *Command Disallowed* error code shall be used.

If the advertising interval range provided by the Host (Advertising_Interval_Min, Advertising_Interval_Max) is outside the advertising interval range supported by the Controller, then the Controller shall return the *Unsupported Feature or Parameter Value* (0x11) error code.

Command Parameters:

Advertising_Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum advertising interval for undirected and low duty cycle directed advertising. Range: 0x0020 to 0x4000 Default: N = 0x0800 (1.28 s) Time = N * 0.625 ms Time Range: 20 ms to 10.24 s

Advertising_Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum advertising interval for undirected and low duty cycle directed advertising. Range: 0x0020 to 0x4000 Default: N = 0x0800 (1.28 s) Time = N * 0.625 ms Time Range: 20 ms to 10.24 s

Advertising_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Connectable and scannable undirected advertising (ADV_IND) (default)
0x01	Connectable high duty cycle directed advertising (ADV_DIRECT_IND, high duty cycle)
0x02	Scannable undirected advertising (ADV_SCAN_IND)
0x03	Non connectable undirected advertising (ADV_NONCONN_IND)

Value	Parameter Description
0x04	Connectable low duty cycle directed advertising (ADV_DIRECT_IND, low duty cycle)
0x05 – 0xFF	Reserved for future use

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address (default)
0x01	Random Device Address
0x02	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the public address.
0x03	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the random address from LE_Set_Random_Address.
0x04 – 0xFF	Reserved for future use

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address (default) or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
0x02 – 0xFF	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the device to be connected.

Advertising_Channel_Map: *Size: 1 Octet*

Value	Parameter Description
00000000b	Reserved for future use
xxxxxxx1b	Channel 37 shall be used
xxxxxx1xb	Channel 38 shall be used
xxxxx1xxb	Channel 39 shall be used
00000111b	Default (all channels enabled)

Advertising_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	Process scan and connection requests from all devices (i.e., the White List is not in use) (default).
0x01	Process connection requests from all devices and only scan requests from devices that are in the White List.
0x02	Process scan requests from all devices and only connection requests from devices that are in the White List.
0x03	Process scan and connection requests only from devices in the White List.
0x04 – 0xFF	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Advertising_Parameters command succeeded.
0x01 – 0xFF	LE_Set_Advertising_Parameters command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Advertising_Parameters command has completed, a Command Complete event shall be generated.

7.8.6 LE Read Advertising Channel Tx Power Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_Advertising_ Channel_Tx_Power	0x0007		Status, Transmit_Power_Level

Description:

The LE_Read_Advertising_Channel_Tx_Power command is used by the Host to read the transmit power level used for LE advertising channel packets.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Advertising_Channel_Tx_Power command succeeded.
0x01 – 0xFF	LE_Read_Advertising_Channel_Tx_Power failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Transmit_Power_Level: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -20 ≤ N ≤ 10 Units: dBm Accuracy: +/- 4 dB

Event(s) Generated (unless masked away):

When the LE_Read_Advertising_Channel_Tx_Power command has completed, a Command Complete event shall be generated.

7.8.7 LE Set Advertising Data Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_Advertising_Data	0x0008	Advertising_Data_Length, Advertising_Data	Status

Description:

The LE_Set_Advertising_Data command is used to set the data used in advertising packets that have a data field.

Only the significant part of the Advertising_Data should be transmitted in the advertising packets, as defined in [Vol 3] Part C, Section 11.

If advertising is currently enabled, the Controller shall use the new data in subsequent advertising events. If an advertising event is in progress when this command is issued, the Controller may use the old or new data for that event. If advertising is currently disabled, the data shall be kept by the Controller and used once advertising is enabled.

Command Parameters:

Advertising_Data_Length: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0x1F	The number of significant octets in the Advertising_Data.

Advertising_Data: *Size: 31 Octets*

Value	Parameter Description
	31 octets of advertising data formatted as defined in [Vol 3] Part C, Section 11.
	All octets zero (default).

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Advertising_Data command succeeded.
0x01 – 0xFF	LE_Set_Advertising_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Advertising_Data command has completed, a Command Complete event shall be generated.

7.8.8 LE Set Scan Response Data Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_Scan_Response_Data	0x0009	Scan_Response_Data_Length, Scan_Response_Data	Status

Description:

This command is used to provide data used in Scanning Packets that have a data field.

Only the significant part of the Scan_Response_Data should be transmitted in the Scanning Packets, as defined in [Vol 3] Part C, Section 11.

If advertising is currently enabled, the Controller shall use the new data in subsequent advertising events. If an advertising event is in progress when this command is issued, the Controller may use the old or new data for that event. If advertising is currently disabled, the data shall be kept by the Controller and used once advertising is enabled.

Command Parameters:

Scan_Response_Data_Length: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0x1F	The number of significant octets in the Scan_Response_Data.

Scan_Response_Data: *Size: 31 Octets*

Value	Parameter Description
	31 octets of Scan_Response_Data formatted as defined in [Vol 3] Part C, Section 11.
	All octets zero (default).

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Scan_Response_Data command succeeded.
0x01 – 0xFF	LE_Set_Scan_Response_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Scan_Response_Data command has completed, a Command Complete event shall be generated.

7.8.9 LE Set Advertising Enable Command[1]

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_ Advertising_ Enable	0x000A	Advertising_Enable	Status

Description:

The LE_Set_Advertising_Enable command is used to request the Controller to start or stop advertising. The Controller manages the timing of advertisements as per the advertising parameters given in the LE_Set_Advertising_Parameters command.

The Controller shall continue advertising until the Host issues an LE_Set_Advertising_Enable command with Advertising_Enable set to 0x00 (Advertising is disabled) or until a connection is created or until the Advertising is timed out due to high duty cycle Directed Advertising. In these cases, advertising is then disabled.

If the advertising parameters' Own_Address_Type parameter is set to 0x01 and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the advertising parameters' Own_Address_Type parameter is set to 0x03, the controller's resolving list did not contain a matching entry, and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Note: Enabling advertising when it is already enabled can cause the random address to change. Disabling advertising when it is already disabled has no effect.

Command Parameters:

Advertising_Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Advertising is disabled (default)
0x01	Advertising is enabled.
0x02 – 0xFF	Reserved for future use

1. This command was formerly called “LE Set Advertise Enable”.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Advertising_Enable command succeeded.
0x01 – 0xFF	LE_Set_Advertising_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Advertising_Enable command has completed, a Command Complete event shall be generated.

If the Advertising_Type parameter is 0x01 (ADV_DIRECT_IND, high duty cycle) and the directed advertising fails to create a connection, an LE Connection Complete or LE Enhanced Connection Complete event shall be generated with the Status code set to Advertising Timeout (0x3C).

If the Advertising_Type parameter is 0x00 (ADV_IND), 0x01 (ADV_DIRECT_IND, high duty cycle), or 0x04 (ADV_DIRECT_IND, low duty cycle) and a connection is created, an LE Connection Complete or LE Enhanced Connection Complete event shall be generated.

Note: There is a possible race condition if the Advertising_Enable parameter is set to 0x00 (Disable) and the Advertising_Type parameter is 0x00, 0x01, or 0x04. The advertisements might not be stopped before a connection is created, and therefore both the Command Complete event and either an LE Connection Complete event or an LE Enhanced Connection Complete event could be generated. This can also occur when high duty cycle directed advertising is timed out and this command disables advertising.

7.8.10 LE Set Scan Parameters Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_Scan_Parameters	0x000B	LE_Scan_Type, LE_Scan_Interval, LE_Scan_Window, Own_Address_Type, Scanning_Filter_Policy	Status

Description:

The LE_Set_Scan_Parameters command is used to set the scan parameters.

The LE_Scan_Type parameter controls the type of scan to perform.

The LE_Scan_Interval and LE_Scan_Window parameters are recommendations from the Host on how long (LE_Scan_Window) and how frequently (LE_Scan_Interval) the Controller should scan (See [Vol 6] Part B, Section 4.5.3). The LE_Scan_Window parameter shall always be set to a value smaller or equal to the value set for the LE_Scan_Interval parameter. If they are set to the same value scanning should be run continuously.

Own_Address_Type parameter indicates the type of address being used in the scan request packets.

The Host shall not issue this command when scanning is enabled in the Controller; if it is the *Command Disallowed* error code shall be used.

Command Parameters:

LE_Scan_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Passive Scanning. No scanning PDUs shall be sent (default)
0x01	Active scanning. Scanning PDUs may be sent.
0x02 – 0xFF	Reserved for future use

LE_Scan_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	This is defined as the time interval from when the Controller started its last LE scan until it begins the subsequent LE scan. Range: 0x0004 to 0x4000 Default: 0x0010 (10 ms) Time = N * 0.625 ms Time Range: 2.5 ms to 10.24 s

LE_Scan_Window: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	The duration of the LE scan. LE_Scan_Window shall be less than or equal to LE_Scan_Interval Range: 0x0004 to 0x4000 Default: 0x0010 (10 ms) Time = N * 0.625 ms Time Range: 2.5 ms to 10.24 s

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address (default)
0x01	Random Device Address
0x02	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the public address.
0x03	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the random address from LE_Set_Random_Address.
All other values	Reserved for future use.

Scanning_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	Accept all advertising packets except directed advertising packets not addressed to this device (default).
0x01	Accept only advertising packets from devices where the advertiser's address is in the White List. Directed advertising packets which are not addressed to this device shall be ignored.
0x02	Accept all advertising packets except directed advertising packets where the initiator's identity address does not address this device. Note: Directed advertising packets where the initiator's address is a resolvable private address that cannot be resolved are also accepted.
0x03	Accept all advertising packets except: • advertising packets where the advertiser's identity address is not in the White List; and • directed advertising packets where the initiator's identity address does not address this device Note: Directed advertising packets where the initiator's address is a resolvable private address that cannot be resolved are also accepted.
0x04 – 0xFF	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Scan_Parameters command succeeded.
0x01 – 0xFF	LE_Set_Scan_Parameters command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Scan_Parameters command has completed, a Command Complete event shall be generated.

7.8.11 LE Set Scan Enable Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_S-can_Enable	0x000C	LE_Scan_Enable, Filter_Duplicates	Status

Description:

The LE_Set_Scan_Enable command is used to start scanning. Scanning is used to discover advertising devices nearby.

The Filter_Duplicates parameter controls whether the Link Layer should filter out duplicate advertising reports (Filtering_Enabled) to the Host, or if the Link Layer should generate advertising reports for each packet received (Filtering_Disabled). See [Vol 6] Part B, Section 4.4.3.5.

If the scanning parameters' Own_Address_Type parameter is set to 0x01 or 0x03 and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the LE_Scan_Enable parameter is set to 0x01 and scanning is already enabled, any change to the Filter_Duplicates setting shall take effect.
Note: Disabling scanning when it is disabled has no effect.

Command Parameters:

LE_Scan_Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Scanning disabled.
0x01	Scanning enabled.
0x02 – 0xFF	Reserved for future use.

Filter_Duplicates: *Size: 1 Octet*

Value	Parameter Description
0x00	Duplicate filtering disabled.
0x01	Duplicate filtering enabled.
0x02 – 0xFF	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Scan_Enable command succeeded.

Value	Parameter Description
0x01 – 0xFF	LE_Set_Scan_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Scan_Enable command has completed, a Command Complete event shall be generated.

Zero or more LE Advertising Reports are generated by the Controller based on advertising packets received and the duplicate filtering. More than one advertising packet may be reported in each LE Advertising Report event.

When the Scanning_Filter_Policy is set to 0x02 or 0x03 (see Section 7.8.10) and a directed advertisement was received where the advertiser used a resolvable private address which the Controller is unable to resolve, an LE Directed Advertising Report event shall be generated instead of an LE Advertising Report Event.

7.8.12 LE Create Connection Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Create _Connection	0x000D	LE_Scan_Interval, LE_Scan_Window, Initiator_Filter_Policy, Peer_Address_Type, Peer_Address, Own_Address_Type, Conn_Interval_Min, Conn_Interval_Max, Conn_Latency, Supervision_Timeout, Minimum_CE_Length, Maximum_CE_Length	

Description:

The LE_Create_Connection command is used to create a Link Layer connection to a connectable advertiser.

The LE_Scan_Interval and LE_Scan_Window parameters are recommendations from the Host on how long (LE_Scan_Window) and how frequently (LE_Scan_Interval) the Controller should scan. The LE_Scan_Window parameter shall be set to a value smaller or equal to the value set for the LE_Scan_Interval parameter. If both are set to the same value, scanning should run continuously.

The Initiator_Filter_Policy is used to determine whether the White List is used. If the White List is not used, the Peer_Address_Type and the Peer_Address parameters specify the address type and address of the advertising device to connect to.

Peer_Address_Type parameter indicates the type of address used in the connectable advertisement sent by the peer. The Host shall not set Peer_Address_Type to either 0x02 or 0x03 if both the Host and the Controller support the LE Set Privacy Mode command. If a Controller that supports the LE Set Privacy Mode command receives the LE Create Connection command with Peer_Address_Type set to either 0x02 or 0x03, it may use either device privacy mode or network privacy mode for that peer device.

Peer_Address parameter indicates the Peer's Public Device Address, Random (static) Device Address, Non-Resolvable Private Address or Resolvable Private Address depending on the Peer_Address_Type parameter.

Own_Address_Type parameter indicates the type of address being used in the connection request packets.

The Conn_Interval_Min and Conn_Interval_Max parameters define the minimum and maximum allowed connection interval. The Conn_Interval_Min parameter shall not be greater than the Conn_Interval_Max parameter.

The Conn_Latency parameter defines the maximum allowed connection latency (see [Vol 6] Part B, Section 4.5.1).

The Supervision_Timeout parameter defines the link supervision timeout for the connection. The Supervision_Timeout in milliseconds shall be larger than (1 + Conn_Latency) * Conn_Interval_Max * 2, where Conn_Interval_Max is given in milliseconds. (See [Vol 6] Part B, Section 4.5.2).

The Minimum_CE_Length and Maximum_CE_Length parameters are informative parameters providing the Controller with the expected minimum and maximum length of the connection events. The Minimum_CE_Length parameter shall be less than or equal to the Maximum_CE_Length parameter.

If the Host issues this command when another LE_Create_Connection command is pending in the Controller, the Controller shall return the error code *Command Disallowed* (0x0C).

If the Own_Address_Type parameter is set to 0x01 and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Own_Address_Type parameter is set to 0x03, the Initiator_Filter_Policy parameter is set to 0x00, the controller's resolving list did not contain a matching entry, and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Own_Address_Type parameter is set to 0x03, the Initiator_Filter_Policy parameter is set to 0x01, and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Command Parameters:

LE_Scan_Interval: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	This is defined as the time interval from when the Controller started its last LE scan until it begins the subsequent LE scan. Range: 0x0004 to 0x4000 Time = N * 0.625 ms Time Range: 2.5 ms to 10.24 s

LE_Scan_Window: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Amount of time for the duration of the LE scan. LE_Scan_Window shall be less than or equal to LE_Scan_Interval Range: 0x0004 to 0x4000 Time = N * 0.625 ms Time Range: 2.5 ms to 10.24 s

Initiator_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	White List is not used to determine which advertiser to connect to. Peer_Address_Type and Peer_Address shall be used.
0x01	White List is used to determine which advertiser to connect to. Peer_Address_Type and Peer_Address shall be ignored.
0x02 – 0xFF	Reserved for future use.

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Public Identity Address (Corresponds to peer's Resolvable Private Address). This value shall only be used by the Host if either the Host or the Controller does not support the LE Set Privacy Mode command.
0x03	Random (static) Identity Address (Corresponds to peer's Resolvable Private Address). This value shall only be used by a Host if either the Host or the Controller does not support the LE Set Privacy Mode command.
0x04 – 0xFF	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the device to be connected

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address

Value	Parameter Description
0x02	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the public address.
0x03	Controller generates Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the random address from the most recent successful LE_Set_Random_Address Command.
0x04 – 0xFF	Reserved for future use

Conn_Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum value for the connection interval. This shall be less than or equal to Conn_Interval_Max. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s.
0x0000 – 0x0005 and 0x0C81 – 0xFFFF	Reserved for future use

Conn_Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum value for the connection interval. This shall be greater than or equal to Conn_Interval_Min. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s.
0x0000 – 0x0005 and 0x0C81 – 0xFFFF	Reserved for future use

Conn_Latency: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3

Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Supervision timeout for the LE Link. (See [Vol 6] Part B, Section 4.5.2) Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s
0x0000 - 0x0009 and 0x0C81 - 0xFFFF	Reserved for future use

Minimum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the minimum length of connection event needed for this LE connection. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms.

Maximum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the maximum length of connection event needed for this LE connection. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms.

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Create_Connection command, the Controller sends the Command Status event to the Host. An LE Connection Complete or LE Enhanced Connection Complete event shall be generated when a connection is created or the connection creation procedure is cancelled. If a connection is created and the Controller supports the LE Channel Selection Algorithm #2 feature, this event shall be immediately followed by an LE Channel Selection Algorithm Event.

Note: No Command Complete event is sent by the Controller to indicate that this command has been completed. Instead, the LE Connection Complete or LE Enhanced Connection Complete event indicates that this command has been completed.

7.8.13 LE Create Connection Cancel Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Create _Connection_Cancel	0x000E		Status

Description:

The LE_Create_Connection_Cancel command is used to cancel the LE_Create_Connection or LE_Extended_Create_Connection commands. This command shall only be issued after the LE_Create_Connection or LE_Extended_Create_Connection commands have been issued, a Command Status event has been received for the LE Create Connection or LE_Extended_Create_Connection commands, and before the LE Connection Complete or LE Enhanced Connection Complete events.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Create_Connection_Cancel command succeeded.
0x01 – 0xFF	LE_Create_Connection_Cancel command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Create_Connection_Cancel command has completed, a Command Complete event shall be generated.

If the LE_Create_Connection_Cancel command is sent to the Controller without a preceding LE_Create_Connection or LE_Extended_Create_Connection command, the Controller shall return a Command Complete event with the error code *Command Disallowed* (0x0C).

If the cancellation was successful then, after the Command Complete event for the LE_Create_Connection_Cancel command, either an LE Connection Complete or an LE Enhanced Connection Complete event shall be generated.

In either case, the event shall be sent with the error code *Unknown Connection Identifier* (0x02).

7.8.14 LE Read White List Size Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_ White_List_Size	0x000F		Status, White_List_Size

Description:

The LE_Read_White_List_Size command is used to read the total number of White List entries that can be stored in the Controller. Note: The number of entries that can be stored is not fixed and the Controller can change it at any time (e.g. because the memory used to store the White List can also be used for other purposes).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_White_List_Size command succeeded.
0x01 – 0xFF	LE_Read_White_List_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

White_List_Size: *Size: 1 Octet*

Value	Parameter Description
0x01 – 0xFF	Total number of White List entries that can be stored in the Controller.
0x00	Reserved for future use

Event(s) Generated (unless masked away):

When the LE_Read_White_List_Size command has completed, a Command Complete event shall be generated.

7.8.15 LE Clear White List Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Clear_White_List	0x0010		Status

Description:

The LE_Clear_White_List command is used to clear the White List stored in the Controller.

This command can be used at any time except when:

- any advertising filter policy uses the White List and advertising is enabled.
- the scanning filter policy uses the White List and scanning is enabled.
- the initiator filter policy uses the White List and an LE_Create_Connection command is outstanding.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Clear_White_List command succeeded.
0x01 – 0xFF	LE_Clear_White_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE Clear White List command has completed, a Command Complete event shall be generated.

7.8.16 LE Add Device To White List Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Add _De-vice_To_White_List	0x0011	Address_Type, Address	Status

Description:

The LE_Add_Device_To_White_List command is used to add a single device to the White List stored in the Controller.

This command can be used at any time except when:

- any advertising filter policy uses the White List and advertising is enabled.
- the scanning filter policy uses the White List and scanning is enabled.
- the initiator filter policy uses the White List and a create connection command is outstanding.

When a Controller cannot add a device to the White List because there is no space available, it shall return the error code *Memory Capacity Exceeded* (0x07).

Address is ignored when Address_Type is set to 0xFF.

Command Parameters:

Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0xFF	Devices sending anonymous advertisements
All other values	Reserved for future use.

Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address or Random Device Address of the device to be added to the White List.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Add_Device_To_White_List command succeeded.
0x01 – 0xFF	LE_Add_Device_To_White_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Add_Device_To_White_List command has completed, a Command Complete event shall be generated.

7.8.17 LE Remove Device From White List Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Remove _Device_From _White_List	0x0012	Address_Type, Address	Status

Description:

The LE_Remove_Device_From_White_List command is used to remove a single device from the White List stored in the Controller.

This command can be used at any time except when:

- any advertising filter policy uses the White List and advertising is enabled.
- the scanning filter policy uses the White List and scanning is enabled.
- the initiator filter policy uses the White List and a create connection command is outstanding.

Address is ignored when Address_Type is set to 0xFF.

Command Parameters:

Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0xFF	Devices sending anonymous advertisements
All other values	Reserved for future use.

Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address or Random Device Address of the device to be removed from the White List.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Remove_Device_From_White_List command succeeded.
0x01 – 0xFF	LE_Remove_Device_From_White_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Remove_Device_From_White_List command has completed, a Command Complete event shall be generated.

7.8.18 LE Connection Update Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Connection_Update	0x0013	Connection_Handle, Conn_Interval_Min, Conn_Interval_Max, Conn_Latency, Supervision_Timeout, Minimum_CE_Length, Maximum_CE_Length	

Description:

The LE_Connection_Update command is used to change the Link Layer connection parameters of a connection. This command may be issued on both the master and slave.

The Conn_Interval_Min and Conn_Interval_Max parameters are used to define the minimum and maximum allowed connection interval. The Conn_Interval_Min parameter shall not be greater than the Conn_Interval_Max parameter.

The Conn_Latency parameter shall define the maximum allowed connection latency.

The Supervision_Timeout parameter shall define the link supervision timeout for the LE link. The Supervision_Timeout in milliseconds shall be larger than (1 + Conn_Latency) * Conn_Interval_Max * 2, where Conn_Interval_Max is given in milliseconds.

The Minimum_CE_Length and Maximum_CE_Length are information parameters providing the Controller with a hint about the expected minimum and maximum length of the connection events. The Minimum_CE_Length shall be less than or equal to the Maximum_CE_Length.

The actual parameter values selected by the Link Layer may be different from the parameter values provided by the Host through this command.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Conn_Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum value for the connection interval. This shall be less than or equal to Conn_Interval_Max. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s.
0x0000-0x0005 and 0x0C81-0xFFFF	Reserved for future use

Conn_Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum value for the connection interval. This shall be greater than or equal to Conn_Interval_Min. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s.
0x0000-0x0005 and 0x0C81-0xFFFF	Reserved for future use

Conn_Latency: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3
0x01F4 – 0xFFFF	Reserved for future use.

Supervision_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Supervision timeout for the LE Link. Range: 0x000A to 0x0C80 Mandatory Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s
0x0001-0x0009 and 0x0C81-0xFFFF	Reserved for future use

Minimum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the minimum length of connection event needed for this LE connection. How this value is used is outside the scope of this specification. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms.

Maximum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the maximum length of connection event needed for this LE connection. How this value is used is outside the scope of this specification. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms.

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Connection_Update command, the Controller sends the Command Status event to the Host. The LE Connection Update Complete event shall be generated after the connection parameters have been applied by the Controller or if the command subsequently fails.

Note: A Command Complete event is not sent by the Controller to indicate that this command has been completed. Instead, the LE Connection Update Complete event indicates that this command has been completed.

7.8.19 LE Set Host Channel Classification Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Set_Host_Channel_Classification	0x0014	Channel_Map	Status

Description:

The LE_Set_Host_Channel_Classification command allows the Host to specify a channel classification for data channels based on its “local information”. This classification persists until overwritten with a subsequent LE_Set_Host_Channel_Classification command or until the Controller is reset using the Reset command (see [Vol 6] Part B, Section 4.5.8.1).

If this command is used, the Host should send it within 10 seconds of knowing that the channel classification has changed. The interval between two successive commands sent shall be at least one second.

This command shall only be used when the local device supports the Master role.

Command Parameters:

Channel_Map: *Size: 5 Octet (37 Bits meaningful)*

Value	Parameter Description
0xXXXXXXXXXX	This parameter contains 37 1-bit fields. The n^{th} such field (in the range 0 to 36) contains the value for the link layer channel index n. Channel n is bad = 0. Channel n is unknown = 1. The most significant bits are reserved and shall be set to 0for future use. At least one channel shall be marked as unknown.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Host_Channel_Classification command succeeded.
0x01 – 0xFF	LE_Set_Host_Channel_Classification command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Host_Channel_Classification command has completed, a Command Complete event shall be generated.

7.8.20 LE Read Channel Map Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_Channel_Map	0x0015	Connection_Handle	Status, Connection_Handle, Channel_Map

Description:

The LE_Read_Channel_Map command returns the current Channel_Map for the specified Connection_Handle. The returned value indicates the state of the Channel_Map specified by the last transmitted or received Channel_Map (in a CONNECT_IND or LL_CHANNEL_MAP_IND message) for the specified Connection_Handle, regardless of whether the Master has received an acknowledgment.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Channel_Map command succeeded.
0x01 – 0xFF	LE_Read_Channel_Map command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Channel_Map: *Size: 5 Octets*

Value	Parameter Description
0xXXXXXXXXXX	This parameter contains 37 1-bit fields. The n^{th} such field (in the range 0 to 36) contains the value for the link layer channel index n. Channel n is unused = 0. Channel n is used = 1. The most significant bits are reserved for future use.

Event(s) Generated (unless masked away):

When the LE_Read_Channel_Map command has completed, a Command Complete event shall be generated.

7.8.21 LE Read Remote Features Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_ Remote_Features	0x0016	Connection_Handle	

Description:

This command requests, from the remote device identified by the connection handle, the features used on the connection and the features supported by the remote device. For details see [Vol 6] Part B, Section 4.6.

This command may be issued on both the master and slave.

Note: If a connection already exists between the two devices and the features have already been fetched on that connection, the Controller may use a cached copy of the features.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Read_Remote_Features command, the Controller shall send the Command Status event to the Host. When the Controller has completed the procedure to determine the remote features or has determined that it will be using a cached copy, the Controller shall send a LE Read Remote Features Complete event to the Host.

The LE Read Remote Features Complete event contains the status of this command and the parameter describing the features used on the connection and the features supported by the remote device.

Note: A Command Complete event is not sent by the Controller to indicate that this command has been completed. Instead, the LE Read Remote Features Complete event indicates that this command has been completed.

7.8.22 LE Encrypt Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Encrypt	0x0017	Key, Plaintext_Data	Status, Encrypted_Data

Description:

The LE_Encrypt command is used to request the Controller to encrypt the Plaintext_Data in the command using the Key given in the command and returns the Encrypted_Data to the Host. The AES-128 bit block cypher is defined in NIST Publication FIPS-197 (http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf).

Command Parameters:

Key: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	128 bit key for the encryption of the data given in the command. The most significant octet of the key corresponds to key[0] using the notation specified in FIPS 197.

Plaintext_Data: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	128 bit data block that is requested to be encrypted. The most significant octet of the PlainText_Data corresponds to in[0] using the notation specified in FIPS 197.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Encrypt command succeeded.
0x01 – 0xFF	LE_Encrypt command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Encrypted_Data: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	128 bit encrypted data block. The most significant octet of the Encrypted_Data corresponds to out[0] using the notation specified in FIPS 197.

Event(s) Generated (unless masked away):

When the LE_Encrypt command has completed, a Command Complete event shall be generated.

7.8.23 LE Rand Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Rand	0x0018		Status, Random_Number

Description:

The LE_Rand command is used to request the Controller to generate 8 octets of random data to be sent to the Host. The Random_Number shall be generated according to [Vol 2] Part H, Section 2 if the LE Feature (LE Encryption) is supported.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Rand command succeeded.
0x01 – 0xFF	LE_Rand command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Random_Number: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX	Random Number

Event(s) Generated (unless masked away):

When the LE_Rand command has completed, a Command Complete event shall be generated.

7.8.24 LE Start Encryption Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Start_ Encryption	0x0019	Connection_Handle, Random_Number, Encrypted_Diversifier, Long_Term_Key	

Description:

The LE_Start_Encryption command is used to authenticate the given encryption key associated with the remote device specified by the Connection_Handle, and once authenticated will encrypt the connection. The parameters are as defined in [Vol 3] Part H, Section 2.4.4.

If the connection is already encrypted then the Controller shall pause connection encryption before attempting to authenticate the given encryption key, and then re-encrypt the connection. While encryption is paused no user data shall be transmitted.

On an authentication failure, the connection shall be automatically disconnected by the Link Layer. If this command succeeds, then the connection shall be encrypted.

This command shall only be used when the local device's role is Master.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Random_Number: *Size: 8 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX	64 bit random number.

Encrypted_Diversifier: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	16 bit encrypted diversifier.

Long_Term_Key: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	128 bit long term key.

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Start_Encryption command it shall send the Command Status event to the Host. If the connection is not encrypted when this command is issued, an Encryption Change event shall occur when encryption has been started for the connection. If the connection is encrypted when this command is issued, an Encryption Key Refresh Complete event shall occur when encryption has been resumed.

Note: A Command Complete event is not sent by the Controller to indicate that this command has been completed. Instead, the Encryption Change or Encryption Key Refresh Complete events indicate that this command has been completed.

7.8.25 LE Long Term Key Request Reply Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Long_ Term_Key_ Request_Reply	0x001A	Connection_Handle, Long_Term_Key	Status, Connection_Handle

Description:

The LE_Long_Term_Key_Request Reply command is used to reply to an LE Long Term Key Request event from the Controller, and specifies the Long_Term_Key parameter that shall be used for this Connection_Handle. The Long_Term_Key is used as defined in [Vol 6] Part B, Section 5.1.3.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Long Term Key: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	128 bit long term key for the given connection.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Long_Term_Key_Request_Reply command succeeded.
0x01 – 0xFF	LE_Long_Term_Key_Request_Reply command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Event(s) Generated (unless masked away):

When the LE_Long_Term_Key_Request_Reply command has completed, a Command Complete event shall be generated.

7.8.26 LE Long Term Key Request Negative Reply Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Long _Term_Key _Request _Negative_Reply	0x001B	Connection_Handle	Status, Connection_Handle

Description:

The LE_Long_Term_Key_Request_Negative_Reply command is used to reply to an LE Long Term Key Request event from the Controller if the Host cannot provide a Long Term Key for this Connection_Handle.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Long_Term_Key_Request_Negative_Reply command succeeded.
0x01 – 0xFF	LE_Long_Term_Key_Request_Negative_Reply command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Event(s) Generated (unless masked away):

When the LE_Long_Term_Key_Request_Negative_Reply command has completed, a Command Complete event shall be generated.

7.8.27 LE Read Supported States Command

Command	OCF	Command parameters	Return Parameters
HCI_LE_Read_ Supported_States	0x001C		Status, LE_States

Description:

The LE_Read_Supported_States command reads the states and state combinations that the link layer supports. See [Vol 6] Part B, Section 1.1.1.

LE_States is an 8-octet bit field. If a bit is set to 1 then this state or state combination is supported by the Controller. Multiple bits in LE_States may be set to 1 to indicate support for multiple state and state combinations.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Supported_States command succeeded.
0x01 – 0xFF	LE_Read_Supported_States command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

LE_States: *Size: 8 Octets*

	SUPPORTED STATES & ROLES									
Bit	Scannable Advertising State	Connectable Advertising State	Non-connectable Advertising State	High Duty Cycle Directed Advertising State	Low Duty Cycle Directed Advertising State	Active Scanning State	Passive Scanning State	Initiating State	Connection State (Master Role)	Connection State (Slave Role)
0			X							
1	X									
2		X								
3				X						
4							X			
5						X				
6								X		
7										X
8			X				X			
9	X						X			

Bit	SUPPORTED STATES & ROLES									
	Scannable Advertising State	Connectable Advertising State	Non-connectable Advertising State	High Duty Cycle Directed Advertising State	Low Duty Cycle Directed Advertising State	Active Scanning State	Passive Scanning State	Initiating State	Connection State (Master Role)	Connection State (Slave Role)
10		X					X			
11				X			X			
12			X			X				
13	X					X				
14		X				X				
15				X		X				
16			X					X		
17	X							X		
18			X						X	
19	X								X	
20			X							X
21	X									X
22							X	X		
23						X		X		
24							X		X	
25						X			X	
26							X			X
27						X				X
28								X	X	
29					X					
30					X		X			
31					X	X				
32		X						X		
33				X				X		
34					X			X		
35		X							X	
36				X					X	
37					X				X	
38		X								X
39				X						X
40					X					X
41								X		X

All bits not listed in this table, and the value with all bits set to 0, are reserved for future use.

Event(s) Generated (unless masked away):

When the LE_Read_Supported_States command has completed, a Command Complete event will be generated.

7.8.28 LE Receiver Test Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Receiver_Test	0x001D	RX_Channel	Status

Description:

This command is used to start a test where the DUT receives test reference packets at a fixed interval. The tester generates the test reference packets.

Command Parameters:

RX_Channel: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	N = (F – 2402) / 2
	Range: 0x00 – 0x27. Frequency Range : 2402 MHz to 2480 MHz

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Receiver_Test command succeeded.
0x01 – 0xFF	LE_Receiver_Test command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Receiver_Test command has completed, a Command Complete event shall be generated.

7.8.29 LE Transmitter Test Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Transmitter_Test	0x001E	TX_Channel, Length_Of_Test_Data, Packet_Payload	Status

Description:

This command is used to start a test where the DUT generates test reference packets at a fixed interval. The Controller shall transmit at maximum power.

An LE Controller supporting the LE_Transmitter_Test command shall support Packet_Payload values 0x00, 0x01 and 0x02. An LE Controller may support other values of Packet_Payload.

Command Parameters:

TX_Channel: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	N = (F – 2402) / 2
	Range: 0x00 – 0x27. Frequency Range : 2402 MHz to 2480 MHz

Length_Of_Test_Data: *Size: 1 Octet*

Value	Parameter Description
0x00-0xFF	Length in bytes of payload data in each packet

Packet_Payload: *Size: 1 Octet*

Value	Parameter Description
0x00	PRBS9 sequence ‘11111111100000111101…’ (in transmission order) as described in [Vol 6] Part F, Section 4.1.5
0x01	Repeated ‘11110000’ (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5
0x02	Repeated ‘10101010’ (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5
0x03	PRBS15 sequence as described in [Vol 6] Part F, Section 4.1.5
0x04	Repeated ‘11111111’ (in transmission order) sequence
0x05	Repeated ‘00000000’ (in transmission order) sequence
0x06	Repeated ‘00001111’ (in transmission order) sequence
0x07	Repeated ‘01010101’ (in transmission order) sequence

Value	Parameter Description
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Transmitter_Test command succeeded.
0x01 – 0xFF	LE_Transmitter_Test command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Transmitter_Test command has completed, a Command Complete event shall be generated.

7.8.30 LE Test End Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Test_End	0x001F		Status, Number_Of_Packets

Description:

This command is used to stop any test which is in progress. The Number_Of_Packets for a transmitter test shall be reported as 0x0000. The Number_Of_Packets is an unsigned number and contains the number of received packets.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Test_End command succeeded.
0x01-0xFF	LE_Test_End command failed See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Number_Of_Packets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Number of packets received

Event(s) Generated (unless masked away):

When the LE_Test_End command has completed, a Command Complete event shall be generated.

7.8.31 LE Remote Connection Parameter Request Reply Command

Command	OCF	Command Parameters	Return Parameters
LE_Remote_Connection_ Parameter_ Request_Reply	0x0020	Connection_Handle, Interval_Min, Interval_Max, Latency, Timeout, Minimum_CE_Length, Maximum_CE_Length	Status, Connection_Handle

Description:

Both the master Host and the slave Host use this command to reply to the HCI LE Remote Connection Parameter Request event. This indicates that the Host has accepted the remote device's request to change connection parameters.

The Interval_Min and Interval_Max parameters define the minimum and maximum allowed connection interval. The Interval_Min parameter shall not be greater than the Interval_Max parameter.

The Latency parameter shall define the maximum allowed slave latency for the connection in number of connection events.

The Timeout parameter shall define the link supervision timeout for the LE link. The Timeout in milliseconds shall be larger than (1 + Latency) * Interval_Max * 2, where Interval_Max is given in milliseconds.

The Minimum_CE_Length and Maximum_CE_Length are information parameters providing the Controller with a hint about the expected minimum and maximum length of the connection events. The Minimum_CE_Length shall be less than or equal to the Maximum_CE_Length.

The actual parameter values selected by the Link Layer may be different from the parameter values provided by the Host through this command.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum value of the connection interval. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s

Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum value of the connection interval. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s

Latency: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Maximum allowed slave latency for the connection specified as the number of connection events. Range: 0x0000 to 0x01F3 (499)

Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Supervision timeout for the connection. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s

Minimum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the minimum length of connection event needed for this LE connection. Range: 0x0000 to 0xFFFF Time = N * 0.625 ms Time Range: 0 ms to 40.9 s

Maximum_CE_Length: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Information parameter about the maximum length of connection event needed for this LE connection. Range: 0x0000 to 0xFFFF Time = N * 0.625 ms Time Range: 0 ms to 40.9 s

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Remote_Connection_Parameter_ Request_Reply command succeeded.
0x01-0xFF	LE_Remote_Connection_Parameter_ Request_Reply command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Events(s) generated (unless masked away):

When the LE_Remote_Connection_Parameter_Request_Reply command has completed, a Command Complete event shall be generated.

7.8.32 LE Remote Connection Parameter Request Negative Reply Command

Command	OCF	Command Parameters	Return Parameters
LE_Remote_Connection_ Parameter_Request_ Negative_Reply	0x0021	Connection_Handle, Reason	Status, Connection_Handle

Description:

Both the master Host and the slave Host use this command to reply to the HCI LE Remote Connection Parameter Request event. This indicates that the Host has rejected the remote device's request to change connection parameters. The reason for the rejection is given in the Reason parameter.

Instead of issuing this command, the Host should try to provide alternative connection parameters to the Link Layer via the HCI LE Remote Connection Parameter Request Reply command (Section 7.8.31).

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Reason: *Size: 1 Octet*

Value	Parameter Description
0xXX	Reason that the connection parameter request was rejected. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Remote_Connection_Parameter_ Request_Negative_Reply command succeeded.
0x01-0xFF	LE_Remote_Connection_Parameter_ Request_Negative_Reply command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Events(s) generated (unless masked away):

When the LE_Remote_Connection_Parameter_ Request_Negative_Reply command has completed, a Command Complete event shall be generated.

7.8.33 LE Set Data Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Data_Length	0x0022	Connection_Handle, TxOctets, TxTime	Status, Connection_Handle

Description:

The LE_Set_Data_Length command allows the Host to suggest maximum transmission packet size and maximum packet transmission time (*connMaxTxOctets* and *connMaxTxTime* - see [Vol 6] Part B, Section 4.5.10) to be used for a given connection. The Controller may use smaller or larger values based on local information.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

TxOctets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Preferred maximum number of payload octets that the local Controller should include in a single Link Layer packet on this connection. Range 0x001B-0x00FB (all other values reserved for future use)

TxTime: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Preferred maximum number of microseconds that the local Controller should use to transmit a single Link Layer packet on this connection. Range 0x0148-0x4290 (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Data_Length command succeeded.
0x01 - 0xFF	LE_Set_Data_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range 0x0000-0x0EFF (all other values reserved for future use)

Event(s) generated (unless masked away):

When the LE_Set_Data_Length command has completed, a Command Complete event shall be generated.

If the command causes the maximum transmission packet size or maximum packet transmission time to change, an LE Data Length Change Event shall be generated.

7.8.34 LE Read Suggested Default Data Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Suggested_Default_Data_Length	0x0023		Status, SuggestedMaxTxOctets, SuggestedMaxTxTime

Description:

The LE_Read_Suggested_Default_Data_Length command allows the Host to read the Host's suggested values (SuggestedMaxTxOctets and SuggestedMaxTxTime) for the Controller's maximum transmitted number of payload octets and maximum packet transmission time to be used for new connections (see [Vol 6] Part B, Section 4.5.10).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Suggested_Default_Data_Length command succeeded
0x01 - 0xFF	LE_Read_Suggested_Default_Data_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

SuggestedMaxTxOctets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The Host's suggested value for the Controller's maximum transmitted number of payload octets to be used for new connections. Range 0x001B-0x00FB (all other values reserved for future use) Default: 0x001B

SuggestedMaxTxTime: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The Host's suggested value for the Controller's maximum packet transmission time to be used for new connections. Range 0x0148-0x4290 (all other values reserved for future use) Default: 0x0148

Event(s) generated (unless masked away):

When the LE_Read_Suggested_Default_Data_Length command has completed, a Command Complete event shall be generated.

7.8.35 LE Write Suggested Default Data Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Write_Suggested_Default_Data_Length	0x0024	SuggestedMaxTxOctets, SuggestedMaxTxTime	Status

Description:

The LE_Write_Suggested_Default_Data_Length command allows the Host to specify its suggested values for the Controller's maximum transmission number of payload octets and maximum packet transmission time to be used for new connections. The Controller may use smaller or larger values for *connInitialMaxTxOctets* and *connInitialMaxTxTime* based on local information.(see [Vol 6] Part B, Section 4.5.10).

Command Parameters:

SuggestedMaxTxOctets: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The Host's suggested value for the Controller's maximum transmitted number of payload octets to be used for new connections. Range 0x001B-0x00FB (all other values reserved for future use)

SuggestedMaxTxTime: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	The Host's suggested value for the Controller's maximum packet transmission time to be used for new connections. Range 0x0148-0x4290 (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Write_Suggested_Default_Data_Length command succeeded.
0x01 - 0xFF	LE_Write_Suggested_Default_Data_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

Event(s) generated (unless masked away):

When the LE_Write_Suggested_Default_Data_Length command has completed, a Command Complete event shall be generated.

7.8.36 LE Read Local P-256 Public Key Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Local_P-256_Public_Key	0x0025		

Description:

The LE_Read_Local_P-256_Public_Key command is used to return the local P-256 public key from the Controller. The Controller shall generate a new P-256 public/private key pair upon receipt of this command.

The keys returned via this command shall not be used when Secure Connections is used over the BR/EDR transport.

Command Parameters:

None.

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Read_Local_P-256_Public_Key command, the Controller shall send the Command Status event to the Host. When the local P-256 public key generation finishes, an LE Read Local P-256 Public Key Complete event shall be generated.

No Command Complete event is sent by the Controller to indicate that this command has been completed.

7.8.37 LE Generate DHKey Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Generate_DHKey	0x0026	Remote_P-256_Public_Key	

Description:

The LE_Generate_DHKey command is used to initiate generation of a Diffie-Hellman key in the Controller for use over the LE transport. This command takes the remote P-256 public key as input. The Diffie-Hellman key generation uses the private key generated by LE_Read_Local_P256_Public_Key command.

The Diffie-Hellman key returned via this command shall not be generated using any keys used for Secure Connections over the BR/EDR transport.

Command Parameters:

Remote_P-256_Public_Key: Size: *64 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX	The remote P-256 public key: X, Y format Octets 31-0: X co-ordinate Octets 63-32: Y co-ordinate Little Endian Format

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Generate_DHKey command, the Controller shall send the Command Status event to the Host. When the DHKey generation finishes, an LE DHKey Generation Complete event shall be generated.

No Command Complete event is sent by the Controller to indicate that this command has been completed.

7.8.38 LE Add Device To Resolving List Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Add_Device_To_ Resolving_List	0x0027	Peer_Identity_Address_Type, Peer_Identity_Address, Peer_IRK, Local_IRK	Status

Description:

The LE_Add_Device_To_Resolving_List command is used to add one device to the list of address translations used to resolve Resolvable Private Addresses in the Controller.

This command cannot be used when address translation is enabled in the Controller and:

- Advertising is enabled
- Scanning is enabled
- Create connection command is outstanding

This command can be used at any time when address translation is disabled in the Controller.

The added device shall be set to Network Privacy mode.

When a Controller cannot add a device to the list because there is no space available, it shall return the error code *Memory Capacity Exceeded* (0x07).

Command Parameters:

Peer_Identity_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Identity Address
0x01	Random (static) Identity Address
0x02 – 0xFF	Reserved for Future Use

Peer_Identity_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public or Random (static) Identity address of the peer device

Peer_IRK: *Size: 16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX	IRK of the peer device

Local_IRK: *Size:16 Octets*

Value	Parameter Description
0xXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX	IRK of the local device

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Add_Device_To_Resolving_List command succeeded
0x01 – 0xFF	LE_Add_Device_To_Resolving_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Add_Device_To_Resolving_List command has completed, a Command Complete event shall be generated.

7.8.39 LE Remove Device From Resolving List Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Remove_Device_From_Resolving_List	0x0028	Peer_Identity_Address_Type, Peer_Identity_Address	Status

Description:

The LE_Remove_Device_From_Resolving_List command is used to remove one device from the list of address translations used to resolve Resolvable Private Addresses in the Controller.

This command cannot be used when address translation is enabled in the Controller and:

- Advertising is enabled
- Scanning is enabled
- Create connection command is outstanding

This command can be used at any time when address translation is disabled in the Controller.

When a Controller cannot remove a device from the resolving list because it is not found, it shall return the error code *Unknown Connection Identifier* (0x02).

Command Parameters:

Peer_Identity_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Identity Address
0x01	Random (static) Identity Address
0x02 – 0xFF	Reserved for Future Use

Peer_Device_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public or Random (static) Identity Address of the peer device

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Remove_Device_From_Resolving_List command succeeded
0x01 – 0xFF	LE_Remove_Device_From_Resolving_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Remove_Device_From_Resolving_List command has completed, a Command Complete event shall be generated.

7.8.40 LE Clear Resolving List Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Clear_Resolving_List	0x0029		Status

Description:

The LE_Clear_Resolving_List command is used to remove all devices from the list of address translations used to resolve Resolvable Private Addresses in the Controller.

This command cannot be used when address translation is enabled in the Controller and:

- Advertising is enabled
- Scanning is enabled
- Create connection command is outstanding

This command can be used at any time when address translation is disabled in the Controller.

Command Parameters:

None

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Clear_Resolving_List command succeeded
0x01 – 0xFF	LE_Clear_Resolving_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Clear_Resolving_List command has completed, a Command Complete event shall be generated.

7.8.41 LE Read Resolving List Size Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Read_Resolving_List_Size	0x002A		Status, Resolving_List_Size

Description:

The LE_Read_Resolving_List_Size command is used to read the total number of address translation entries in the resolving list that can be stored in the Controller. Note: The number of entries that can be stored is not fixed and the Controller can change it at any time (e.g. because the memory used to store the list can also be used for other purposes).

Command Parameters:

None

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Read_Resolving_List_Size command succeeded
0x01 – 0xFF	LE_Read_Resolving_List_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Resolving_List_Size: *Size:1 Octet*

Value	Parameter Description
0xXX	Number of address translation entries in the resolving list

Event(s) Generated (unless masked away):

When the LE_Read_Resolving_List_Size command has completed, a Command Complete event shall be generated.

7.8.42 LE Read Peer Resolvable Address Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Read_ Peer_Resolvable_Address	0x002B	Peer_Identity_Address_ Type, Peer_Identity_Address	Status, Peer_Resolvable_ Address

Description:

The LE_Read_Peer_Resolvable_Address command is used to get the current peer Resolvable Private Address being used for the corresponding peer Public and Random (static) Identity Address. The peer's resolvable address being used may change after the command is called.

This command can be used at any time.

When a Controller cannot find a Resolvable Private Address associated with the Peer Identity Address, it shall return the error code *Unknown Connection Identifier* (0x02).

Command Parameters:

Peer_Identity_Address_Type *Size: 1 Octet*

Value	Parameter Description
0x00	Public Identity Address
0x01	Random (static) Identity Address
0x02 – 0xFF	Reserved for Future Use

Peer_Identity_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public or Random (static) Identity Address of the peer device

Return Parameters:

Status *Size:1 Octet*

Value	Parameter Description
0x00	LE_Read_Peer_Resolvable_Address command succeeded
0x01 – 0xFF	LE_Read_Peer_Resolvable_Address command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Peer_Resolvable_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Resolvable Private Address being used by the peer device

Event(s) Generated (unless masked away):

When the LE_Read_Peer_Resolvable_Address command has completed, a Command Complete event shall be generated.

7.8.43 LE Read Local Resolvable Address Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Local_Resolvable_Address	0x002C	Peer_Identity_Address_Type, Peer_Identity_Address	Status, Local_Resolvable_Address

Description:

The LE_Read_Local_Resolvable_Address command is used to get the current local Resolvable Private Address being used for the corresponding peer Identity Address. The local's resolvable address being used may change after the command is called.

This command can be used at any time.

When a Controller cannot find a Resolvable Private Address associated with the Peer Identity Address, it shall return the error code *Unknown Connection Identifier* (0x02).

Command Parameters:

Peer_Identity_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Identity Address
0x01	Random (static) Identity Address
0x02 – 0xFF	Reserved for Future Use

Peer_Identity_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Identity Address or Random (static) Identity Address of the peer device, 48 bit value.

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Read_Local_Resolvable_Address command succeeded
0x01 – 0xFF	LE_Read_Local_Resolvable_Address command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Local_Resolvable_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Resolvable Private Address being used by the local device

Event(s) Generated (unless masked away):

When the LE_Read_Local_Resolvable_Address command has completed, a Command Complete event shall be generated.

7.8.44 LE Set Address Resolution Enable Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Set_Address_Resolution_Enable	0x002D	Address_Resolution_Enable	Status

Description:

The LE_Set_Address_Resolution_Enable command is used to enable resolution of Resolvable Private Addresses in the Controller. This causes the Controller to use the resolving list whenever the Controller receives a local or peer Resolvable Private Address.

This command can be used at any time except when:

- Advertising is enabled
- Scanning is enabled
- Create connection command is outstanding

Note: enabling address resolution when it is already enabled, or disabling it when it is already disabled, has no effect.

Command Parameters:

Address_Resolution_Enable: *Size:1 Octet*

Value	Parameter Description
0x00	Address Resolution in Controller disabled (default)
0x01	Address Resolution in Controller enabled
0x02 – 0xFF	Reserved for Future Use

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Set_Address_Resolution_Enable command succeeded
0x01 – 0xFF	LE_Set_Address_Resolution_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Address_Resolution_Enable command has completed, a Command Complete event shall be generated.

7.8.45 LE Set Resolvable Private Address Timeout Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Set_Resolvable_Private_Address_Timeout	0x002E	RPA_Timeout	Status

Description:

The LE_Set_Resolvable_Private_Address_Timeout command set the length of time the Controller uses a Resolvable Private Address before a new resolvable private address is generated and starts being used.

This timeout applies to all addresses generated by the Controller.

Command Parameters:

RPA_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	RPA_Timeout measured in s Range for N: 0x0001 – 0xA1B8 (1 s – approximately 11.5 hours) Default: N= 0x0384 (900 s or 15 minutes)

Return Parameters:

Status: *Size:1 Octet*

Value	Parameter Description
0x00	LE_Set_Resolvable_Private_Address_Timeout command succeeded
0x01 – 0xFF	LE_Set_Resolvable_Private_Address_Timeout command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Resolvable_Private_Address_Timeout command has completed, a Command Complete event shall be generated.

7.8.46 LE Read Maximum Data Length Command

Command	OCF	Command Parameters	Return parameters
HCI_LE_Read_Maximum_Data_Length	0x002F		Status, supportedMaxTxOctets, supportedMaxTxTime, supportedMaxRxOctets, supportedMaxRxTime

Description:

The LE_Read_Maximum_Data_Length command allows the Host to read the Controller's maximum supported payload octets and packet duration times for transmission and reception (supportedMaxTxOctets and supportedMaxTxTime, supportedMaxRxOctets, and supportedMaxRxTime, see [Vol 6] Part B, Section 4.5.10).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_Maximum_Data_Length command succeeded.
0x01 - 0xFF	LE_Read_Maximum_Data_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and description.

supportedMaxTxOctets: *Size: 2 Octet*

Value	Parameter Description
0xXXXX	Maximum number of payload octets that the local Controller supports for transmission of a single Link Layer packet on a data connection. Range 0x001B-0x00FB (all other values reserved for future use)

supportedMaxTxTime: *Size: 2 Octet*

Value	Parameter Description
0xXXXX	Maximum time, in microseconds, that the local Controller supports for transmission of a single Link Layer packet on a data connection. Range 0x0148-0x4290 all other values reserved for future use)

supportedMaxRxOctets: *Size: 2 Octet*

Value	Parameter Description
0xXXXX	Maximum number of payload octets that the local Controller supports for reception of a single Link Layer packet on a data connection. Range 0x001B-0x00FB (all other values reserved for future use)

supportedMaxRxTime: *Size: 2 Octet*

Value	Parameter Description
0xXXXX	Maximum time, in microseconds, that the local Controller supports for reception of a single Link Layer packet on a data connection. Range 0x0148-0x4290 all other values reserved for future use)

Event(s) generated (unless masked away):

When the LE_Read_Maximum_Data_Length command has completed, a Command Complete event shall be generated.

7.8.47 LE Read PHY Command

Command	OCF	Command Parameter	Return Parameters
HCI_LE_Read_PHY	0x0030	Connection_Handle	Status, Connection_Handle, TX_PHY, RX_PHY

Description:

The LE_Read_PHY command is used to read the current transmitter PHY and receiver PHY on the connection identified by the Connection_Handle.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range:0x0000-0x0EFF (all other values reserved for future use)

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Read_PHY command succeeded.
0x01 – 0xFF	LE_Read_PHY command failed. See Part D, Error Codes for a list of error codes and descriptions.

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range:0x0000-0x0EFF (all other values reserved for future use)

TX_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	The transmitter PHY for the connection is LE 1M
0x02	The transmitter PHY for the connection is LE 2M
0x03	The transmitter PHY for the connection is LE Coded
All other values	Reserved for future use

RX_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	The receiver PHY for the connection is LE 1M
0x02	The receiver PHY for the connection is LE 2M
0x03	The receiver PHY for the connection is LE Coded
All other values	Reserved for future use

Event(s) Generated (unless masked away):

When the LE_Read_PHY command has completed, a Command Complete event shall be generated.

7.8.48 LE Set Default PHY Command

Command	OCF	Command Parameter	Return Parameters
HCI_LE_Set_Default_PHY	0x0031	ALL_PHYS, TX_PHYS, RX_PHYS	Status

Description:

The LE_Set_Default_PHY command allows the Host to specify its preferred values for the transmitter PHY and receiver PHY to be used for all subsequent connections over the LE transport.

The ALL_PHYS parameter is a bit field that allows the Host to specify, for each direction, whether it has no preference among the PHYs that the Controller supports in a given direction or whether it has specified particular PHYs that it prefers in the TX_PHYS or RX_PHYS parameter.

The TX_PHYS parameter is a bit field that indicates the transmitter PHYs that the Host prefers the Controller to use. If the ALL_PHYS parameter specifies that the Host has no preference, the TX_PHYS parameter is ignored; otherwise at least one bit shall be set to 1.

The RX_PHYS parameter is a bit field that indicates the receiver PHYs that the Host prefers the Controller to use. If the ALL_PHYS parameter specifies that the Host has no preference, the RX_PHYS parameter is ignored; otherwise at least one bit shall be set to 1.

Command Parameters:

ALL_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host has no preference among the transmitter PHYs supported by the Controller
1	The Host has no preference among the receiver PHYs supported by the Controller
2-7	Reserved for future use

TX_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host prefers to use the LE 1M transmitter PHY (possibly among others)
1	The Host prefers to use the LE 2M transmitter PHY (possibly among others)
2	The Host prefers to use the LE Coded transmitter PHY (possibly among others)

Bit number	Meaning
3 – 7	Reserved for future use

RX_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host prefers to use the LE 1M receiver PHY (possibly among others)
1	The Host prefers to use the LE 2M receiver PHY (possibly among others)
2	The Host prefers to use the LE Coded receiver PHY (possibly among others)
3 – 7	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Set_Default_PHY command succeeded.
0x01 – 0xFF	LE_Set_Default_PHY command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Default_PHY command has completed, a Command Complete event shall be generated.

7.8.49 LE Set PHY Command

Command	OCF	Command Parameter	Return Parameters
HCI_LE_Set_PHY	0x0032	Connection_Handle, ALL_PHYS, TX_PHYS, RX_PHYS, PHY_options	

Description:

The LE_Set_PHY command is used to set the PHY preferences for the connection identified by the Connection_Handle. The Controller might not be able to make the change (e.g. because the peer does not support the requested PHY) or may decide that the current PHY is preferable.

The ALL_PHYS parameter is a bit field that allows the Host to specify, for each direction, whether it has no preference among the PHYs that the Controller supports in a given direction or whether it has specified particular PHYs that it prefers in the TX_PHYS or RX_PHYS parameter.

The TX_PHYS parameter is a bit field that indicates the transmitter PHYs that the Host prefers the Controller to use. If the ALL_PHYS parameter specifies that the Host has no preference, the TX_PHYS parameter is ignored; otherwise at least one bit shall be set to 1.

The RX_PHYS parameter is a bit field that indicates the receiver PHYs that the Host prefers the Controller to use. If the ALL_PHYS parameter specifies that the Host has no preference, the RX_PHYS parameter is ignored; otherwise at least one bit shall be set to 1.

If, for at least one direction, the Host has specified a preference and the current PHY is not one of those preferred, the Controller shall request a change. Otherwise the Controller may, but need not, request a change.

The PHY preferences provided by the LE Set PHY command override those provided via the LE Set Default PHY command (Section 7.8.48) or any preferences previously set using the LE Set PHY command on the same connection.

The PHY_options parameter is a bit field that allows the Host to specify options for PHYs. The default value for a new connection shall be all zero bits. The Controller may override any preferred coding for transmitting on the LE Coded PHY.

The Host may specify a preferred coding even if it prefers not to use the LE Coded transmitter PHY since the Controller may override the PHY preference.

Command Parameters:

Connection_Handle: *Size: 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

ALL_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host has no preference among the transmitter PHYs supported by the Controller
1	The Host has no preference among the receiver PHYs supported by the Controller
2 – 7	Reserved for future use

TX_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host prefers to use the LE 1M transmitter PHY (possibly among others)
1	The Host prefers to use the LE 2M transmitter PHY (possibly among others)
2	The Host prefers to use the LE Coded transmitter PHY (possibly among others)
3 – 7	Reserved for future use

RX_PHYS: *Size: 1 Octet*

Bit number	Meaning
0	The Host prefers to use the LE 1M receiver PHY (possibly among others)
1	The Host prefers to use the LE 2M receiver PHY (possibly among others)
2	The Host prefers to use the LE Coded receiver PHY (possibly among others)
3 – 7	Reserved for future use

PHY_options: *Size: 2 Octets*

Bit number	Meaning
0 – 1	0 = the Host has no preferred coding when transmitting on the LE Coded PHY 1 = the Host prefers that S=2 coding be used when transmitting on the LE Coded PHY 2 = the Host prefers that S=8 coding be used when transmitting on the LE Coded PHY 3 = Reserved for future use
2 – 15	Reserved for future use

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Set_PHY command, the Controller shall send the Command Status event to the Host. The LE PHY Update Complete event shall be generated either when one or both PHY changes or when the Controller determines that neither PHY will change immediately.

Note: If the peer negotiation resulted in no change to either PHY, this is not an error and the Update Complete event will contain a status indicating success.

Note: A Command Complete event is not sent by the Controller to indicate that this command has been completed. Instead, the LE PHY Update Complete event indicates that this command has been completed. The LE PHY Update Complete event may also be issued autonomously by the Link Layer.

7.8.50 LE Enhanced Receiver Test Command

Command	OCF	Command Parameters	Return Parameter
HCI_LE_Enhanced_Receiver_Test	0x0033	RX_Channel, PHY, Modulation_Index	Status

Description:

This command is used to start a test where the DUT receives test reference packets at a fixed interval. The tester generates the test reference packets.

Command Parameters:

RX_Channel: *Size: 1 Octet*

Value	Parameter Description
N=0xXX	N = (F-2402) / 2 Range: 0x00 – 0x27. Frequency Range: 2402 MHz to 2480 MHz

PHY: *Size: 1 Octet*

Value	Parameter Description
0x00	Reserved for future use
0x01	Receiver set to use the LE 1M PHY
0x02	Receiver set to use the LE 2M PHY
0x03	Receiver set to use the LE Coded PHY
0x04 – 0xFF	Reserved for future use

Modulation_Index: *Size: 1 Octet*

Value	Parameter Description
0x00	Assume transmitter will have a standard modulation index
0x01	Assume transmitter will have a stable modulation index
0x02 – 0xFF	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Enhanced_Receiver_Test command succeeded.

Value	Parameter Description
0x01 – 0xFF	LE_Enhanced_Receiver_Test command failed. See Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Enhanced_Receiver_Test command has completed, a Command Complete event shall be generated.

7.8.51 LE Enhanced Transmitter Test Command

Command	OCF	Command Parameters	Return Parameter
HCI_LE_Enhanced_Transmitter_Test	0x0034	TX_Channel, Length_Of_Test_Data, Packet_Payload, PHY	Status

Description:

This command is used to start a test where the DUT generates test reference packets at a fixed interval. The Controller shall transmit at maximum power.

An LE Controller supporting the LE_Enhanced Transmitter_Test command shall support Packet_Payload values 0x00, 0x01 and 0x02. An LE Controller supporting the LE Coded PHY shall also support Packet_Payload value 0x04. An LE Controller may support other values of Packet_Payload.

Command Parameters:

TX_Channel: *Size: 1 Octet*

Value	Parameter Description
N=0xXX	N = (F-2402) / 2 Range: 0x00 – 0x27 Frequency Range: 2402 MHz to 2480 MHz

Length_Of_Test_Data: *Size: 1 Octet*

Value	Parameter Description
0x00-0xFF	Length in bytes of payload data in each packet

Packet_Payload: *Size: 1 Octet*

Value	Parameter Description
0x00	PRBS9 sequence ‘11111111100000111101…’ (in transmission order) as described in [Vol 6] Part F, Section 4.1.5
0x01	Repeated ‘11110000’ (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5
0x02	Repeated ‘10101010’ (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5
0x03	PRBS15 sequence as described in [Vol 6] Part F, Section 4.1.5
0x04	Repeated ‘11111111’ (in transmission order) sequence
0x05	Repeated ‘00000000’ (in transmission order) sequence

Value	Parameter Description
0x06	Repeated ‘00001111’ (in transmission order) sequence
0x07	Repeated ‘01010101’ (in transmission order) sequence
0x08 – 0xFF	Reserved for future use

PHY: *Size: 1 Octet*

Value	Parameter Description
0x00	Reserved for future use
0x01	Transmitter set to use the LE 1M PHY
0x02	Transmitter set to use the LE 2M PHY
0x03	Transmitter set to use the LE Coded PHY with S=8 data coding
0x04	Transmitter set to use the LE Coded PHY with S=2 data coding
0x05 – 0xFF	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	LE_Enhanced_Transmitter_Test command succeeded.
0x01 – 0xFF	LE_Enhanced_Transmitter_Test command failed.[Vol 2] Part D, Section 1.3 for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Enhanced_Transmitter_Test command has completed, a Command Complete event shall be generated.

7.8.52 LE Set Advertising Set Random Address Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Advertising_Set_Random_Address	0x0035	Advertising_Handle, Random_Address	Status

Description:

The LE_Set_Advertising_Set_Random_Address command is used by the Host to set the random device address specified by the Random_Address parameter. This address is used in the Controller (see [Vol 6] Part B, Section 1.3.2) for the advertiser's address contained in the advertising PDUs for the advertising set specified by the Advertising_Handle parameter.

If the Host issues this command while an advertising set using connectable advertising is enabled, the Controller shall return the error code *Command Disallowed* (0x0C). The Host may issue this command at any other time.

If this command is used to change the address, the new random address shall take effect for advertising no later than the next successful LE Extended Set Advertising Enable Command and for periodic advertising no later than the next successful LE Periodic Advertising Enable Command.

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Advertising_Random_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Random Device Address as defined by [Vol 6] Part B, Section 1.3.2

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Advertising_Set_Random_Address command succeeded
0x01 – 0xFF	HCI_LE_Set_Advertising_Set_Random_Address command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions

Event(s) Generated (unless masked away):

When the LE_Set_Advertising_Set_Random_Address command has completed, a Command Complete event shall be generated.

7.8.53 LE Set Extended Advertising Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_Advertising_Parameters	0x0036	Advertising_Handle, Advertising_Event_Properties, Primary_Advertising_Interval_Min, Primary_Advertising_Interval_Max, Primary_Advertising_Channel_Map, Own_Address_Type, Peer_Address_Type, Peer_Address, Advertising_Filter_Policy, Advertising_Tx_Power, Primary_Advertising_PHY, Secondary_Advertising_Max_Skip, Secondary_Advertising_PHY, Advertising_SID, Scan_Request_Notification_Enable	Status, Selected_Tx_Power

Description:

The LE_Set_Extended_Advertising_Parameters command is used by the Host to set the advertising parameters.

The Advertising_Handle parameter identifies the advertising set whose parameters are being configured.

The Advertising_Event_Properties parameter describes the type of advertising event that is being configured and its basic properties. The type shall be one supported by the Controller. In particular, the following restrictions apply to this parameter:

- If legacy advertising PDU types are being used, then the parameter value shall be one of those specified in Table 7.2. If the advertising set already contains data, the type shall be one that supports advertising data and the amount of data shall not exceed 31 octets.

Event Type	PDU Type	Advertising Event Properties	Advertising Data
Connectable and scannable undirected	ADV_IND	00010011b	Supported
Connectable directed (low duty cycle)	ADV_DIRECT_IND	00010101b	Not allowed
Connectable directed (high duty cycle)	ADV_DIRECT_IND	00011101b	Not allowed
Scannable undirected	ADV_SCAN_IND	00010010b	Supported
Non-connectable and non-scannable undirected	ADV_NONCONN_IND	00010000b	Supported

Table 7.2: Advertising Event Properties values for legacy PDUs

- If extended advertising PDU types are being used (bit 4 = 0) then:
  The advertisement shall not be both connectable and scannable.
  High duty cycle directed connectable advertising (≤ 3.75 ms advertising interval) shall not be used (bit 3 = 0).

If the Advertising_Event_Properties parameter does not describe an event type supported by the Controller, contains an invalid bit combination, or specifies a type that does not support advertising data when the advertising set already contains some, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

The parameters beginning with“Secondary” are only valid when extended advertising PDU types are being used (bit 4 = 0).

The Own_Address_Type parameter shall be ignored for anonymous advertising (bit 5 = 1).

If Directed advertising is selected, the Peer_Address_Type and Peer_Address shall be valid and the Advertising_Filter_Policy parameter shall be ignored.

The Primary_Advertising_Interval_Min parameter shall be less than or equal to the Primary_Advertising_Interval_Max parameter. The Primary_Advertising_Interval_Min and Primary_Advertising_Interval_Max parameters should not be the same value so that the Controller can choose the best advertising interval given other activities.

For high duty cycle connectable directed advertising event type (ADV_DIRECT_IND), the Primary_Advertising_Interval_Min and Primary_Advertising_Interval_Max parameters are not used and shall be ignored.

If the primary advertising interval range provided by the Host (Primary_Advertising_Interval_Min, Primary_Advertising_Interval_Max) is outside the advertising interval range supported by the Controller, then the Controller shall return the error code *Unsupported Feature or Parameter Value* (0x11).

The Primary_Advertising_Channel_Map is a bit field that indicates the advertising channels that shall be used when transmitting advertising packets. At least one channel bit shall be set in the Primary_Advertising_Channel_Map parameter.

The Own_Address_Type parameter specifies the type of address being used in the advertising packets. For random addresses, the address is specified by the LE_Set_Advertising_Set_Random_Address command.

If Own_Address_Type equals 0x02 or 0x03, the Peer_Address parameter contains the peer's Identity Address and the Peer_Address_Type parameter contains the peer's Identity Type (i.e., 0x00 or 0x01). These parameters are used to locate the corresponding local IRK in the resolving list; this IRK is used to generate their own address used in the advertisement.

The Advertising_Tx_Power parameter indicates the maximum power level at which the advertising packets are to be transmitted on the advertising channels. The Controller shall choose a power level lower than or equal to the one specified by the Host.

The Primary_Advertising_PHY parameter indicates the PHY on which the advertising packets are transmitted on the primary advertising channel. If legacy advertising PDUs are being used, the Primary_Advertising_PHY shall indicate the LE 1M PHY. The Secondary_Advertising_PHY parameter indicates the PHY on which the advertising packets are be transmitted on the secondary advertising channel.

The Secondary_Advertising_Max_Skip parameter is the maximum number of advertising events that can be skipped before the AUX_ADV_IND can be sent.

The Advertising_SID parameter specifies the value to be transmitted in the Advertising SID subfield of the ADI field of the Extended Header of those advertising channel PDUs that have an ADI field. If the advertising set only uses PDUs that do not contain an ADI field, Advertising_SID is ignored.

The Scan_Request_Notification_Enable parameter indicates whether the Controller shall send notifications upon the receipt of a scan request PDU that is in response to an advertisement from the specified advertising set that contains its device address and is from a scanner that is allowed by the advertising filter policy.

If the Host issues this command when advertising is enabled for the specified advertising set, the Controller shall return the error code *Command Disallowed* (0x0C).

If periodic advertising is enabled for the advertising set and the Secondary_Advertising_PHY parameter does not specify the PHY currently being used for the periodic advertising, the Controller shall return the error code *Command Disallowed* (0x0C).

If the Advertising_Handle does not identify an existing advertising set and the Controller is unable to support a new advertising set at present, the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Advertising_Event_Properties: *Size: 2 Octets*

Bit number	Parameter Description
0	Connectable advertising
1	Scannable advertising
2	Directed advertising
3	High Duty Cycle Directed Connectable advertising (≤ 3.75 ms Advertising Interval)
4	Use legacy advertising PDUs
5	Omit advertiser's address from all PDUs ("anonymous advertising")
6	Include TxPower in the extended header of the advertising PDU
All other bits	Reserved for future use

Primary_Advertising_Interval_Min: *Size: 3 Octets*

Value	Parameter Description
N = 0xXXXXXX	Minimum advertising interval for undirected and low duty cycle directed advertising. Range: 0x000020 to 0xFFFFFF Time = N * 0.625 ms Time Range: 20 ms to 10,485.759375 s

Primary_Advertising_Interval_Max: *Size: 3 Octets*

Value	Parameter Description
N = 0xXXXXXX	Maximum advertising interval for undirected and low duty cycle directed advertising. Range: 0x000020 to 0xFFFFFF Time = N * 0.625 ms Time Range: 20 ms to 10,485.759375 s

Primary_Advertising_Channel_Map: *Size: 1 Octet*

Bit number	Parameter Description
0	Channel 37 shall be used
1	Channel 38 shall be used
2	Channel 39 shall be used
All other bits	Reserved for future use

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the public address.
0x03	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, use the random address from LE_Set_Advertising_Set_Random_Address.
All other values	Reserved for future use

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
All other values	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the device to be connected.

Advertising_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	Process scan and connection requests from all devices (i.e., the White List is not in use)
0x01	Process connection requests from all devices and only scan requests from devices that are in the White List
0x02	Process scan requests from all devices and only connection requests from devices that are in the White List.
0x03	Process scan and connection requests only from devices in the White List.
All other values	Reserved for future use

Advertising_Tx_Power: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm
127	Host has no preference

Primary_Advertising_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	Primary advertisement PHY is LE 1M
0x03	Primary advertisement PHY is LE Coded
All other values	Reserved for future use

Secondary_Advertising_Max_Skip: *Size: 1 Octet*

Value	Parameter Description
0x00	AUX_ADV_IND shall be sent prior to the next advertising event
0x01-0xFF	Maximum advertising events the Controller can skip before sending the AUX_ADV_IND packets on the secondary advertising channel

Secondary_Advertising_PHY: *Size: 1 Octet*

Value	Parameter Description
0x01	Secondary advertisement PHY is LE 1M
0x02	Secondary advertisement PHY is LE 2M
0x03	Secondary advertisement PHY is LE Coded
All other values	Reserved for future use

Advertising_SID: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0x0F	Value of the Advertising SID subfield in the ADI field of the PDU
All other values	Reserved for future use

Scan_Request_Notification_Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Scan request notifications disabled
0x01	Scan request notifications enabled
All other values	Reserved for future use

Return Parameters

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Advertising_Parameters command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Advertising_Parameters command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions

Selected_Tx_Power: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm

Event(s) Generated (unless masked away):

When the LE_Set_Extended_Advertising_Parameters command has completed, a Command Complete event shall be generated. The Selected_Tx_Power return parameter indicates the transmit power selected by the Controller. The Controller shall not change the transmit power for this advertising set without being directed to by the Host.

7.8.54 LE Set Extended Advertising Data Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_ Advertising_Data	0x0037	Advertising_Handle, Operation, Fragment_Preference, Advertising_Data_Length, Advertising_Data	Status

Description:

The LE_Set_Extended_Advertising_Data command is used to set the data used in advertising PDUs that have a data field. This command may be issued at any time after an advertising set identified by the Advertising_Handle parameter has been created using the LE Set Extended Advertising Parameters Command (see Section 7.8.53), regardless of whether advertising in that set is enabled or disabled.

If advertising is currently enabled for the specified advertising set, the Controller shall use the new data in subsequent extended advertising events for this advertising set. If an extended advertising event is in progress when this command is issued, the Controller may use the old or new data for that event.

If advertising is currently disabled for the specified advertising set, the data shall be kept by the Controller and used once advertising is enabled for that set. The data shall be discarded when the advertising set is removed.

Only the significant part of the advertising data should be transmitted in the advertising packets as defined in [Vol 3] Part C, Section 11.

The Host may set the advertising data in one or more operations using the Operation parameter in the command. If the combined length of the data exceeds the capacity of the advertising set identified by the Advertising_Handle parameter (see Section 7.8.57 LE Read Maximum Advertising Data Length Command) or the amount of memory currently available, all the data shall be discarded and the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

If Operation indicates the start of new data (values 0x01 or 0x03), then any existing partial or complete advertising data shall be discarded. If the Advertising_Data_Length parameter is zero and Operation is 0x03, any existing partial or complete data shall be deleted (with no new data provided).

If Operation is 0x04, the behavior is the same as if the current advertising data had been sent again; this can be used to cause the Advertising DID value to be updated (see [Vol 6] Part B, Section 4.4.2.11).

The Fragment_Preference parameter provides a hint to the Controller as to whether advertising data should be fragmented.

If the advertising set specifies a type that does not support advertising data, the Controller shall return the error code *Invalid HCI Parameters* (0x12).

If the advertising set uses legacy advertising PDUs that support advertising data and either Operation is not 0x03 or the Advertising_Data_Length parameter exceeds 31 octets, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If Operation is 0x04 and:

- advertising is currently disabled for the advertising set;
- the advertising set contains no data;
- the advertising set uses legacy PDUs; or
- Advertising_Data_Length is not zero;

then the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If Operation is not 0x03 or 0x04 and Advertising_Data_Length is zero, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If advertising is currently enabled for the specified advertising set and Operation does not have the value 0x03 or 0x04, the Controller shall return the error code *Command Disallowed* (0x0C).

If the advertising set corresponding to the Advertising_Handle parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Operation: *Size: 1 Octet*

Value	Parameter Description
0x00	Intermediate fragment of fragmented extended advertising data
0x01	First fragment of fragmented extended advertising data
0x02	Last fragment of fragmented extended advertising data
0x03	Complete extended advertising data

Value	Parameter Description
0x04	Unchanged data (just update the Advertising DID)
All other values	Reserved for future use

Fragment_Preference : *Size: 1 Octet*

Value	Parameter Description
0x00	The Controller may fragment all Host advertising data
0x01	The Controller should not fragment or should minimize fragmentation of Host advertising data
All other values	Reserved for future use

Advertising_Data_Length: *Size: 1 Octet*

Value	Parameter Description
0 – 251	The number of octets in the Advertising Data parameter
All other values	Reserved for future use

Advertising_Data: *Size: Advertising_Data_Length Octets*

Value	Parameter Description
	Advertising data formatted as defined in [Vol 3] Part C, Section 11 Note: This parameter has a variable length.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Advertising_Data command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Advertising_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions

Event(s) Generated (unless masked away):

When the LE_Set_Extended_Advertising_Data command has completed, a Command Complete event shall be generated.

7.8.55 LE Set Extended Scan Response Data Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_ Scan_Response_Data	0x0038	Advertising_Handle, Operation, Fragment_Preference, Scan_Response_Data_Length, Scan_Response_Data	Status

Description:

The LE_Set_Extended_Scan_Response_Data command is used to provide scan response data used in scanning response PDUs. This command may be issued at any time after the advertising set identified by the Advertising_Handle parameter has been created using the LE Set Extended Advertising Parameters Command (see Section 7.8.53) regardless of whether advertising in that set is enabled or disabled.

If advertising is currently enabled for the specified advertising set, the Controller shall use the new data in subsequent extended advertising events for this advertising set. If an extended advertising event is in progress when this command is issued, the Controller may use the old or new data for that event.

If advertising is currently disabled for the specified advertising set, the data shall be kept by the Controller and used once advertising is enabled for that set. The data shall be discarded when the advertising set is removed.

Only the significant part of the scan response data should be transmitted in the advertising packets as defined in [Vol 3] Part C, Section 11.

The Host may set the scan response data in one or more operations using the Operation parameter in the command. If the combined length of the data exceeds the capacity of the advertising set identified by the Advertising_Handle parameter (see Section 7.8.57 LE Read Maximum Advertising Data Length Command) or the amount of memory currently available, all the data shall be discarded and the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

If Operation indicates the start of new data (values 0x01 or 0x03), then any existing partial or complete scan response data shall be discarded. If the Scan_Response_Data_Length parameter is zero, then Operation shall be 0x03; this indicates that any existing partial or complete data shall be deleted and no new data provided.

The Fragment_Preference parameter provides a hint to the Controller as to whether advertising data should be fragmented.

If the advertising set is non-scannable and the Host uses this command other than to delete existing data, the Controller shall return the error code *Invalid HCI Parameters* (0x12).

If the advertising set uses scannable legacy advertising PDUs and either Operation is not 0x03 or the Scan_Response_Data_Length parameter exceeds 31 octets, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If advertising is currently enabled for the specified advertising set and Operation does not have the value 0x03, the Controller shall return the error code *Command Disallowed* (0x0C).

If the advertising set corresponding to the Advertising_Handle parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Operation: *Size: 1 Octet*

Value	Parameter Description
0x00	Intermediate fragment of fragmented scan response data
0x01	First fragment of fragmented scan response data
0x02	Last fragment of fragmented scan response data
0x03	Complete scan response data
All other values	Reserved for future use

Fragment_Preference: *Size: 1 Octet*

Value	Parameter Description
0x00	The Controller may fragment all scan response data
0x01	The Controller should not fragment or should minimize fragmentation of scan response data
All other values	Reserved for future use

Scan_Response_Data_Length: *Size: 1 Octet*

Value	Parameter Description
0 – 251	The number of octets in the Scan_Response Data parameter
All other values	Reserved for future use

Scan_Response_Data: *Size: Scan_Response_Data_Length Octets*

Value	Parameter Description
	Scan response data formatted as defined in [Vol 3] Part C, Section 11 Note: This parameter has a variable length.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Scan_Response_Data command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Scan_Response_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions

Event(s) Generated (unless masked away):

When the LE_Set_Extended_Scan_Response_Data command has completed, a Command Complete event shall be generated.

7.8.56 LE Set Extended Advertising Enable Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_Advertising_Enable	0x0039	Enable, Number_of_Sets, Advertising_Handle[i], Duration[i], Max_Extended_Advertising_Events[i]	Status

Description:

The LE_Set_Extended_Advertising_Enable command is used to request the Controller to enable or disable one or more advertising sets using the advertising sets identified by the Advertising_Handle[i] parameter. The Controller manages the timing of advertisements in accordance with the advertising parameters given in the LE_Set_Extended_Advertising_Parameters command. The Number_of_Sets parameter is the number of advertising sets contained in the parameter arrays. If Enable and Number_of_Sets are both set to 0x00, then all advertising sets are disabled.

The Controller shall only start an advertising event when the corresponding advertising set is enabled. The Controller shall continue advertising until all advertising sets have been disabled. This can happen when the Host issues an LE_Set_Extended_Advertising_Enable command with the Enable parameter set to 0x00 (Advertising is disabled), a connection is created, the duration specified in the Duration[i] parameter expires, or the number of extended advertising events transmitted for the set exceeds the Max_Extended_Advertising_Events[i] parameter.

The Duration[i] parameter indicates the duration for which that advertising set is enabled. The duration begins at the start of the first advertising event of this advertising set. The Controller should not start an extended advertising event that it cannot complete within the duration.

If the advertising is high duty cycle connectable directed advertising, then Duration[i] shall be less than or equal to 1.28 seconds and shall not be equal to 0.

The Max_Extended_Advertising_Events[i] parameter, if non-zero, indicates the maximum number of extended advertising events that shall be sent prior to disabling the extended advertising set even if the Duration[i] parameter has not expired.

Duration[i] and Max_Extended_Advertising_Events[i] are ignored when Enable is set to 0x00.

If the LE_Set_Extended_Advertising_Enable command is sent again for an advertising set while that set is enabled, the timer used for the duration and the number of events counter are reset and any change to the random address shall take effect.

Disabling the advertising set identified by the Advertising_Handle[i] parameter does not disable any periodic advertising associated with that set.

Note: disabling an advertising set that is already disabled has no effect.

If the same advertising set is identified by more than one entry in the Advertising_Handle[i] arrayed parameter, then the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the advertising set corresponding to the Advertising_Handle[i] parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

If the advertising data or scan response data in the advertising set is not complete, the Controller shall return the error code *Command Disallowed* (0x0C).

If the advertising set uses connectable extended advertising PDUs and the advertising data in the advertising set will not fit in the AUX_ADV_IND PDU, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Note: The maximum amount of data that will fit in the PDU depends on which options are selected and on the maximum length of PDU that the Controller is able to transmit.

If the Enable parameter is set to 0x01 (Advertising is enabled) and Number_of_Sets is set to 0x00, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the advertising set's Own_Address_Type parameter is set to 0x01 and the random address for the advertising set has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the advertising set's Own_Address_Type parameter is set to 0x03, the controller's resolving list did not contain a matching entry, and the random address for the advertising set has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Command Parameters:

Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Advertising is disabled
0x01	Advertising is enabled
All other values	Reserved for future use

Number_of_Sets: *Size: 1 Octet*

Value	Parameter Description
0x00	Disable all advertising sets
0x01 – 0x3F	Number of advertising sets to enable or disable
All other values	Reserved for future use

Advertising_Handle[i]: *Size: 1 Octet * Number_of_Sets*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Duration[i]: *Size: 2 Octets * Number_of_Sets*

Value	Parameter Description
0x0000	No advertising duration. Advertising to continue until the Host disables it.
N = 0xXXXX	Advertising duration Range: 0x0001 – 0xFFFF Time = N * 10 ms Time Range: 10 ms to 655,350 ms

Max_Extended_Advertising_Events[i]: *Size: 1 Octet * Number_of_Sets*

Value	Parameter Description
N = 0xXX	Maximum number of extended advertising events the Controller shall attempt to send prior to terminating the extended advertising
0x00	No maximum number of advertising events.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Advertising_Enable command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Advertising_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Set_Extended_Advertising_Enable command has completed, a Command Complete event shall be generated.

If the Duration[i] parameter is set to a value other than 0x0000, an LE Advertising Set Terminated event shall be generated when the duration specified in the Duration[i] parameter expires.

If the Max_Extended_Advertising_Events[i] parameter is set to a value other than 0x00, an LE Advertising Set Terminated event shall be generated when the maximum number of extended advertising events has been transmitted by the Controller.

If the advertising set is connectable and a connection gets created, an LE Connection Complete event shall be generated followed by an LE Advertising Set Terminated event with the Status parameter set to 0x00.

If the advertising set is for high duty cycle connectable directed advertising that fails to create a connection before the duration expires, an LE Connection Complete event shall be generated with the Status parameter set to the error code *Advertising Timeout* (0x3C).

Note: If this command is used to disable advertising at about the same time that a connection is established or the advertising duration expires, there is a possible race condition in that it is possible to receive both an LE Connection Complete event and the Command Complete event for this command.

7.8.57 LE Read Maximum Advertising Data Length Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Maximum_ Advertising_Data_Length	0x003A		Status, Maximum_Advertising_ Data_Length

Description:

The LE_Read_Maximum_Advertising_Data_Length command is used to read the maximum length of data supported by the Controller for use as advertisement data or scan response data in an advertising event or as periodic advertisement data.

Note: The maximum amount may be fragmented across multiple PDUs (see [Vol 6] Part B, Section 2.3.4.9).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Read_Maximum_Advertising_Data_Length command succeeded
0x01 – 0xFF	HCI_LE_Read_Maximum_Advertising_Data_Length command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Maximum_Advertising_Data_Length: *Size: 2 Octets*

Value	Parameter Description
0x001F – 0x0672	Maximum supported advertising data length
All other values	Reserved for future use

Event(s) Generated (unless masked away):

When the HCI_LE_Read_Maximum_Advertising_Data_Length command has completed, a Command Complete event shall be generated.

7.8.58 LE Read Number of Supported Advertising Sets Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Number_of_ Supported_Advertising_Sets	0x003B		Status, Num_Supported_ Advertising_Sets

Description:

The LE_Read_Number_of_Supported_Advertising_Sets command is used to read the maximum number of advertising sets supported by the advertising Controller at the same time. Note: The number of advertising sets that can be supported is not fixed and the Controller can change it at any time because the memory used to store advertising sets can also be used for other purposes.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Read_Number_of_Supported_Advertising_Sets command succeeded
0x01 – 0xFF	HCI_LE_Read_Number_of_Supported_Advertising_Sets command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Num_Supported_Advertising_Sets: *Size: 1 Octet*

Value	Parameter Description
0x01 – 0xF0	Number of advertising sets supported at the same time
All other values	Reserved for future use

Event(s) Generated (unless masked away):

When the HCI_LE_Read_Number_of_Supported_Advertising_Sets command has completed, a Command Complete event shall be generated.

7.8.59 LE Remove Advertising Set Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Remove_Advertising_Set	0x003C	Advertising_Handle	Status

Description:

The LE_Remove_Advertising_Set command is used to remove an advertising set from the Controller.

If the advertising set corresponding to the Advertising_Handle parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42). If advertising on the advertising set is enabled, then the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Remove_Advertising_Set command succeeded
0x01 – 0xFF	HCI_LE_Remove_Advertising_Set command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Remove_Advertising_Set command has completed, a Command Complete event shall be generated.

7.8.60 LE Clear Advertising Sets Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Clear_Advertising_Sets	0x003D		Status

Description:

The LE_Clear_Advertising_Sets command is used to remove all existing advertising sets from the Controller.

If advertising is enabled on any advertising set, then the Controller shall return the error code *Command Disallowed* (0x0C).

Note: All advertising sets are cleared on HCI reset.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Clear_Advertising_Sets command succeeded
0x01 – 0xFF	HCI_LE_Clear_Advertising_Sets command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Clear_Advertising_Sets command has completed, a Command Complete event shall be generated.

7.8.61 LE Set Periodic Advertising Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Periodic_ Advertising_Parameters	0x003E	Advertising_Handle, Periodic_Advertising_Interval_Min, Periodic_Advertising_Interval_Max, Periodic_Advertising_Properties	Status

Description:

The LE_Set_Periodic_Advertising_Parameters command is used by the Host to set the parameters for periodic advertising.

The Advertising_Handle parameter identifies the advertising set whose periodic advertising parameters are being configured. If the corresponding advertising set does not already exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

The Periodic_Advertising_Interval_Min parameter shall be less than or equal to the Periodic_Advertising_Interval_Max parameter. The Periodic_Advertising_Interval_Min and Periodic_Advertising_Interval_Max parameters should not be the same value to enable the Controller to determine the best advertising interval given other activities.

The Periodic_Advertising_Properties parameter indicates which fields should be included in the advertising packet.

If the advertising set identified by the Advertising_Handle specified anonymous advertising, the Controller shall return the error code *Invalid HCI Parameters* (0x12).

If the Host issues this command when periodic advertising is enabled for the specified advertising set, the Controller shall return the error code *Command Disallowed* (0x0C).

If the Advertising_Handle does not identify an advertising set that is already configured for periodic advertising and the Controller is unable to support more periodic advertising at present, the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify a periodic advertisement
All other values	Reserved for future use

Periodic_Advertising_Interval_Min: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Minimum advertising interval for periodic advertising. Range: 0x0006 to 0xFFFF Time = N * 1.25 ms Time Range: 7.5ms to 81.91875 s

Periodic_Advertising_Interval_Max: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Maximum advertising interval for periodic advertising. Range: 0x0006 to 0xFFFF Time = N * 1.25 ms Time Range: 7.5ms to 81.91875 s

Periodic_Advertising_Properties: *Size: 2 Octets*

Bit Number	Parameter Description
6	Include TxPower in the advertising PDU
All other bits	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Periodic_Advertising_Parameters command succeeded
0x01 – 0xFF	HCI_LE_Set_Periodic_Advertising_Parameters command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Periodic_Advertising_Parameters command has completed, a Command Complete event shall be generated.

7.8.62 LE Set Periodic Advertising Data Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Periodic_Advertising_Data	0x003F	Advertising_Handle, Operation, Advertising_Data_Length, Advertising_Data	Status

Description:

The LE_Set_Periodic_Advertising_Data command is used to set the data used in periodic advertising PDUs. This command may be issued at any time after the advertising set identified by the Advertising_Handle parameter has been configured for periodic advertising using the LE_Set_Periodic_Advertising_Parameters Command (see Section 7.8.61), regardless of whether advertising in that set is enabled or disabled. If the advertising set has not been configured for periodic advertising, then the Controller shall return the error code *Command Disallowed* (0x0C).

If advertising is currently enabled for the specified advertising set, the Controller shall use the new data in subsequent periodic advertising events for this advertising set. If a periodic advertising event is in progress when this command is issued, the Controller may use the old or new data for that event.

If periodic advertising is currently disabled for the specified advertising set, the data shall be kept by the Controller and used once periodic advertising is enabled for that set. The data shall be discarded when the advertising set is removed.

Only the significant part of the periodic advertising data should be transmitted in the advertising packets as defined in [Vol 3] Part C, Section 11.

The Host may set the periodic advertising data in one or more operations using the Operation parameter in the command. If the combined length of the data exceeds the capacity of the advertising set identified by the Advertising_Handle parameter (see Section 7.8.57 LE Read Maximum Advertising Data Length Command) or the amount of memory currently available, all the data shall be discarded and the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

If Operation indicates the start of new data (values 0x01 or 0x03), then any existing partial or complete data shall be discarded. If the Advertising_Data_Length parameter is 0, then Operation shall be 0x03; this indicates that any existing partial or complete data shall be deleted and no new data provided.

If periodic advertising is currently enabled for the specified advertising set and Operation does not have the value 0x03, the Controller shall return the error code *Command Disallowed* (0x0C).

If the advertising set corresponding to the Advertising_Handle parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

Command Parameters:

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Operation: *Size: 1 Octet*

Value	Parameter Description
0x00	Intermediate fragment of fragmented periodic advertising data
0x01	First fragment of fragmented periodic advertising data
0x02	Last fragment of fragmented periodic advertising data
0x03	Complete periodic advertising data
All other values	Reserved for future use

Advertising_Data_Length: *Size: 1 Octet*

Value	Parameter Description
0 – 252	The number of octets in the Advertising Data parameter
All other values	Reserved for future use

Advertising_Data: *Size: Advertising_Data_Length Octets*

Value	Parameter Description
	Periodic advertising data formatted as defined in [Vol 3] Part C, Section 11. Note: This parameter has a variable length.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Periodic_Advertising_Data command succeeded
0x01 – 0xFF	HCI_LE_Set_Periodic_Advertising_Data command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Periodic_Advertising_Data command has completed, a Command Complete event shall be generated.

7.8.63 LE Set Periodic Advertising Enable Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Periodic_Advertising_Enable	0x0040	Enable, Advertising_Handle	Status

Description:

The LE_Set_Periodic_Advertising_Enable command is used to request the Controller to enable or disable the periodic advertising for the advertising set specified by the Advertising_Handle parameter (ordinary advertising is not affected).

If the advertising set is not currently enabled (see the LE_Set_Extended_Advertising_Enable command), the periodic advertising is not started until the advertising set is enabled. Once the advertising set has been enabled, the Controller shall continue periodic advertising until the Host issues an LE_Set_Periodic_Advertising_Enable command with Enable set to 0x00 (periodic advertising is disabled). Disabling the advertising set has no effect on the periodic advertising once the advertising set has been enabled.

The Controller manages the timing of advertisements in accordance with the advertising parameters given in the LE_Set_Periodic_Advertising_Parameters command.

If the advertising set corresponding to the Advertising_Handle parameter does not exist, the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

If the periodic advertising data in the advertising set is not complete, the Controller shall return the error code *Command Disallowed* (0x0C).

Note: Enabling periodic advertising when it is already enabled can cause the random address to change. Disabling periodic advertising when it is already disabled has no effect.

Command Parameters:

Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Periodic advertising is disabled (default)
0x01	Periodic advertising is enabled
All other values	Reserved for future use

Advertising_Handle: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0xEF	Used to identify an advertising set
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Periodic_Advertising_Enable command succeeded
0x01 – 0xFF	HCI_LE_Set_Periodic_Advertising_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Set_Perodic_Advertising_Enable command has completed, a Command Complete event shall be generated.

7.8.64 LE Set Extended Scan Parameters Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_ Scan_Parameters	0x0041	Own_Address_Type Scanning_Filter_Policy Scanning_PHYs, Scan_Type[i], Scan_Interval[i], Scan_Window[i]	Status

Description:

The LE_Set_Extended_Scan_Parameters command is used to set the extended scan parameters to be used on the advertising channels.

The Scanning_PHYs parameter indicates the PHY(s) on which the advertising packets should be received on the primary advertising channel. The Host may enable one or more scanning PHYs. The Scan_Type[i], Scan_Interval[i], and Scan_Window[i] parameters array elements are ordered in the same order as the set bits in the Scanning_PHY parameter, starting from bit 0. The number of array elements is determined by the number of bits set in the Scanning_PHY parameter.

The Scan_Type[i] parameter specifies the type of scan to perform.

The Scan_Interval[i] and Scan_Window[i] parameters are recommendations from the Host on how long (Scan_Window[i]) and how frequently (Scan_Interval[i]) the Controller should scan (see [Vol 6] Part B, Section 4.5.3); however the frequency and length of the scan is implementation specific. If the requested scan cannot be supported by the implementation, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

The Own_Address_Type parameter indicates the type of address being used in the scan request packets.

If the Host issues this command when scanning is enabled in the Controller, the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, then use the public address.
0x03	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, then use the random address from LE_Set_Random_Address.
All other values	Reserved for future use

Scanning_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	Accept all advertising packets except directed advertising packets not addressed to this device
0x01	Accept only advertising packets from devices where the advertiser's address is in the White List. Directed advertising packets which are not addressed to this device shall be ignored.
0x02	Accept all advertising packets except directed advertising packets where the initiator's identity address does not address this device. Note: directed advertising packets where the initiator's address is a resolvable private address that cannot be resolved are also accepted.
0x03	Accept all advertising packets except: • advertising packets where the advertiser's identity address is not in the White List; and • directed advertising packets where the initiator's identity address does not address this device Note: directed advertising packets where the initiator's address is a resolvable private address that cannot be resolved are also accepted.
All other values	Reserved for future use

Scanning_PHYs: *Size: 1 Octet*

Bit number	Parameter Description
0	Scan advertisements on the LE 1M PHY
2	Scan advertisements on the LE Coded PHY
All other bits	Reserved for future use

Scan_Type[i]: *Size: 1 Octet * bits set in Scanning_PHYs*

Value	Parameter Description
0x00	Passive Scanning. No scan request PDUs shall be sent.
0x01	Active Scanning. Scan request PDUs may be sent.
All other values	Reserved for future use

Scan_Interval[i]: *Size: 2 Octets * bits set in Scanning_PHYs*

Value	Parameter Description
N = 0xXXXX	Time interval from when the Controller started its last scan until it begins the subsequent scan on the primary advertising channel. Range: 0x0004 to 0xFFFF Time = N * 0.625 ms Time Range: 2.5 ms to 40.959375 s

Scan_Window[i]: *Size: 2 Octets * bits set in Scanning_PHYs*

Value	Parameter Description
N = 0xXXXX	Duration of the scan on the primary advertising channel. Range: 0x0004 to 0xFFFF Time = N * 0.625 ms Time Range: 2.5 ms to 40.959375 s

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Scan_Parameters command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Scan_Parameters command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Extended_Scan_Parameters command has completed, a Command Complete event shall be generated.

7.8.65 LE Set Extended Scan Enable Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Set_Extended_Scan_Enable	0x0042	Enable, Filter_Duplicates, Duration, Period	Status

Description:

The LE_Set_Extended_Scan_Enable command is used to enable or disable scanning.

The Enable parameter determines whether scanning is enabled or disabled. If it is disabled, the remaining parameters are ignored.

The Filter_Duplicates parameter controls whether the Link Layer should filter out duplicate advertising reports (filtering duplicates enabled) to the Host or if the Link Layer should generate advertising reports for each packet received (filtering duplicates disabled). See [Vol 6] Part B, Section 4.4.3.5.

If the Filter_Duplicates parameter is set to 0x00, all advertisements received from advertisers shall be sent to the Host in advertising report events.

If the Filter_Duplicates parameter is set to 0x01, duplicate advertisements should not be sent to the Host in advertising report events until scanning is disabled.

If the Filter_Duplicates parameter is set to 0x02, duplicate advertisements in a single scan period should not be sent to the Host in advertising report events; this setting shall only be used if Period is non-zero. If Filter_Duplicates is set to 0x2 and Period to zero, the Controller shall return the Invalid error code *HCI Command Parameters* (0x12).

If the Duration parameter is zero or both the Duration parameter and Period parameter are non-zero, the Controller shall continue scanning until scanning is disabled by the Host issuing an LE_Set_Extended_Scan_Enable command with the Enable parameter set to 0x00 (Scanning is disabled). The Period parameter is ignored when the Duration parameter is zero.

If the Duration parameter is non-zero and the Period parameter is zero, the Controller shall continue scanning until the duration specified in the Duration parameter has expired.

If both the Duration and Period parameters are non-zero and the Duration parameter is greater than or equal to the Period parameter, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

When the Duration and Period parameters are non-zero, the Controller shall scan for the duration of the Duration parameter within a scan period specified by the Period parameter. After the scan period has expired, a new scan period shall begin and scanning shall begin again for the duration specified. The scan periods continue until the Host disables scanning.

If the LE_Set_Extended_Scan_Enable command is sent while scanning is enabled, the timers used for duration and period are reset to the new parameter values and a new scan period is started. Any change to the Filter_Duplicates setting or the random address shall take effect. Note: Disabling scanning when it is disabled has no effect.

Note: The duration of a scan period refers to the time spent scanning on both the primary and secondary advertising channels. However, expiry of the duration does not prevent the Link Layer from scanning for and receiving auxiliary packets of received advertisements.

If the scanning parameters' Own_Address_Type parameter is set to 0x01 or 0x03 and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Command Parameters:

Enable: *Size: 1 Octet*

Value	Parameter Description
0x00	Scanning disabled
0x01	Scanning enabled
All other values	Reserved for future use

Filter_Duplicates: *Size: 1 Octet*

Value	Parameter Description
0x00	Duplicate filtering disabled
0x01	Duplicate filtering enabled
0x02	Duplicate filtering enabled, reset for each scan period
All other values	Reserved for future use

Duration: *Size: 2 Octets*

Value	Parameter Description
0x0000	Scan continuously until explicitly disable
N = 0xXXXX	Scan duration Range: 0x0001 – 0xFFFF Time = N * 10 ms Time Range: 10 ms to 655.35 s

Period: *Size: 2 Octets*

Value	Parameter Description
0x0000	Periodic scanning disabled
N = 0xXXXX	Time interval from when the Controller started its last Scan_Duration until it begins the subsequent Scan_Duration. Range: 0x0001 – 0xFFFF Time = N * 1.28 sec Time Range: 1.28 s to 83,884.8 s

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Extended_Scan_Enable command succeeded
0x01 – 0xFF	HCI_LE_Set_Extended_Scan_Enable command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the LE_Set_Extended_Scan_Enable command has completed, a Command Complete event shall be generated.

Zero or more LE Extended Advertising Reports are generated by the Controller based on any advertising packets received and the duplicate filtering in effect. More than one advertising packet may be reported in each LE Advertising Report event. If the LE_Set_Extended_Scan_Parameters Command Scanning_Filter_Policy parameter is set to 0x02 or 0x03 (see Section 7.8.64), LE Directed Advertising Report events may also be generated.

At the end of a single scan (Duration non-zero but Period zero), an LE Scan Timeout event shall be generated.

7.8.66 LE Extended Create Connection Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Extended_Create_Connection	0x0043	Initiator_Filter_Policy, Own_Address_Type, Peer_Address_Type, Peer_Address, Initiating_PHYs, Scan_Interval[i], Scan_Window[i], Conn_Interval_Min[i], Conn_Interval_Max[i], Conn_Latency[i], Supervision_Timeout[i], Minimum_CE_Length[i], Maximum_CE_Length[i]	

Description:

The LE_Extended_Create_Connection command is used to create a Link Layer connection to a connectable advertiser.
LE_Extended_Create_Connection command can be used in place of LE_Create_Connection command.

The Initiator_Filter_Policy parameter is used to determine whether the White List is used. If the White List is not used, the Peer_Address_Type and the Peer_Address parameters specify the address type and address of the advertising device to connect to.

The Own_Address_Type parameter indicates the type of address being used in the connection request packets.

The Peer_Address_Type parameter indicates the type of address used in the connectable advertisement sent by the peer.

The Peer_Address parameter indicates the Peer's Public Device Address, Random (static) Device Address, Non-Resolvable Private Address, or Resolvable Private Address depending on the Peer_Address_Type parameter.

The Initiating_PHYs parameter indicates the PHY(s) on which the advertising packets should be received on the primary advertising channel and the PHYs for which connection parameters have been specified. The Host may enable one or more initiating PHYs. The array elements of the arrayed parameters are ordered in the same order as the set bits in the Initiating_PHYs parameter, starting from bit 0. The number of array elements is determined by the number of bits set in the Initiating_PHYs parameter. When a connectable

advertisement is received and a connection request is sent on one PHY, scanning on any other PHYs is terminated.

The Scan_Interval[i] and Scan_Window[i] parameters are recommendations from the Host on how long (Scan_Window[i]) and how frequently (Scan_Interval[i]) the Controller should scan (see [Vol 6] Part B, Section 4.5.3); however the frequency and length of the scan is implementation specific. If the requested scan cannot be supported by the implementation, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12). If bit 1 is set in Initiating_PHYs, the values for the LE 2M PHY are ignored.

The Conn_Interval_Min[i] and Conn_Interval_Max[i] parameters define the minimum and maximum allowed connection interval. The Conn_Interval_Min[i] parameter shall not be greater than the Conn_Interval_Max[i] parameter.

The Conn_Latency[i] parameter defines the maximum allowed connection latency (see [Vol 6] Part B, Section 4.5.1).

The Supervision_Timeout[i] parameter defines the link supervision timeout for the connection. The Supervision_Timeout[i] in milliseconds shall be larger than (1 + Conn_Latency[i]) * Conn_Interval_Max[i] * 2, where Conn_Interval_Max[i] is given in milliseconds (see [Vol 6] Part B, Section 4.5.2).

The Minimum_CE_Length[i] and Maximum_CE_Length[i] parameters are informative parameters providing the Controller with the expected minimum and maximum length of the connection events. The Minimum_CE_Length[i] parameter shall be less than or equal to the Maximum_CE_Length[i] parameter.

Where the connection is made on a PHY whose bit is not set in the Initiating_PHYs parameter, the Controller shall use the Conn_Interval_Min[i], Conn_Interval_Max[i], Conn_Latency[i], Supervision_Timeout[i], Minimum_CE_Length[i], and Maximum_CE_Length[i] parameters for an implementation-chosen PHY whose bit is set in the Initiating_PHYs parameter.

If the Host issues this command when another LE_Extended_Create_Connection command is pending in the Controller, the Controller shall return the error code *Command Disallowed* (0x0C).

If the Own_Address_Type parameter is set to 0x01 and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Own_Address_Type parameter is set to 0x03, the Initiator_Filter_Policy parameter is set to 0x00, the controller's resolving list did not contain a matching entry, and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Own_Address_Type parameter is set to 0x03, the Initiator_Filter_Policy parameter is set to 0x01, and the random address for the device has not been initialized, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Initiating_PHYs parameter does not have at least one bit set for a PHY allowed for scanning on the primary advertising channel, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

Command Parameters:

Initiating_Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	White List is not used to determine which advertiser to connect to. Peer_Address_Type and Peer_Address shall be used.
0x01	White List is used to determine which advertiser to connect to. Peer_Address_Type and Peer_Address shall be ignored.
All other values	Reserved for future use

Own_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
0x02	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, then use the public address.
0x03	Controller generates the Resolvable Private Address based on the local IRK from the resolving list. If the resolving list contains no matching entry, then use the random address from the most recent successful LE_Set_Random_Address Command.
All other values	Reserved for future use

Peer_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
All other values	Reserved for future use

Peer_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the device to be connected.

Initiating_PHYs: *Size: 1 Octet*

Bit number	Parameter Description
0	Scan connectable advertisements on the LE 1M PHY. Connection parameters for the LE 1M PHY are provided.
1	Connection parameters for the LE 2M PHY are provided.
2	Scan connectable advertisements on the LE Coded PHY. Connection parameters for the LE Coded PHY are provided.
All other bits	Reserved for future use

Scan_Interval[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Time interval from when the Controller started its last scan until it begins the subsequent scan on the primary advertising channel. Range: 0x0004 to 0xFFFF Time = N * 0.625 ms Time Range: 2.5 ms to 40.959375 s

Scan_Window[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Duration of the scan on the primary advertising channel. Range: 0x0004 to 0xFFFF Time = N * 0.625 ms Time Range: 2.5 ms to 40.959375 s

Conn_Interval_Min[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Minimum value for the connection interval. This shall be less than or equal to Conn_Interval_Max[i]. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s
All other values	Reserved for future use

Conn_Interval_Max[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Maximum value for the connection interval. This shall be greater than or equal to Conn_Interval_Max[i]. Range: 0x0006 to 0x0C80 Time = N * 1.25 ms Time Range: 7.5 ms to 4 s
All other values	Reserved for future use

Conn_Latency[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3
All other values	Reserved for future use

Supervision_Timeout[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Supervision timeout for the LE Link. (See [Vol 6] Part B, Section 4.5.2) Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 s
All other values	Reserved for future use

Minimum_CE_Length[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Informative parameter recommending the minimum length of connection event needed for this LE connection. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms

Maximum_CE_Length[i]: *Size: 2 Octets * bits set in Initiating_PHYs*

Value	Parameter Description
N = 0xXXXX	Informative parameter recommending the maximum length of connection event needed for this LE connection. Range: 0x0000 – 0xFFFF Time = N * 0.625 ms

Return Parameters:

None.

Event(s) Generated (unless masked away):

When the Controller receives the LE_Extended_Create_Connection command, the Controller sends the Command Status event to the Host. An LE Enhanced Connection Complete event shall be generated when a connection is created or the connection creation procedure is cancelled. If a connection is created, this event shall be immediately followed by an LE Channel Selection Algorithm Event.

Note: No Command Complete event is sent by the Controller to indicate that this command has been completed. Instead, the LE Enhanced Connection Complete event indicates that this command has been completed.

7.8.67 LE Periodic Advertising Create Sync Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Periodic_ Advertising_Create_Sync	0x0044	Filter_Policy, Advertising_SID, Advertiser_Address_Type, Advertiser_Address, Skip, Sync_Timeout, Unused	

Description:

The LE_Periodic_Advertising_Create_Sync command is used to synchronize with periodic advertising from an advertiser and begin receiving periodic advertising packets.

This command may be issued whether or not scanning is enabled and scanning may be enabled and disabled (see the LE Set Extended Scan Enable Command) while this command is pending. However, synchronization can only occur when scanning is enabled. While scanning is disabled, no attempt to synchronize will take place.

The Filter_Policy parameter is used to determine whether the Periodic Advertiser List is used. If the Periodic Advertiser List is not used, the Advertising_SID, Advertiser Address_Type, and Advertiser Address parameters specify the periodic advertising device to listen to; otherwise they are ignored.

The Advertising_SID parameter, if used, specifies the value that must match the Advertising SID subfield in the ADI field of the received advertisement for it to be used to synchronize.

The Skip parameter specifies the number of consecutive periodic advertising packets that the receiver may skip after successfully receiving a periodic advertising packet.

The Sync_Timeout parameter specifies the maximum permitted time between successful receives. If this time is exceeded, synchronization is lost.

The Unused parameter is reserved for future use.

Irrespective of the value of the Skip parameter, the Controller should stop skipping packets before the Sync_Timeout would be exceeded.

If the Host issues this command when another LE_Periodic_Advertising_Create_Sync command is pending (see page 1380), the Controller shall return the error code *Command Disallowed* (0x0C).

If the Host issues this command for a periodic advertising set from an advertiser that the Controller is already synchronized to, the Controller shall return the error code *Connection Already Exists* (0x0B).

Command Parameters:

Filter_Policy: *Size: 1 Octet*

Value	Parameter Description
0x00	Use the Advertising_SID, Advertising_Address_Type, and Advertising_Address parameters to determine which advertiser to listen to.
0x01	Use the Periodic Advertiser List to determine which advertiser to listen to.
All other values	Reserved for future use

Advertising_SID: *Size: 1 Octet*

Value	Parameter Description
0x00 – 0x0F	Advertising SID subfield in the ADI field used to identify the Periodic Advertising
All other values	Reserved for future use

Advertising_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address
0x01	Random Device Address
All other values	Reserved for future use

Advertiser_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the advertiser

Skip: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	The number of periodic advertising packets that can be skipped after a successful receive Range: 0x0000 to 0x01F3

Sync_Timeout: *Size: 2 Octets*

Value	Parameter Description
N = 0xXXXX	Synchronization timeout for the periodic advertising Range: 0x000A to 0x4000 Time = N*10 ms Time Range: 100 ms to 163.84 s

Unused:[1] *Size: 1 Octet*

Value	Parameter Description
0x00	This value must be used by the Host
All other values	Reserved for future use

Return Parameters:

None.

Event(s) generated (unless masked away):

When the LE_Periodic_Advertising_Create_Sync command has been received, the Controller sends the Command Status event to the Host. An LE Periodic Advertising Sync Established event shall be generated when the Controller starts receiving periodic advertising packets; until the event is generated, the command is considered to be pending.

When the Controller receives periodic advertising packets, it sends LE Periodic Advertising Report events to the Host.

Note: No Command Complete event is sent by the Controller to indicate that this command has been completed. Instead, the LE Periodic Advertising Sync Established event indicates that this command has been completed.

1. This parameter is intended to be used in a future feature.

7.8.68 LE Periodic Advertising Create Sync Cancel Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Periodic_Advertising_Create_Sync_Cancel	0x0045		Status

Description:

The LE_Periodic_Advertising_Create_Sync_Cancel command is used to cancel the LE_Periodic_Advertising_Create_Sync command while it is pending.

If the Host issues this command while no LE_Periodic_Advertising_Create_Sync command is pending, the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Periodic_Advertising_Create_Sync_Cancel command succeeded
0x01 – 0xFF	HCI_LE_Periodic_Advertising_Create_Sync_Cancel command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the LE_Periodic_Advertising_Create_Sync_Cancel command has completed, the Controller sends a Command Complete event to the Host.

After the Command Complete is sent and if the cancellation was successful, the Controller sends a LE Periodic Advertising Sync Established event to the Host with the error code *Operation Cancelled by Host* (0x44).

7.8.69 LE Periodic Advertising Terminate Sync Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Periodic_Advertising_ Terminate_Sync	0x0046	Sync_Handle	Status

Description:

The LE_Periodic_Advertising_Terminate_Sync command is used to stop reception of the periodic advertising identified by the Sync_Handle parameter.

If the Host issues this command when another LE_Periodic_Advertising_Create_Sync command is pending (see below), the Controller shall return the error code *Command Disallowed* (0x0C).

If the periodic advertising corresponding to the Sync_Handle parameter does not exist, then the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

Command Parameters:

Sync_Handle: *Size: 2 Octets (12 bits meaningful)*

Value	Parameter Description
0xXXXX	Sync_Handle to be used to identify the periodic advertiser Range: 0x0000-0x0EFF
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Periodic_Advertising_Terminate_Sync command succeeded
0x01 – 0xFF	HCI_LE_Periodic_Advertising_Terminate_Sync command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the LE_Periodic_Advertising_Terminate_Sync command has completed, a Command Complete event shall be generated.

7.8.70 LE Add Device To Periodic Advertiser List Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Add_Device_To_Periodic_Advertiser_List	0x0047	Advertiser_Address_Type, Advertiser_Address, Advertising_SID	Status

Description:

The LE_Add_Device_To_Periodic_Advertiser_List command is used to add a single device to the Periodic Advertiser list stored in the Controller. Any additions to the Periodic Advertiser list take effect immediately. If the device is already on the list, the Controller shall return the error code *Invalid HCI Command Parameters* (0x12).

If the Host issues this command when an LE_Periodic_Advertising_Create_Sync command is pending, the Controller shall return the error code *Command Disallowed* (0x0C).

When a Controller cannot add a device to the Periodic Advertiser list because the list is full, the Controller shall return the error code *Memory Capacity Exceeded* (0x07).

Command Parameters:

Advertiser_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
All other values	Reserved for future use

Advertiser_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the advertiser

Advertising_SID: *Size: 1 Octet*

Value	Parameter Description
0x00-0x0F	Advertising SID subfield in the ADI field used to identify the Periodic Advertising
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Add_Device_To_Periodic_Advertiser_List command succeeded
0x01 – 0xFF	HCI_LE_Add_Device_To_Periodic_Advertiser_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Add_Device_To_Periodic_Advertiser_List command has completed, a Command Complete event shall be generated.

7.8.71 LE Remove Device From Periodic Advertiser List Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Remove_Device_From_Periodic_Advertiser_List	0x0048	Advertiser_Address_Type, Advertiser_Address, Advertising_SID	Status

Description:

The LE_Remove_Device_From_Periodic_Advertiser_List command is used to remove one device from the list of Periodic Advertisers stored in the Controller. Removals from the Periodic Advertisers List take effect immediately.

If the Host issues this command when an LE_Periodic_Advertising_Create_Sync command is pending, the Controller shall return the error code *Command Disallowed* (0x0C).

When a Controller cannot remove a device from the Periodic Advertiser list because it is not found, the Controller shall return the error code *Unknown Advertising Identifier* (0x42).

Command Parameters:

Advertiser_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Device Address or Public Identity Address
0x01	Random Device Address or Random (static) Identity Address
All other values	Reserved for future use

Advertiser_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Device Address, Random Device Address, Public Identity Address, or Random (static) Identity Address of the advertiser

Advertising_SID: *Size: 1 Octet*

Value	Parameter Description
0x00-0x0F	Advertising SID subfield in the ADI field used to identify the Periodic Advertising
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Remove_Device_From_Periodic_Advertiser_List command succeeded
0x01 – 0xFF	HCI_LE_Remove_Device_From_Periodic_Advertiser_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Remove_Device_From_Periodic_Advertiser_List command has completed, a Command Complete event shall be generated.

7.8.72 LE Clear Periodic Advertiser List Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Clear_Periodic_Advertiser_List	0x0049		Status

Description:

The LE_Clear_Periodic_Advertiser_List command is used to remove all devices from the list of Periodic Advertisers in the Controller.

If this command is used when an LE_Periodic_Advertising_Create_Sync command is pending, the Controller shall return the error code *Command Disallowed* (0x0C).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Clear_Periodic_Advertiser_List command succeeded
0x01 – 0xFF	HCI_LE_Clear_Periodic_Advertiser_List command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Clear_Periodic_Advertiser_List command has completed, a Command Complete event shall be generated.

7.8.73 LE Read Periodic Advertiser List Size Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Periodic_ Advertiser_List_Size	0x004A		Status, Periodic_Advertiser_List_Size

Description:

The LE_Read_Periodic_Advertiser_List_Size command is used to read the total number of Periodic Advertiser list entries that can be stored in the Controller. Note: The number of entries that can be stored is not fixed and the Controller can change it at any time (e.g., because the memory used to store the list can also be used for other purposes).

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Read_Periodic_Advertiser_List_Size command succeeded
0x01 – 0xFF	HCI_LE_Read_Periodic_Advertiser_List_Size command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Periodic_Advertiser_List_Size: *Size: 1 Octet*

Value	Parameter Description
0x01 – 0xFF	Total number of Periodic Advertiser list entries that can be stored in the Controller
0x00	Reserved for future use

Event(s) Generated (unless masked away):

When the HCI_LE_Read_Periodic_Advertiser_List_Size command has completed, a Command Complete event shall be generated.

7.8.74 LE Read Transmit Power Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_Transmit_Power	0x004B		Status, Min_ Tx_Power, Max_ Tx_Power

Description:

The LE_Read_Transmit_Power command is used to read the minimum and maximum transmit powers supported by the Controller.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Read_Transmit_Power command succeeded
0x01 – 0xFF	HCI_LE_Read_Transmit_Power command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Min_Tx_Power: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm

Max_Tx_Power: *Size: 1 Octet*

Value	Parameter Description
N = 0xXX	Size: 1 Octet (signed integer) Range: -127 ≤ N ≤ +126 Units: dBm

Event(s) Generated (unless masked away):

When the HCI_LE_Read _Transmit_Power command has completed, a Command Complete event shall be generated.

7.8.75 LE Read RF Path Compensation Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Read_RF_Path_Compensation	0x004C		Status, RF_Tx_Path_Compensation_Value, RF_Rx_Path_Compensation_Value

Description:

The LE_Read_RF_Path_Compensation command is used to read the RF Path Compensation Values parameter used in the Tx Power Level and RSSI calculation.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Read_RF_Path_Compensation command succeeded
0x01 – 0xFF	HCI_LE_Read_RF_Path_Compensation command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

RF_Tx_Path_Compensation_Value: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Size: 2 Octets (signed integer) Range: -128.0 dB (0xFB00) ≤ N ≤ 128.0 dB (0x0500) Units: 0.1 dB

RF_Rx_Path_Compensation_Value: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Size: 2 Octets (signed integer) Range: -128.0 dB (0xFB00) ≤ N ≤ 128.0 dB (0x0500) Units: 0.1 dB

Event(s) Generated (unless masked away):

When the HCI_LE_Read_RF_Path_Compensation command has completed, a Command Complete event shall be generated.

7.8.76 LE Write RF Path Compensation Command

Command	OCF	Command Parameters	Return Parameters
HCI_LE_Write_RF_Path_Compensation	0x004D	RF_Tx_Path_Compensation_Value, RF_Rx_Path_Compensation_Value	Status

Description:

The LE_Write_RF_Path_Compensation command is used to indicate the RF path gain or loss between the RF transceiver and the antenna contributed by intermediate components. A positive value means a net RF path gain and a negative value means a net RF path loss. The RF Tx Path Compensation Value parameter shall be used by the Controller to calculate radiative Tx Power Level used in the TxPower field in the Extended Header using the following equation:

Radiative Tx Power Level = Tx Power Level at RF transceiver output + RF Tx Path Compensation Value

For example, if the Tx Power Level is +4 (dBm) at RF transceiver output and the RF Path Compensation Value is -1.5 (dB), the radiative Tx Power Level is +4+(-1.5) = 2.5 (dBm).

The RF Rx Path Compensation Value parameter shall be used by the Controller to calculate the RSSI value reported to the Host.

Command Parameters:

RF_Tx_Path_Compensation_Value: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Size: 2 Octets (signed integer) Range: -128.0 dB (0xFB00) ≤ N ≤ 128.0 dB (0x0500) Units: 0.1 dB

RF_Rx_Path_Compensation_Value: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Size: 2 Octets (signed integer) Range: -128.0 dB (0xFB00) ≤ N ≤ 128.0 dB (0x0500) Units: 0.1 dB

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Write_RF_Path_Compensation command succeeded
0x01 – 0xFF	HCI_LE_Write_RF_Path_Compensation command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Write_RF_Path_Compensation command has completed, a Command Complete event shall be generated.

7.8.77 LE Set Privacy Mode Command

Command	OCF	Command Parameters	Return Parameter
HCI_LE_Set_Privacy_Mode	0x004E	Peer_Identity_Address_Type, Peer_Identity_Address, Privacy_Mode	Status

Description:

The HCI_LE_Set_Privacy_Mode command is used to allow the Host to specify the privacy mode to be used for a given entry on the resolving list. The effect of this setting is specified in [Vol 6] Part B, Section 4.7.

When an entry on the resolving list is removed, the mode associated with that entry shall also be removed.

This command cannot be used when address translation is enabled in the Controller and:

- Advertising is enabled
- Scanning is enabled
- Create connection command is outstanding

This command can be used at any time when address translation is disabled in the Controller.

If the device is not on the resolving list, the Controller shall return the error code *Unknown Connection Identifier (0x02)*.

Command Parameters:

Peer_Identity_Address_Type: *Size: 1 Octet*

Value	Parameter Description
0x00	Public Identity Address
0x01	Random (static) Identity Address
All other values	Reserved for future use

Peer Identity_Address: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	Public Identity Address or Random (static) Identity Address of the advertiser

Privacy_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	Use Network Privacy Mode for this peer device (default)
0x01	Use Device Privacy Mode for this peer device
All other values	Reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	HCI_LE_Set_Privacy_Mode command succeeded
0x01 - 0xFF	HCI_LE_Set_Privacy_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) Generated (unless masked away):

When the HCI_LE_Set_Privacy_Mode command has completed, a Command Complete event shall be generated.

APPENDIX A DEPRECATED COMMANDS, EVENTS AND CONFIGURATION PARAMETERS

Commands, events and configuration parameters in this section were in prior versions of the specification, but have been determined not to be required.

They may be implemented by a Controller to allow for backwards compatibility with a Host utilizing a prior version of the specification.

A Host should not use these commands.

A.1 READ PAGE SCAN MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Read_Page_Scan_Mode	0x03	0x003D		Status, Page_Scan_Mode

Description:

This command is used to read the default Page Scan Mode configuration parameter of the local BR/EDR Controller. See Section A.10.2.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Page_Scan_Mode command succeeded.
0x01-0xFF	Read_Page_Scan_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Page_Scan_Mode: *Size: 1 Octet*

Value	Parameter Description
See Appendix A, Section A.10.2.	

Event(s) generated (unless masked away):

When the Read_Page_Scan_Mode command has completed, a Command Complete event will be generated.

A.2 WRITE PAGE SCAN MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Write_Page_Scan_Mode	0x03	0x003E	Page_Scan_Mode	Status

Description:

This command is used to write the default Page Scan Mode configuration parameter of the local BR/EDR Controller. See Section A.10.2

Command Parameters:

Page_Scan_Mode: *Size: 1 Octet*

Value	Parameter Description
See Section A.10.2.	

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Page_Scan_Mode command succeeded.
0x01-0xFF	Write_Page_Scan_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Page_Scan_Mode command has completed, a Command Complete event will be generated.

A.3 READ PAGE SCAN PERIOD MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Read_Page_Scan_Period_Mode	0x03	0x003B		Status, Page_Scan_Period_Mode

Description:

This command is used to read the mandatory Page_Scan_Period_Mode configuration parameter of the local BR/EDR Controller. See Section 6.10.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Page_Scan_Period_Mode command succeeded.
0x01-0xFF	Read_Page_Scan_Period_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Page_Scan_Period_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	P0
0x01	P1
0x02	P2
All other values	Reserved for future use.

Event(s) generated (unless masked away):

When the Read_Page_Scan_Period_Mode command has completed, a Command Complete event will be generated.

A.4 WRITE PAGE SCAN PERIOD MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Write_Page_Scan_Period_Mode	0x03	0x003C	Page_Scan_Period_Mode	Status

Description:

This command is used to write the mandatory Page_Scan_Period_Mode configuration parameter of the local BR/EDR Controller. See Section 6.10.

Command Parameters:

Page_Scan_Period_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	P0
0x01	P1
0x02	P2. **Default.**
All other values	Reserved for future use.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Page_Scan_Period_Mode command succeeded.
0x01-0xFF	Write_Page_Scan_Period_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Page_Scan_Period_Mode command has completed, a Command Complete event will be generated.

A.5 ADD SCO CONNECTION COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Add_SCO_Connection	0x01	0x0007	Connection_Handle, Packet_Type	

Description:

This command will cause the Link Manager to create a SCO connection using the ACL connection specified by the Connection_Handle command parameter. This command causes the local BR/EDR Controller to create a SCO connection. The Link Manager will determine how the new connection is established. This connection is determined by the current state of the device, its piconet, and the state of the device to be connected. The Packet_Type command parameter specifies which packet types the Link Manager should use for the connection. The Link Manager must only use the packet type(s) specified by the Packet_Type command parameter for sending HCI SCO Data Packets. Multiple packet types may be specified for the Packet_Type command parameter by performing a bitwise OR operation of the different packet types. The Link Manager may choose which packet type is to be used from the list of acceptable packet types. A Connection_Handle for this connection is returned in the Connection Complete event (see below).

Note: A SCO connection can only be created when an ACL connection already exists. For a definition of the different packet types, see the [Vol 2] Part B, Baseband Specification.

Note: At least one packet type must be specified. The Host should enable as many packet types as possible for the Link Manager to perform efficiently. However, the Host must not enable packet types that the local device does not support.

Command Parameters:

Connection_Handle *Size 2 Octets (12 Bits meaningful)*

Value	Parameter Description
0xXXXX	Connection_Handle Range: 0x0000-0x0EFF (all other values reserved for future use)

Packet_Type: *Size: 2 Octets*

Value	Parameter Description
0x0001	Reserved for future use.
0x0002	Reserved for future use.
0x0004	Reserved for future use.
0x0008	Reserved for future use.
0x0010	Reserved for future use.
0x0020	HV1
0x0040	HV2
0x0080	HV3
0x0100	Reserved for future use.
0x0200	Reserved for future use.
0x0400	Reserved for future use.
0x0800	Reserved for future use.
0x1000	Reserved for future use.
0x2000	Reserved for future use.
0x4000	Reserved for future use.
0x8000	Reserved for future use.

Return Parameters:

None.

Event(s) generated (unless masked away):

When the Controller receives the Add_SCO_Connection command, it sends the Command Status event to the Host. In addition, when the LM determines the connection is established, the local Controller will send a Connection Complete event to its Host, and the remote Controller will send a Connection Complete event or a Synchronous Connection Complete event to the Host. The Connection Complete event contains the Connection_Handle if this command is successful.

Note: No Command Complete event will be sent by the Controller to indicate that this command has been completed. Instead, the Connection Complete event will indicate that this command has been completed.

A.6 PAGE SCAN MODE CHANGE EVENT

Event	Event Code	Event Parameters
Page Scan Mode Change	0x1F	BD_ADDR, Page_Scan_Mode

Description:

The Page Scan Mode Change event indicates that the connected remote BR/EDR Controller with the specified BD_ADDR has successfully changed the Page_Scan_Mode.

Event Parameters:

BD_ADDR: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	BD_ADDR of the remote device.

Page_Scan_Mode: *Size: 1 Octet*

Value	Parameter Description
0x00	Mandatory Page Scan Mode.
0x01	Optional Page Scan Mode I.
0x02	Optional Page Scan Mode II.
0x03	Optional Page Scan Mode III.
0x04 – 0xFF	Reserved for Future Use.

A.7 READ COUNTRY CODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Read_Country_Code	0x04	0x0007		Status, Country_Code

Description:

This command will read the value for the Country_Code return parameter. The Country_Code defines which range of frequency band of the ISM 2.4 GHz band will be used by the device. Each country has local regulatory bodies regulating which ISM 2.4 GHz frequency ranges can be used.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Country_Code command succeeded.
0x01-0xFF	Read_Country_Code command failed. See [Vol 2] Part D, Error Codes for error codes and descriptions.

Country_Code: *Size: 1 Octet*

Value	Parameter Description
0x00	North America & Europe* and Japan
0x01	France
All other values	Reserved for future use.

*. Except France

Event(s) generated (unless masked away):

When the Read_Country_Code command has completed, a Command Complete event will be generated.

A.8 READ ENCRYPTION MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Read_Encryption_Mode	0x03	0x0021		Status, Encryption_Mode

Description:

This command will read the value for the Encryption_Mode configuration parameter. See Section A.10.1.

Command Parameters:

None.

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Read_Encryption_Mode command succeeded.
0x01-0xFF	Read_Encryption_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Encryption_Mode: *Size: 1 Octet*

Value	Parameter Description
See Section A.10.1	

Event(s) generated (unless masked away):

When the Read_Encryption_Mode command has completed, a Command Complete event will be generated.

A.9 WRITE ENCRYPTION MODE COMMAND

Command	OGF	OCF	Command Parameters	Return Parameters
HCI_Write_Encryption_Mode	0x03	0x0022	Encryption_Mode	Status

Description:

This command will write the value for the Encryption_Mode configuration parameter. See Section A.10.1.

Command Parameters:

Encryption_Mode: *Size: 1 Octet*

Value	Parameter Description
See Section A.10.1.	

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Write_Encryption_Mode command succeeded.
0x01-0xFF	Write_Encryption_Mode command failed. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

Event(s) generated (unless masked away):

When the Write_Encryption_Mode command has completed, a Command Complete event will be generated.

A.10 DEPRECATED PARAMETERS

A.10.1 Encryption Mode

The Encryption_Mode parameter controls if the local device requires encryption to the remote device at connection setup (between the Create_Connection command or acceptance of an incoming ACL connection and the corresponding Connection Complete event). At connection setup, only devices with the Authentication_Enabled configuration parameter set to required and the Encryption_Mode configuration parameter set to required will try to encrypt the physical link to the other device.

Note: Changing this parameter does not affect existing connections.

A temporary link key is used when both broadcast and point-to-point traffic are encrypted.

The Host must not specify the Encryption_Mode parameter with more encryption capability than its local device currently supports, although the parameter is used to request the encryption capability to the remote device. Note that the Host must not request the command with the Encryption_Mode parameter set to 0x01, when the local device does not support encryption.

Note: For encryption to be used, both devices must support and enable encryption.

Value	Parameter Description
0x00	Encryption not required.
0x01	Encryption required for all connections.
All other values	Reserved for future use.

Note: In the Connection Complete event the Encryption_Mode parameter will show whether encryption was successfully turned on. If the remote device does not support encryption or has set Encryption_Mode to 0x01 when the local device has not, the encryption mode returned in the Connection Complete event may or may not equal the encryption mode set in the Write_Encryption_Mode command.

A.10.2 Page Scan Mode

The Page_Scan_Mode parameter indicates the page scan mode that is used for default page scan. Currently one mandatory page scan mode and three optional page scan modes are defined. Following an inquiry response, if the Baseband timer T_mandatory_pscan has not expired, the mandatory page

scan mode must be applied. For details see the [Vol 2] Part B, Baseband Specification (Keyword: Page Scan Mode, FHS Packet, T_mandatory_pscan)

Value	Parameter Description
0x00	Mandatory Page Scan Mode
0x01	Optional Page Scan Mode I
0x02	Optional Page Scan Mode II
0x03	Optional Page Scan Mode III
All other values	Reserved for future use

A.10.3 Page Scan Period Mode

Every time an inquiry response message is sent, the BR/EDR Controller will start a timer (T_mandatory_pscan), the value of which is dependent on the Page_Scan_Period_Mode. As long as this timer has not expired, the BR/EDR Controller will use the mandatory page scan mode for all following page scans.

Note: The timer T_mandatory_pscan will be reset at each new inquiry response. For details see [Vol 2] Part B, Baseband Specification.

Value	Parameter Description
0x00	P0
0x01	P1
0x02	P2
All other values	Reserved for future use.

MESSAGE SEQUENCE CHARTS

Examples of interactions between Host Controller Interface Commands and Events and Link Manager Protocol Data Units are represented in the form of message sequence charts. The message sequence charts also present interaction examples of HCI with AMP (Alternate MAC and PHY) Controllers. These charts show typical interactions and do not indicate all possible protocol behavior.

CONTENTS

1 INTRODUCTION

This section shows typical interactions between Host Controller Interface (HCI) Commands and Events and Link Manager (LM) Protocol Data Units (PDU) on the BR/EDR Controller. It focuses on the message sequence charts (MSCs) for the procedures specified in "Host Controller Interface Functional Specification" with regard to LM Procedures from "Link Manager Protocol Specification" and PALs found in [Vol 5] Part A.

This section illustrates only the most useful scenarios, it does not cover all possible alternatives. Furthermore, the message sequence charts do not consider errors over the air interface or Host interface. In all message sequence charts it is assumed that all events are not masked, so the Host Controller will not filter out any events.

The sequence of messages in these message sequence charts is for illustrative purposes. The messages may be sent in a different order where allowed by the Link Manager, PAL, or HCI sections. If any of these charts differ with text in the Baseband, Link Manager, PAL, or HCI sections, the text in those sections shall be considered normative. This section is informative.

1.1 NOTATION

The notation used in the message sequence charts (MSCs) consists of ovals, elongated hexagons, boxes, lines, and arrows. The vertical lines terminated on the top by a shadow box and at the bottom by solid oval indicate a protocol entity that resides in a device. MSCs describe interactions between these entities and states those entities may be in.

The following symbols represent interactions and states:

Oval	Defines the context for the message sequence chart.
Hexagon	Indicates a condition needed to start the transactions below this hexagon. The location and width of the Hexagon indicates which entity or entities make this decision.
Box	Replaces a group of transactions. May indicate a user action, or a procedure in the baseband.
Dashed Box	Optional group of transactions.
Solid Arrow	Represents a message, signal or transaction. Can be used to show LMP and HCI traffic. Some baseband packet traffic is also shown. These are prefixed by BB followed by either the type of packet, or an indication that there is an ACK signal in a packet.
Dashed Arrow	Represents an optional message, signal or transaction. Can be used to show LMP and HCI traffic.

1.2 FLOW OF CONTROL

Some message sequences are split into several charts. These charts are marked in sequence with different step numbers with multiple paths through with optional letters after the step numbers. Numbers indicate normal or required ordering. The letters represent alternative paths. For example, Step 4 is after Step 3, and Step 5a could be executed instead of Step 5b.

1.3 EXAMPLE MSC

The protocol entities represented in the example shown in Figure 1.1 illustrate the interactions of two devices named A and B. Note that each device includes a Host and a LM entity in this example. Other MSCs in this section may show the interactions of more than two devices.

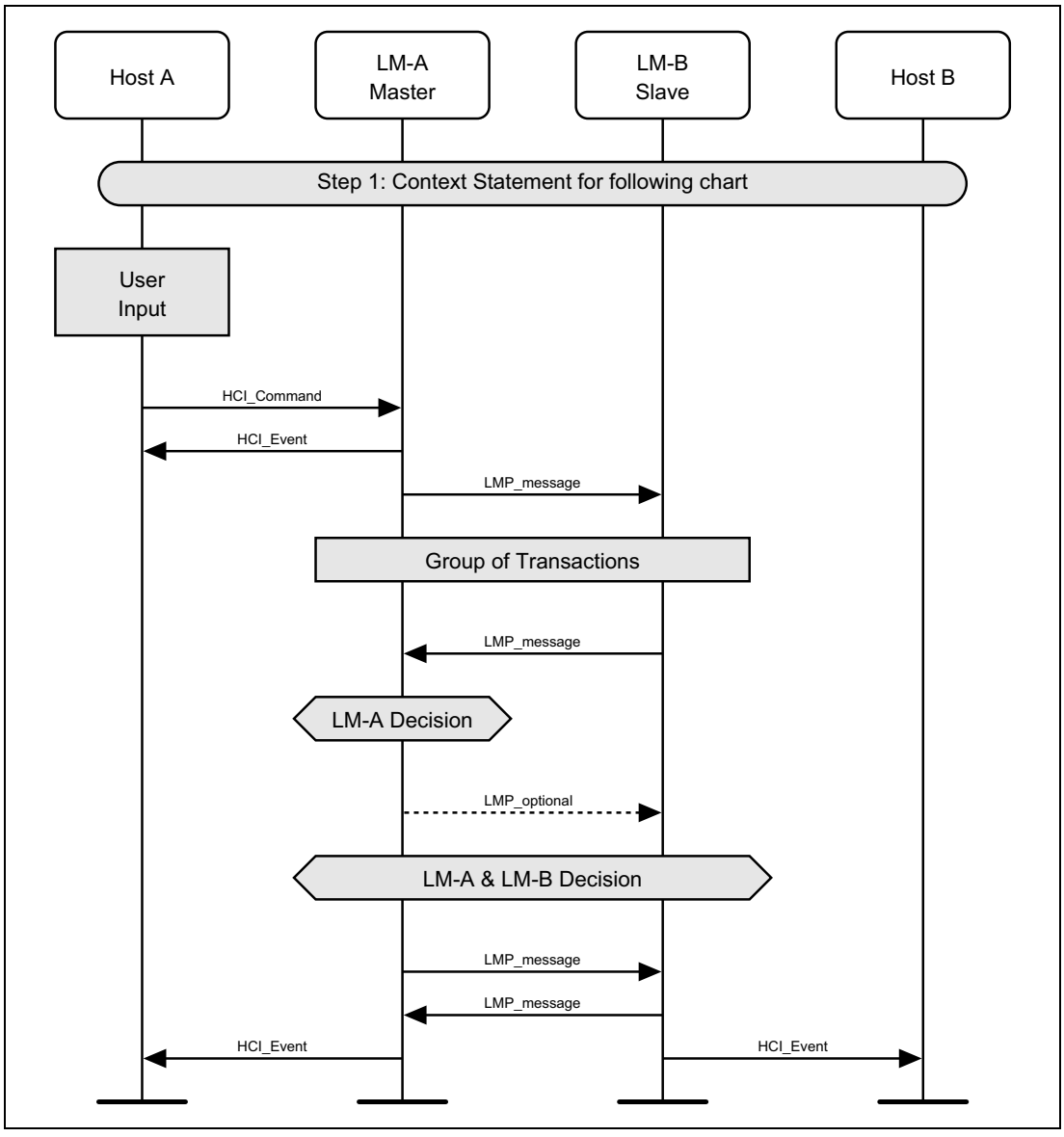

Figure 1.1: Example MSC

2 SERVICES WITHOUT CONNECTION REQUEST

2.1 REMOTE NAME REQUEST

The service Remote Name Request is used to find out the name of the remote device without requiring an explicit ACL Connection.

Step 1: The Host sends an HCI_Set_Event_Mask with the bit of Remote Host Supported Features Notification Event (bit 60) set and an HCI_Remote_Name_Request command expecting that its local device will automatically try to connect to the remote device. (See Figure 2.1.)

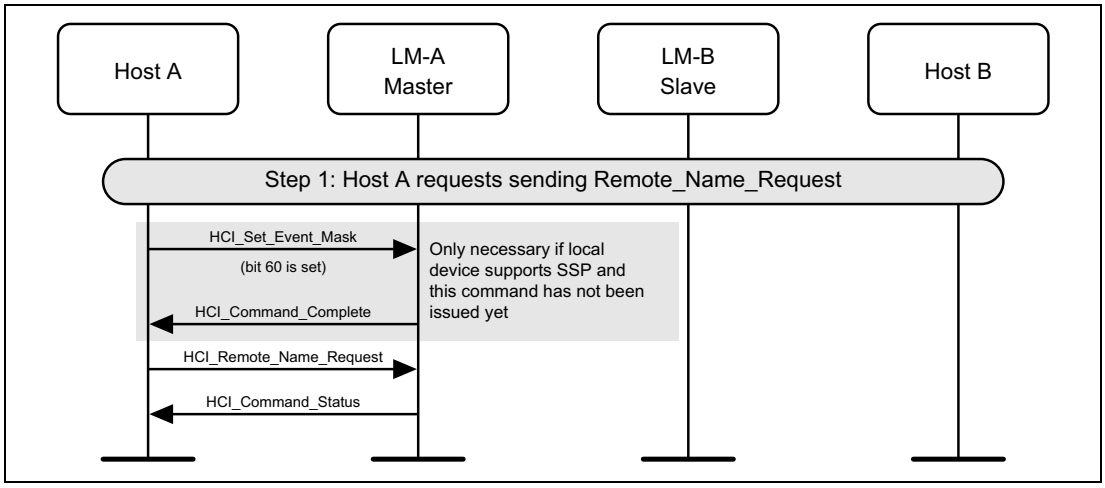

Figure 2.1: Remote name request

Step 2a: If an ACL Connection does not exist device A pages device B. After the Baseband paging procedure, the local device attempts to get the remote device's extended features, send an HCI_Remote_Device_Supported_Features_Notification event, get the remote name, disconnect, and return the name of the remote device to the Host. (See Figure 2.2.)

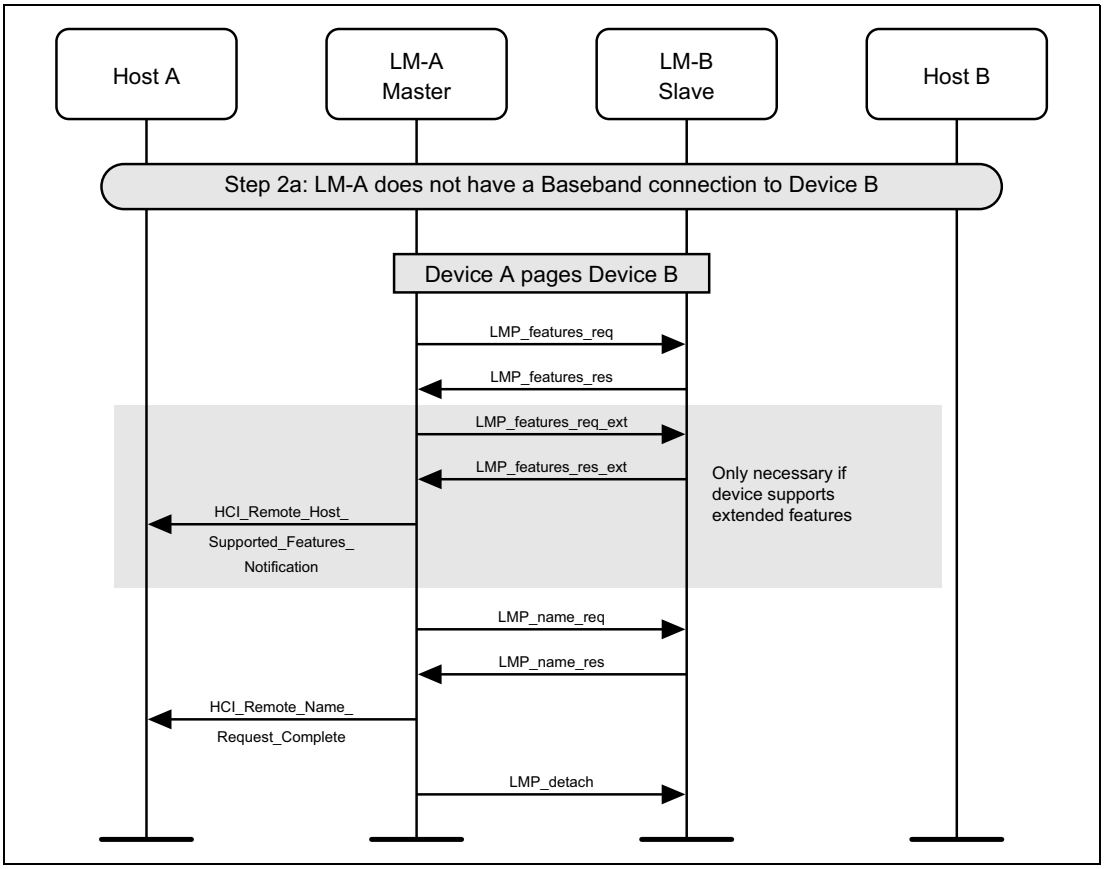

Figure 2.2: Remote name request if no current baseband connection

Step 2b: If an ACL Connection exists when the request is made, then the Remote Name Request procedure will be executed like an optional service. No Paging and no ACL disconnect is done. (See Figure 2.3.)

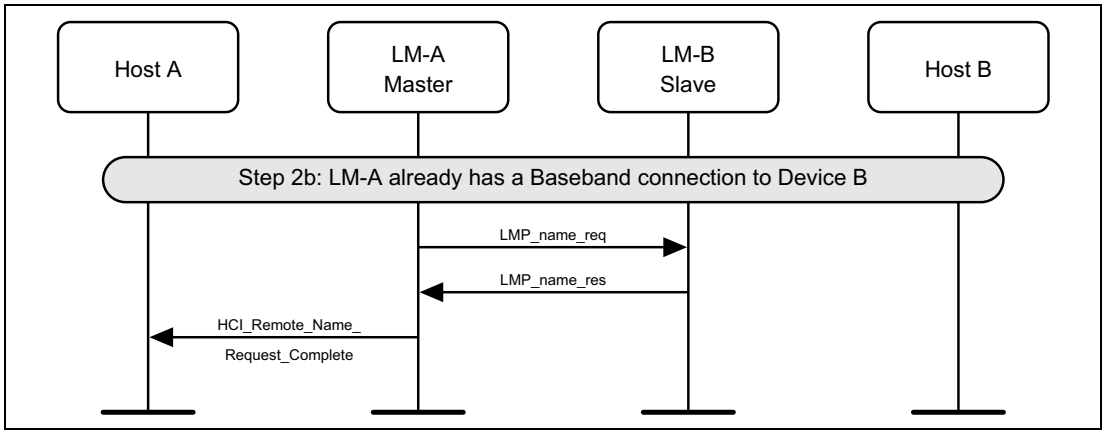

Figure 2.3: Remote name request with baseband connection

2.2 ONE-TIME INQUIRY

Inquiry is used to detect and collect nearby devices.

Step 1: The Host sends an HCI_Inquiry command. (See Figure 2.4.)

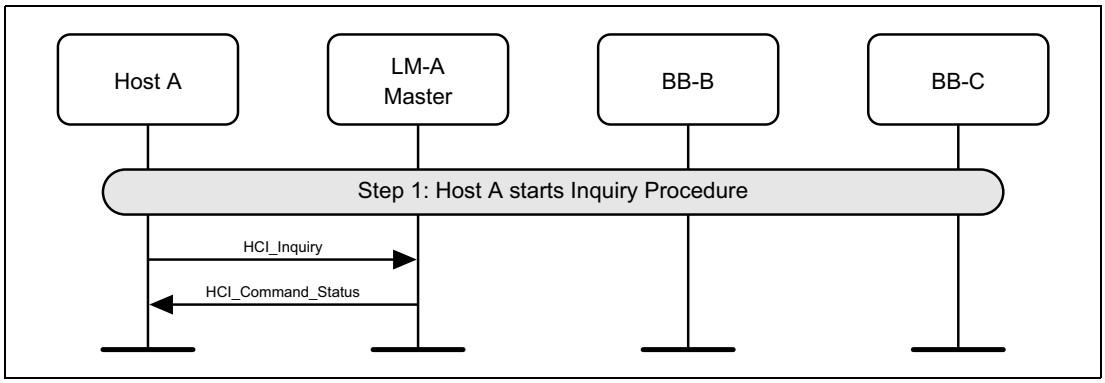

Figure 2.4: Host A starts inquiry procedure

Step 2: The Controller will start the Baseband inquiry procedure with the specified Inquiry Access Code and Inquiry Length. When Inquiry Responses are received, the Controller extracts the required information and returns the information related to the found devices using one or more Inquiry Result events to the Host. (See Figure 2.5.)

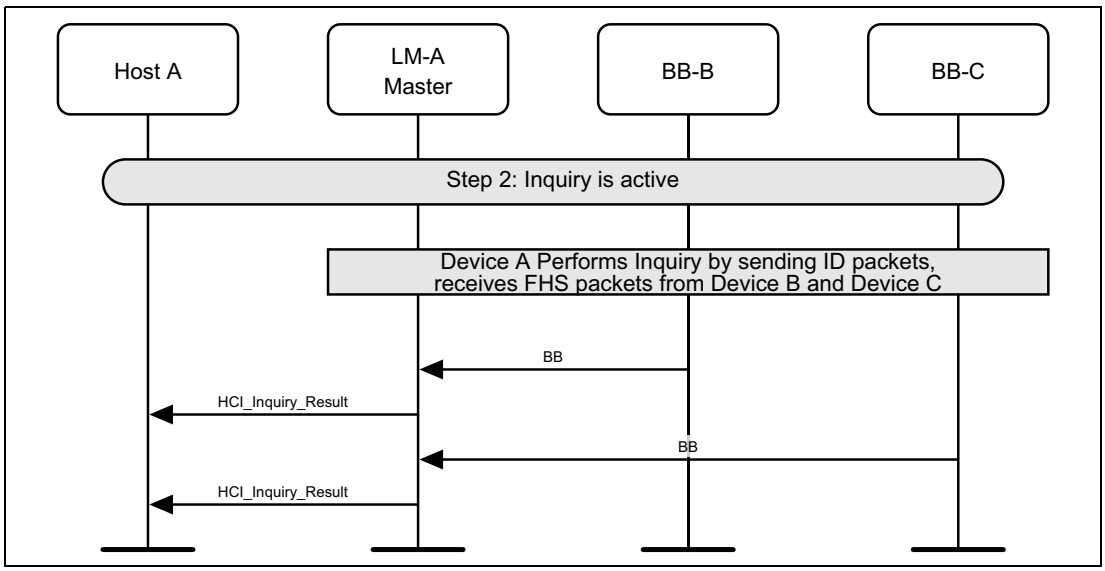

Figure 2.5: LM-A performs inquiry and reports result

Step 3a: If the Host wishes to terminate an Inquiry, the HCI_Inquiry_Cancel command is used to immediately stop the inquiry procedure. (See Figure 2.6.)

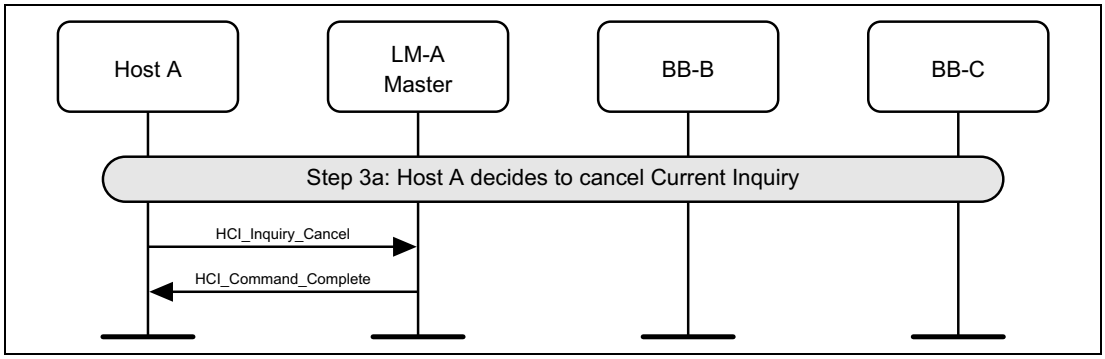

Figure 2.6: Host A cancels inquiry

Step 3b: If the Inquiry procedure is completed due to the number of results obtained, or the Inquiry Length has expired, an Inquiry Complete event is returned to the Host. (See Figure 2.7.)

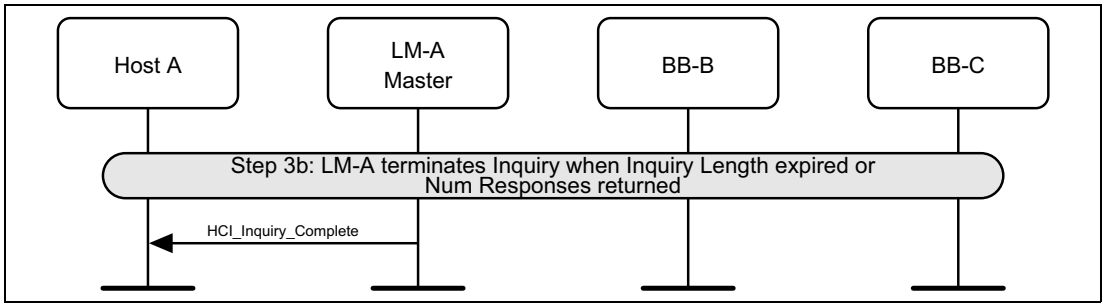

Figure 2.7: LM-A terminates current inquiry

2.3 PERIODIC INQUIRY

Periodic inquiry is used when the inquiry procedure is to be repeated periodically.

Step 1: The Hosts sends an HCI_Periodic_Inquiry_Mode command. (See Figure 2.8.)

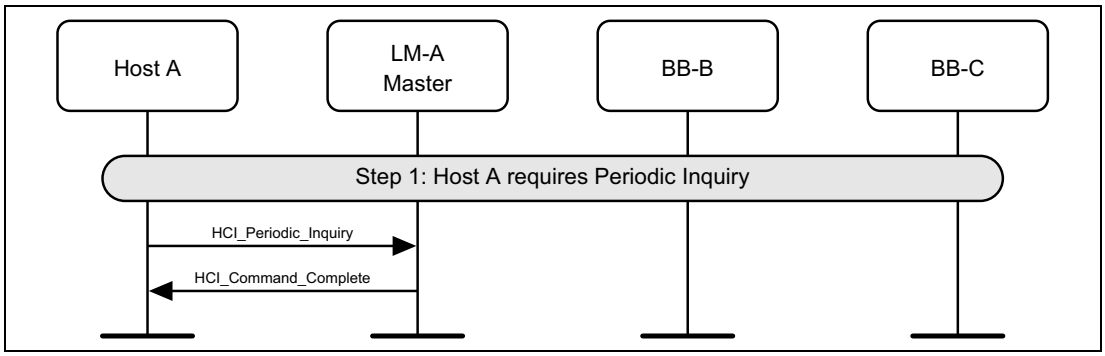

Figure 2.8: Host A starts periodic inquiry

Step 2: The Controller will start a periodic Inquiry. In the inquiry cycle, one or several Inquiry Result events will be returned. (See Figure 2.9.)

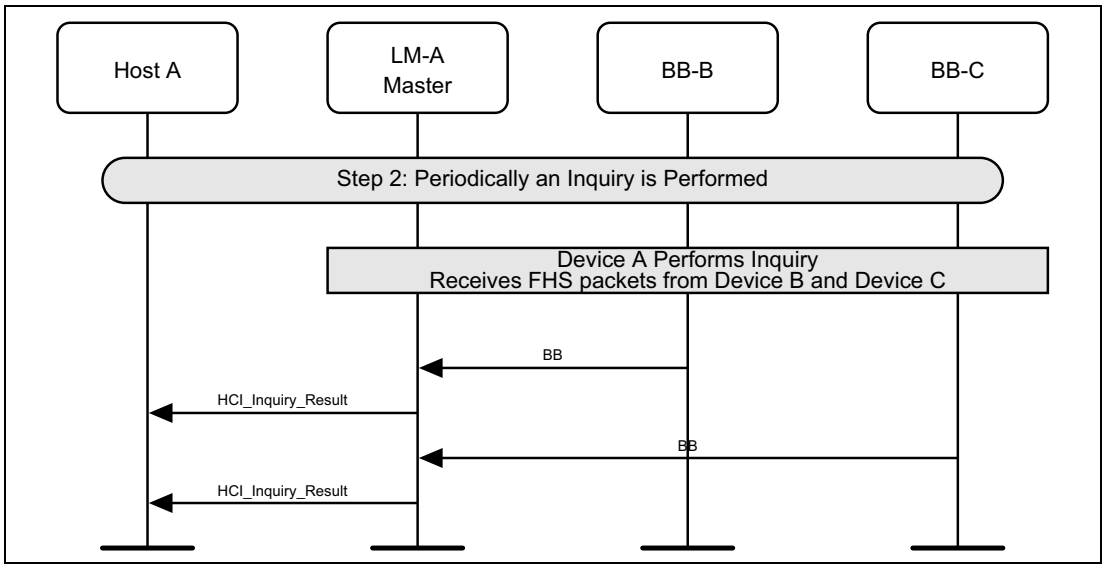

Figure 2.9: LM-A periodically performs an inquiry and reports result

Step 3: An Inquiry Complete event will be returned to the Host when the current periodic inquiry has finished. (See Figure 2.10.)

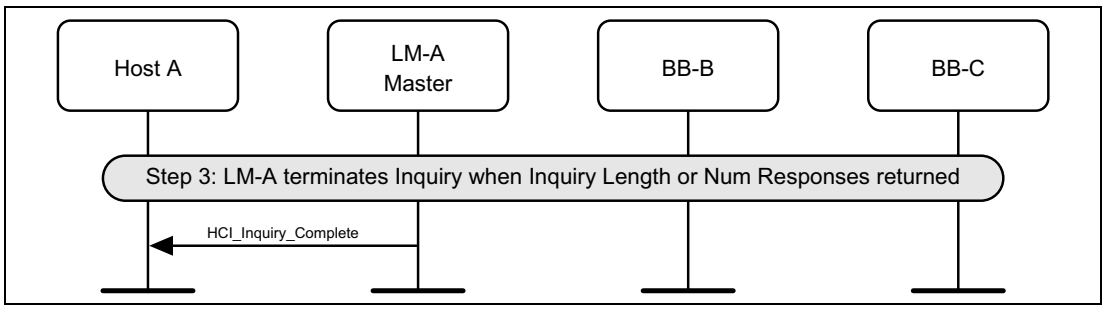

Figure 2.10: LM-A terminates current inquiry

Step 4: The periodic Inquiry can be stopped using the HCI_Exit_Periodic_Inquiry_Mode command. (See Figure 2.11.)

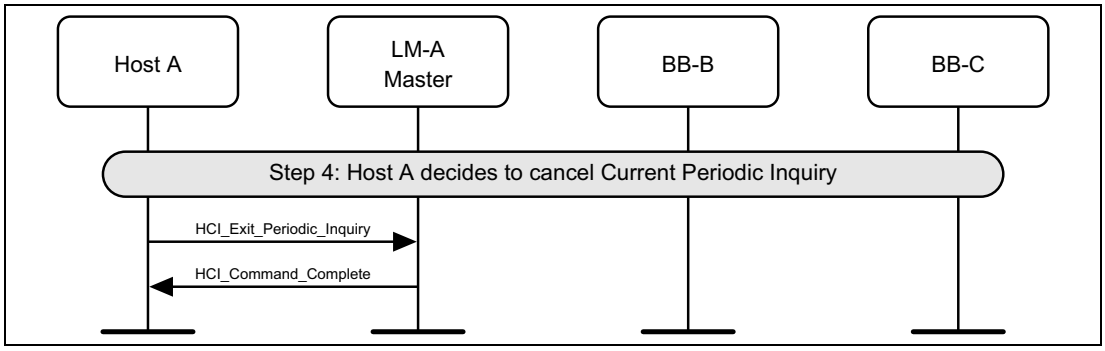

Figure 2.11: Host A decides to exit periodic inquiry

3 ACL CONNECTION ESTABLISHMENT AND DETACHMENT

A flow diagram of the establishment and detachment of a connection between two devices is shown in Figure 3.1. The process is illustrated in 9 distinct steps. A number of these steps may be optionally performed, such as authentication and encryption. Some steps are required, such as the Connection Request and Setup Complete steps. The steps in the overview diagram directly relate to the steps in the following message sequence charts.

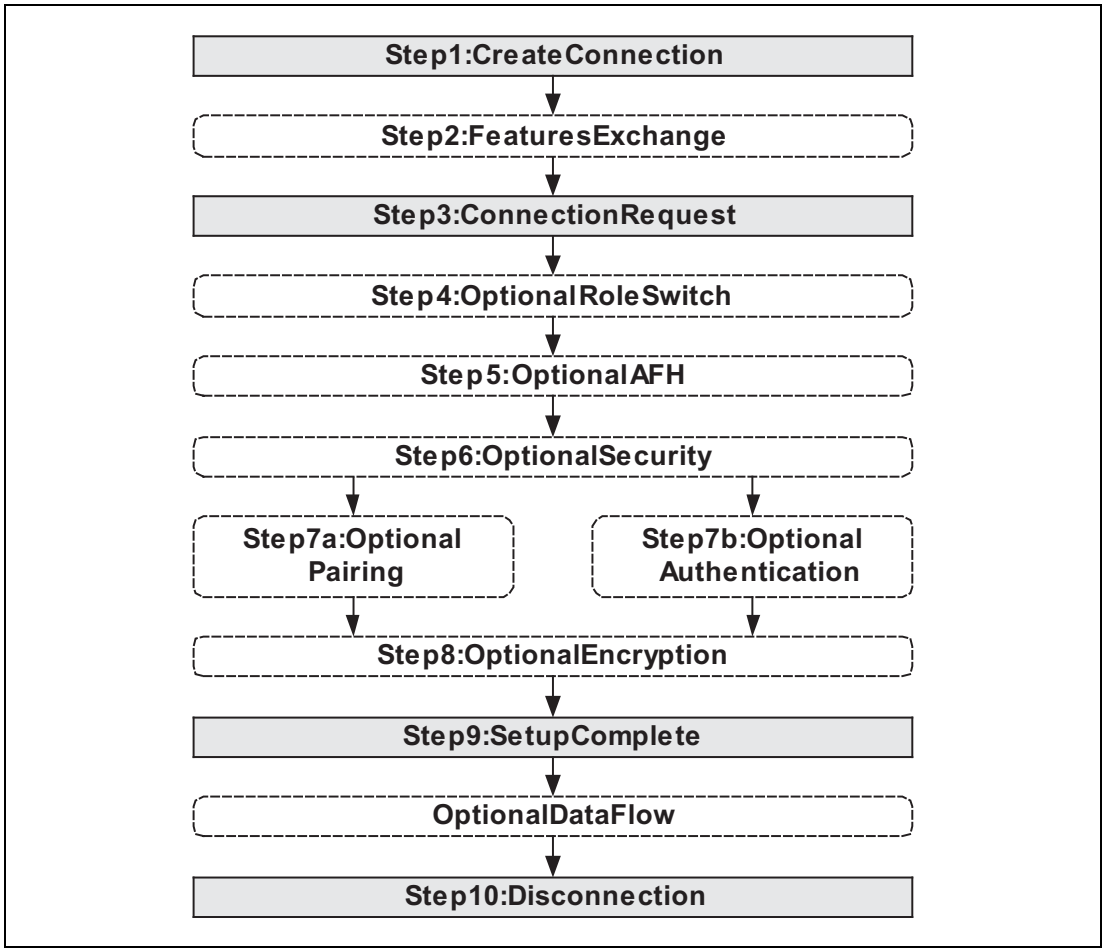

Figure 3.1: Overview diagram for connection setup

3.1 CONNECTION SETUP

Step 1: The Host sends an HCI_Create_Connection command to the Controller. The Controller then performs a Baseband paging procedure with the specified BD_ADDR. (See Figure 3.2.)

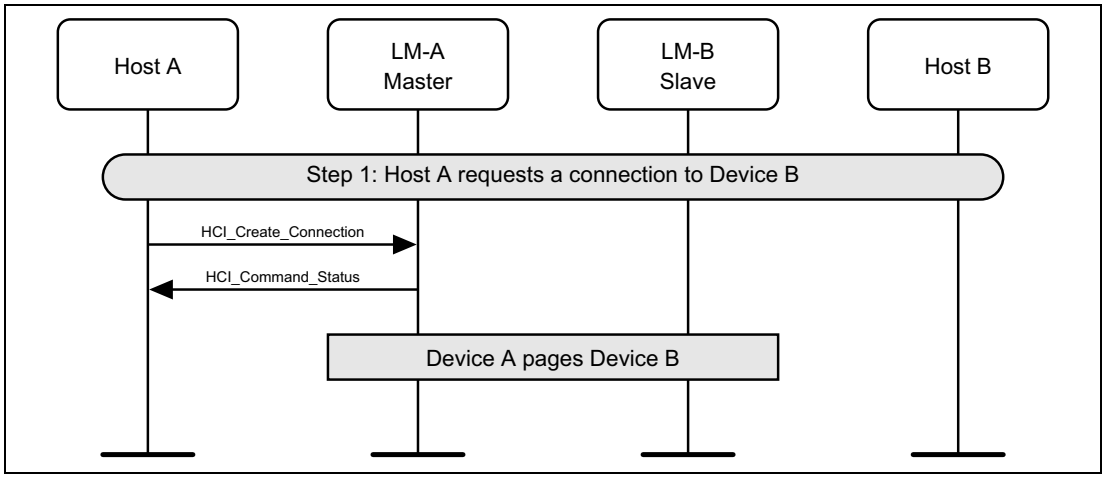

Figure 3.2: Host A requests connection with device B

Step 2: Optionally, the LM may decide to exchange features. (See Figure 3.3.)

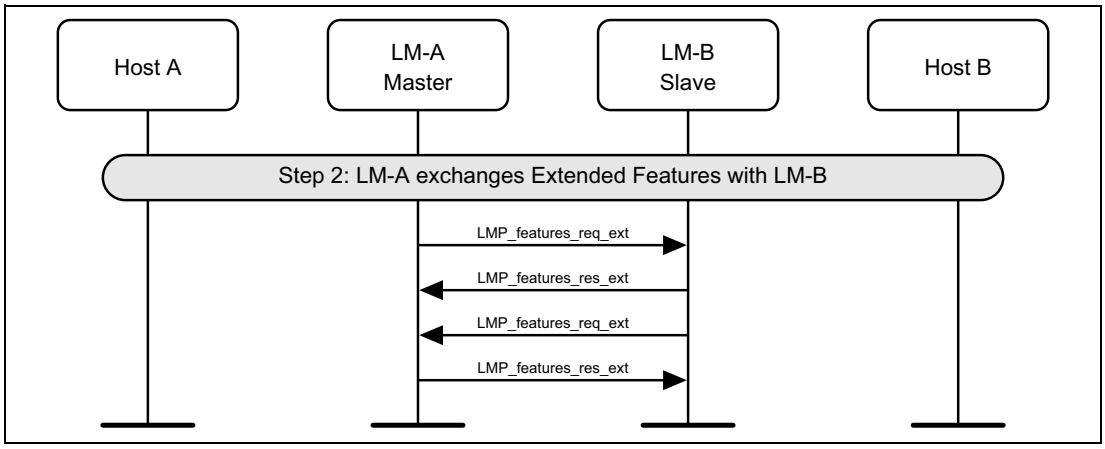

Figure 3.3: LM-A and LM-B exchange features

Step 3: The LM on the master will request an LMP_Host_connection_req PDU. The LM on the slave will then confirm that a connection is OK, and if so, what role is preferred. (See Figure 3.4)

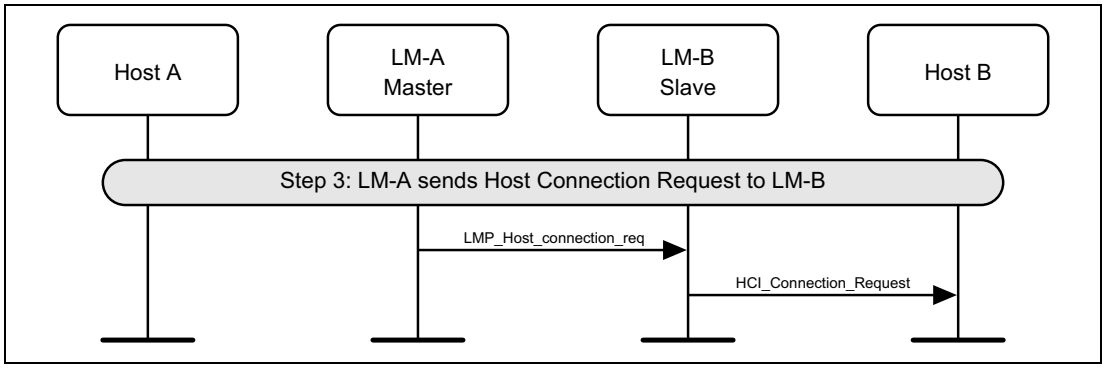

Figure 3.4: LM-A requests Host connection

Step 4a: The remote Host rejects this connection, and the link is terminated. (See Figure 3.5.)

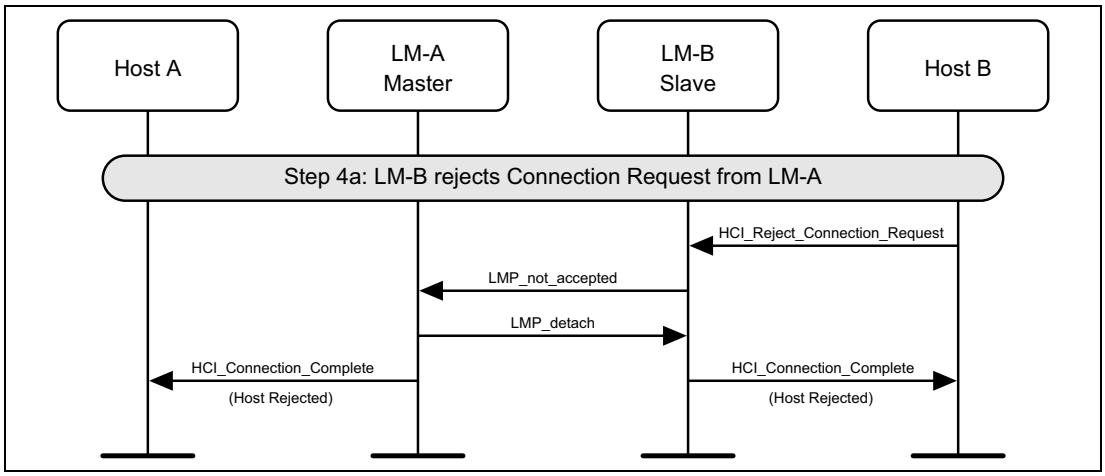

Figure 3.5: Device B rejects connection request

Step 4b: The remote Host accepts this connection. (See Figure 3.6.)

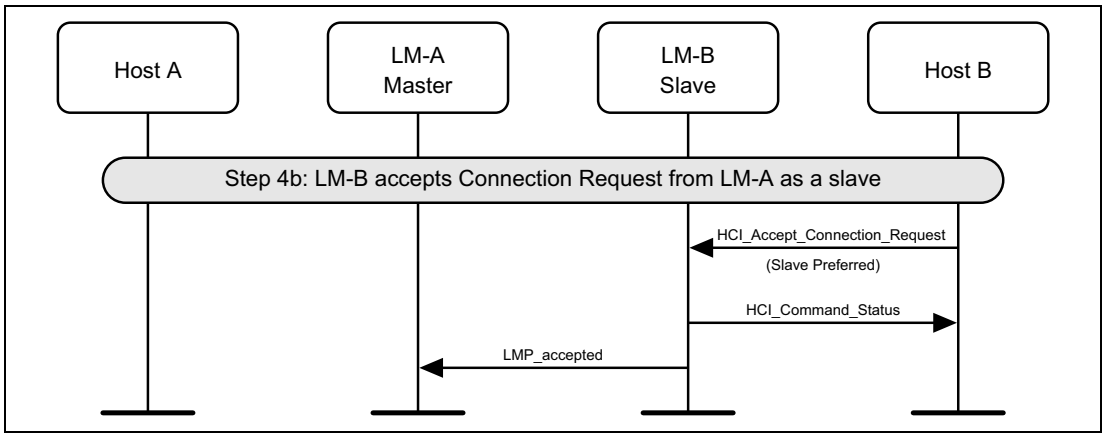

Figure 3.6: Device B accepts connection request

Step 4c: The remote Host accepts this connection but with the preference of being a master. This will cause a role switch to occur before the LMP_accepted for the LMP_Host_connection_req PDU is sent. (See Figure 3.7.)

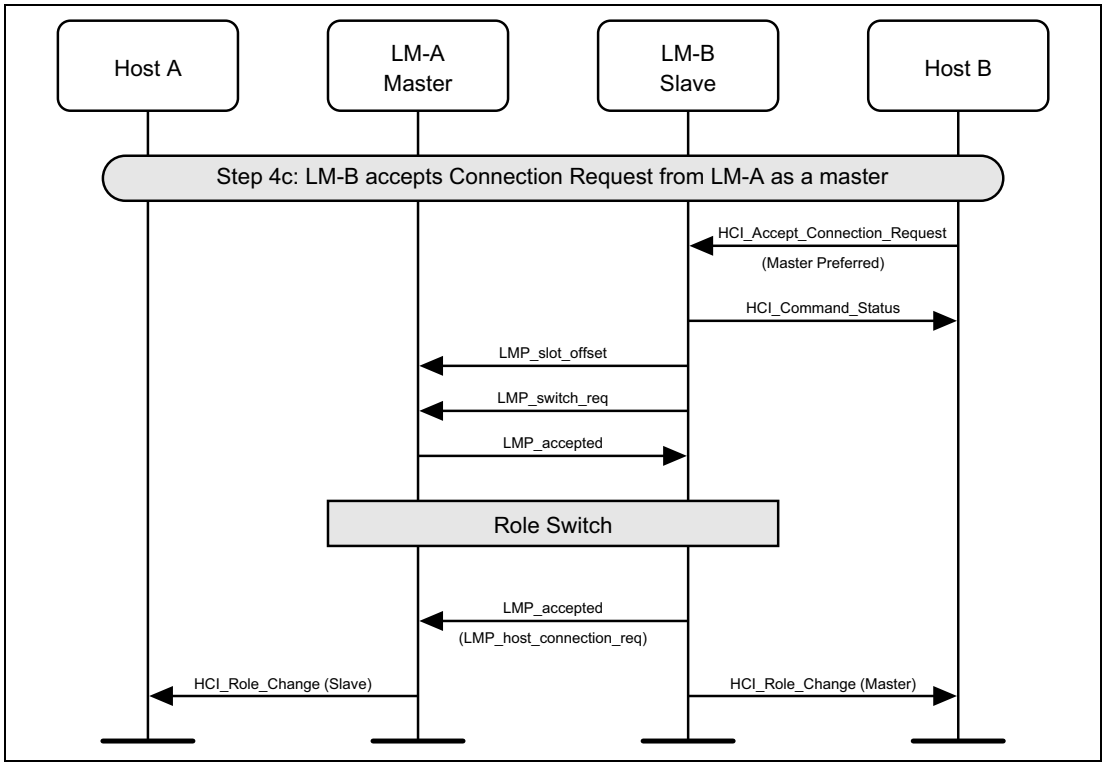

Figure 3.7: Device B accepts connection requests as master

Step 5: After the features have been exchanged and AFH support is determined to be available, the master may at any time send an LMP_set_AFH and LMP_channel_classification_req PDU. (See Figure 3.8.)

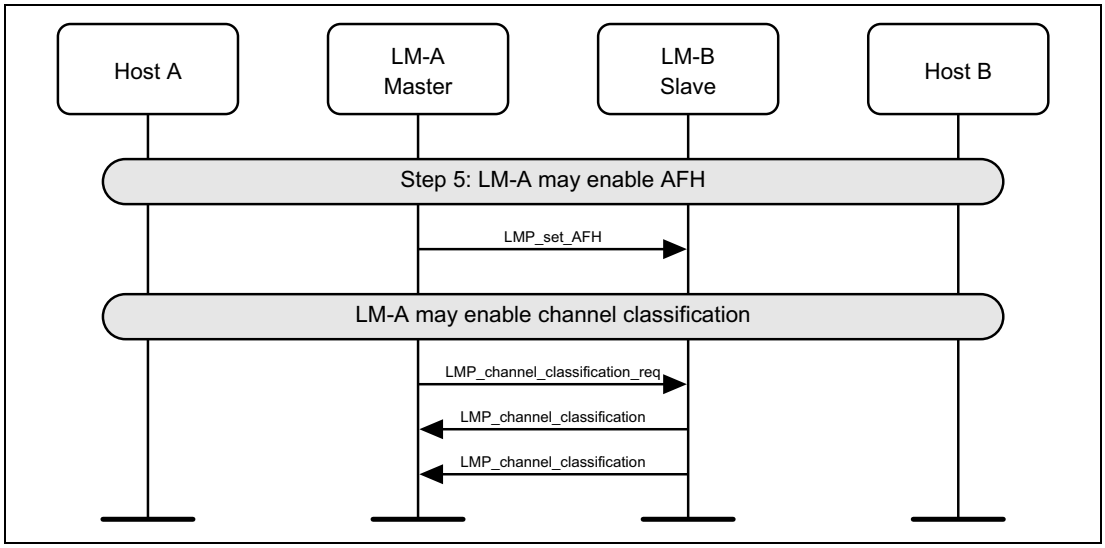

Figure 3.8: LM-A starts adaptive frequency hopping

Step 6: The LM will request if authentication is required. It does this by requesting the Link Key for this connection from the Host. (See Figure 3.9.)

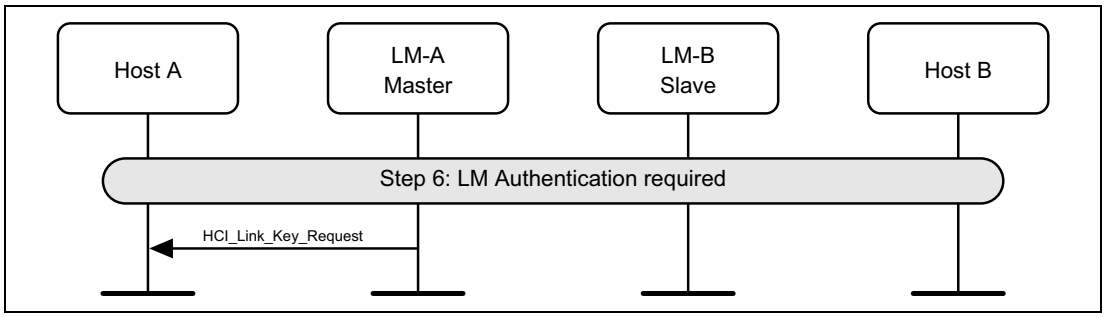

Figure 3.9: Authentication initiated

Step 7a: If authentication is required by the higher layers and the devices to be connected do not have a common link key, a pairing procedure will be used. The LM will have requested a link key from the Host for this connection. If there is a negative reply, then a PIN code will be requested. This PIN code will be requested on both sides of the connection, and authentication performed based on this PIN code. The last step is for the new link key for this connection to be passed to the Host so that it may store it for future connections. (See Figure 3.10.)

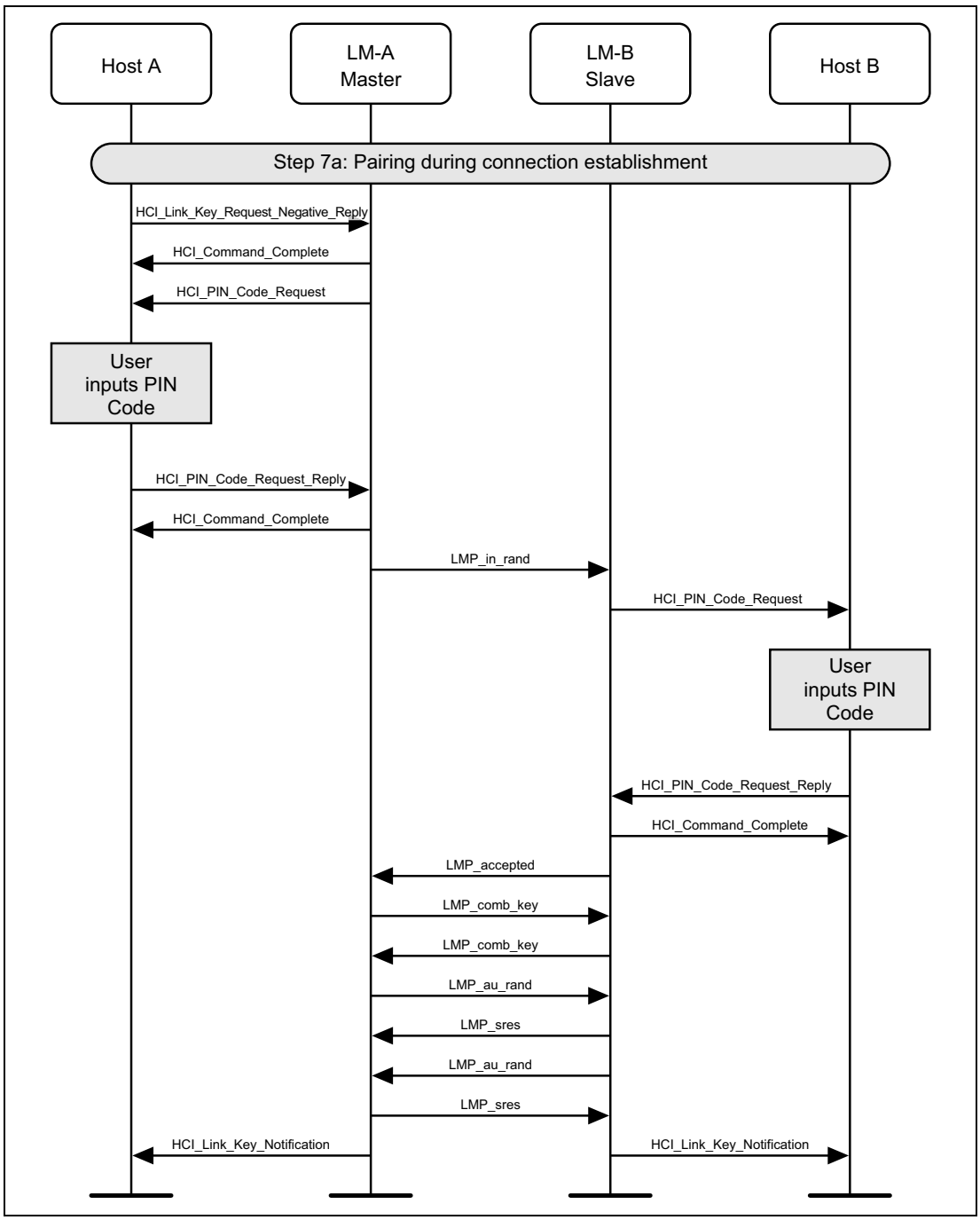

Figure 3.10: Pairing during connection setup

Step 7b: If a common link key exists between the devices, then pairing is not needed. The LM will have asked for a link key from the Host for this connection. If this is a positive reply, then the link key is used for authentication. If the configuration parameter Authentication_Enable is set, then the authentication procedure must be executed. This MSC only shows the case when Authentication_Enable is set on both sides. (See Figure 3.11.)

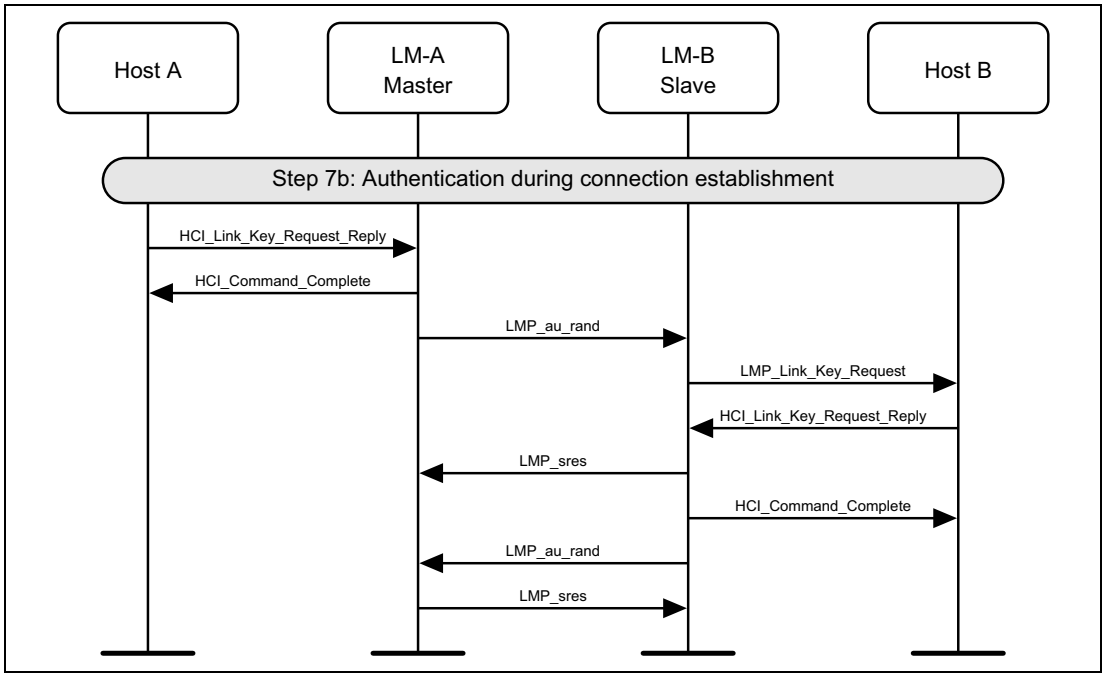

Figure 3.11: Authentication during connection setup

Step 8: Once the pairing or authentication procedure is successful, the encryption procedure may be started. This MSC only shows the set up of an encrypted point-to-point connection. (See Figure 3.12.)

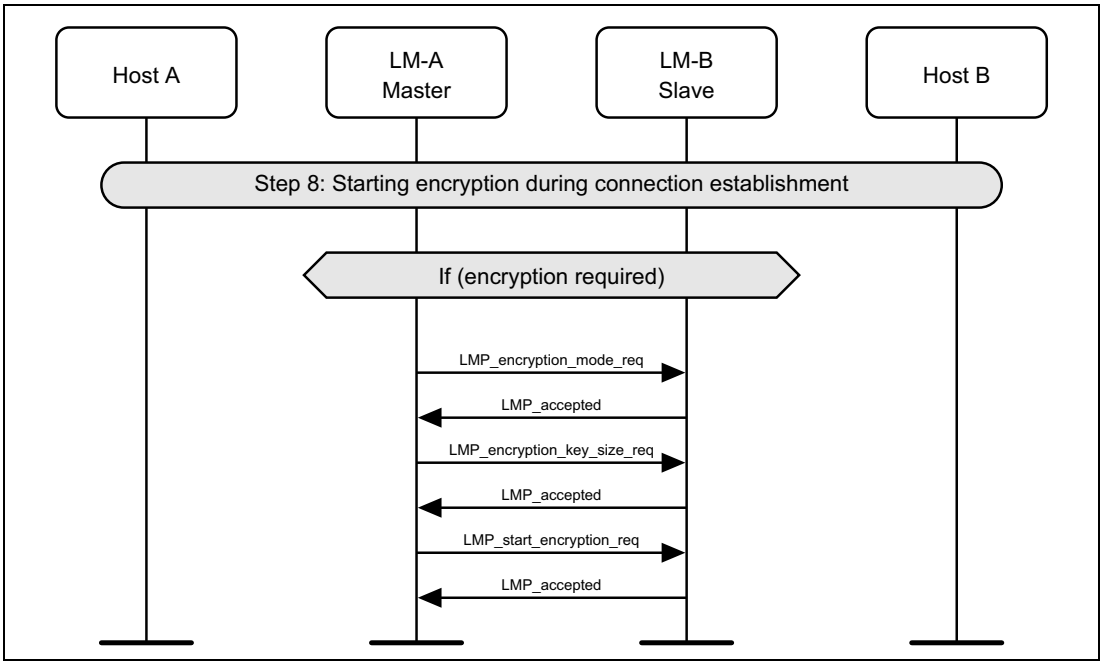

Figure 3.12: Starting encryption during connection setup

Step 9: The LMs indicate that the connection is setup by sending LMP_setup_complete PDU. This will cause the Host to be notified of the new connection handle, and this connection may be used to send higher layer data such as L2CAP information. (See Figure 3.13.)

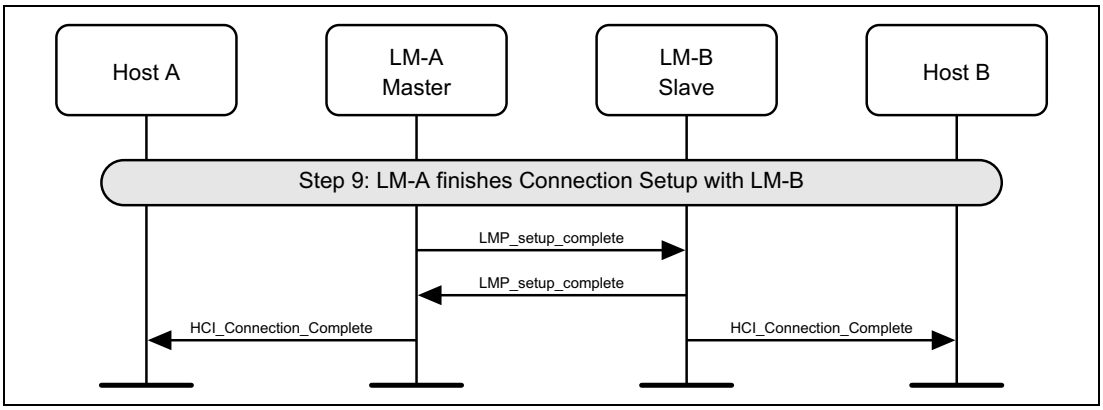

Figure 3.13: LM-A and LM-B finishes connection setup

Step 10: Once the connection is no longer needed, either device may terminate the connection using the HCI_Disconnect command and LMP_detach message PDU. The disconnection procedure is one-sided and does not need an explicit acknowledgment from the remote LM. The use of ARQ Acknowledgment from the Baseband is needed to ensure that the remote LM has received the LMP_detach PDU. (See Figure 3.14.)

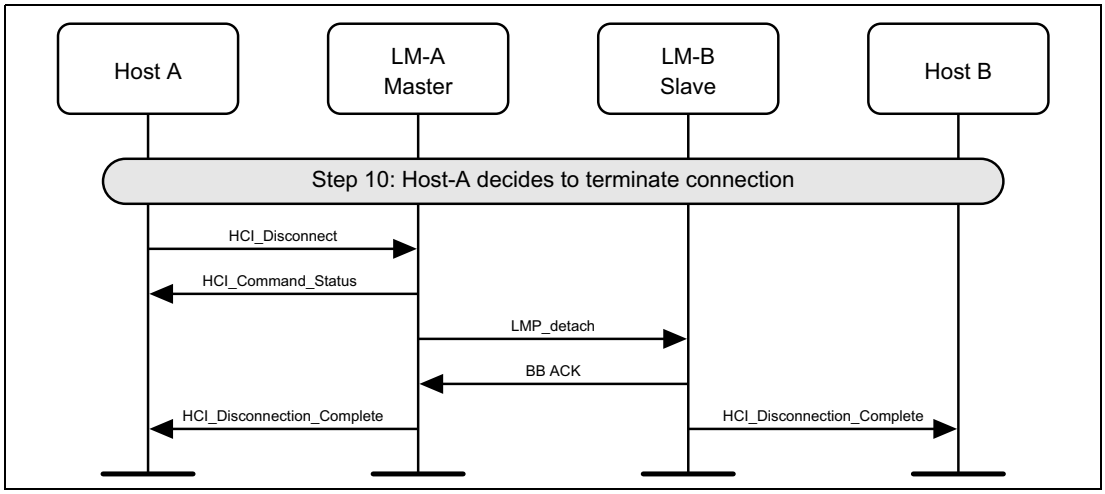

Figure 3.14: Host A decides to disconnect

4 OPTIONAL ACTIVITIES AFTER ACL CONNECTION ESTABLISHMENT

4.1 AUTHENTICATION REQUESTED

Step 1: Authentication can be explicitly executed at any time after a connection has been established. If no Link Key is available then the Link Key is required from the Host. (See Figure 4.1.)

Note: If the Controller or LM and the Host do not have the Link Key a PIN Code Request event will be sent to the Host to request a PIN Code for pairing. A procedure identical to that used during Connection Setup (Section 3.1, Step 7a:) will be used. (See Figure 3.10.)

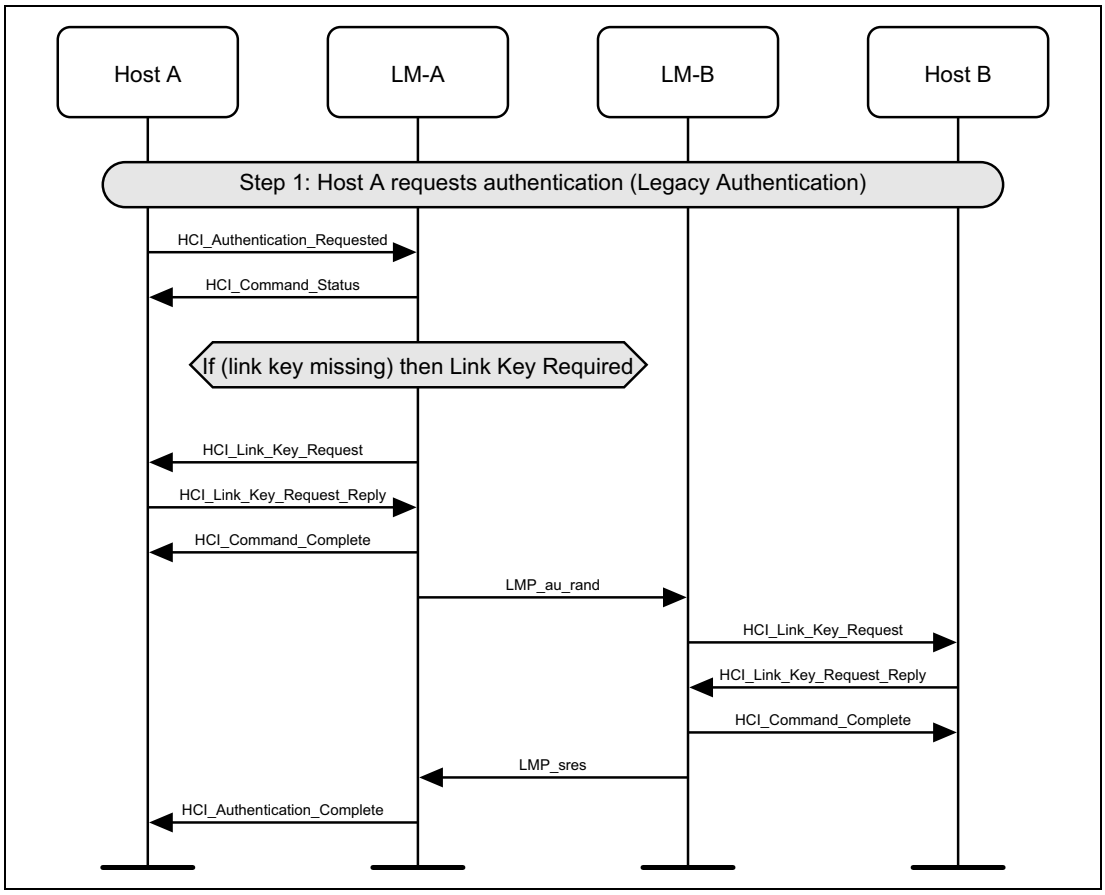

Figure 4.1: Authentication requested (Legacy Authentication)

When both devices support Secure Connections, Secure Authentication is used.

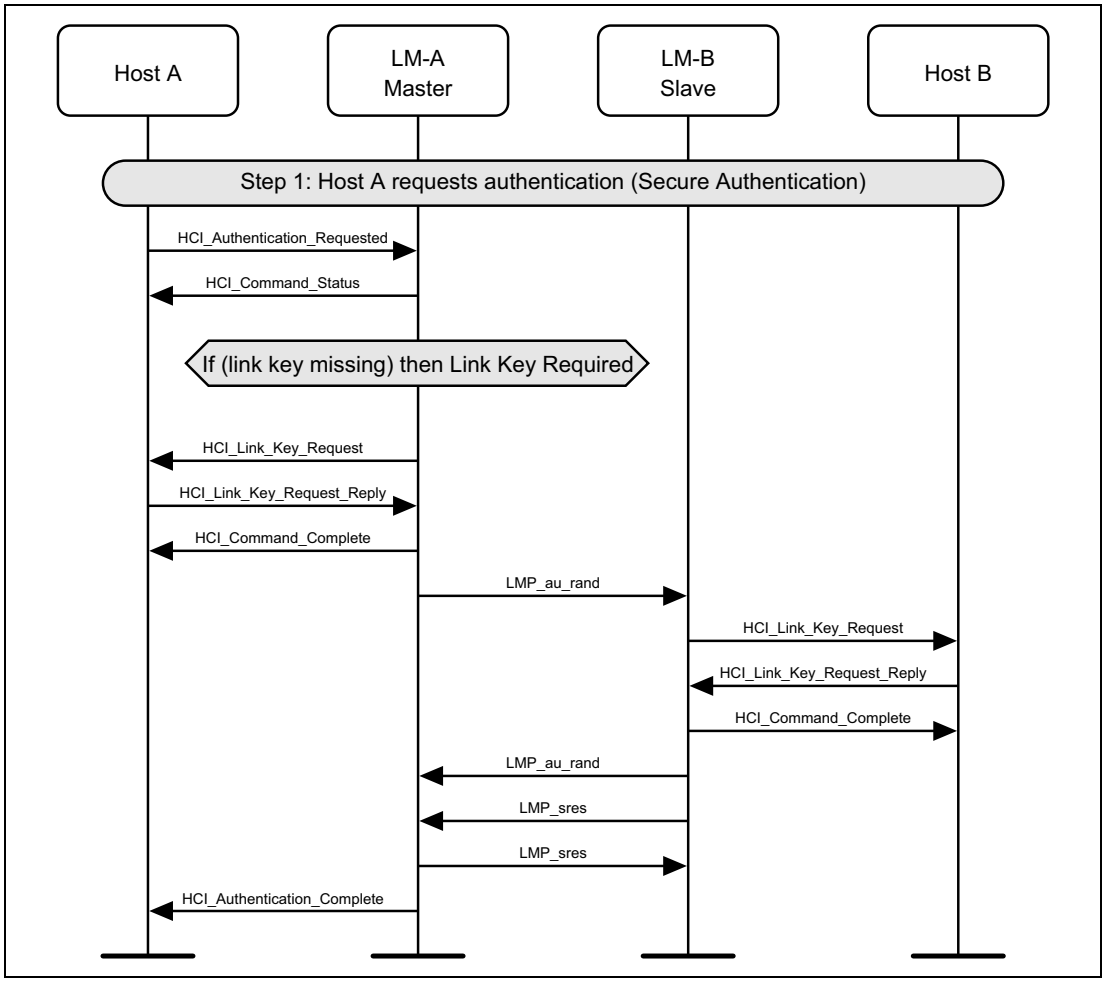

Figure 4.2: Authentication requested (Secure Authentication)

4.2 SIMPLE PAIRING MESSAGE SEQUENCE CHARTS

A flow diagram of simple pairing between two devices is shown in Figure 4.3. The process is illustrated in 11 distinct steps. A number of these steps have a number of different options.

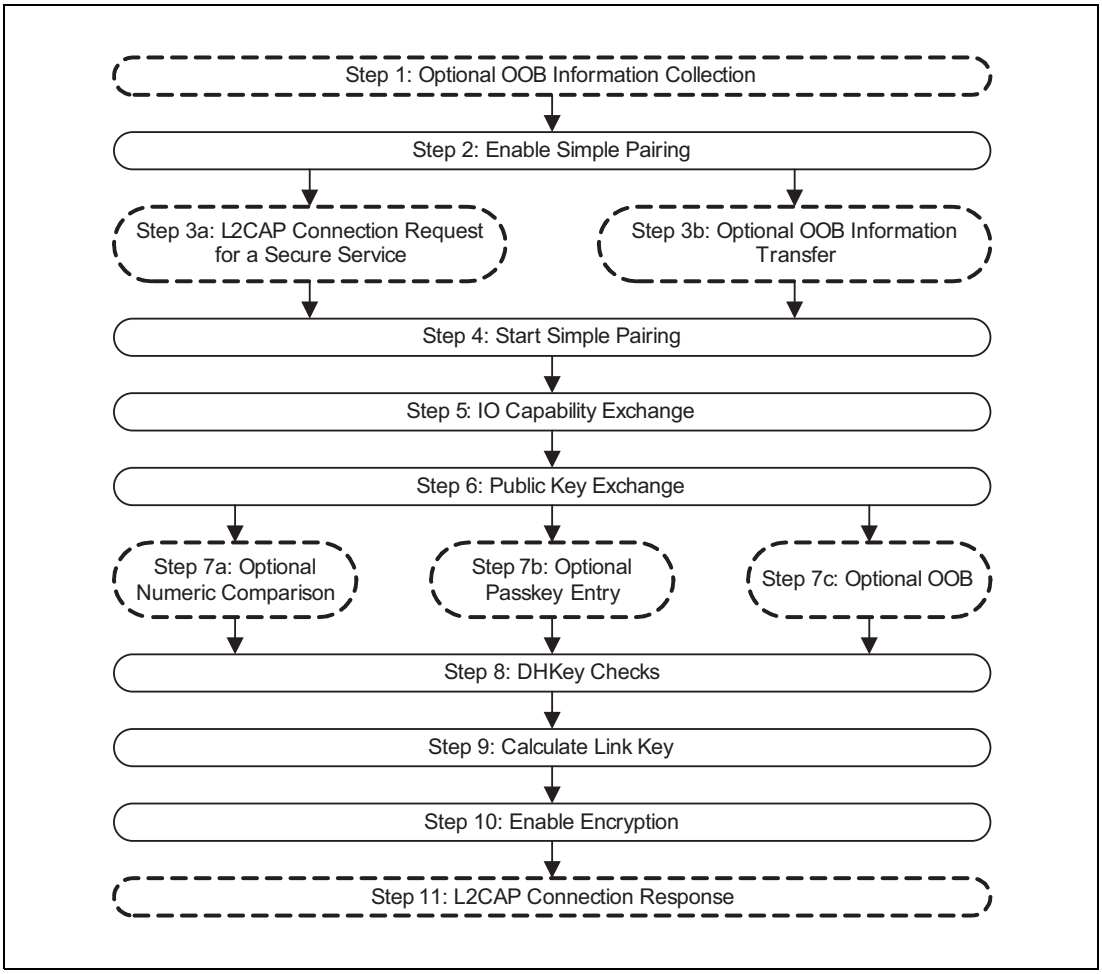

Figure 4.3: Simple pairing, flow diagram

4.2.1 Optional OOB Information Collection

If a device supports OOB information exchange, then the Host should request the C and R values from the Controller that need to be sent by OOB. It is then assumed that the Host transfers this information to the OOB system. Note: This could occur a long time before, for example at the factory for a passive tag.

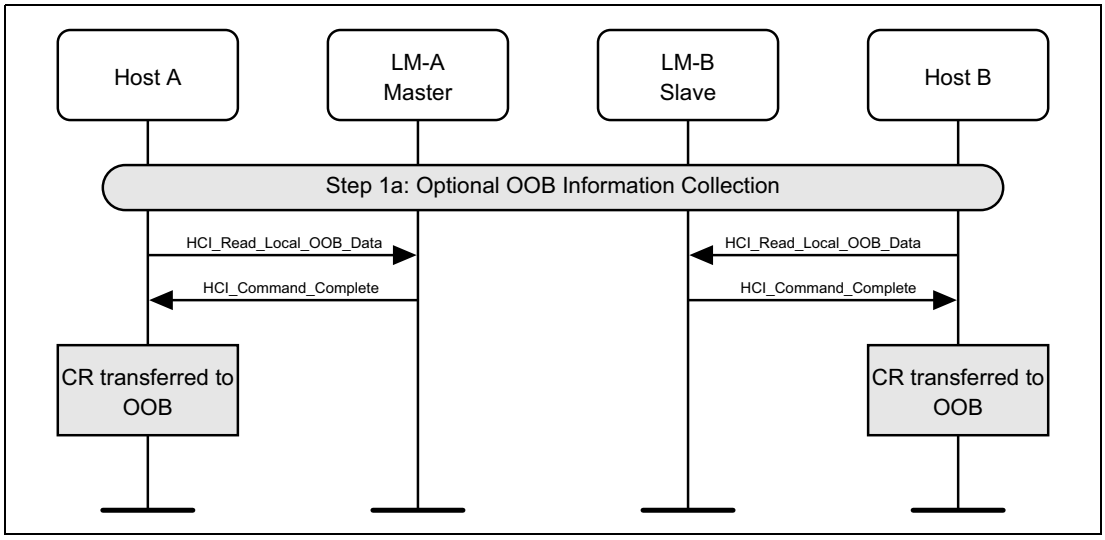

Figure 4.4: Optional OOB information collection (P-192 only)

When the Controller and Host support Secure Connections, the HCI_Read_Local_OOB_Extended_Data command is used instead of HCI_Read_Local_OOB_Data.

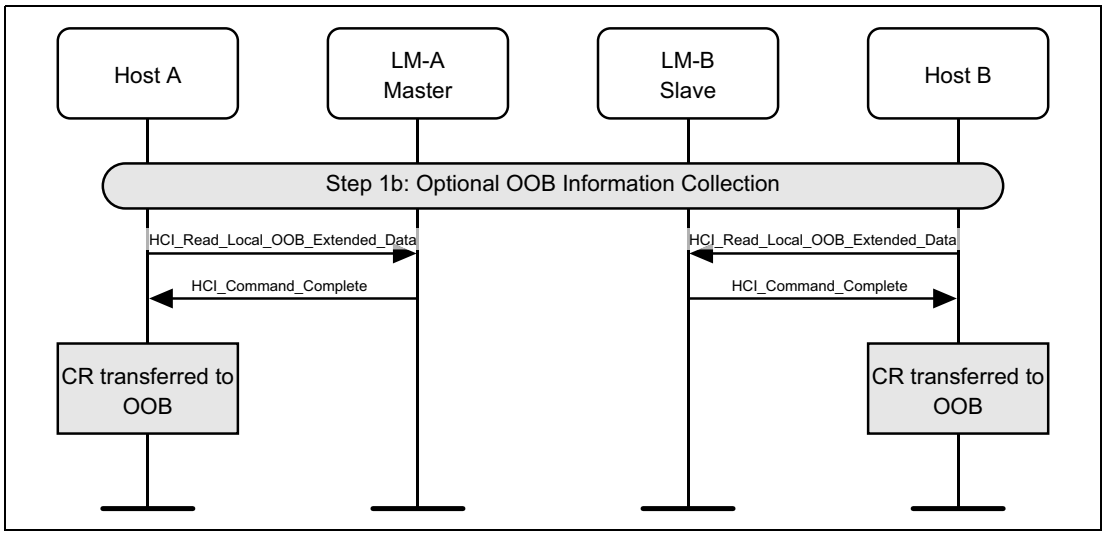

Figure 4.5: Optional OOB information collection (P-192 and P-256)

4.2.2 Enable Simple Pairing and Secure Connections

To enable simple pairing, a device must use the Write Simple Pairing Mode command. This should be done before any other connections that may use simple pairing are created.

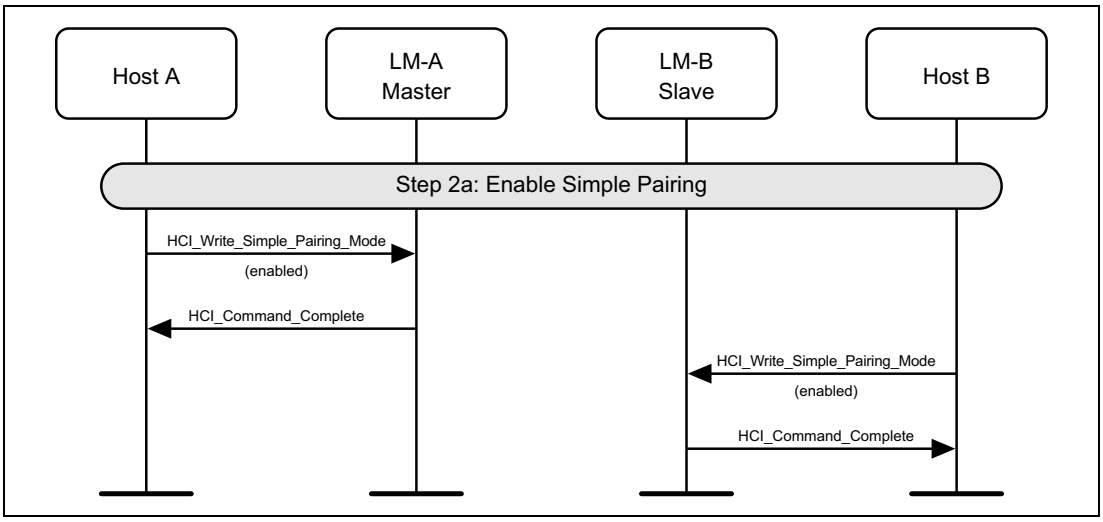

Figure 4.6: Enable simple pairing

To configure the Controller to use Secure Connections HCI commands and events, a device must use the HCI_Write_Secure_Connections_Host_Support command. This should be done before any connections are created.

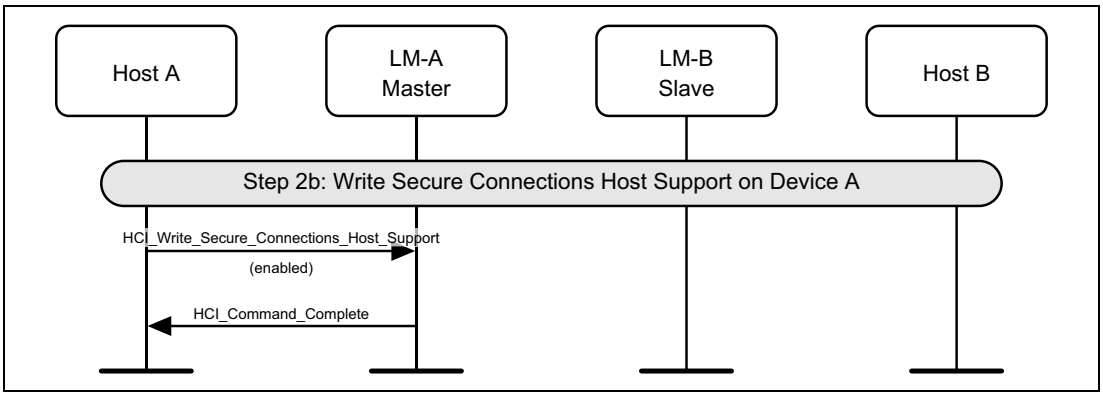

Figure 4.7: Enable Secure Connections Host support

To configure the Controller to enforce a maximum interval between packets containing a MIC (when AES-CCM encryption is used), a device must use the HCI_Write_Authenticated_Payload_Timeout command.

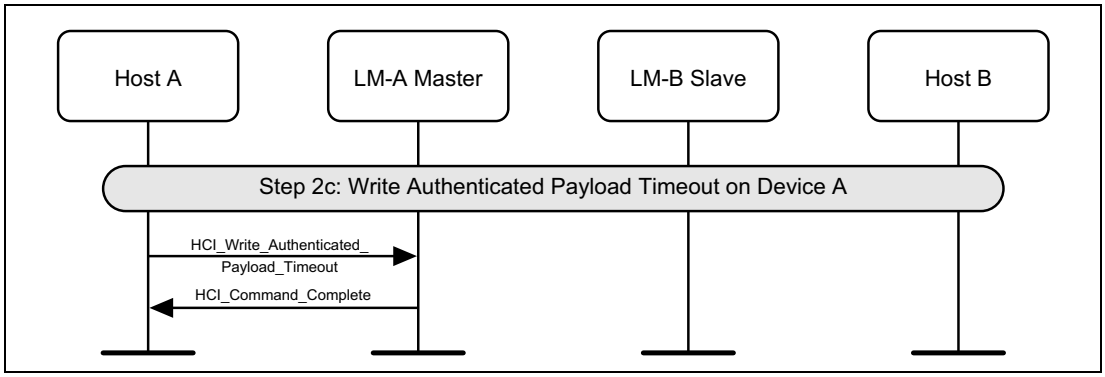

Figure 4.8: Set Authenticated_Payload_Timeout

4.2.3 Connection Establishment

Simple pairing, once it is enabled, is triggered by one of two possible actions. It could be triggered by an L2CAP connection request to a service that requires security, or it could be triggered by an OOB transfer of information.

4.2.4 L2CAP Connection Request for a Secure Service

Once a connection has been established between two devices, if a device requests an L2CAP connection to a service that requires authentication and encryption, then the device will start simple pairing.

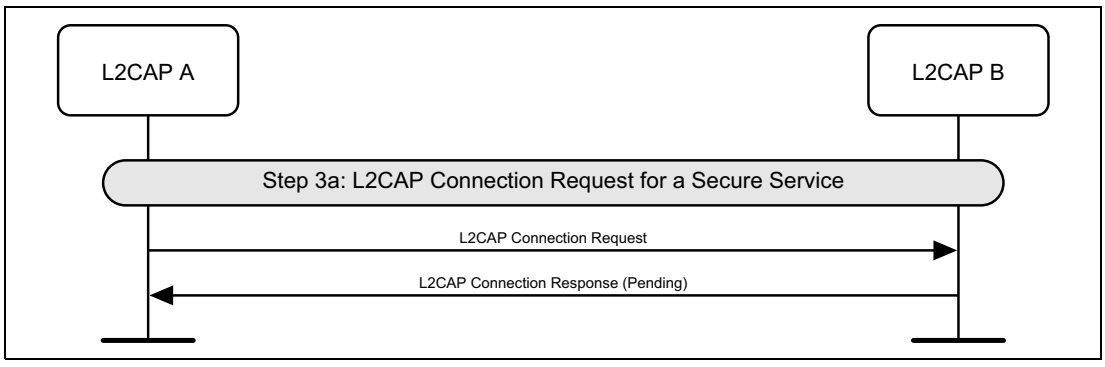

Figure 4.9: L2CAP connection request for a secure service

4.2.5 Optional OOB Information Transfer

Even if a Bluetooth connection has not been established between two devices, an OOB transfer can occur that transfers the Bluetooth Device Address of the device, and other OOB information for authentication. If an OOB transfer occurs, then the Host can start simple pairing.

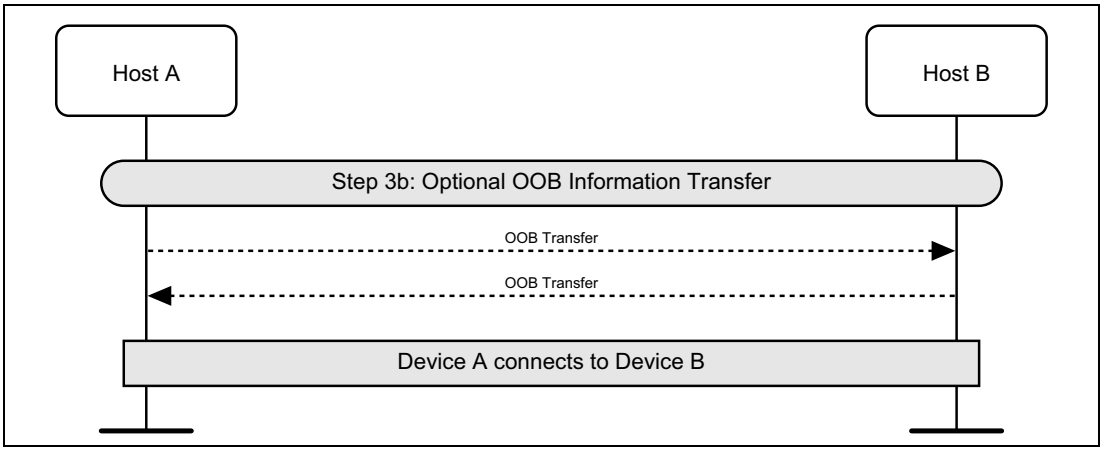

Figure 4.10: Optional OOB information transfer

4.2.6 Start Simple Pairing

Once the Host has determined that simple pairing should start, it issues an Authentication Requested command to the Controller. This will cause the Controller to generate a request for a link key. If the Host has a link key for this connection, then pairing is not required, and the link key can be used immediately once it has been authenticated. Simple Pairing will only be used if a Link_Key_Request_Negative_Reply Command is sent from the Host to the Controller on the initiating side.

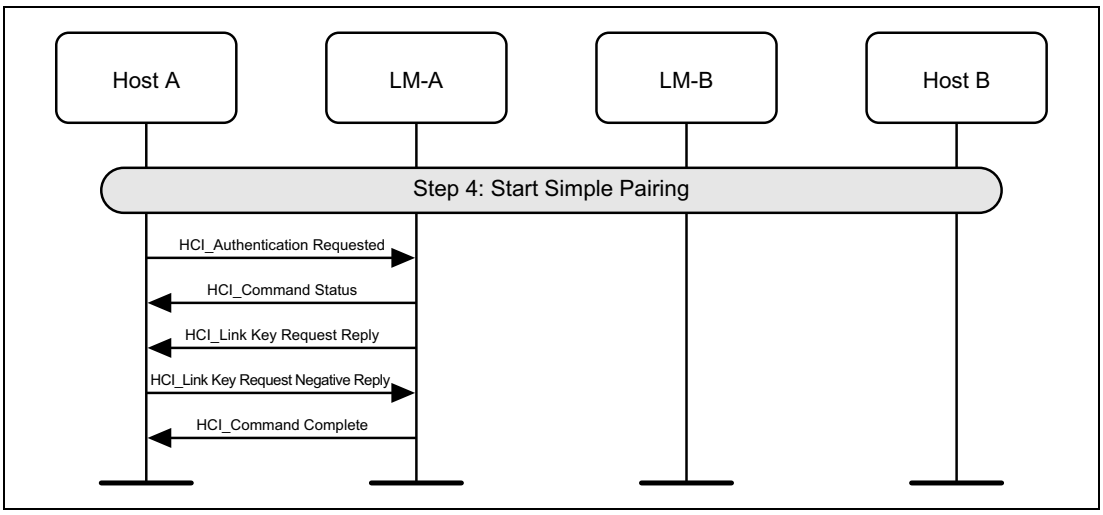

Figure 4.11: Start simple pairing

4.2.7 IO Capability Exchange

To be able to determine the correct authentication algorithm to use, the input / output capabilities of the two devices are exchanged.

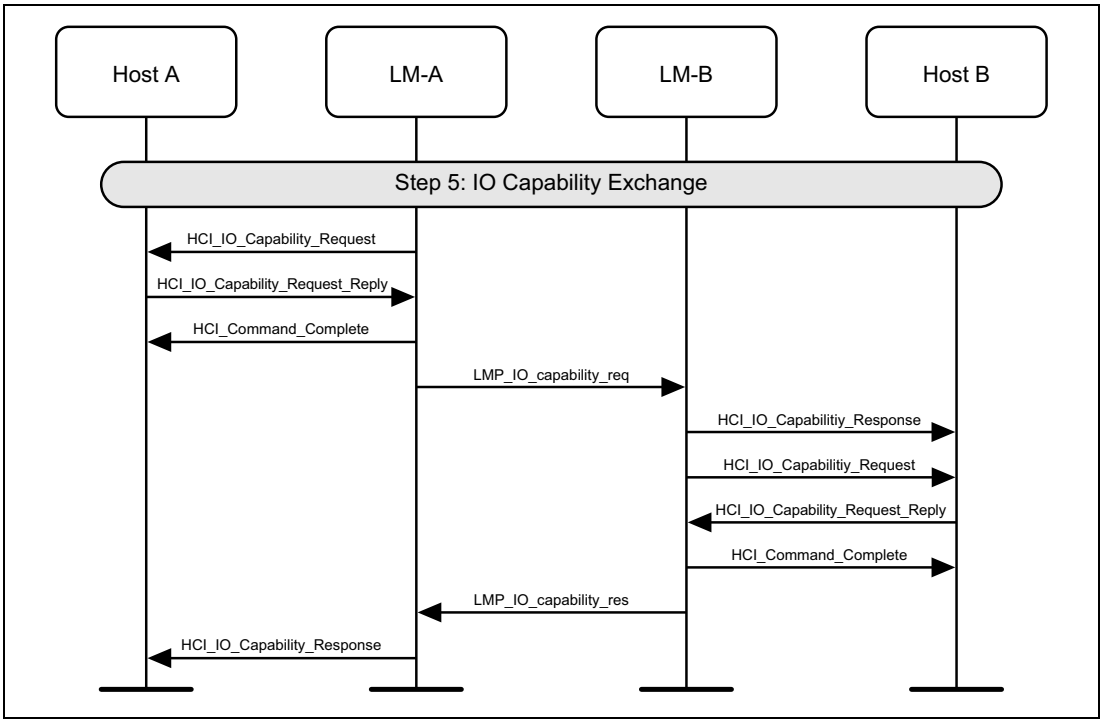

Figure 4.12: IO capability exchange

4.2.8 Public Key Exchange

Next the public keys are exchanged between the two devices. Once a device has received the public key of the peer device, it can start to calculate the Diffie Hellman Key (DHKey). This may take a long time, and should be started early, so that user interaction can hide the calculation time. The DHKey is not required until step 8.

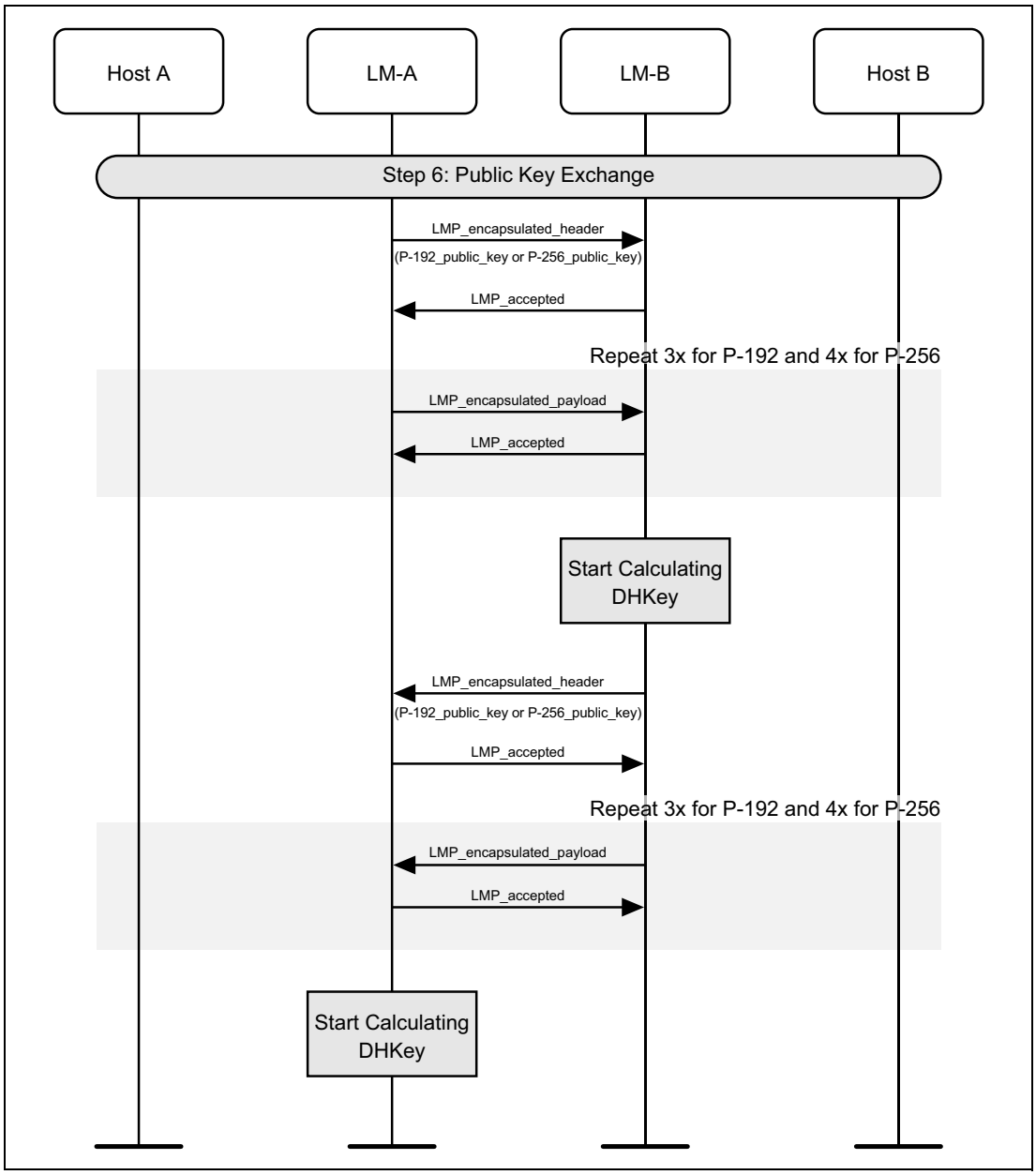

Figure 4.13: Public key exchange

4.2.9 Authentication

A device can be authenticated by using one of three algorithms. The choice of algorithm is determined by the combination of the IO capabilities of the two devices.

4.2.10 Numeric Comparison

The numeric comparison step will be done when both devices have output capabilities, or if one of the devices has no input or output capabilities. If both devices have output capabilities, this step requires the displaying of a user confirmation value. This value should be displayed until the end of step 8. If one or both devices do not have output capabilities, the same protocol is used but the Hosts will skip the step asking for the user confirmation.

Note: The sequence for Just Works is identical to that of Numeric Comparison with the exception that the Host will not show the numbers to the user.

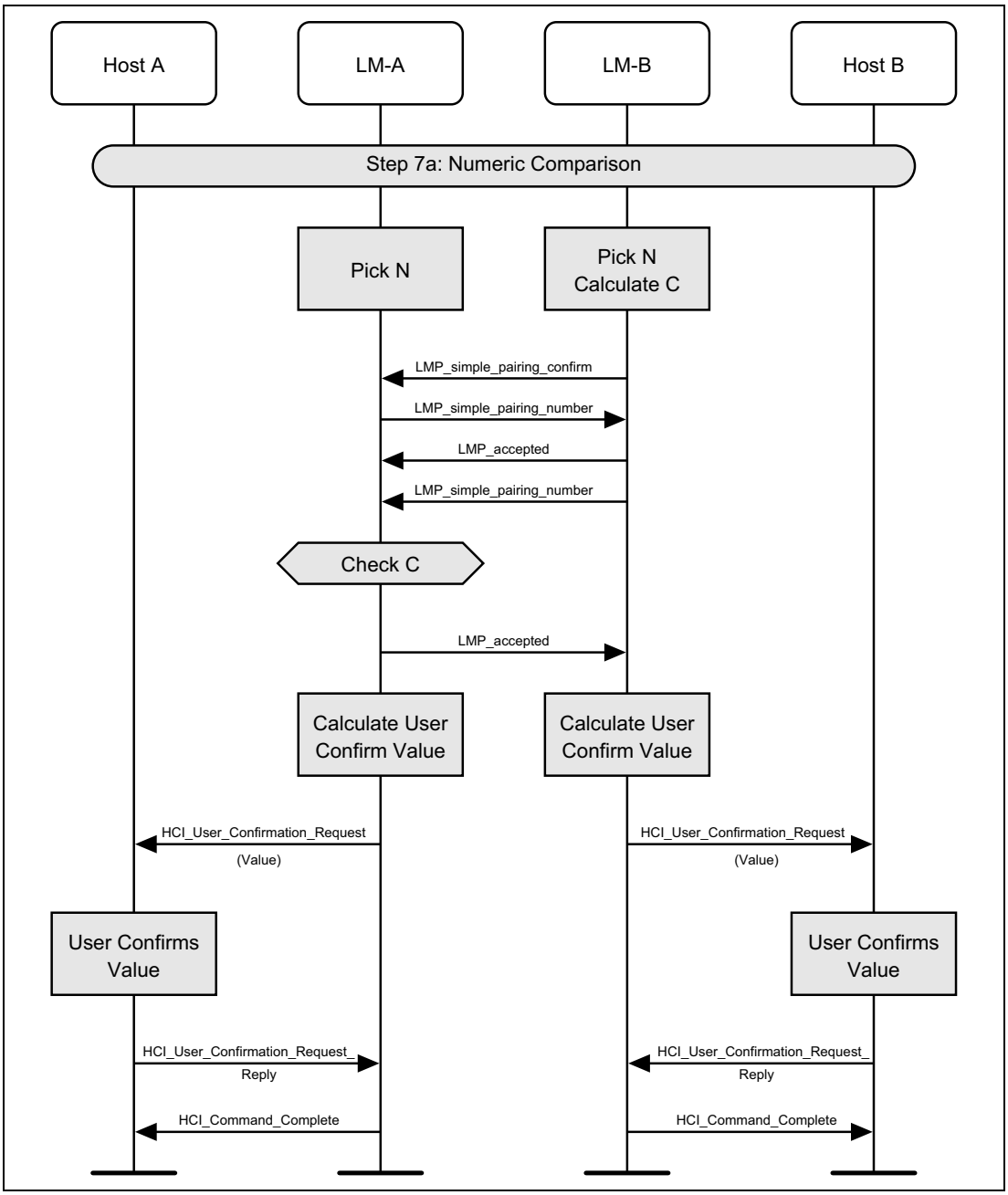

Figure 4.14: Numeric comparison authentication

4.2.11 Numeric Comparison Failure on Initiating Side

If the numeric comparison fails on the initiating side due to the user indicating that the confirmation values do not match, Simple Pairing is terminated.

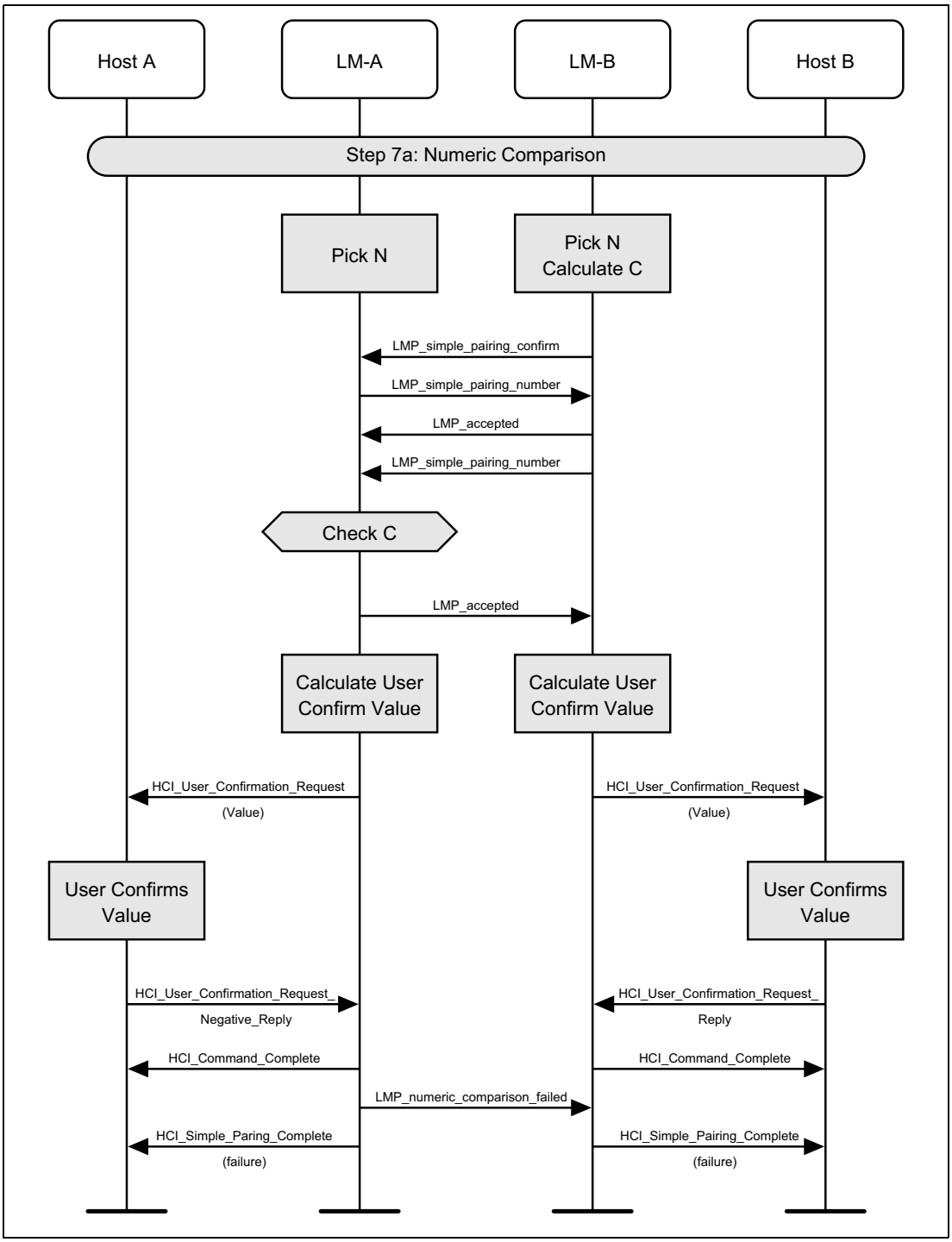

Figure 4.15: Numeric comparison authentication (failure on initiating side)

4.2.12 Numeric Comparison Failure on Responding Side

If the numeric comparison fails on the responding side due to the user indicating that the confirmation values do not match, Simple Pairing is terminated.

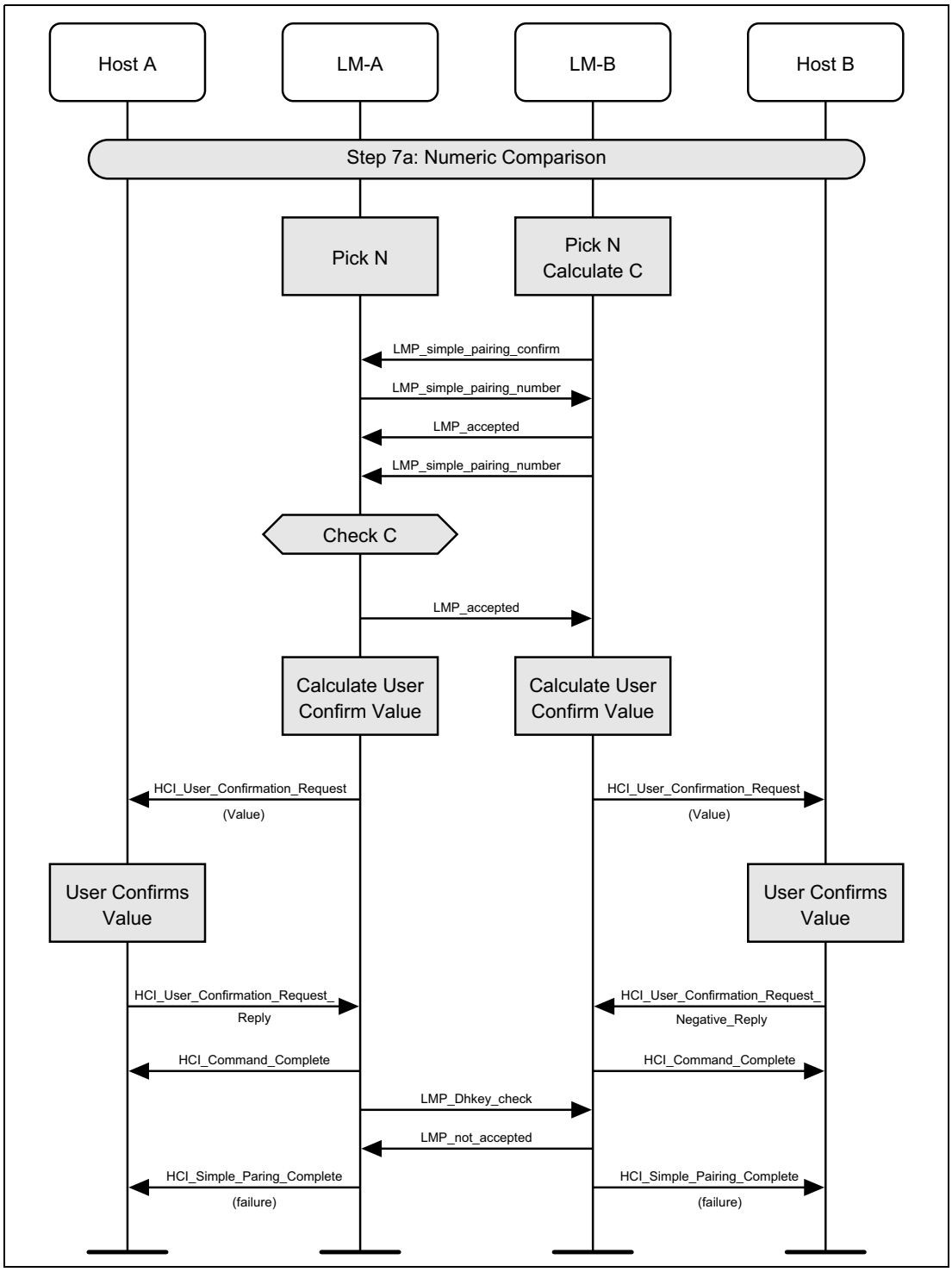

Figure 4.16: Numeric comparison failure on responding side

4.2.13 Passkey Entry

The Passkey entry step is used in two cases: when one device has numeric input only and the other device has either a display or numeric input capability or when both devices only have numeric input capability. In this step, one device display a number to be entered by the other device or the user enters a number on both devices. This number should be displayed until the end of step 8. Key press notification messages are shown during the user input phase.

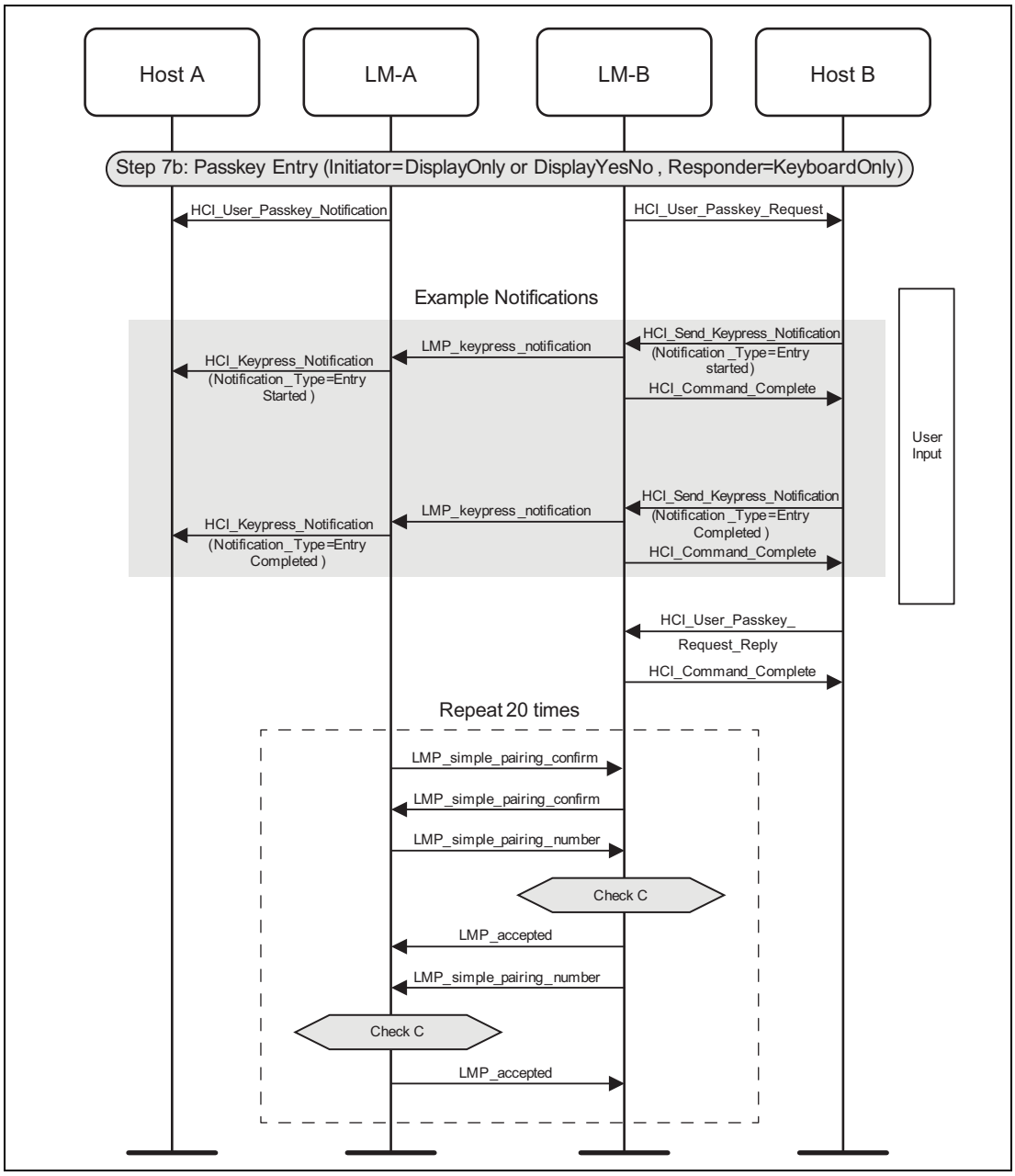

Figure 4.17: Passkey entry authentication

4.2.14 Passkey Entry Failure on Responding Side

If the passkey entry fails on the responding side, Simple Pairing is terminated.

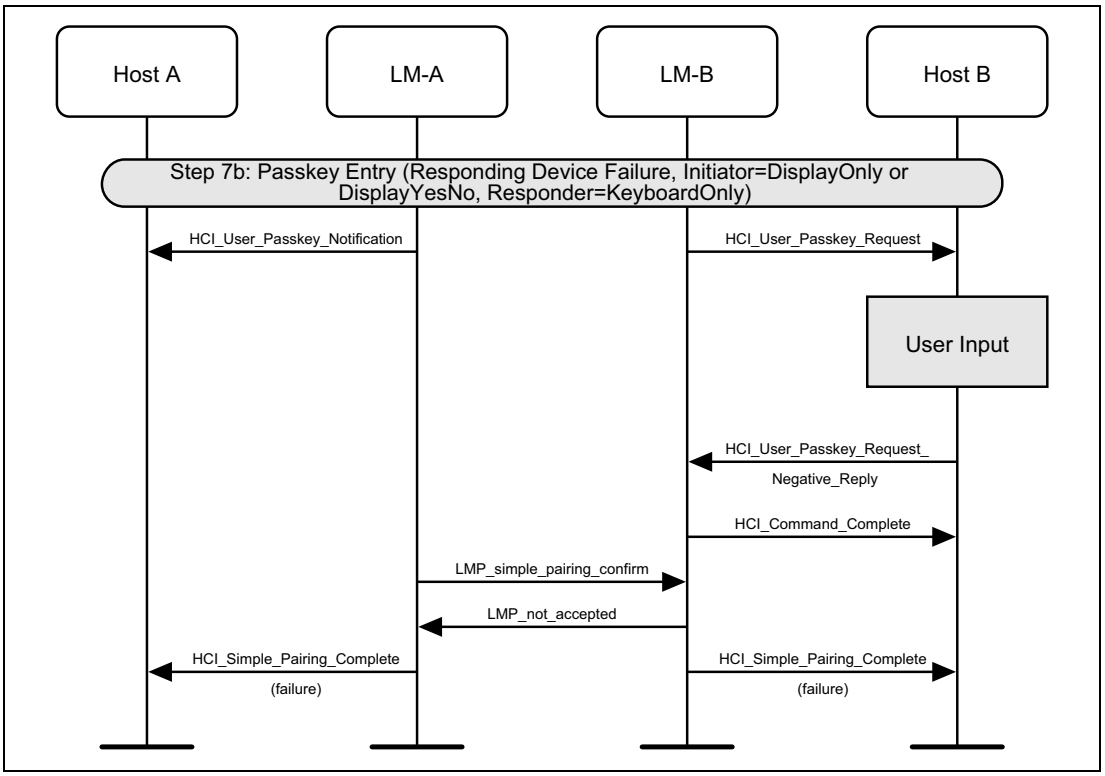

Figure 4.18: Passkey entry failure on responding side

4.2.15 Passkey Entry Failure on Initiator Side

If the passkey entry fails on the initiating side, Simple Pairing is terminated. Note that this is only possible if the initiating LM side sends an HCI User Passkey Request event.

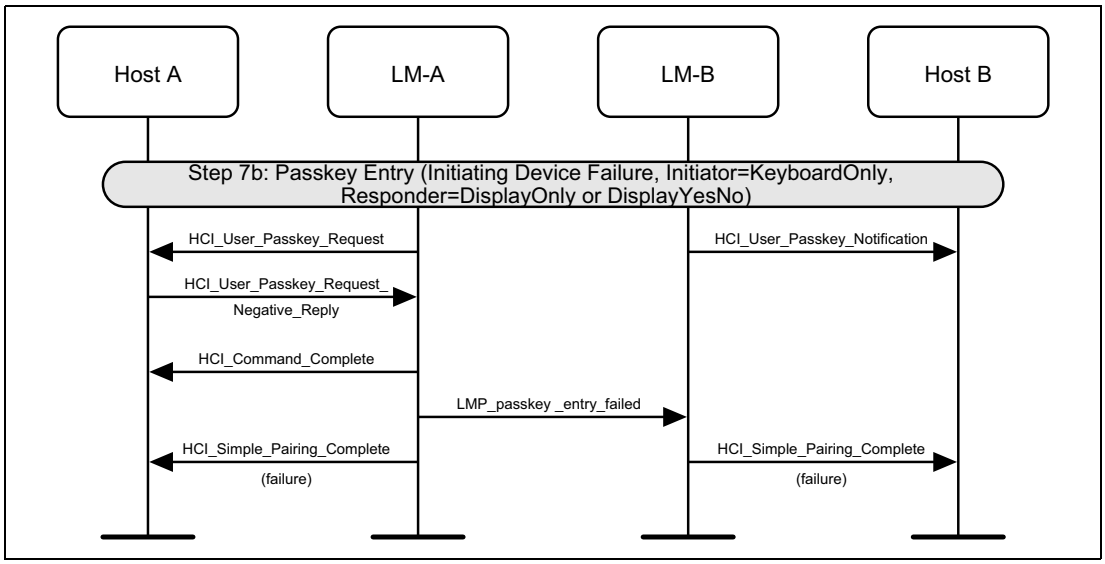

Figure 4.19: Passkey entry failure on initiating side

4.2.16 Out of Band

The OOB authentication will only be done when both devices have some OOB information to use. This step requires no user interaction.

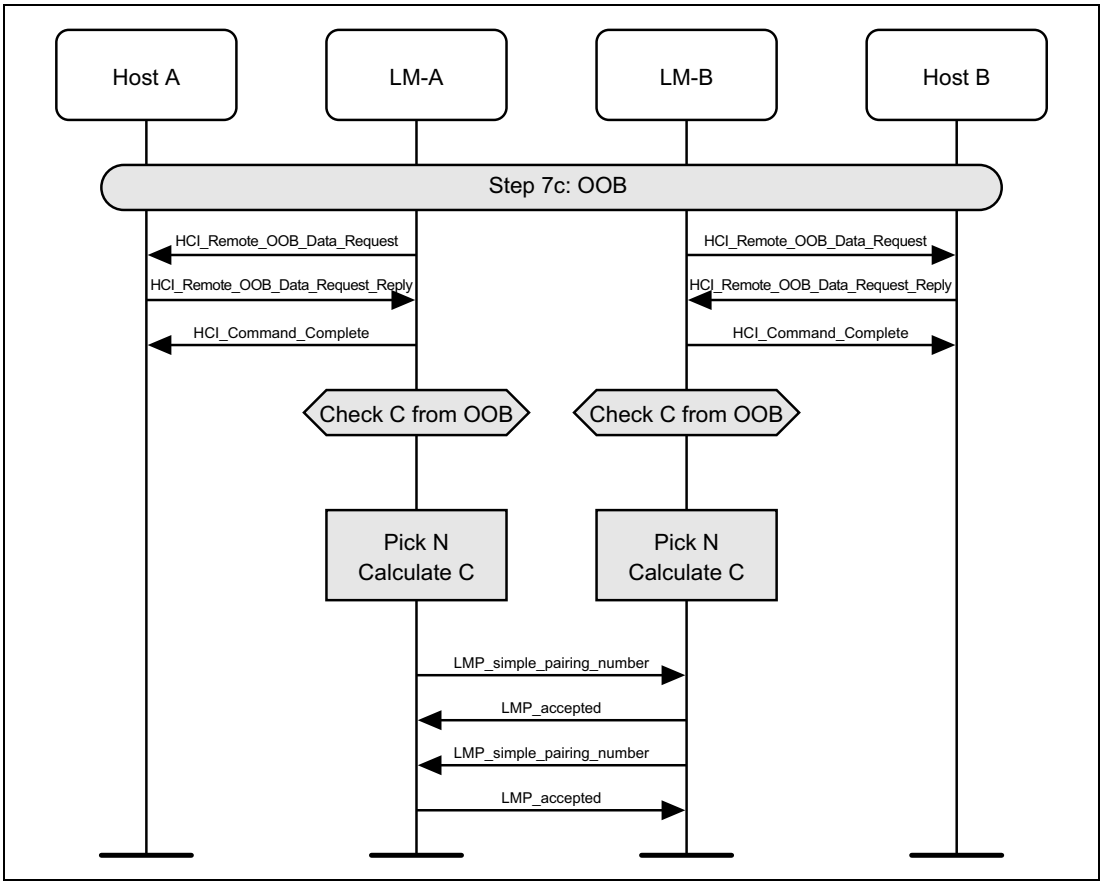

Figure 4.20: OOB authentication (P-192)

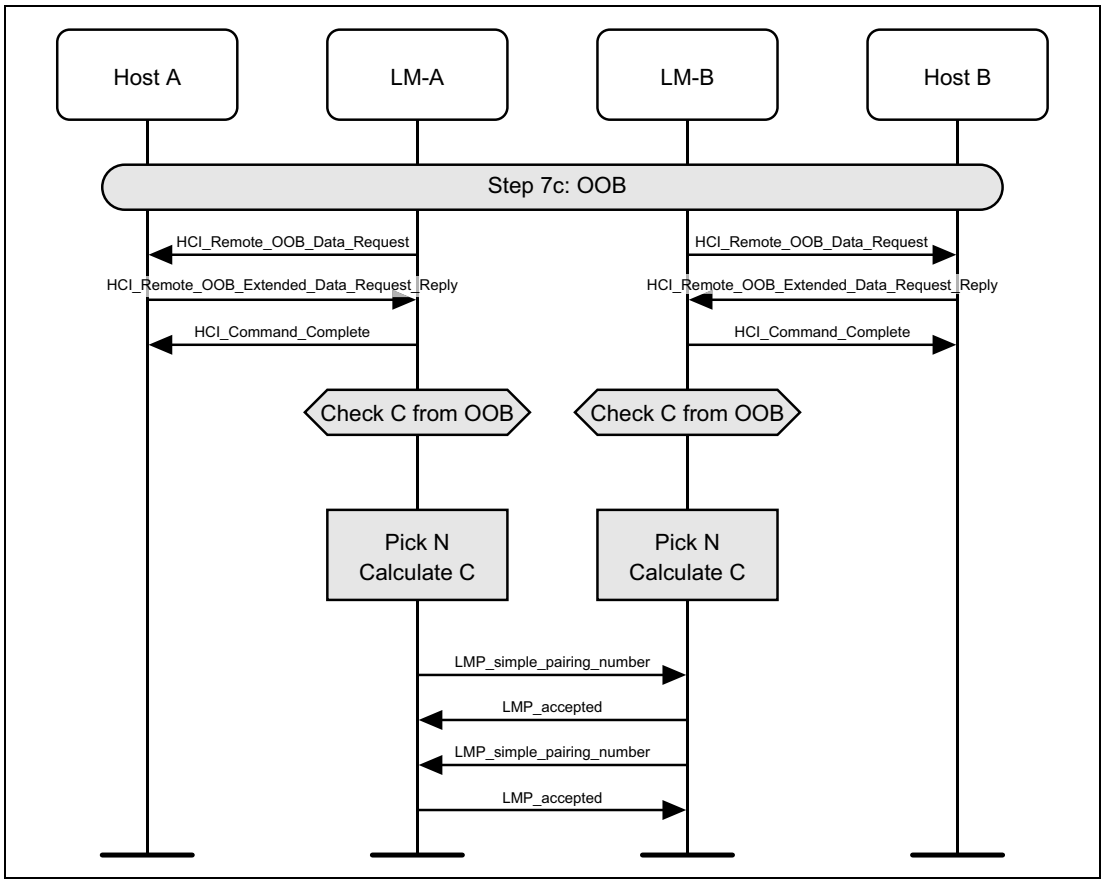

Figure 4.21: OOB authentication (P-256)

4.2.17 OOB Failure on Initiator Side

If the initiating side does not have OOB information, Simple Pairing is terminated.

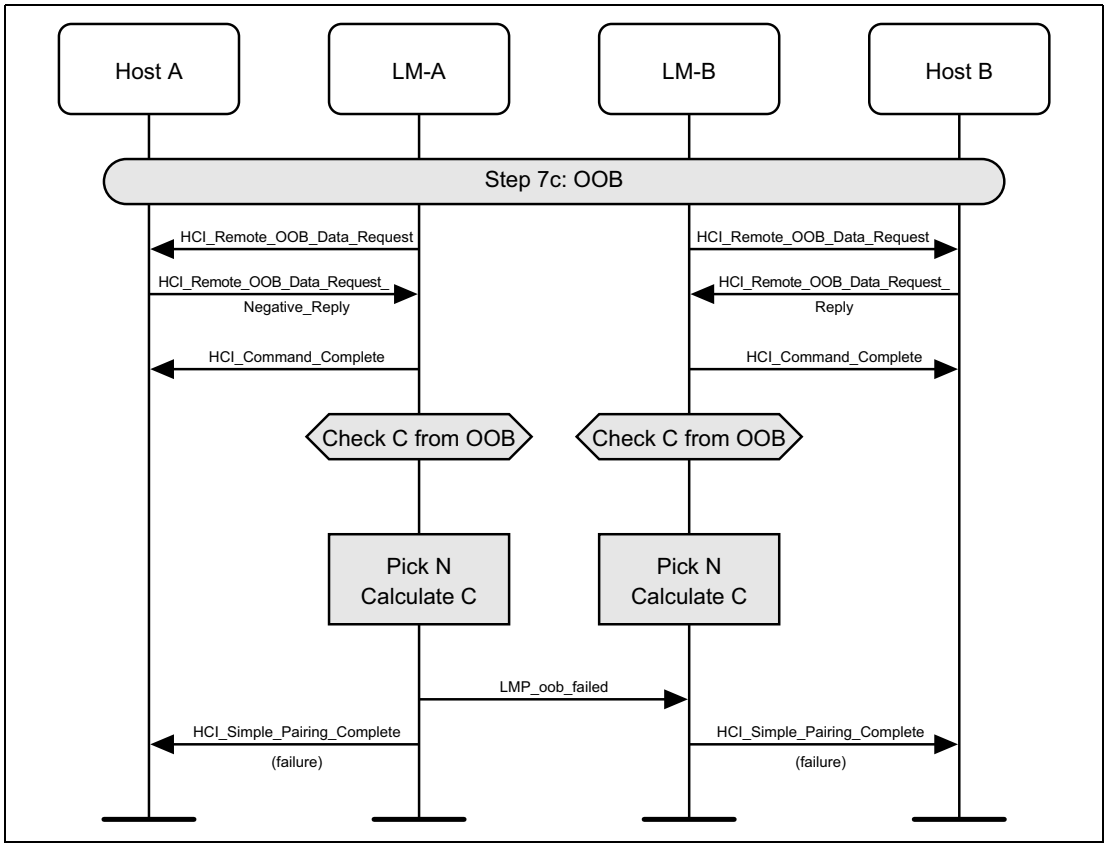

Figure 4.22: OOB authentication failure on initiating side

4.2.18 DHKey Checks

Once the devices have been authenticated, and the DHKey calculation has completed, the DHKey value generated is checked. If this succeeds, then both devices would have finished displaying information to the user about the process, and therefore a message is sent from the Controller to the Host to notify it to stop displaying this information.

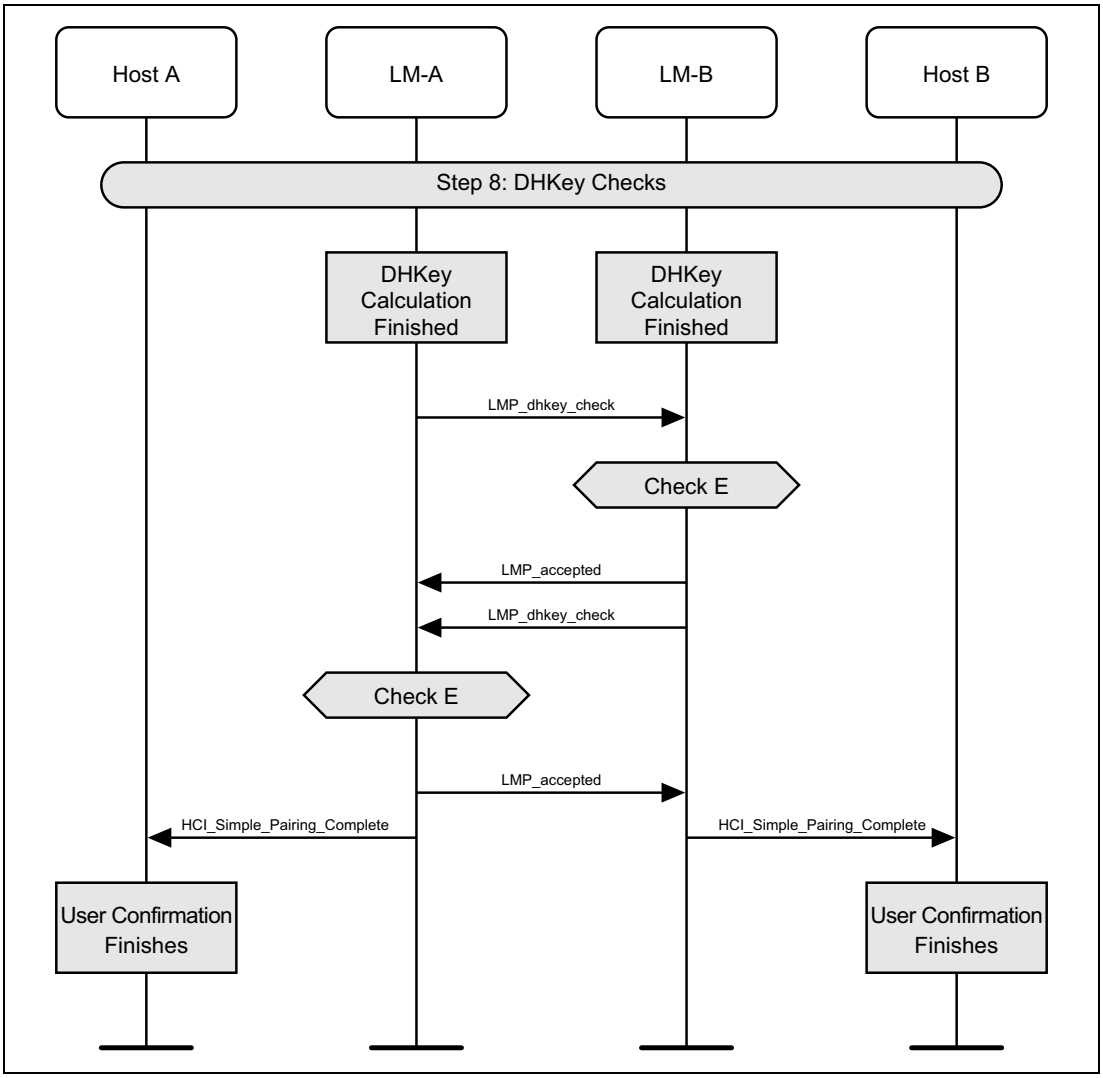

Figure 4.23: DHKey checks

4.2.19 Calculate Link Key

Once simple pairing is complete, the link key can be calculated from the DHKey, and this should be used as input to a standard mutual authentication. Once this is complete, a Link Key Notification event will be generated.

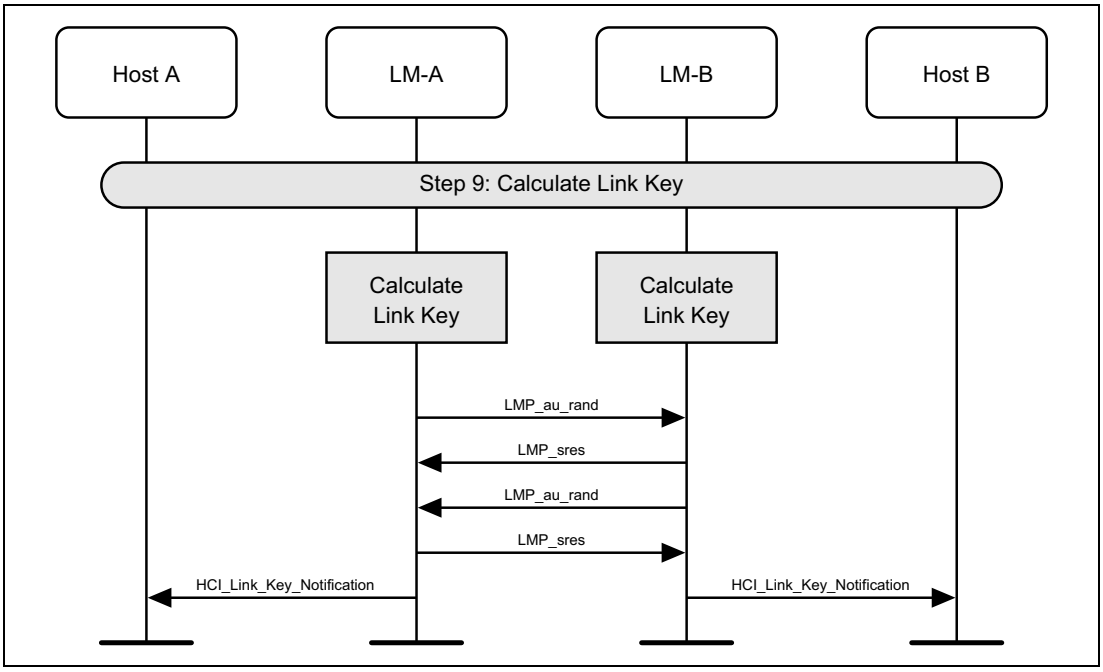

Figure 4.24: Calculate link key

4.2.20 Enable Encryption

Once the link key has been notified to the Host, the Authentication Requested command will complete with an Authentication Complete event. The Host can then turn on encryption using the standard methods.

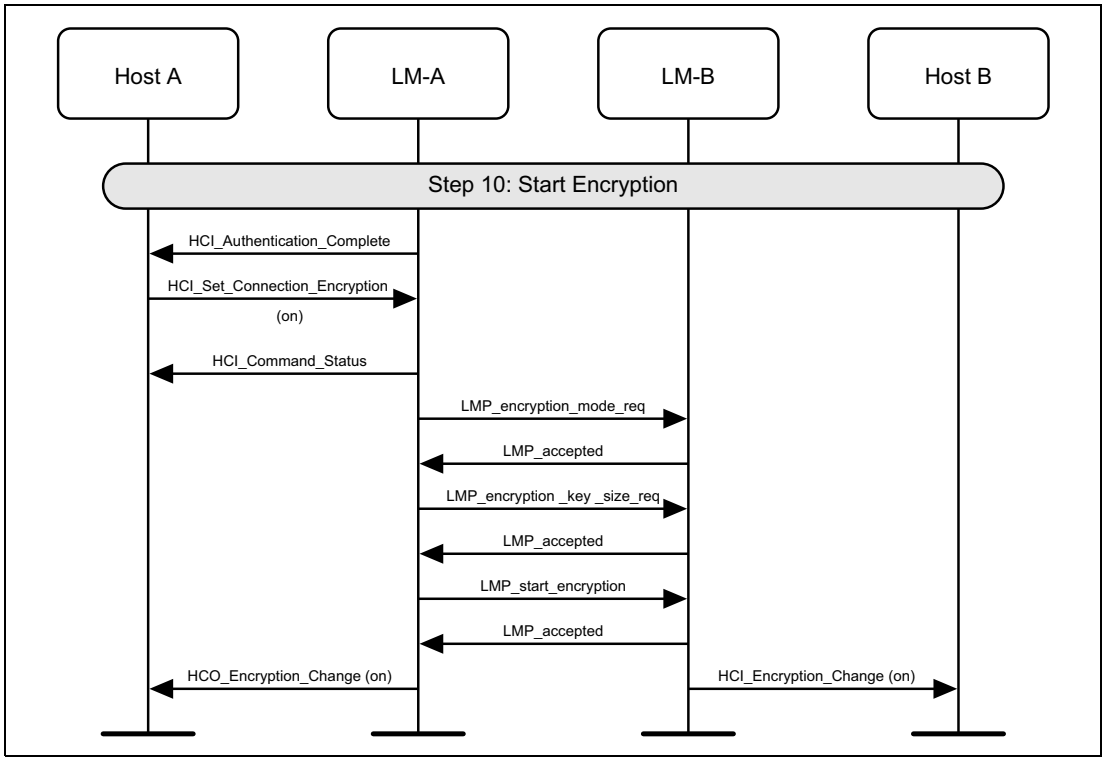

Figure 4.25: Start encryption

4.2.21 L2CAP Connection Response

If this simple pairing was triggered by an L2CAP Connection Request, then only after all of the above steps have completed can the L2CAP Connection Response message be sent.

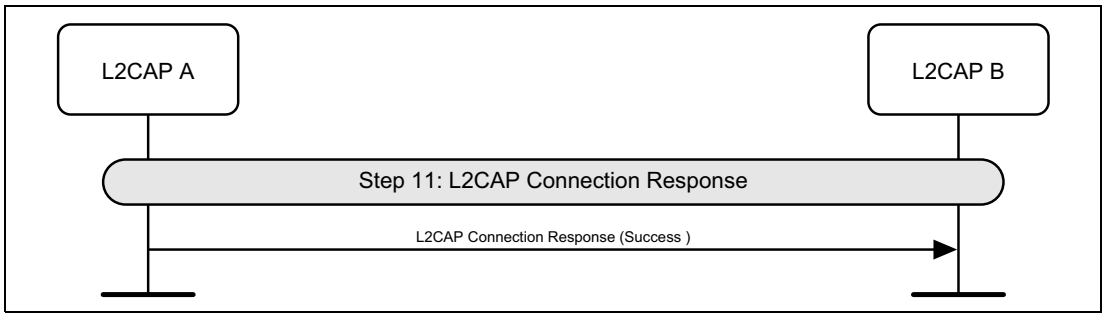

Figure 4.26: L2CAP connection response

4.2.22 LMP Ping

When the Authenticated Payload Timeout has nearly expired, the Link Manager will force the remote device to send a packet containing a MIC by sending the LMP_ping_req PDU.

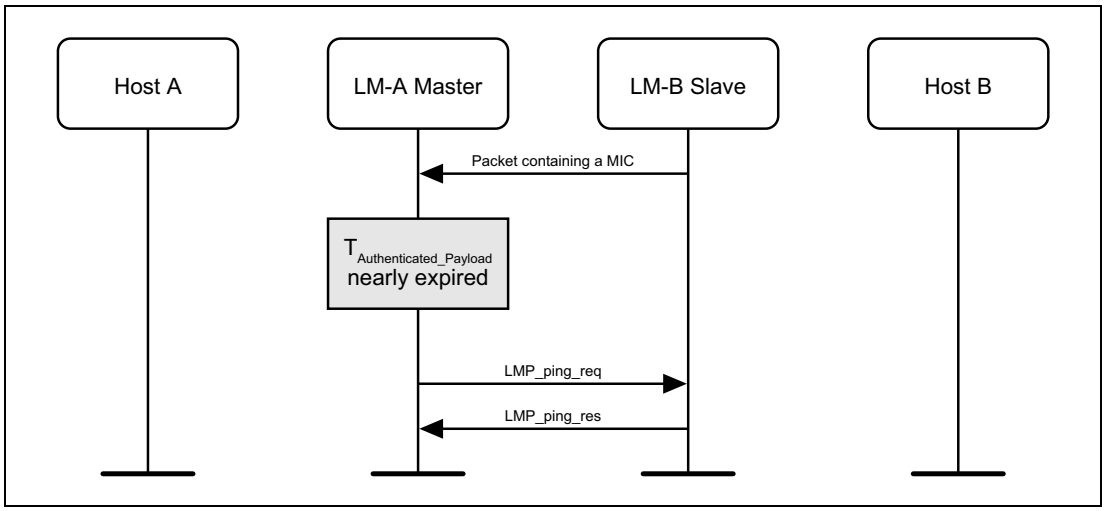

Figure 4.27: Successful Ping

When a packet with a MIC has not been received within the Authenticated Payload Timeout, the Host is notified that the timer has expired.

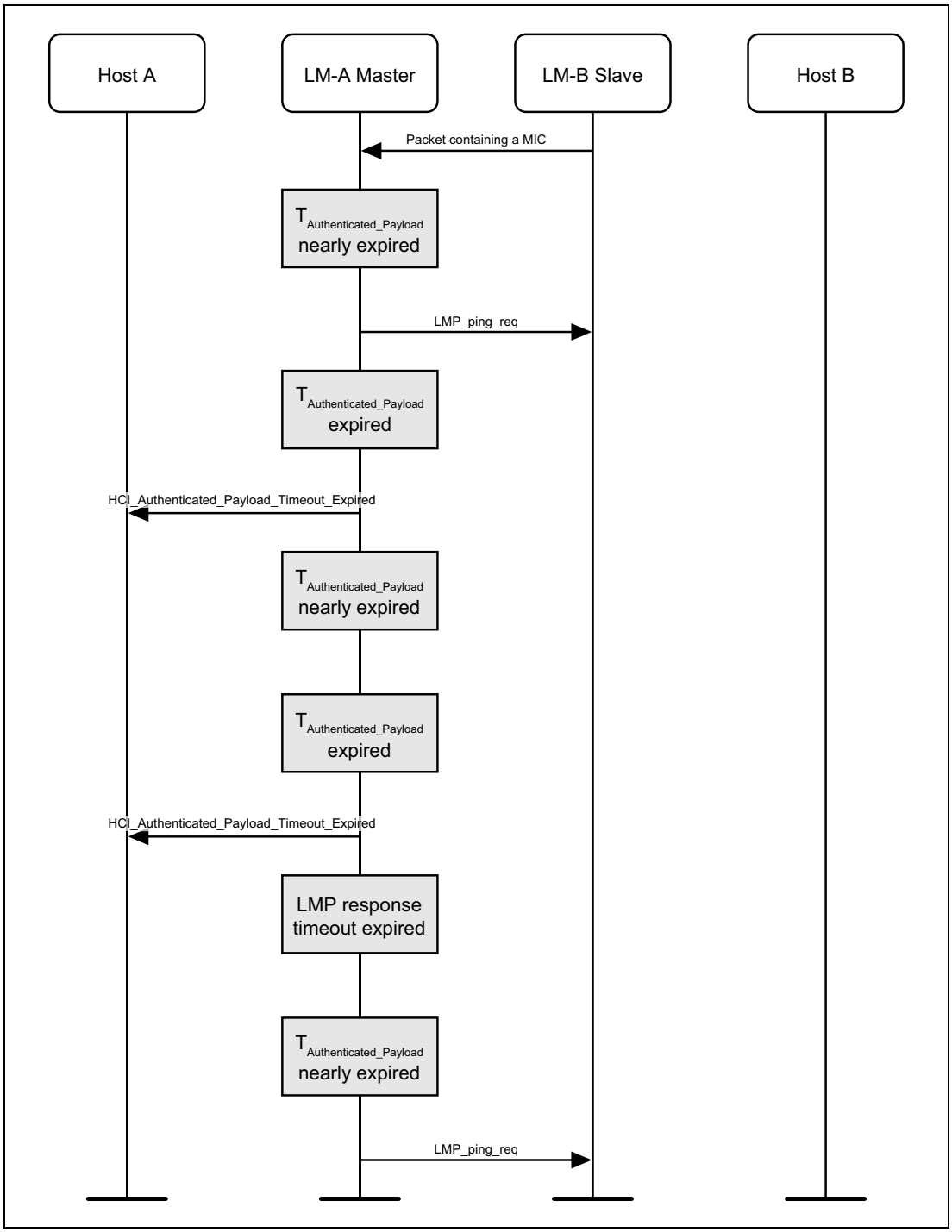

Figure 4.28: Unsuccessful Ping

4.3 LINK SUPERVISION TIMEOUT CHANGED EVENT

When enabled by the Host, the slave generates an HCI_Link_Supervision_Timeout_Changed event after the LMP_supervision_timeout PDU is received.

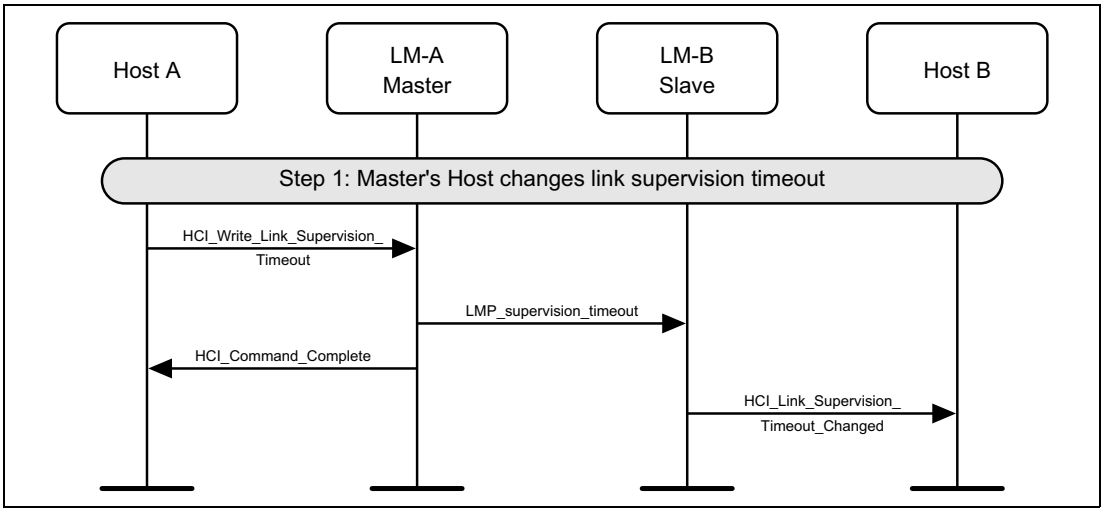

Figure 4.29: Link supervision timeout event

4.4 SET CONNECTION ENCRYPTION

Step 1: The Host may at any time turn on encryption using the HCI_Set_Connection_Encryption command. This command can be originated from either the master or slave sides. Only the master side is shown in Figure 4.30. If this command is sent from a slave, the only difference is that the LMP_encryption_mode_req PDU will be sent from the slave. The LMP_encryption_key_size_req and LMP_start_encryption_req PDUs will always be requested from the master. (See Figure 4.30.)

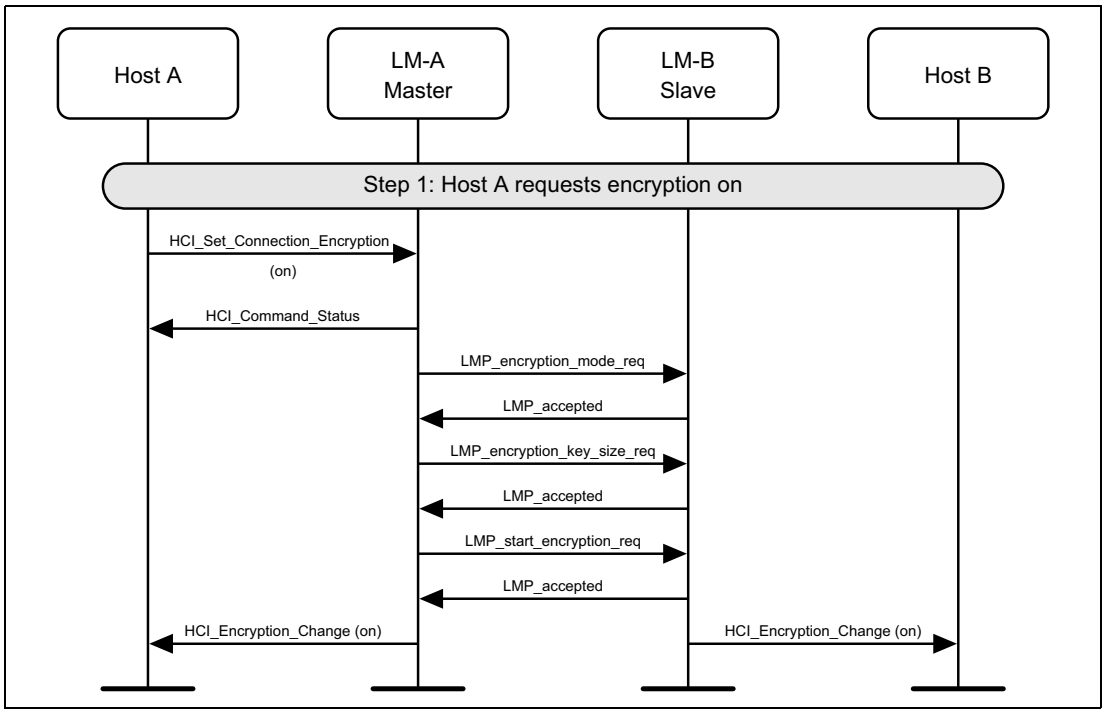

Figure 4.30: Encryption requested

Step 2: To terminate the use of encryption, The HCI_Set_Connection_Encryption command is used. (See Figure 4.31.)

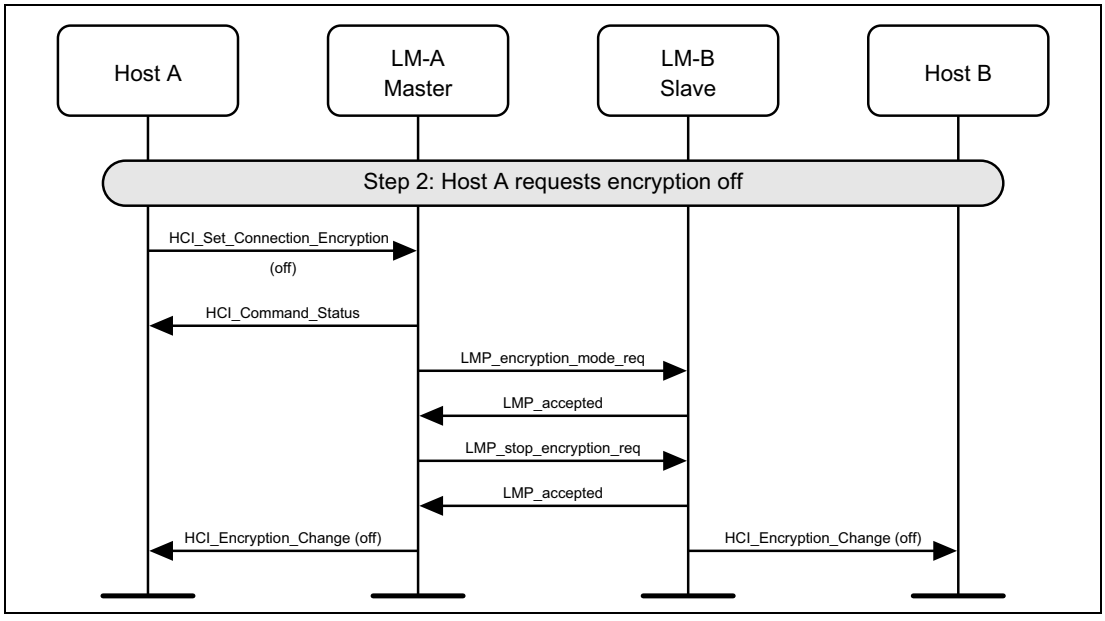

Figure 4.31: Encryption off requested

4.5 CHANGE CONNECTION LINK KEY

Step 1: The master Host (Host A) may change the connection link key using the HCI_Change_Connection_Link_Key command. A new link key will be generated and the Hosts will be notified of this new link key. (See Figure 4.32.)

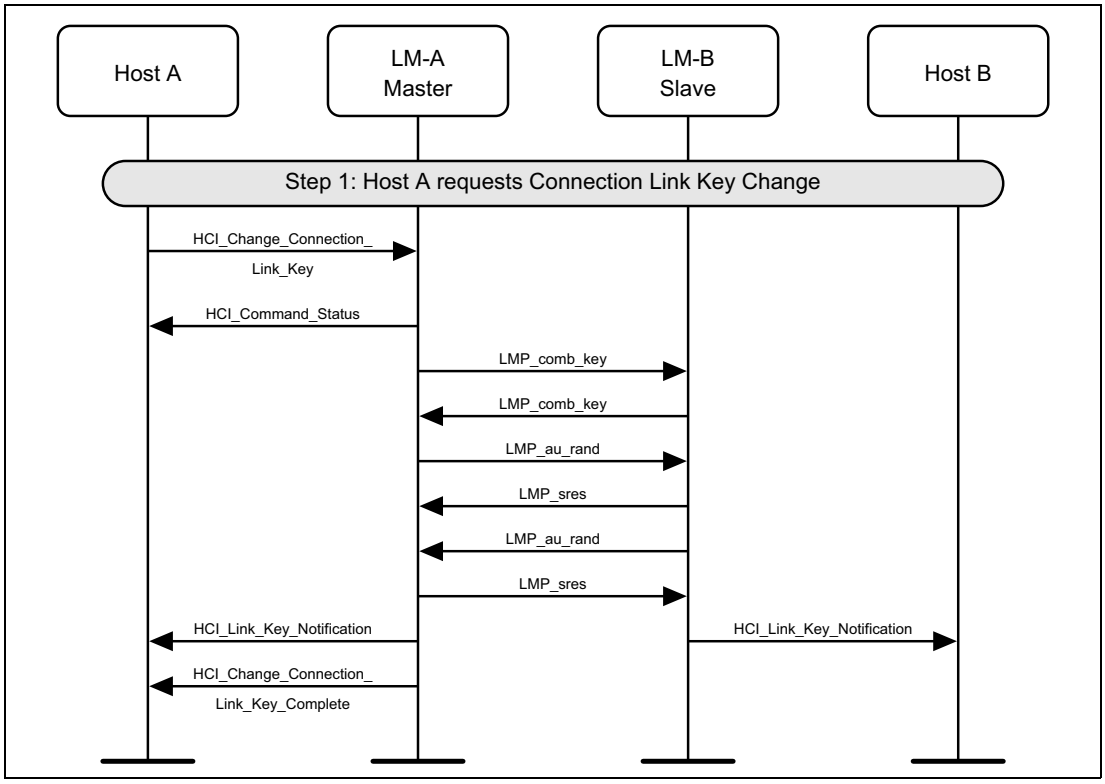

Figure 4.32: Change connection link key

4.6 CHANGE CONNECTION LINK KEY WITH ENCRYPTION PAUSE AND RESUME

Step 1: The master Host (Host A) may change the connection link key using the HCI_Change_Connection_Link_Key command. A new link key will be generated and the Hosts will be notified of this new link key. Encryption will then be paused and resumed, immediately using this new link key to generate a new encryption key. (See Figure 4.33.)

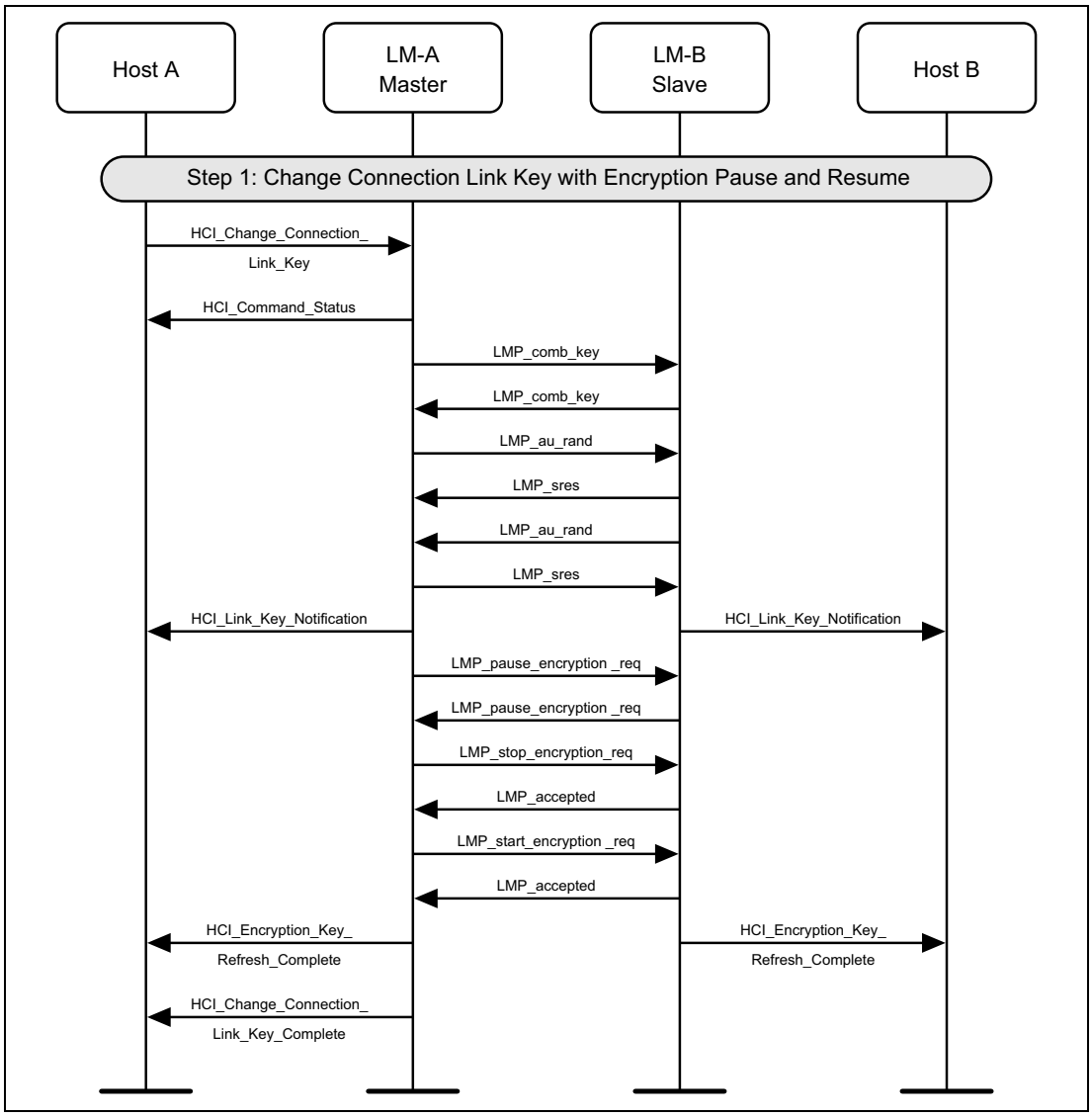

Figure 4.33: Change connection link key with encryption pause resume

4.7 MASTER LINK KEY

Step 1: The Host changes to a Master Link Key from a Semi-permanent Link Key using the HCI_Master_Link_Key command when at least one device does not support Encryption Pause Resume. (See Figure 4.34.)

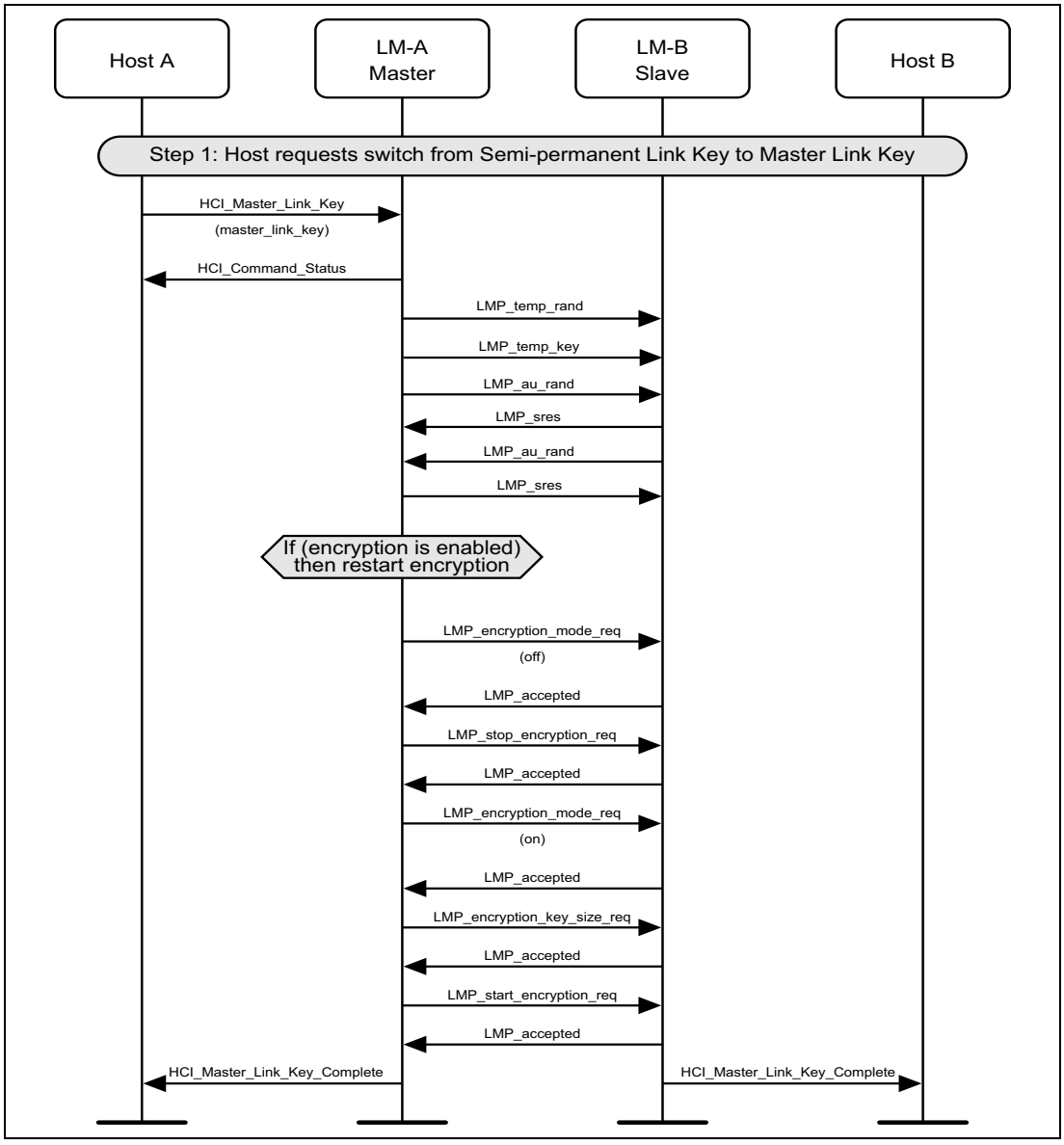

Figure 4.34: Change to master link key

Step 2: The Host changes to a Semi-permanent Link Key from a Master Link Key using the HCI_Master_Link_Key command. (See Figure 4.35.)

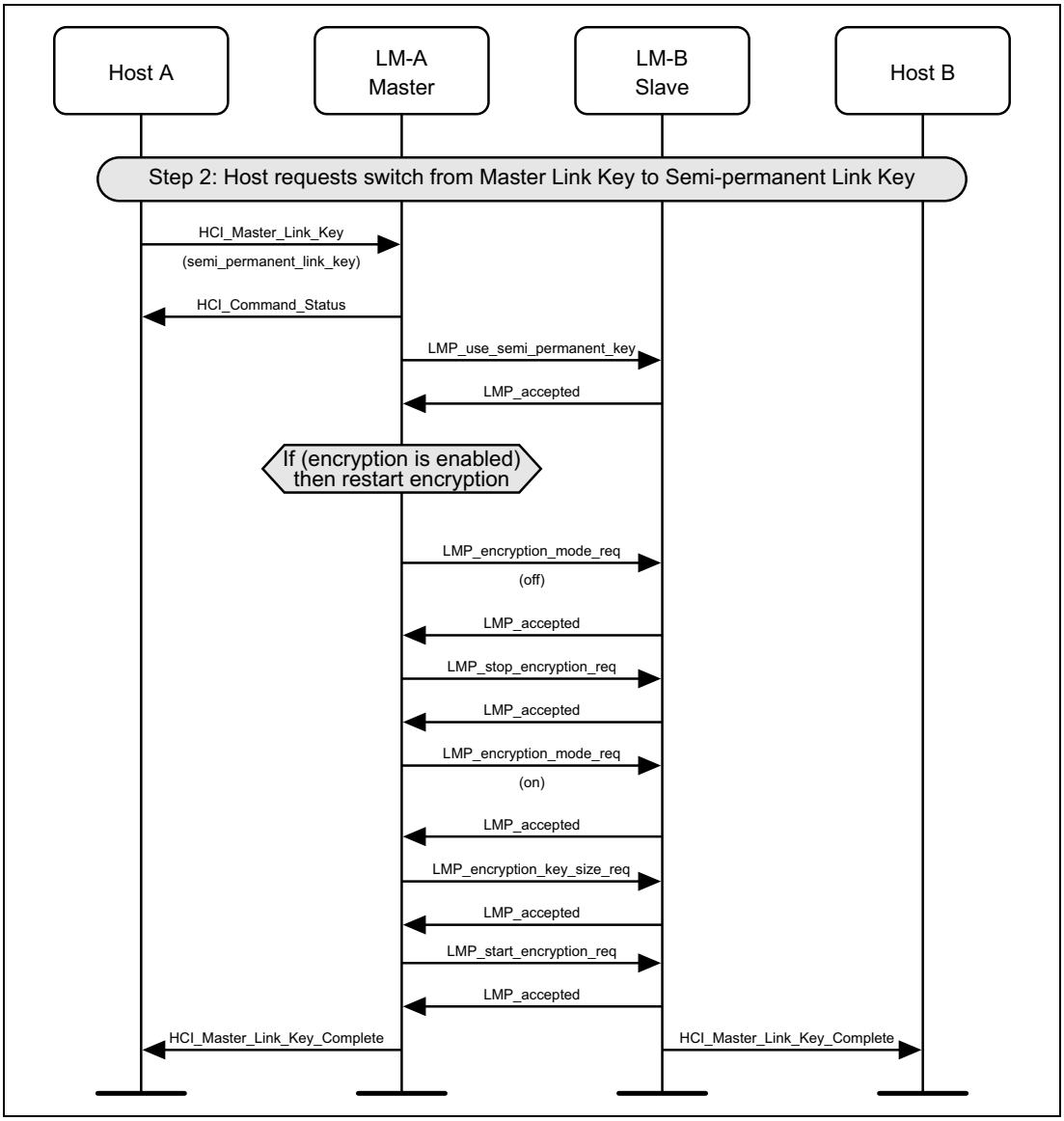

Figure 4.35: Change to semi permanent link key

4.8 READ REMOTE SUPPORTED FEATURES

Using the HCI_Read_Remote_Supported_Features command the supported LMP Features of a remote device can be read. (See Figure 4.36.)

If the remote supported features have been obtained previously then the Controller may return them without sending any LMP PDUs.

Step 1: The Host requests the supported features of a remote device.

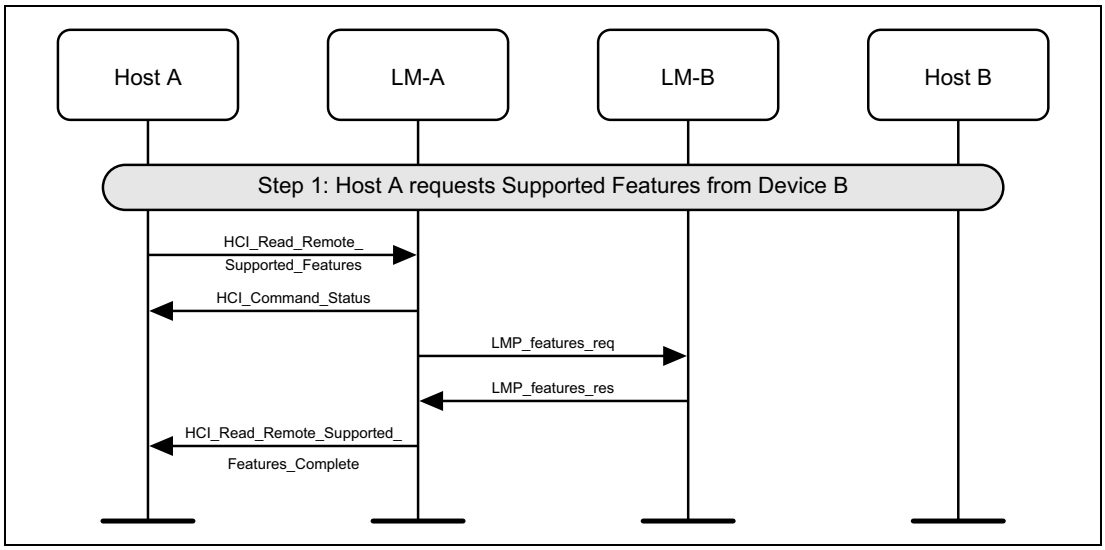

Figure 4.36: Read remote supported features

4.9 READ REMOTE EXTENDED FEATURES

Using the HCI_Read_Remote_Extended_Features command the extended LMP features of a remote device can be read. (See Figure 4.37.)

If the remote extended features have been obtained previously then the Controller may return them without sending any LMP PDUs.

Step 1: The Host requests the extended features of a remote device.

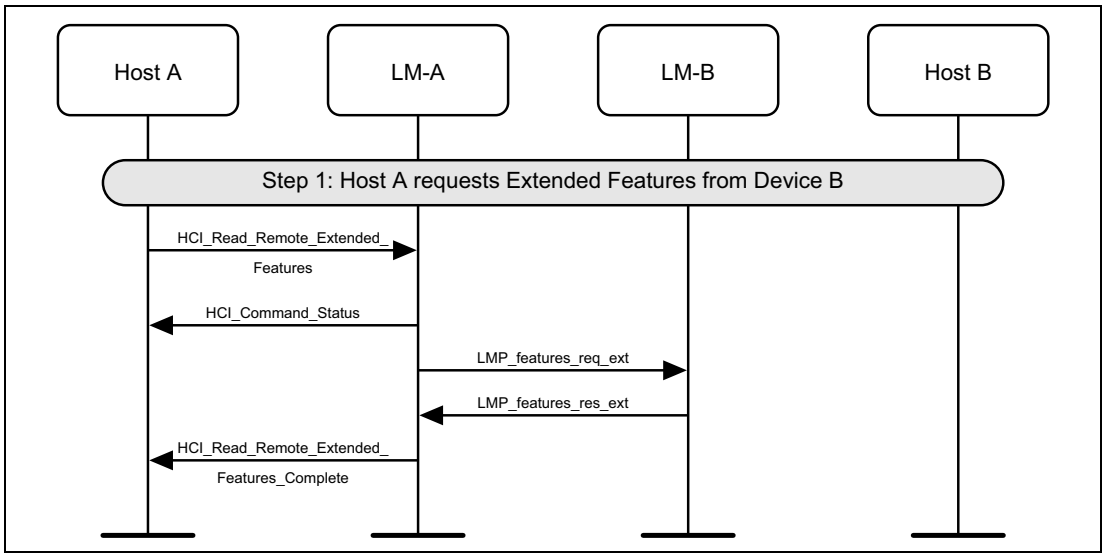

Figure 4.37: Read remote extended features

4.10 READ CLOCK OFFSET

Using the HCI_Read_Clock_Offset command the device acting as the master can read the Clock Offset of a slave. The Clock Offset can be used to speed up the paging procedure in a later connection attempt. If the command is requested from the slave device, the Controller will directly return a Command Status event and a Read Clock Offset Complete event without sending any LMP PDUs. (See Figure 4.38.)

Step 1: The Host requests the clock offset of a remote device.

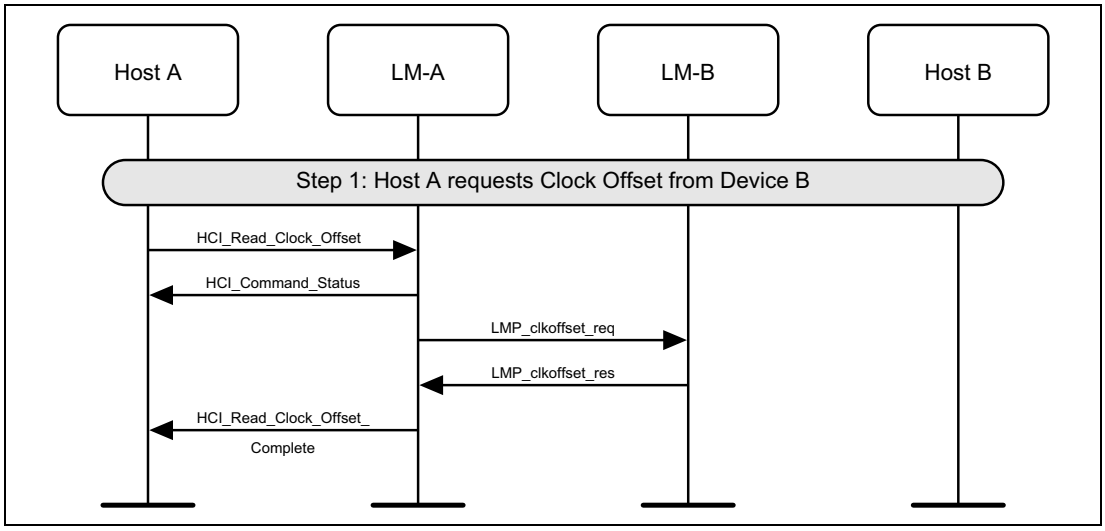

Figure 4.38: Read clock offset

4.11 ROLE SWITCH ON AN ENCRYPTED LINK USING ENCRYPTION PAUSE AND RESUME

The HCI_Switch_Role command can be used to explicitly switch the current master / slave role of the local device with the specified device. The master Host (A) requests a role switch with a slave. This will first pause encryption, and then send the switch request, and the slave will respond with the slot offset and accepted. The role switch is performed by doing the TDD switch and piconet switch. Encryption is resumed, and finally an HCI_Role_Change event is sent on both sides. (Figure 4.39)

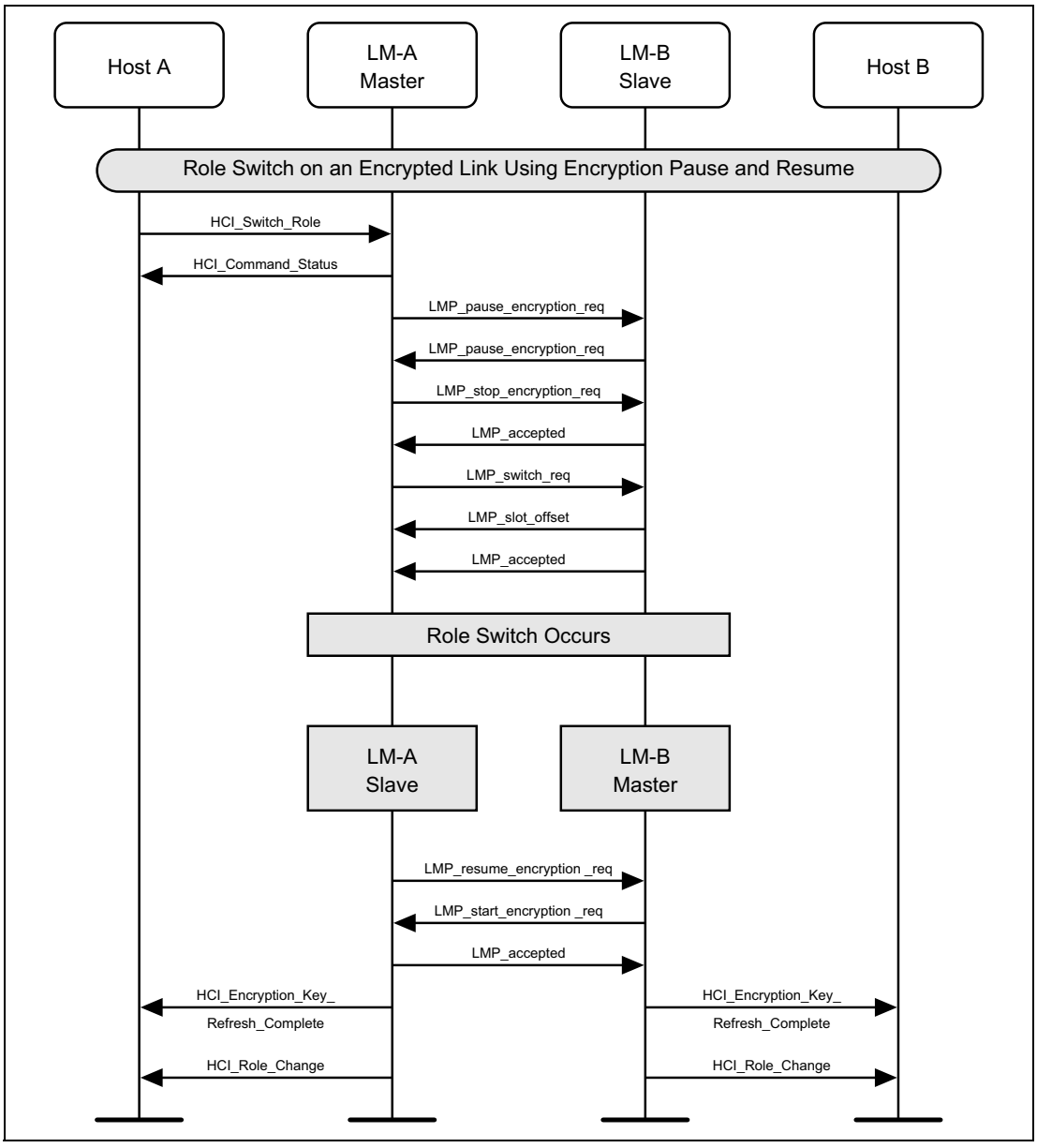

Figure 4.39: Role switch on an encrypted link using encryption pause and resume

4.12 REFRESHING ENCRYPTION KEYS

The HCI_Refresh_Encryption_Key command may be used by the master's Host to explicitly pause and resuming encryption to refresh the encryption key. After encryption is resumed an HCI_Encryption_Key_Refresh_Complete event is sent on both sides. (See Figure 4.40).

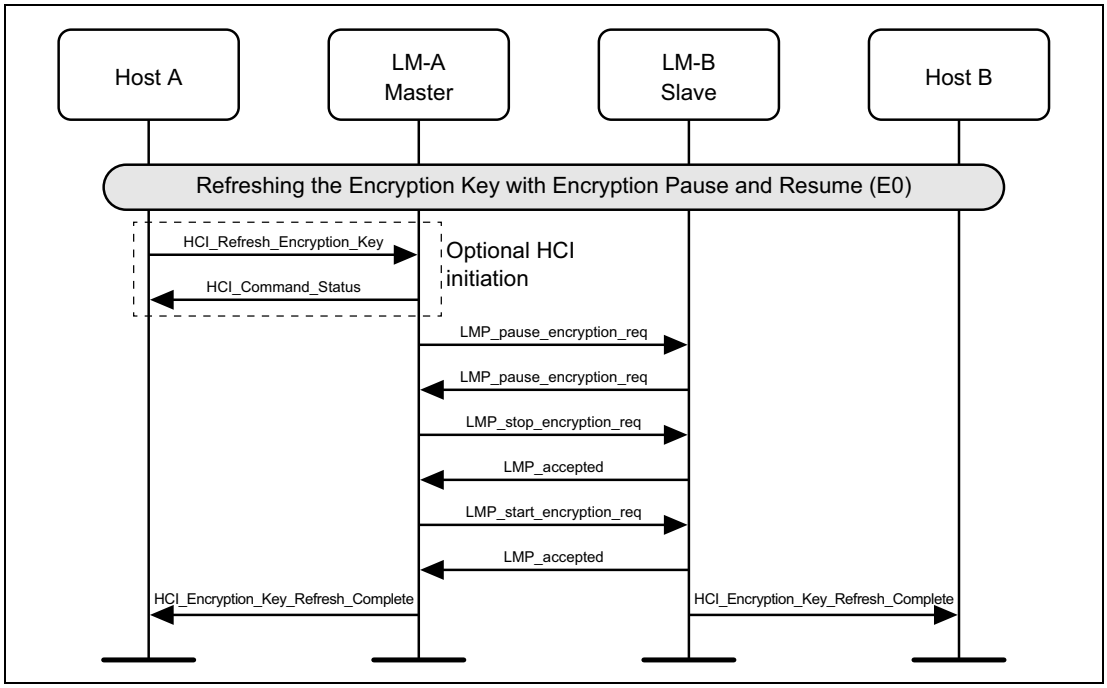

Figure 4.40: Refreshing encryption keys (E0)

When both devices support Secure Connections, the encryption key refresh sequence is performed as follows.

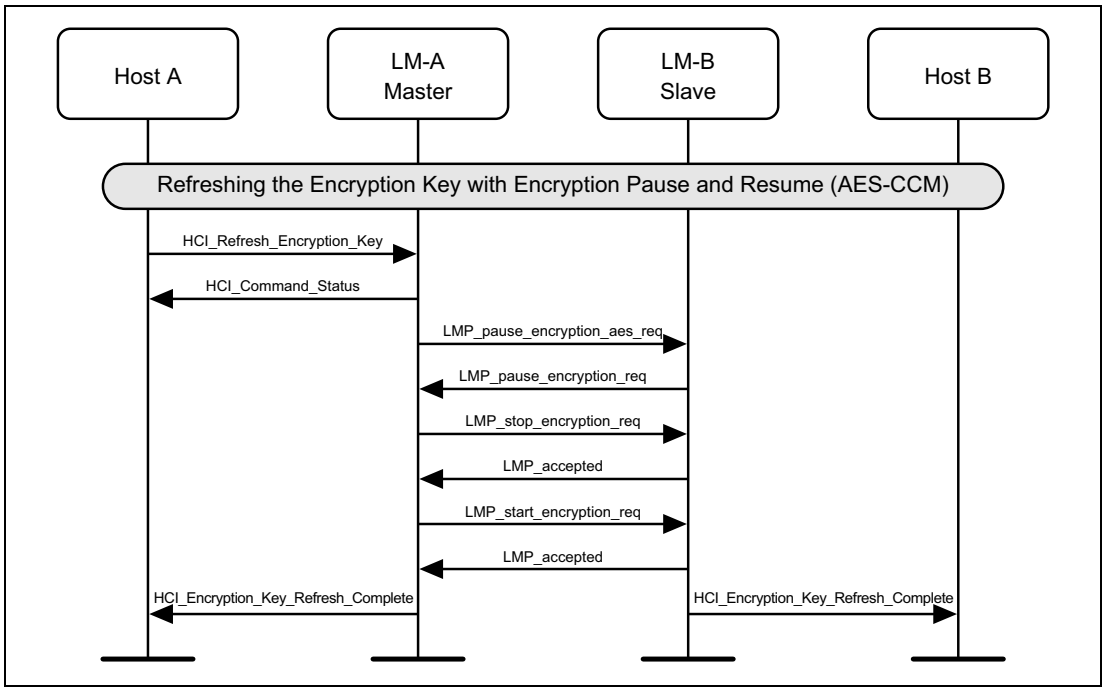

Figure 4.41: Refreshing encryption keys (AES-CCM)

4.13 READ REMOTE VERSION INFORMATION

Using the HCI_Read_Remote_Version_Information command the version information of a remote device can be read. (See Figure 4.42.)

If the remote version information has been obtained previously then the Controller may return them without sending any LMP PDUs.

Step 1: The Host requests the version information of a remote device.

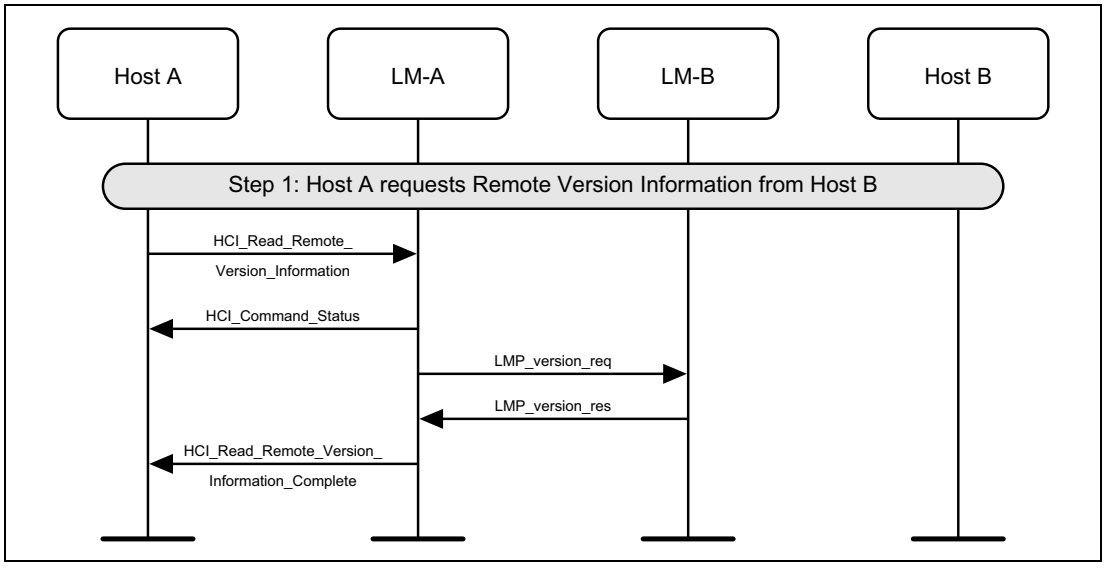

Figure 4.42: Read remote version information

4.14 QOS SETUP

Using the HCI_Flow_Specification command the Quality of Service (QoS) and Flow Specification requirements of a connection can be notified to a Controller. The Controller may then change the quality of service parameters with a remote device. (See Figure 4.43.)

Step 1: The Host sends QoS parameters to a remote device.

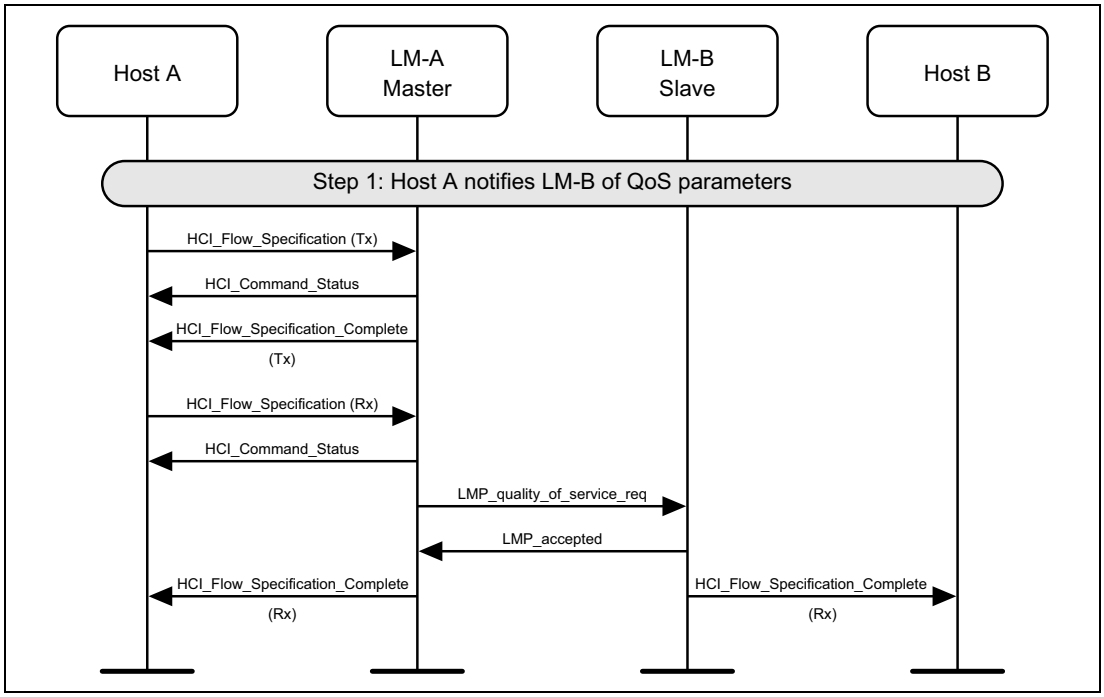

Figure 4.43: QoS flow specification

4.15 SWITCH ROLE

The HCI_Switch_Role command can be used to explicitly switch the current master / slave role of the local device with the specified device.

Step 1a: The master Host (A) requests a role switch with a slave. This will send the switch request, and the slave will respond with the slot offset and accepted. (See Figure 4.44.)

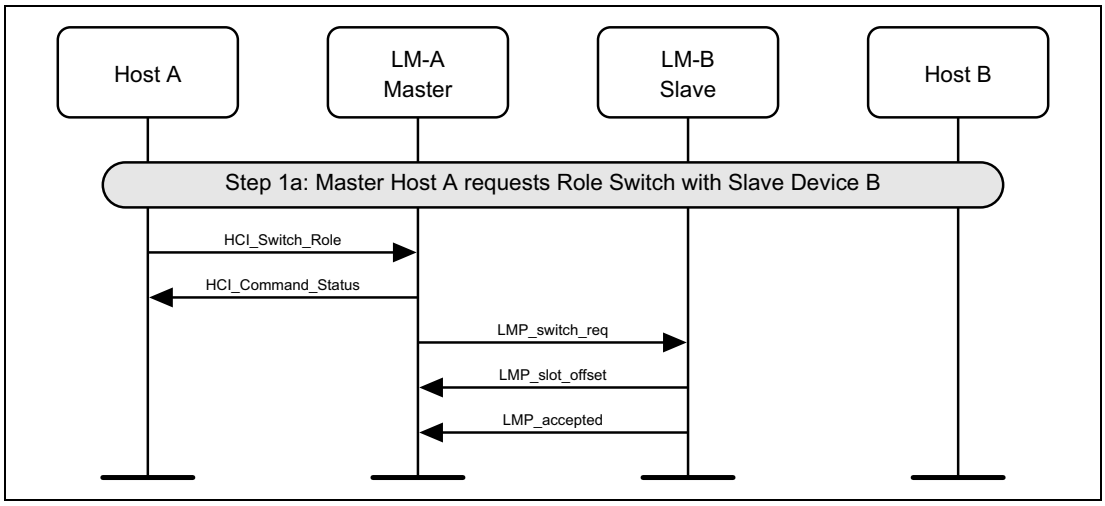

Figure 4.44: Master requests role switch

Step 1b: The slave Host (B) requests a role switch with a master. This will send the slot offset and the switch request, and the master will respond with a LMP_accepted PDU. (See Figure 4.45.)

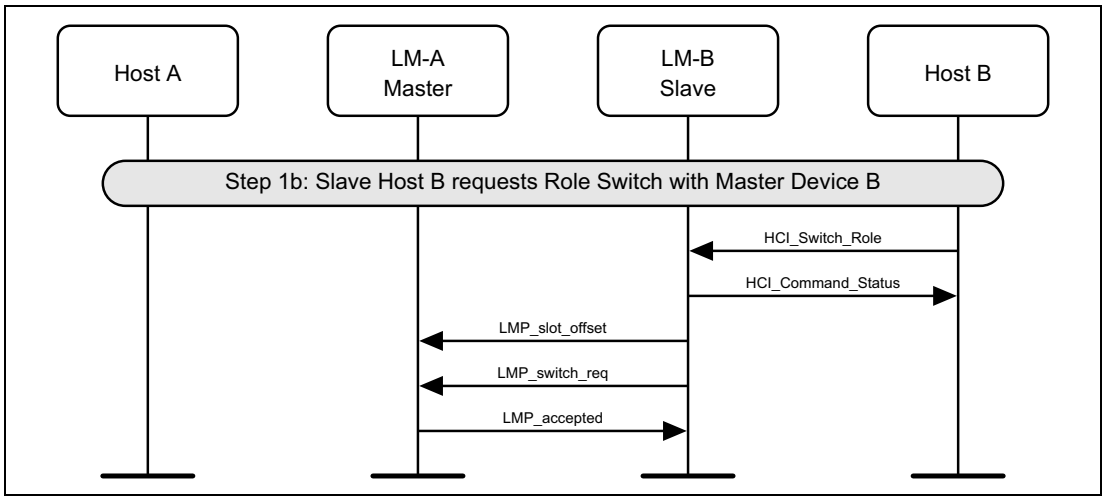

Figure 4.45: Slave requests role switch

Step 2: The role switch is performed by doing the TDD switch and piconet switch. Finally an HCI_Role_Change event is sent on both sides. (See Figure 4.46.)

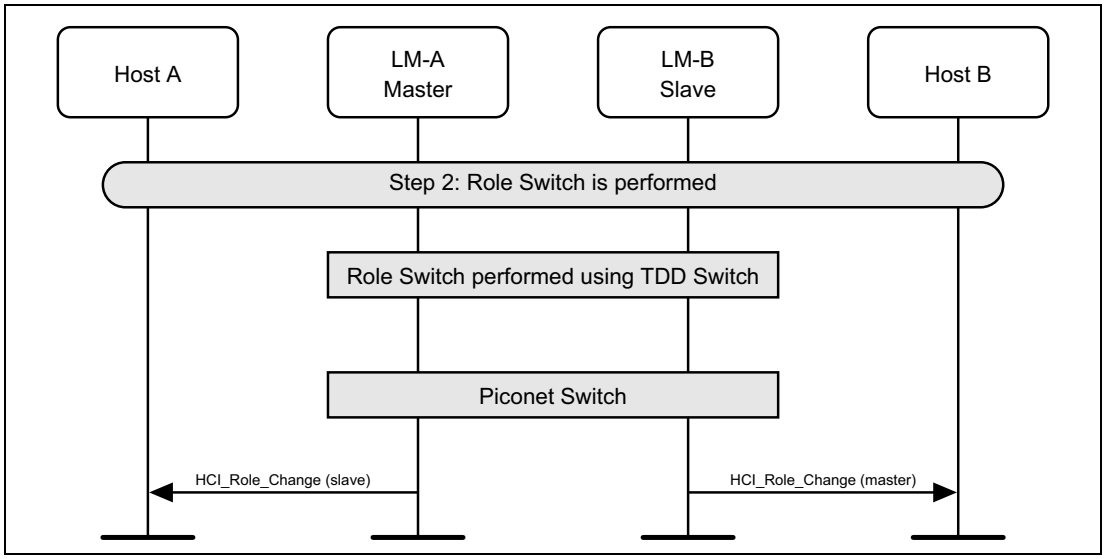

Figure 4.46: Role switch is performed

4.16 AMP PHYSICAL LINK CREATION AND DISCONNECT

A flow diagram of the AMP link establishment and detachment of a connection between two devices is shown in Figure 4.47.

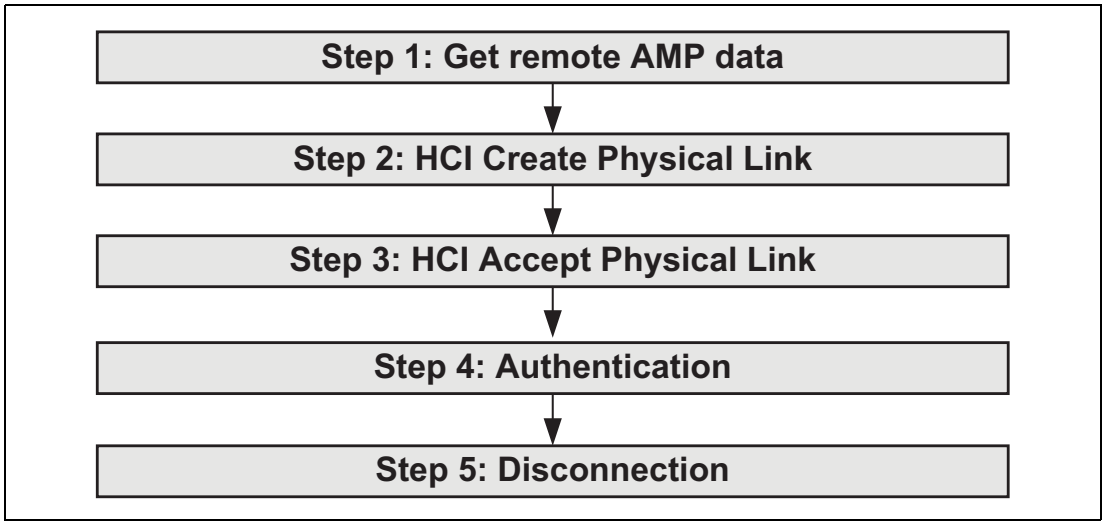

Figure 4.47: Overview diagram for physical link creation and disconnection

4.16.1 Physical Link Establishment

The process of establishing a Physical Link consists of 4 steps.

Step 1: Host A uses the BR/EDR Controller to request AMP_Info data from Host B in order to create an AMP connection. Host B gets this information from PAL B using HCI Read Local AMP Info. Host B returns the information to Host A over the BR/EDR radio.

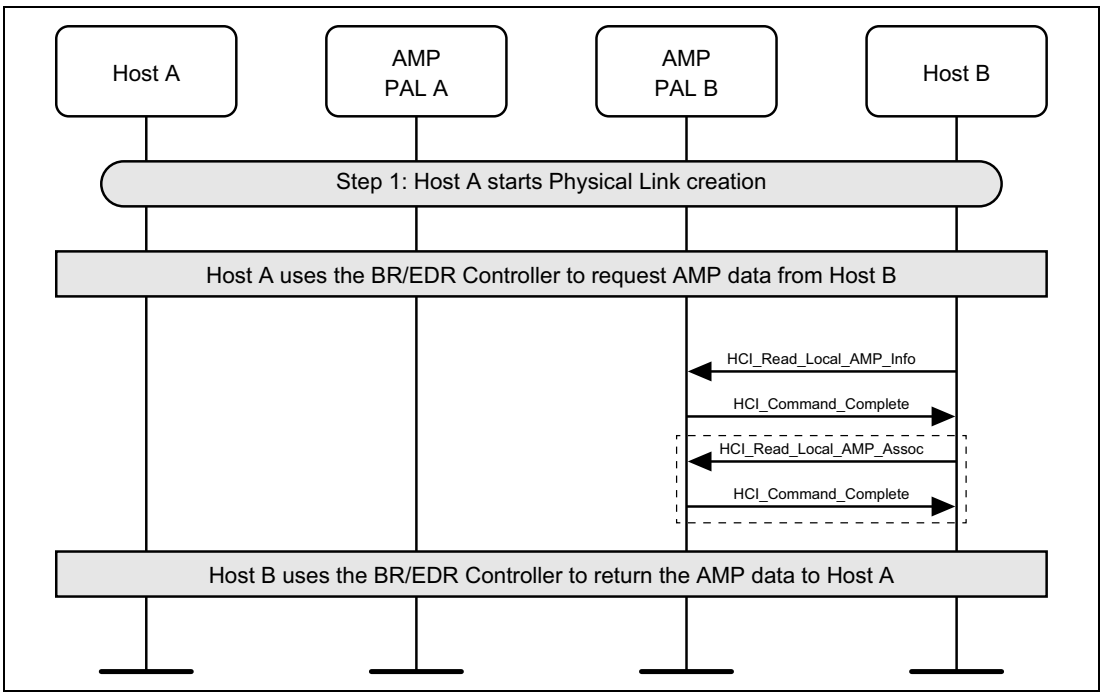

Figure 4.48: Get remote AMP data

Step 2: Host A sends an HCI Create Physical Link command to its AMP Controller. AMP Controller A determines which channel will be used, and provides channel information to its Host. AMP Controller A joins or creates that channel. Note use of dotted rectangles for zero or multiple uses of read or write AMP_Assoc.

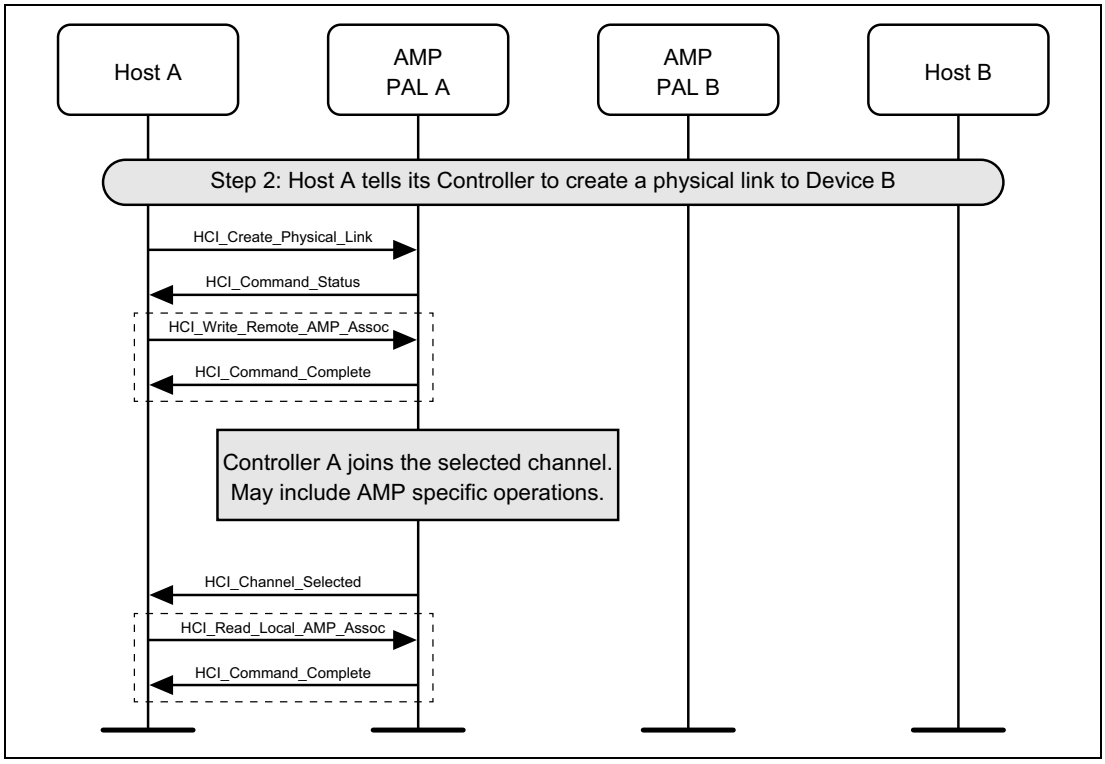

Figure 4.49: Host A tells its Controller to create the physical link

Step 3: Host A uses the BR/EDR radio to request a physical link to B. Host B tells its AMP Controller to accept a physical link from Device A.

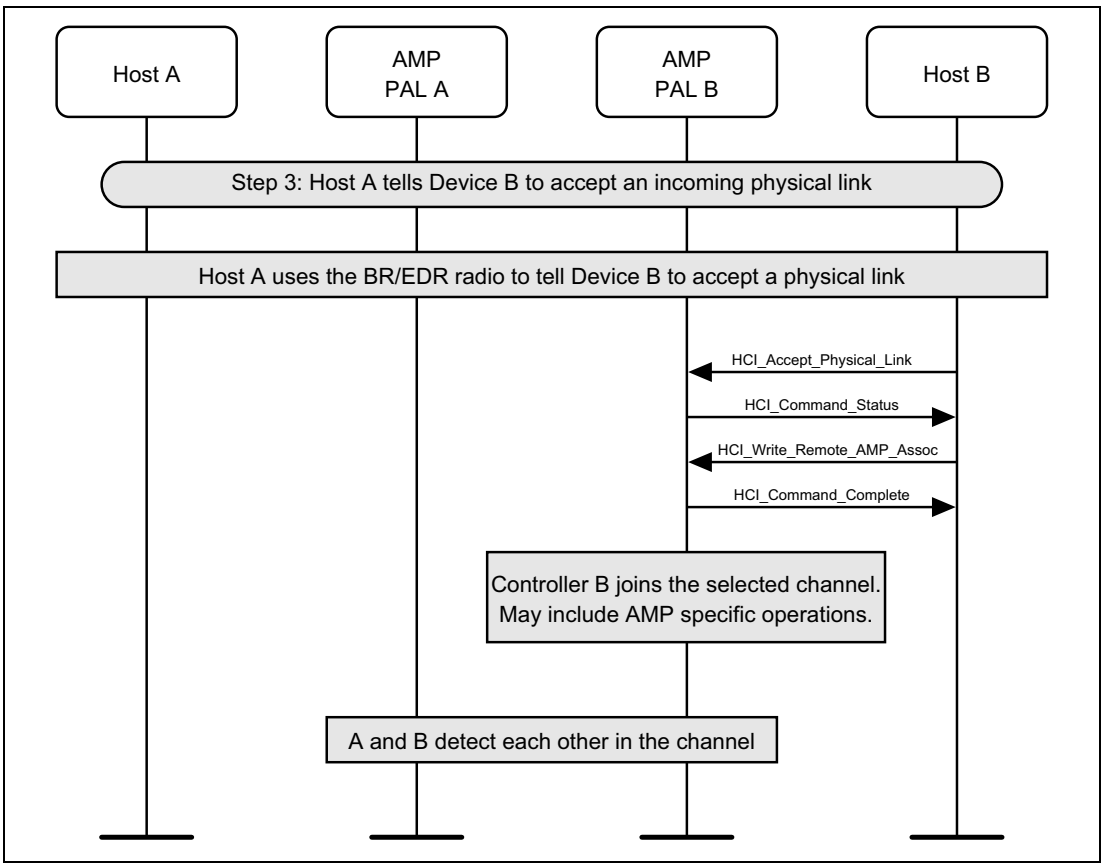

Figure 4.50: Host A tells Host B to accept an incoming physical link

Step 4: The AMP Controllers perform security operations. When the handshake is complete, both devices inform their Hosts that the link is ready for use. Note that the mechanism used to transport the authentication messages is defined by each PAL.

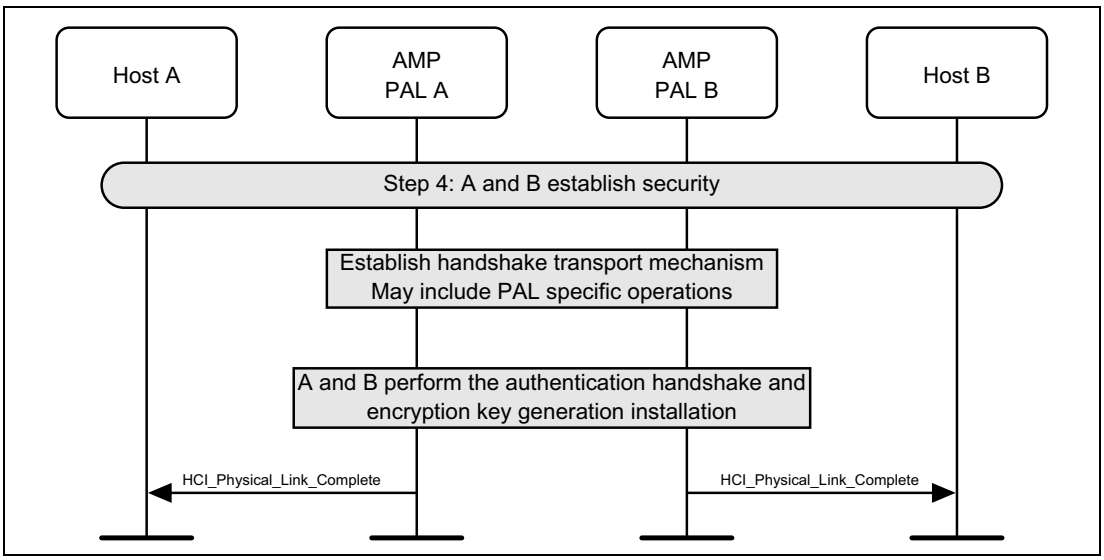

Figure 4.51: A and B establish AMP physical link security

Step 5: Host A sends a Physical Link Disconnect command to its AMP Controller. AMP Controllers A and B do whatever AMP specific action is required to meet the request. Each AMP Controller sends the Physical Link Disconnect Complete event to its Host. Both devices can now leave the AMP channel.

Note that disconnection of any active Logical Links is not shown in Figure 4.52.

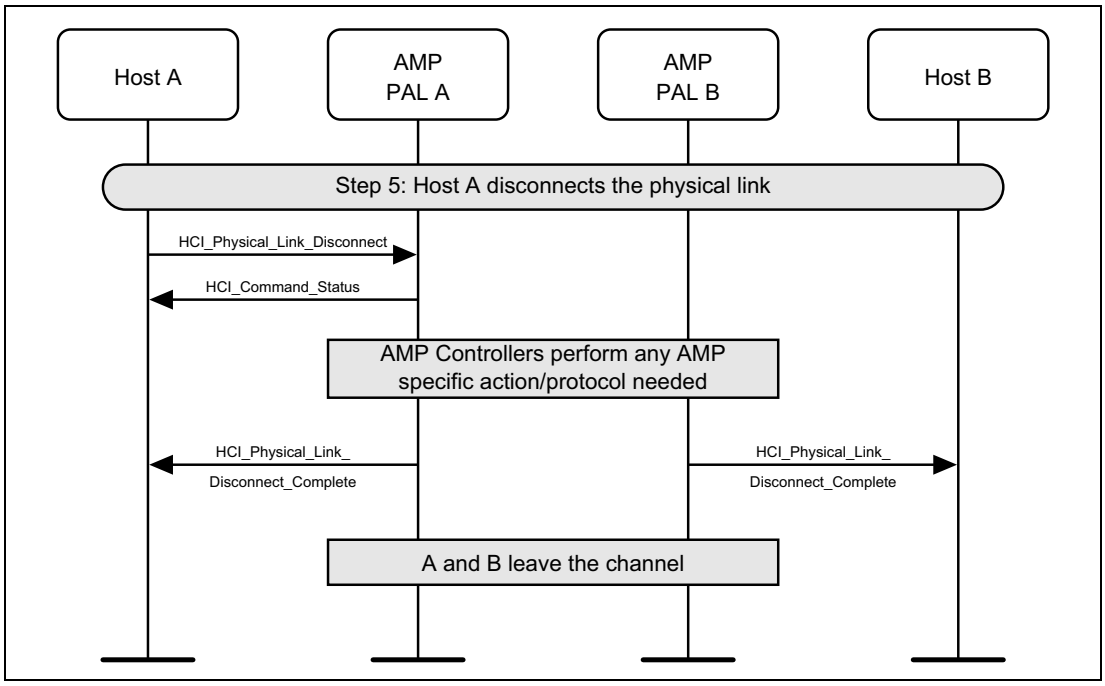

Figure 4.52: Host A disconnects the physical link

Step 6: During normal operation the AMP Controller may alert its Host to issues on the link.

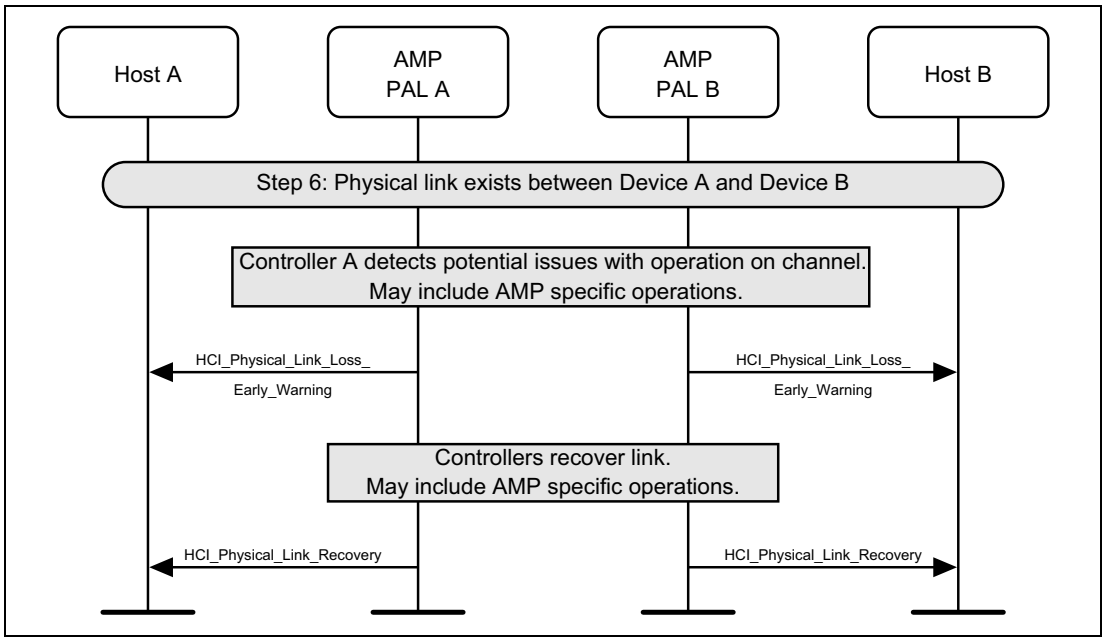

Figure 4.53: Controller reports link loss to its Host

4.16.2 Logical Link Creation

Step 1: Host A sends a Logical Link Create command to its AMP Controller. AMP Controllers A and B do whatever AMP specific action is required to meet the bandwidth request. Each AMP Controller sends the Logical Link Creation Complete event to its Host. Both devices can now pass data traffic over the AMP channel.

A flow diagram of the establishment of a Guaranteed logical connection between two devices is shown in Figure 4.54.

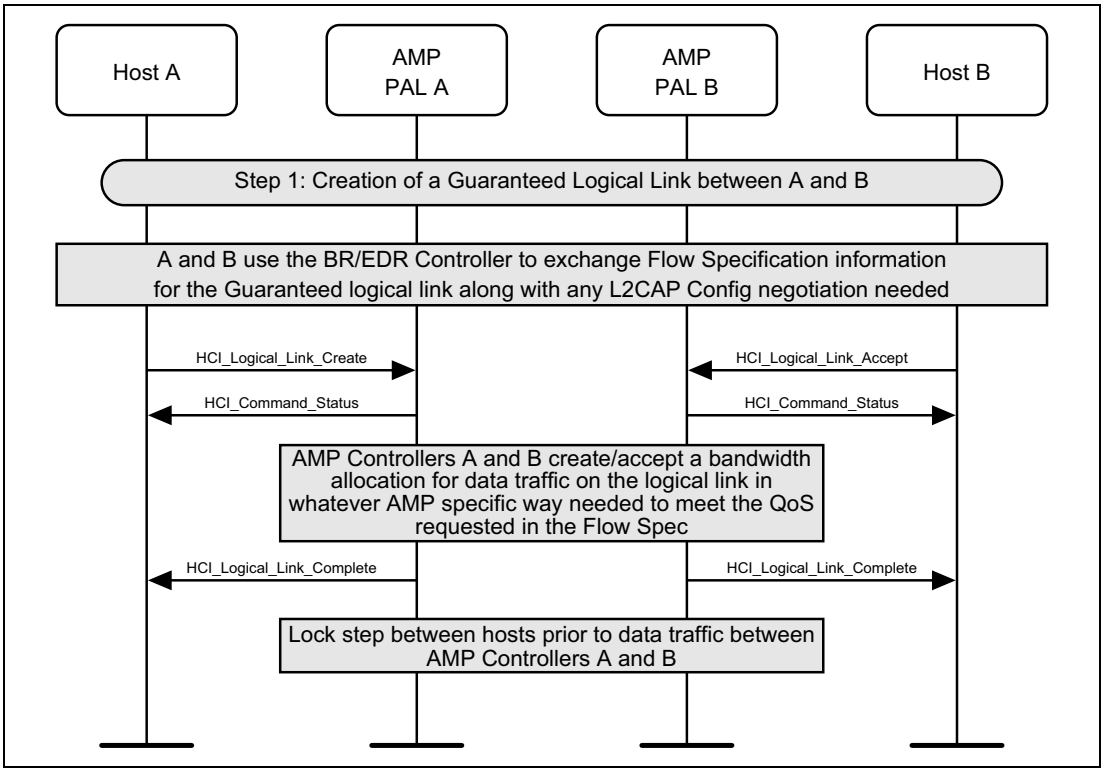

Figure 4.54: Guaranteed logical link creation

Step 2: Host A sends a Logical Link Disconnect command to its AMP Controller. AMP Controllers A and B do whatever AMP specific action is required to meet the request. Each AMP Controller sends the Logical Link Disconnect Complete event to its Host.

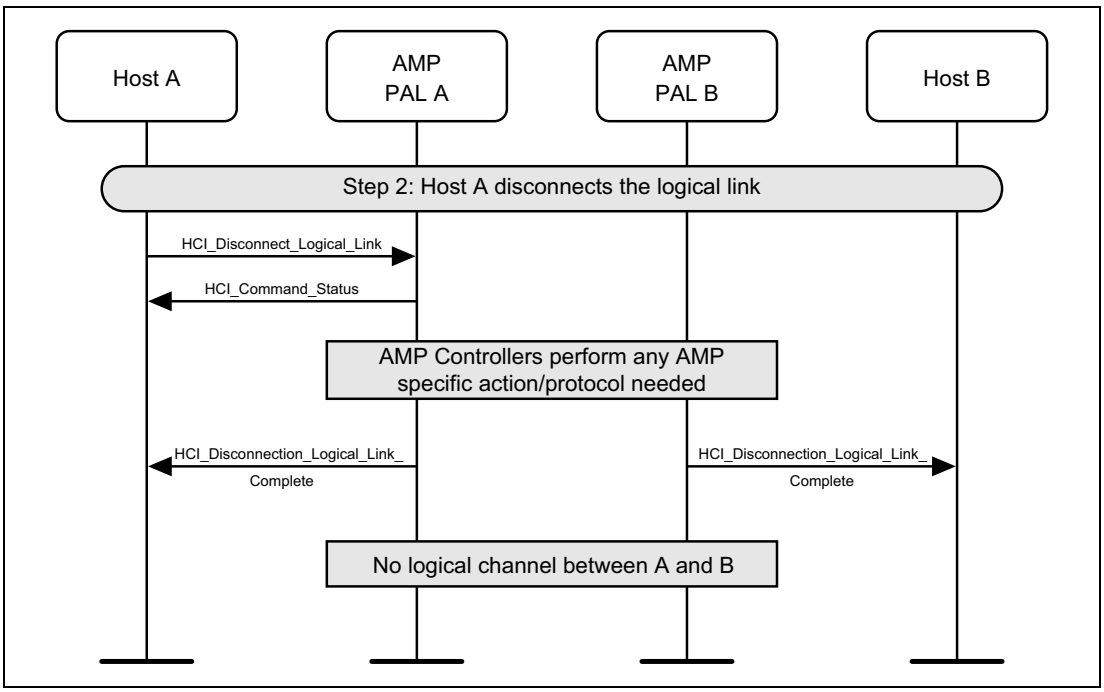

Figure 4.55: Host A disconnects the logical link

Step 3: During normal operation the Host may modify logical link characteristics.

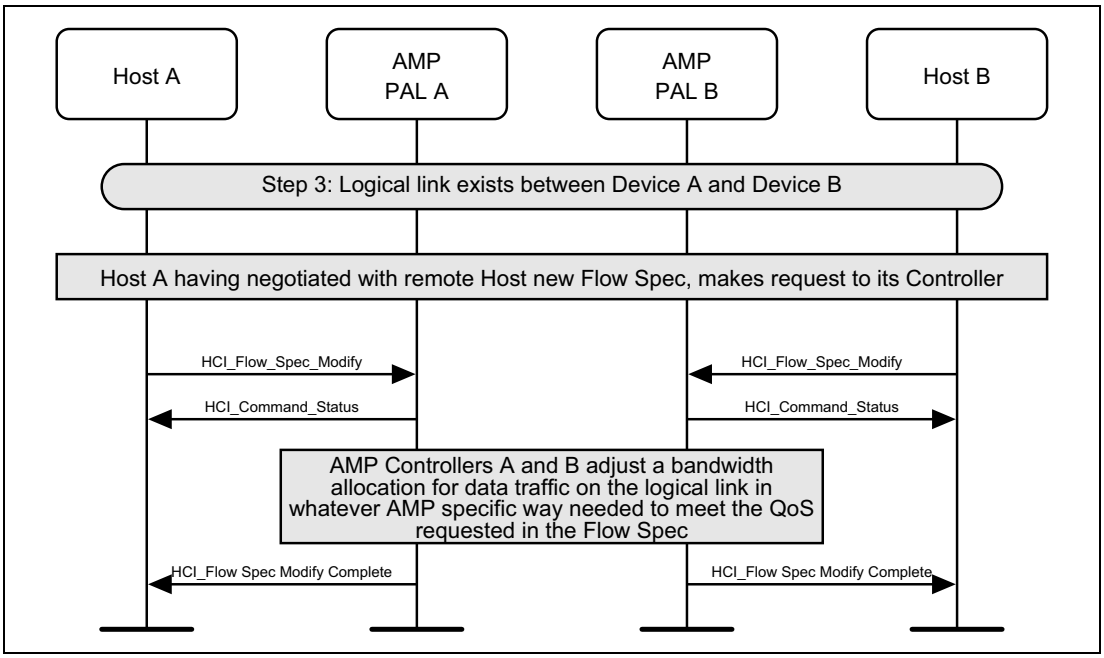

Figure 4.56: Host A modifies Flow_Spec on an existing logical link

4.17 AMP TEST MODE SEQUENCE CHARTS

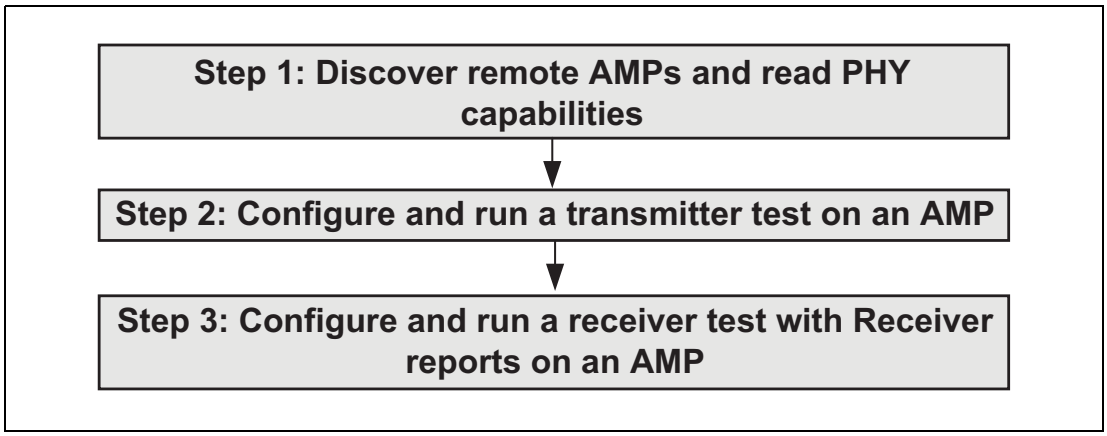

Figure 4.57: Overview diagram for AMP test mode

4.17.1 Discover the AMP Present and Running Transmitter and Receiver Tests

The process of discovering the number of AMPs and running transmitter and receiver tests is detailed in the following three steps.

Step 1: The tester sends an AMP Discovery Request to the AMP Test Manager of the DUT over the BR/EDR ACL connection. The AMP Test Manager will reply with the AMP Discover Response to the tester with a list of available AMP and type over the BR/EDR ACL connection. The tester then requests the PHY capabilities for each of the AMP it may test.

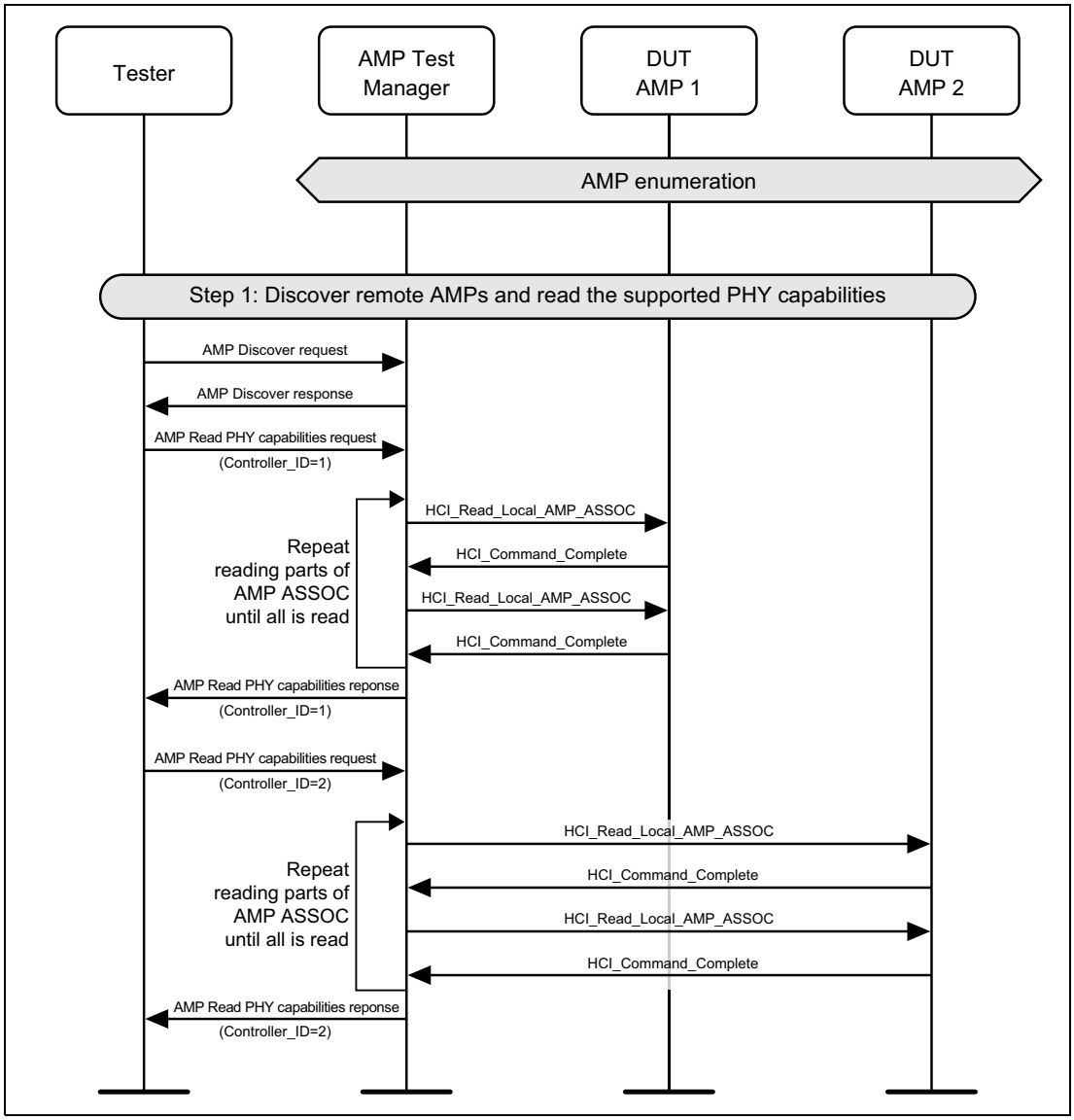

Figure 4.58: Discover remote AMPs and their PHY capabilities

Step 2: In order to configure a transmitter test, the Tester sends an HCI_AMP_Test_Command to the AMP Test Manager of the DUT using the L2CAP AMP Test Message for the AMP Controller indicated by the Controller_ID. The AMP Test Manager sends on the HCI_AMP_Test_Command on to the AMP indicated by the Controller_ID. When the HCI_AMP_Start_Test_Event is returned from the AMP Controller, the event will be sent via the AMP Test Manager back to the Tester within an L2CAP AMP Test message.

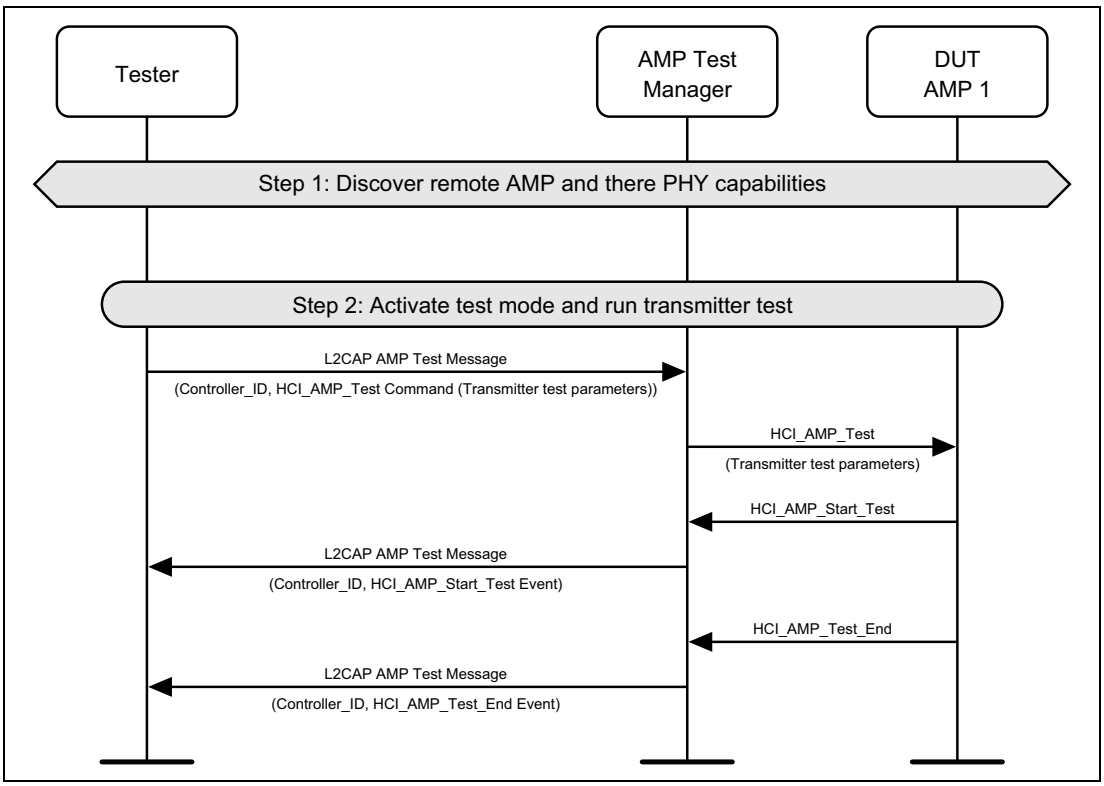

Figure 4.59: Activate test mode and run a transmitter test

Step 3: In order to Enable AMP Receiver Reports, the Tester sends an AMP test command to the AMP Test Manager of the DUT using the L2CAP AMP Test message for the AMP Controller indicated by the Controller_ID. The Command_Complete_Event is returned to the Tester via the AMP Test Manager in an L2CAP AMP Test Message.

In order to configure a receiver test, the Tester sends an HCI_AMP_Test_Command to the AMP Test Manager of the DUT using the L2CAP AMP Test Message for the AMP Controller indicated by the Controller_ID. The AMP Test Manager sends on the HCI_AMP_Test_Command on to the AMP indicated by the Controller_ID. The HCI_AMP_Start_Event is returned to the Tester via the AMP Test Manager in an L2CAP AMP Test Message.

AMP_Receiver_Reports and the HCI_Test_End_Event are sent back to the Tester via the AMP Test Manager from the Controller and then the Recever reports is disabled by the Tester using the HCI_Enable_AMP_Receiver_Reports command.

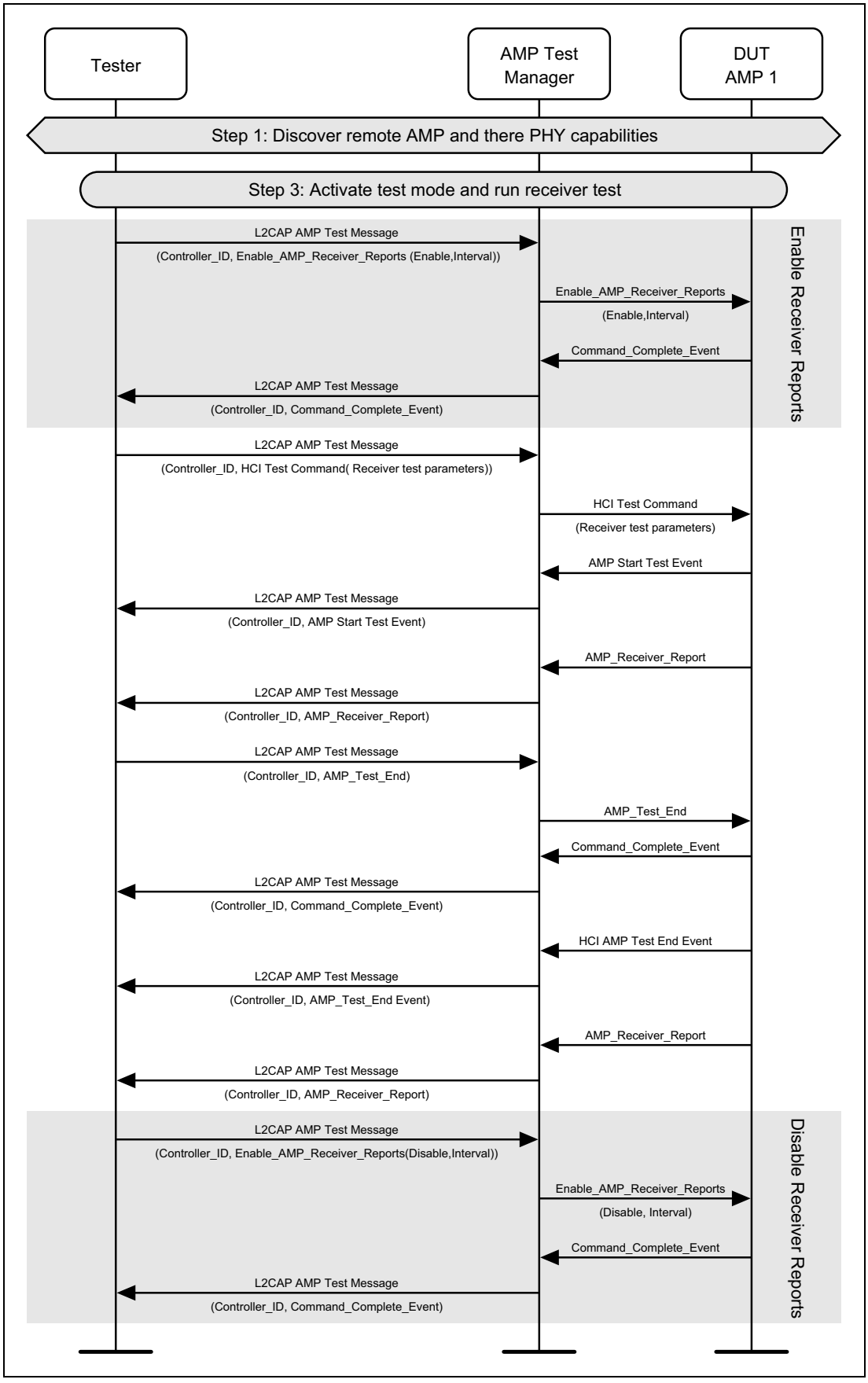

Figure 4.60: Configure and run a receiver test with receiver reports on an AMP

4.18 SLOT AVAILABILITY MASK

A flow diagram of SAM negotiation between two devices is shown in Figure 4.61. The setup of SAM may be triggered by the Link Manager for MWS coexistence or topology management purposes. For MWS coexistence, SAM LMP sequences may be triggered by the HCI commands "Set_External_Frame_Configuration" and "Set_MWS_PATTERN_Configuration" or by the real-time signals (e.g. MWS_PATTERN_Index, FRAME_SYNC, etc) from the Coexistence Logical Interface (see [Vol 7] Part A), as these contain information for the SAM_Index to be activated and the SAM anchor point for MWS coexistence. Piconet Clock Adjustment may be performed to create more available slot pairs per MWS frame before initiating the LMP_SAM_switch sequence.

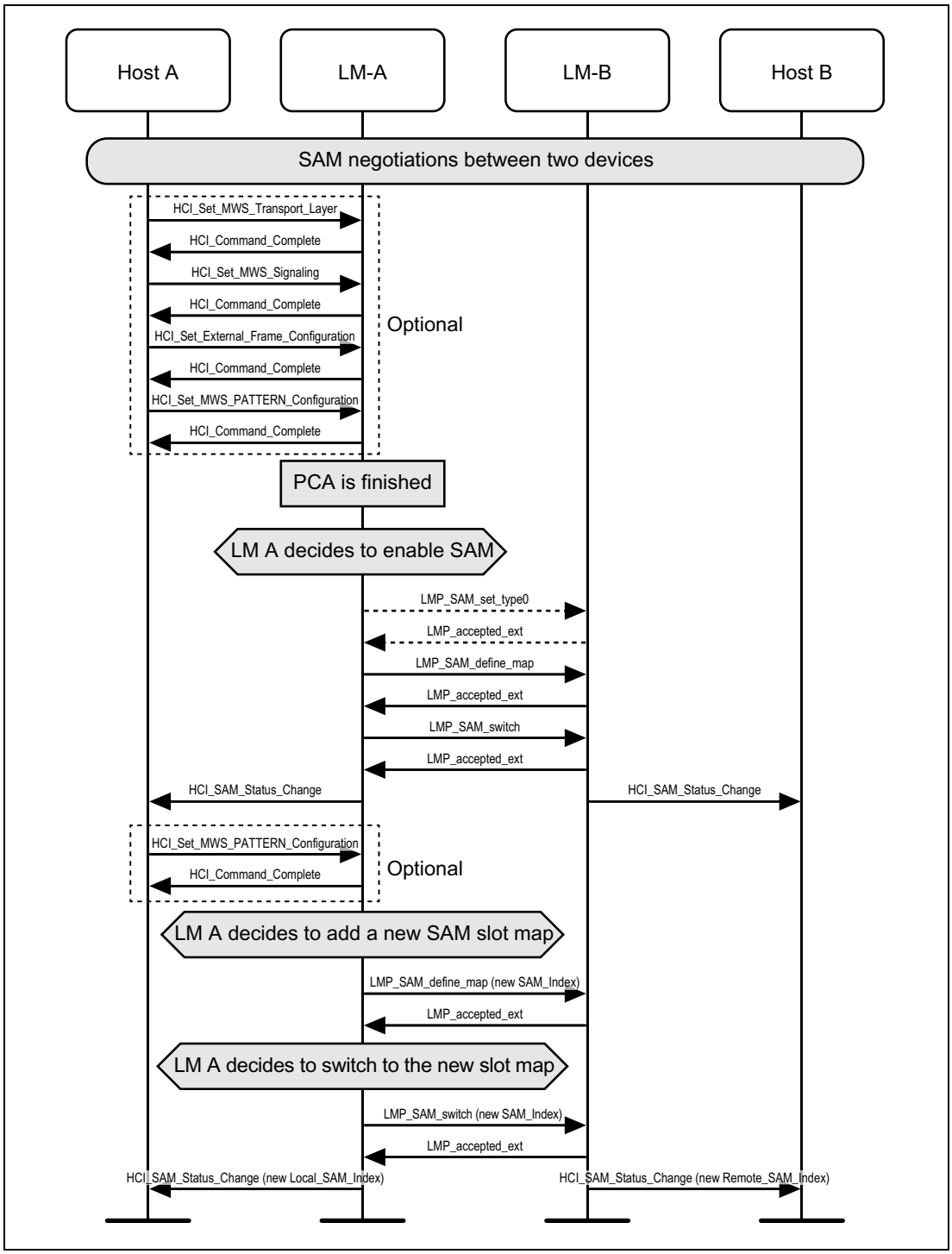

Figure 4.61: SAM negotiations between two devices

4.19 LMP TRANSACTION COLLISION

The Link Managers of both the master and slave may initiate the same LMP transaction at the same time.

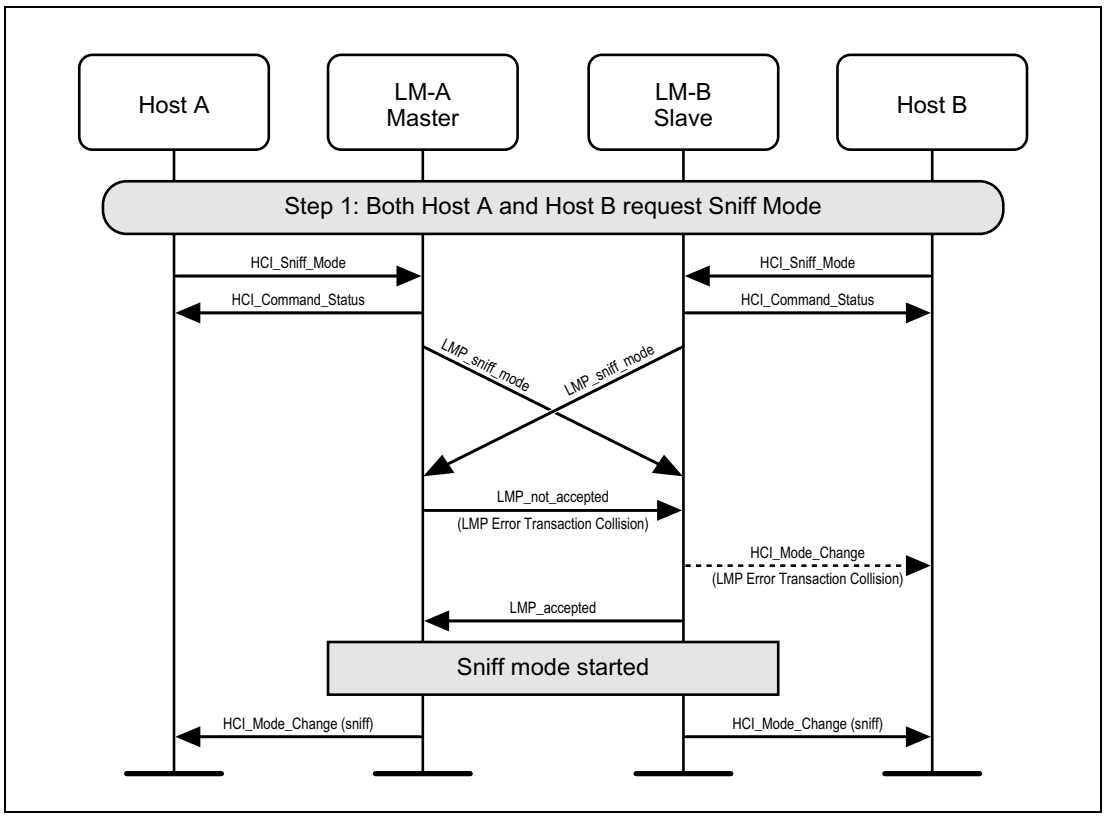

Figure 4.62: LMP Transaction Collision

5 SYNCHRONOUS CONNECTION ESTABLISHMENT AND DETACHMENT

5.1 SYNCHRONOUS CONNECTION SETUP

Using the HCI_Setup_Synchronous_Connection command, a Host can add a synchronous logical channel to the link. A synchronous logical link can be provided by creating a SCO or an eSCO logical transport.

Note: An ACL Connection must be established before a synchronous connection can be created.

Step 1a: Master device requests a synchronous connection with a device. (See Figure 5.1.)

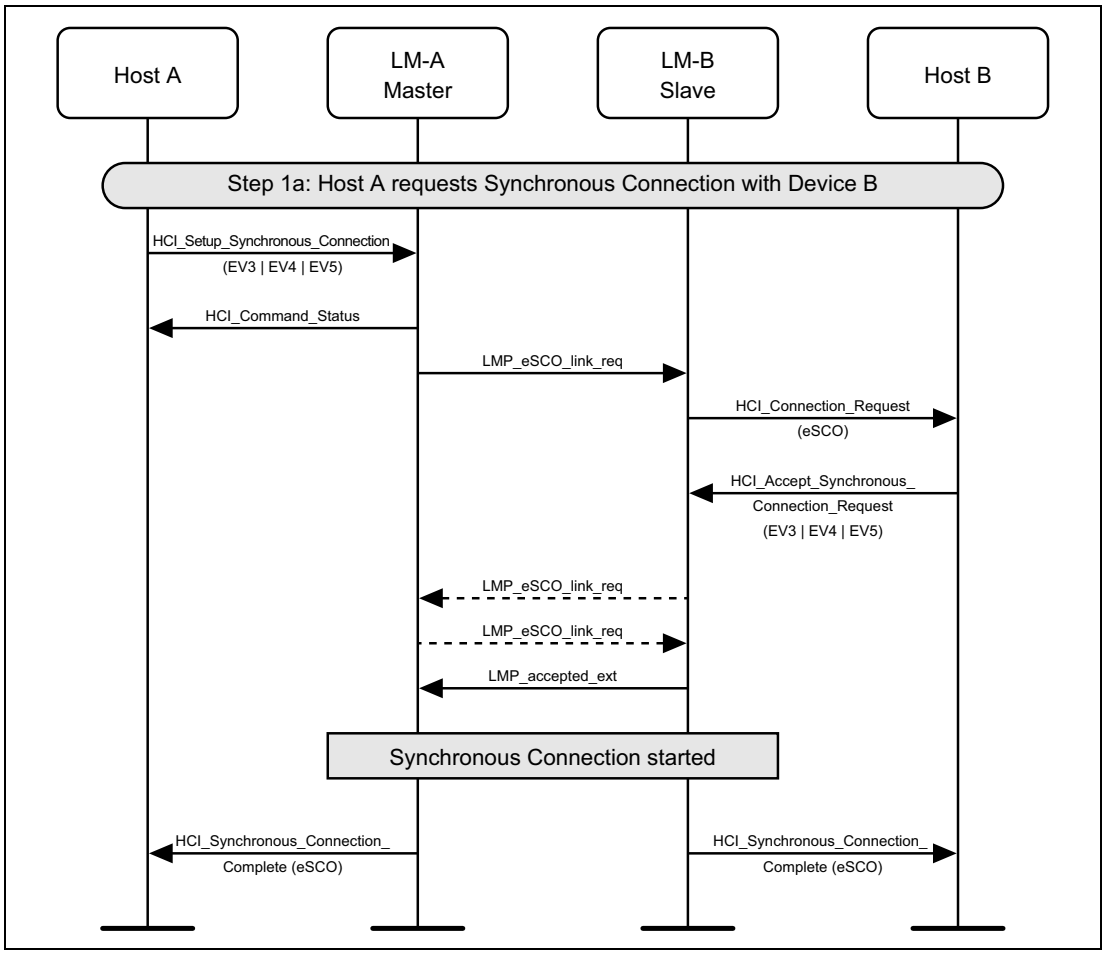

Figure 5.1: Master requests synchronous EV3, EV4 or EV5 connection

Step 1b: Slave device requests a synchronous connection with a device. (See Figure 5.2.)

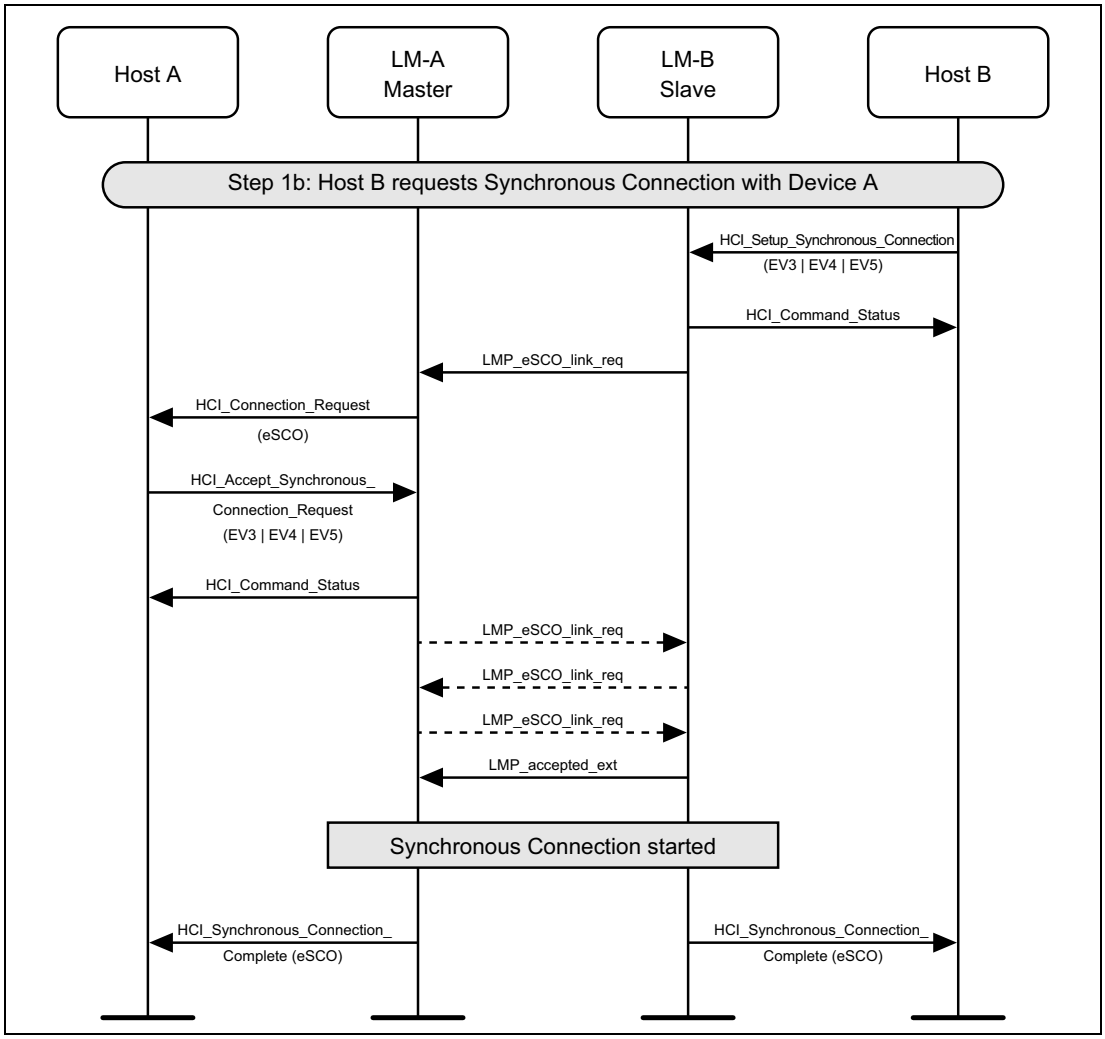

Figure 5.2: Slave requests synchronous EV3, EV4 or EV5 connection

Step 1c: Master device requests a SCO connection with a device. (See Figure 5.3.)

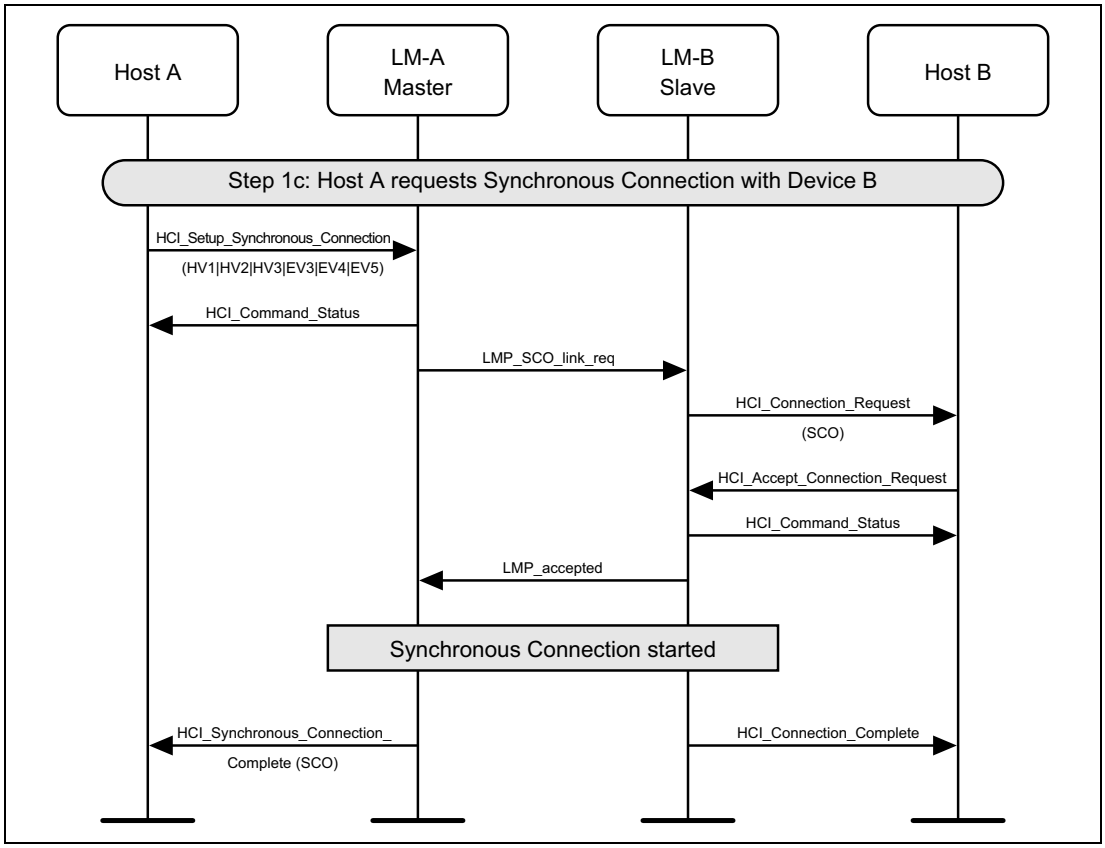

Figure 5.3: Master requests synchronous connection using SCO

Step 1d: Master device requests a SCO connection with a device. (See Figure 5.4.)

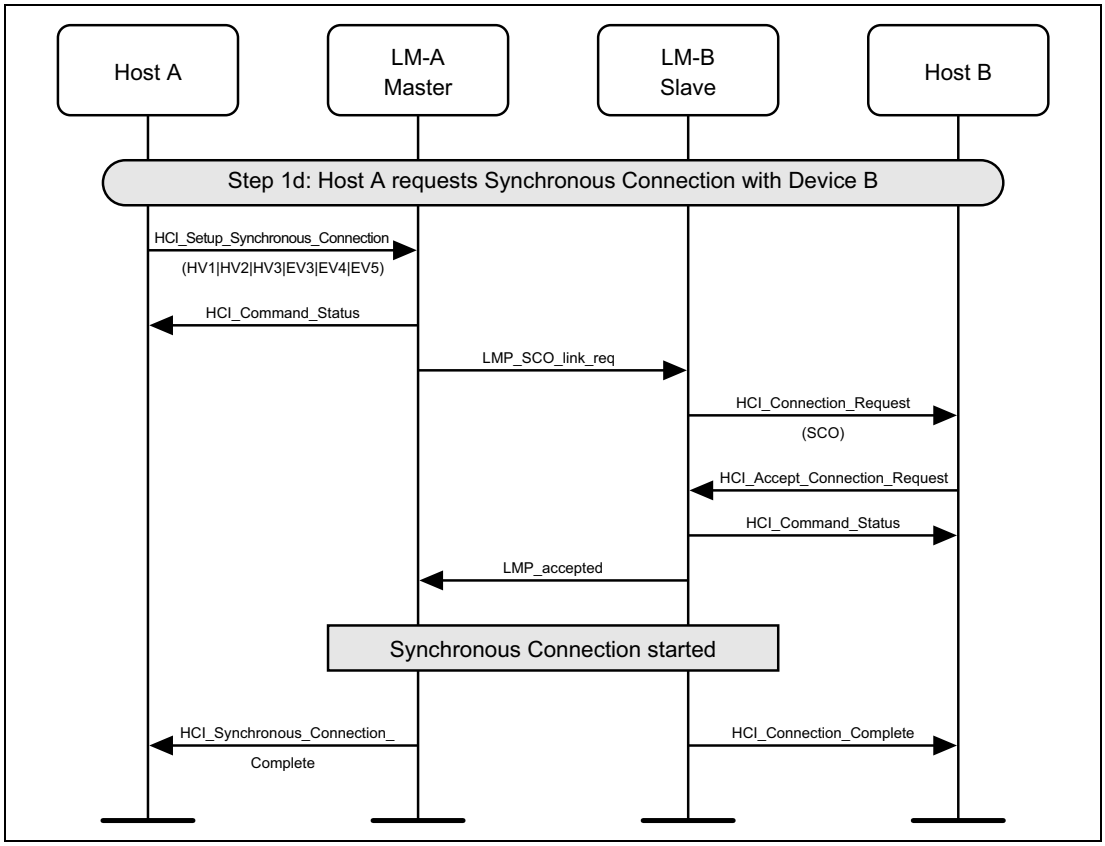

Figure 5.4: Master requests synchronous connection with legacy slave

Step 1e: Host device requests a SCO connection with a device. (See Figure 5.5.)

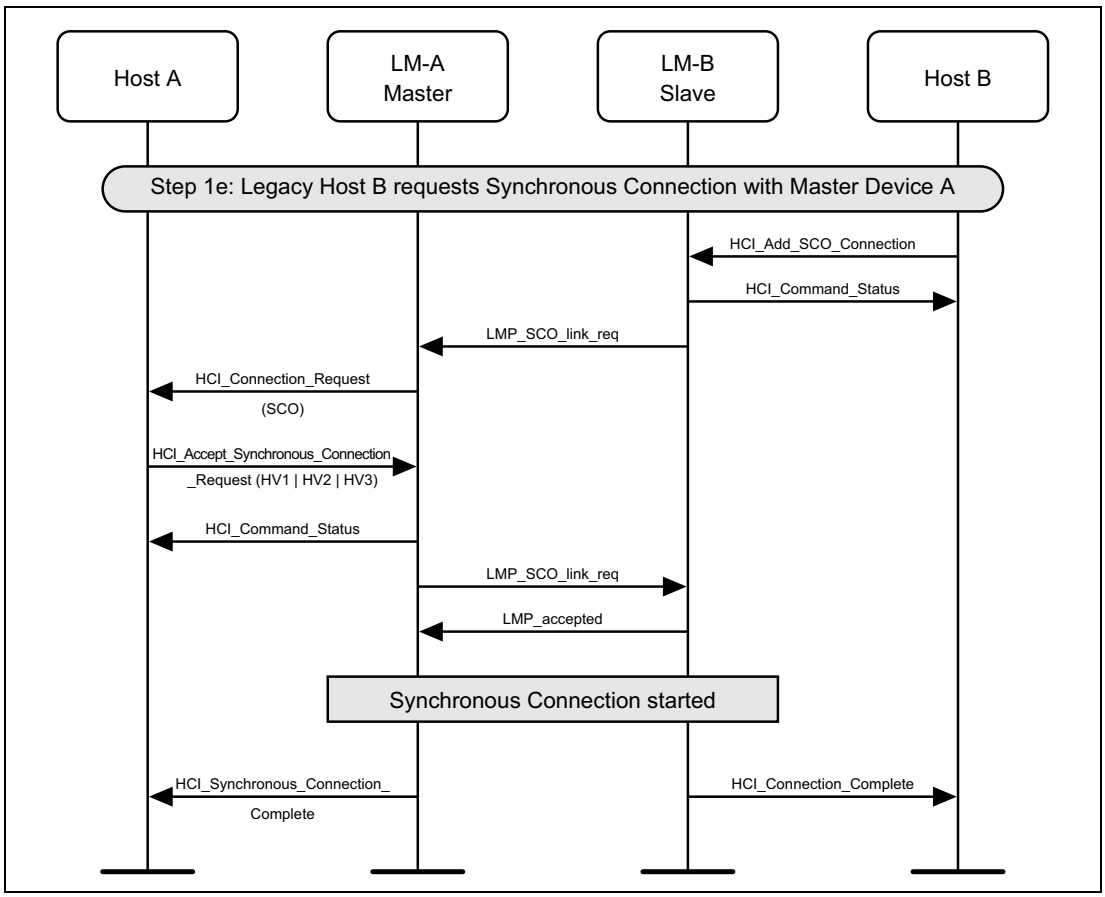

Figure 5.5: Any device that supports only SCO connections requests a synchronous connection with a device

Step 2a: Master renegotiates eSCO connection (see Figure 5.6.)

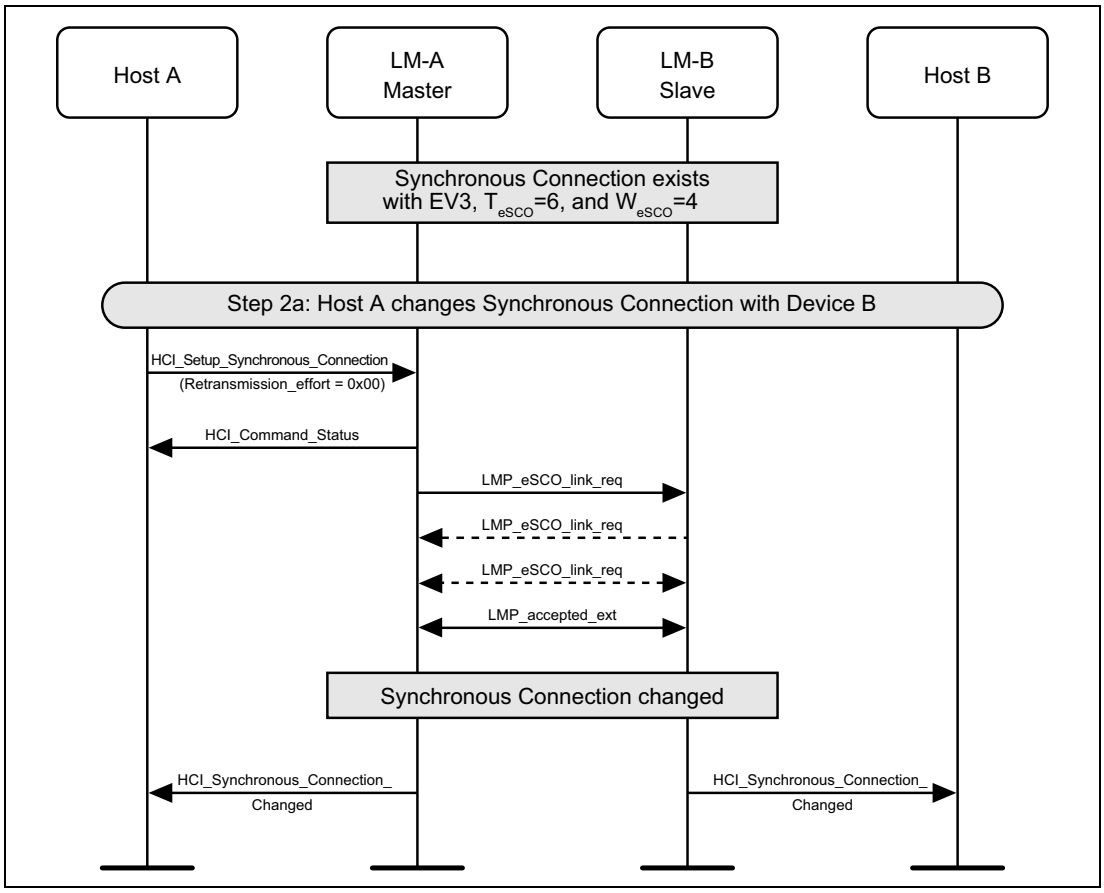

Figure 5.6: Master renegotiates eSCO connection

Step 2b: Slave renegotiates eSCO connection (see Figure 5.7.)

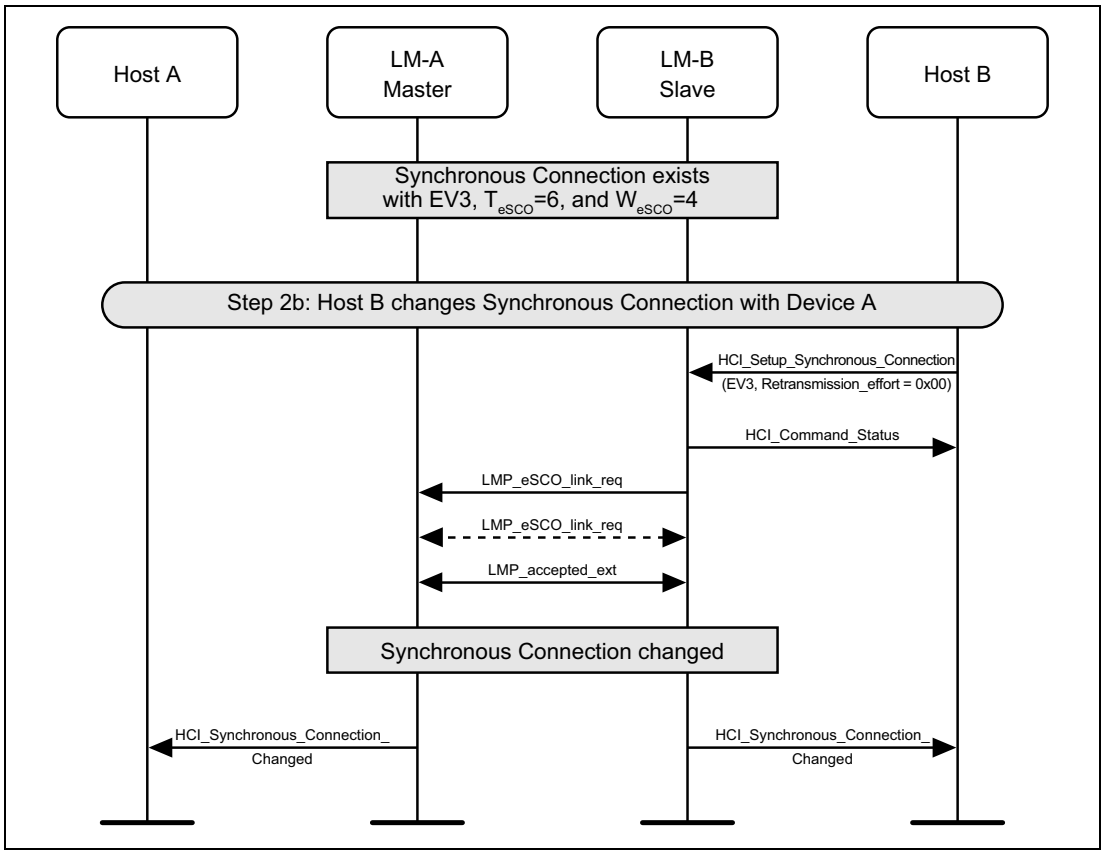

Figure 5.7: Slave renegotiates eSCO connection

Step 3a: eSCO Disconnection. (See Figure 5.8.)

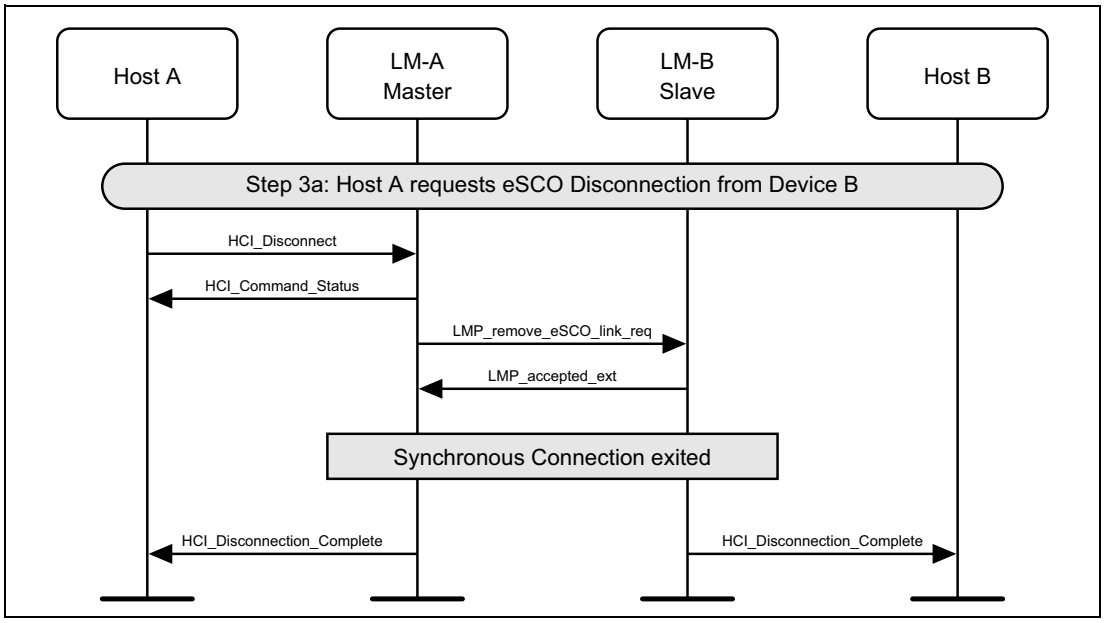

Figure 5.8: Synchronous disconnection of eSCO connection

Step 3b: SCO Disconnection. (See Figure 5.9.)

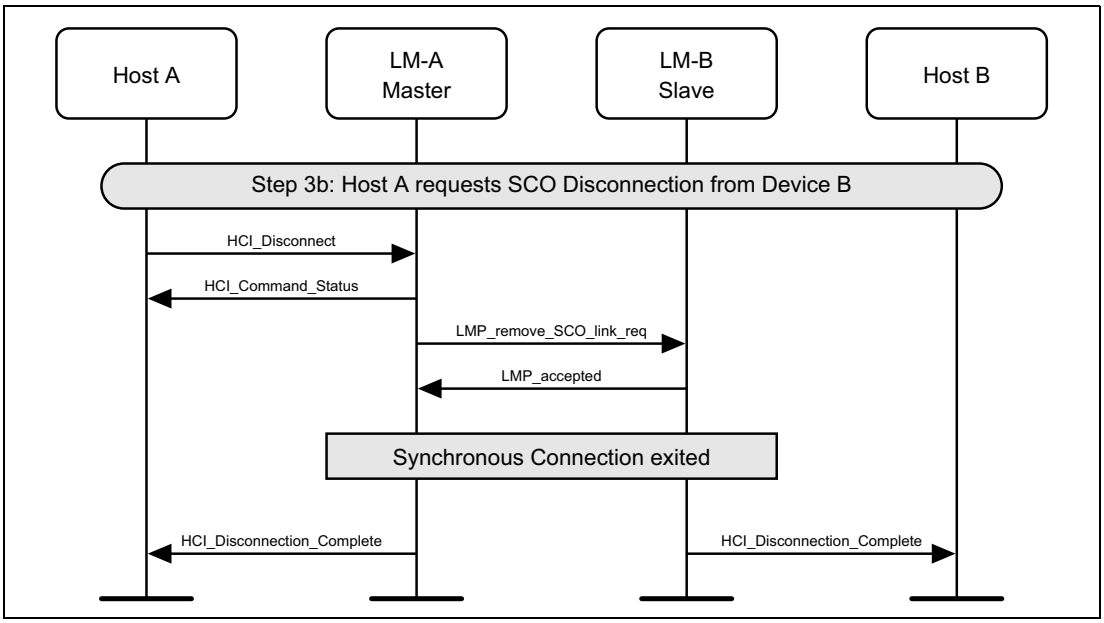

Figure 5.9: Synchronous disconnection of SCO connection

5.2 SYNCHRONOUS CONNECTION SETUP WITH ENHANCED SYNCHRONOUS COMMANDS

Using the HCI_Enhanced_Setup_Synchronous_Connection command, a Host can add a synchronous logical channel to the link. A synchronous logical link can be provided by creating a SCO or an eSCO logical transport.

Note: An ACL Connection must be established before a synchronous connection can be created.

Step 1a: Master device requests a synchronous connection with a slave device.

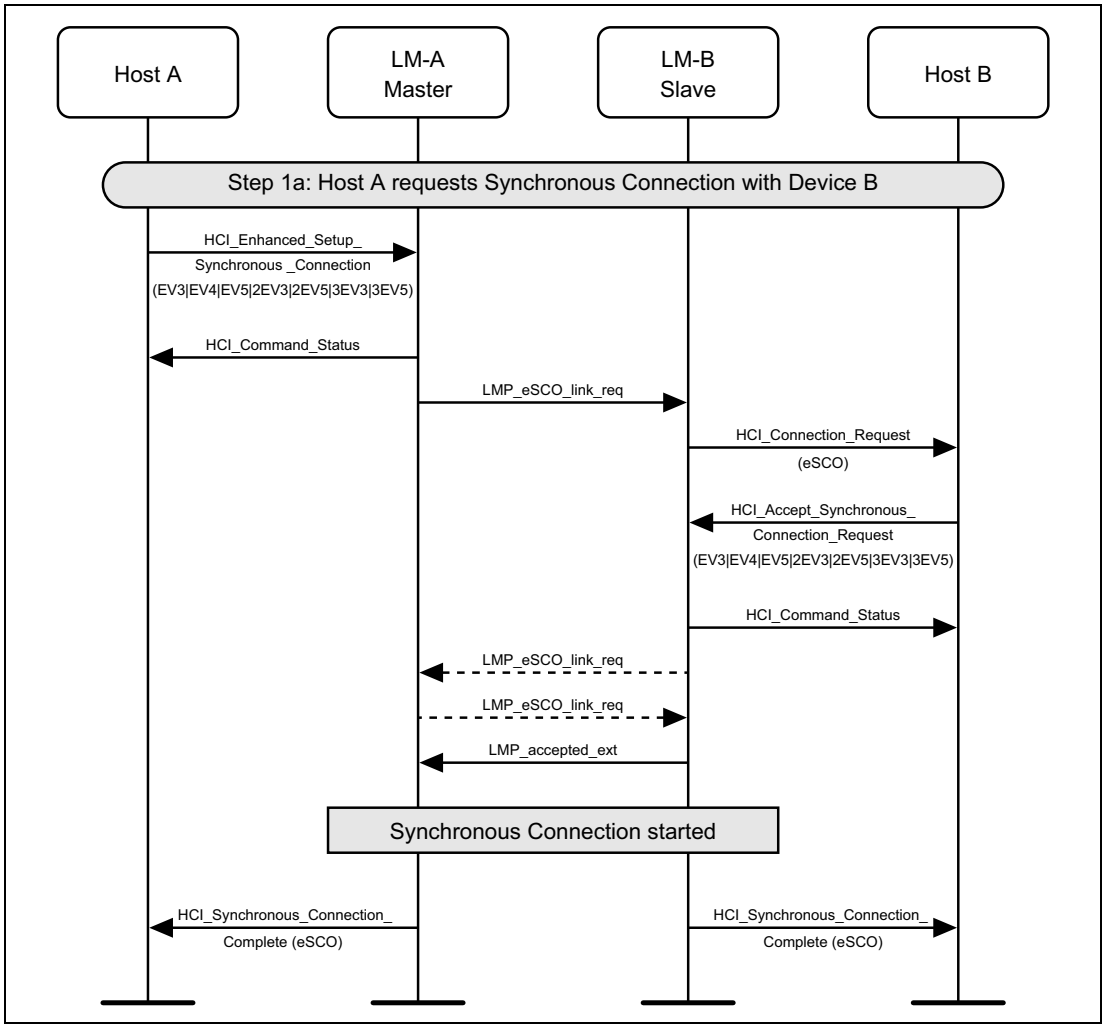

Figure 5.10: Master requests synchronous connection (EV3, EV4, EV5, 2-EV3, 2-EV5, 3-EV3, or 3-EV5)

Step 1b: Slave device requests a synchronous connection with a master device.

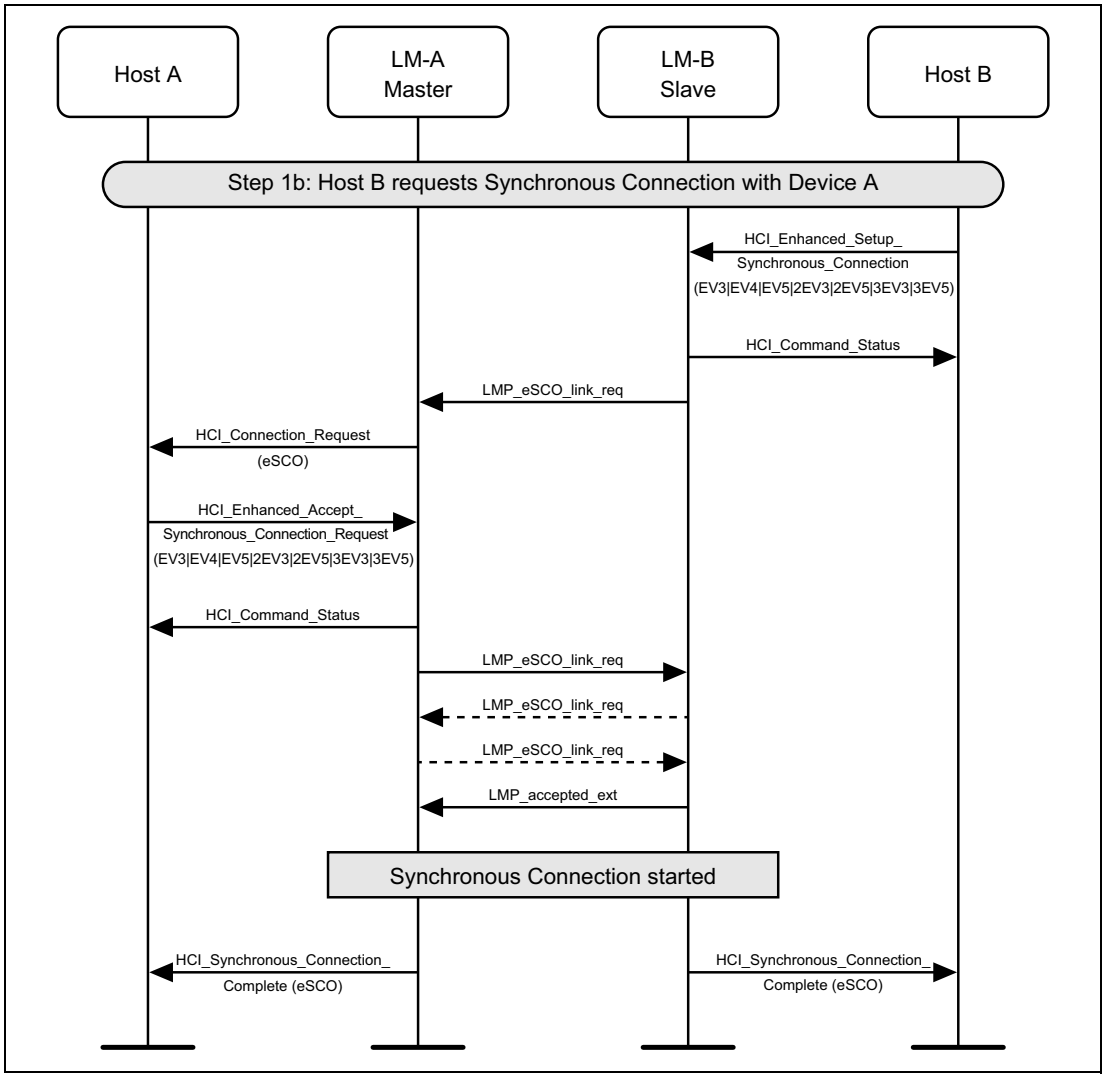

Figure 5.11: Slave requests synchronous connection (EV3, EV4, EV5, 2-EV3, 2-EV5, 3-EV3, or 3-EV5)

Step 1c: Master device requests a SCO connection with a slave device.

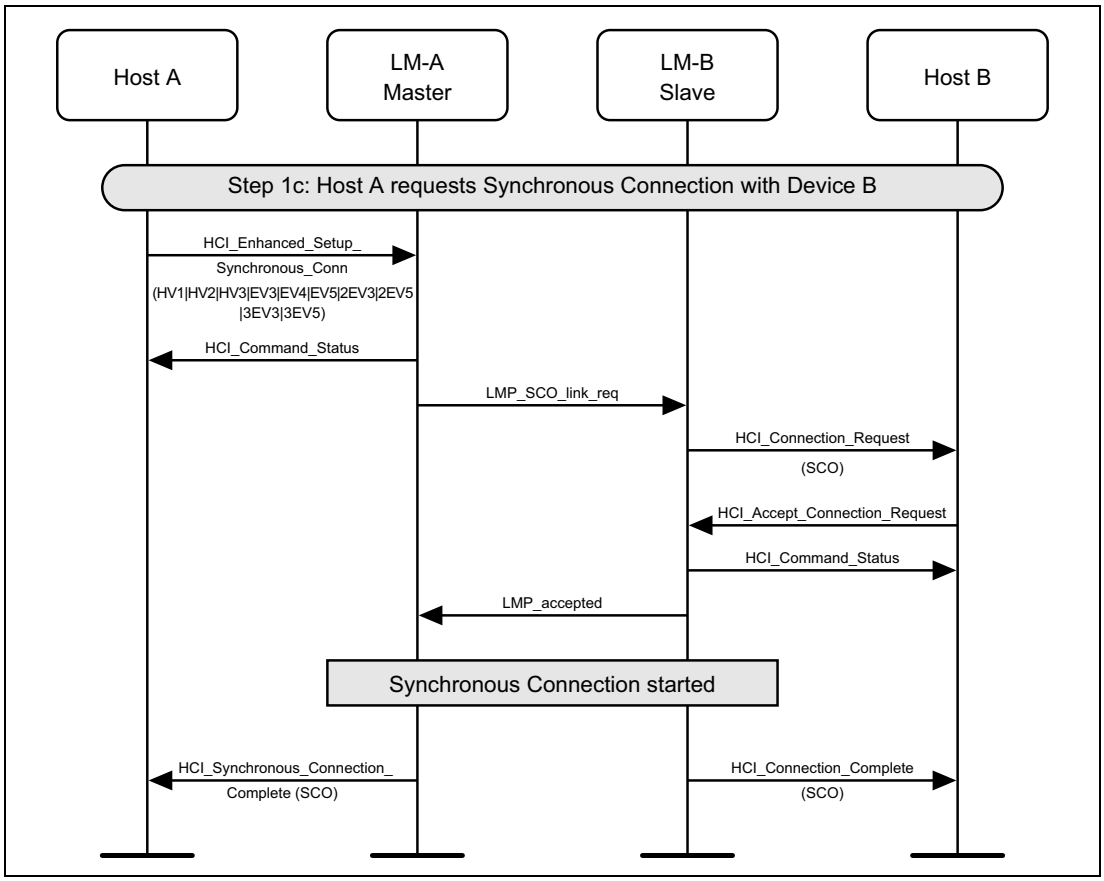

Figure 5.12: Master requests synchronous connection (HV1, HV2, HV3, EV3, EV4, EV5, 2EV3, 2EV5, 3EV3 or 3EV5)

Step 1d: Slave device requests a SCO connection with a master device.

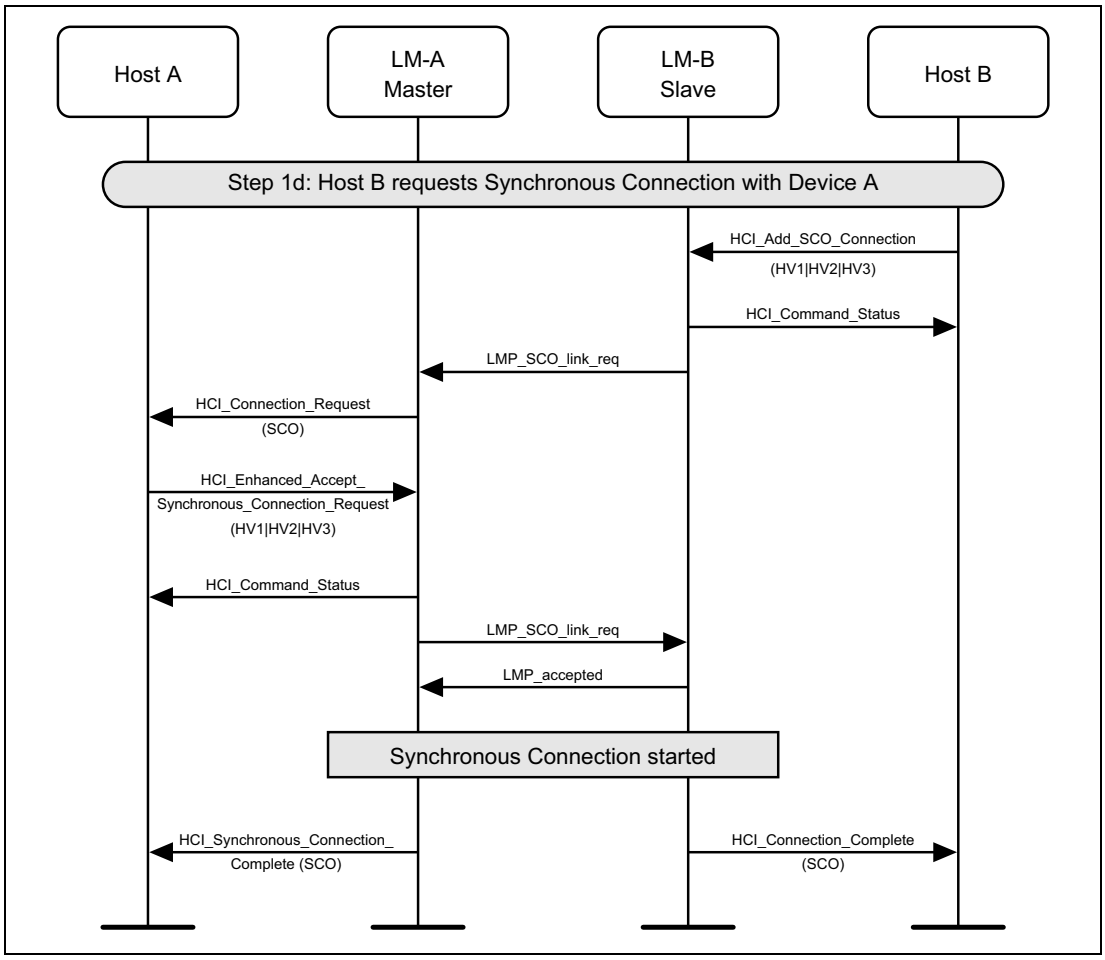

Figure 5.13: Slave requests synchronous connection (HV1, HV2, or HV3)

Step 2a: Master renegotiates eSCO connection.

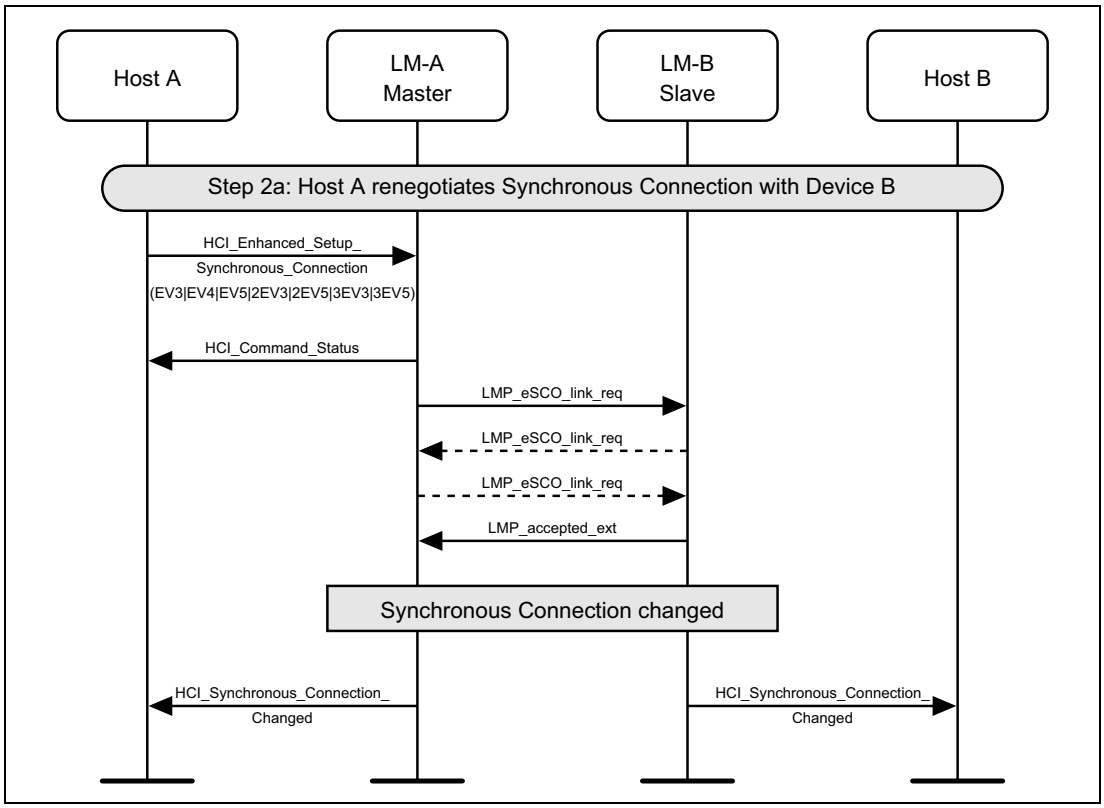

Figure 5.14: Master renegotiates synchronous connection parameter change

Step 2b: Slave renegotiates eSCO connection.

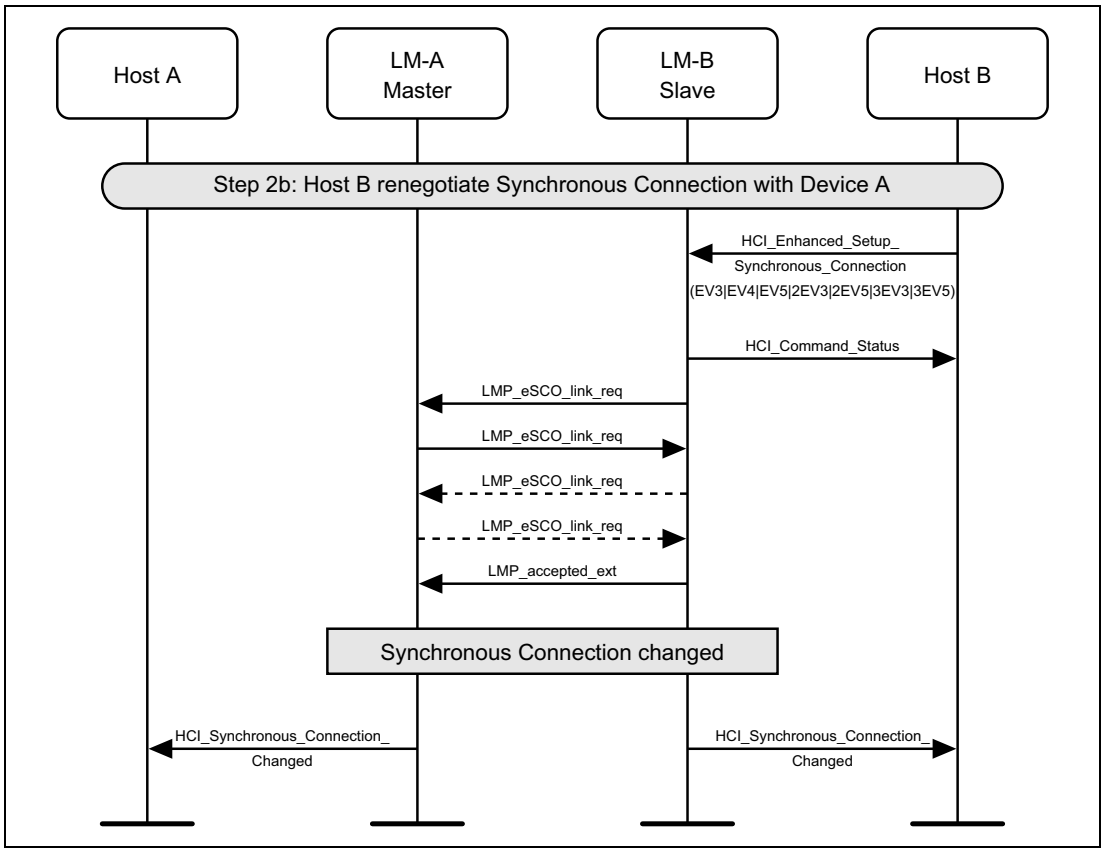

Figure 5.15: Slave renegotiates synchronous connection parameter change

6 SNIFF AND HOLD

Entry into Sniff mode or Hold mode requires an established ACL Connection.

6.1 SNIFF MODE

The HCI_Sniff_Mode command is used to enter sniff mode.
The HCI_Exit_Sniff_Mode command is used to exit sniff mode.

Step 1: Host requests to enter sniff mode. Multiple LMP_sniff_req PDUs may be sent as the parameters for sniff mode are negotiated. (See Figure 6.1.)

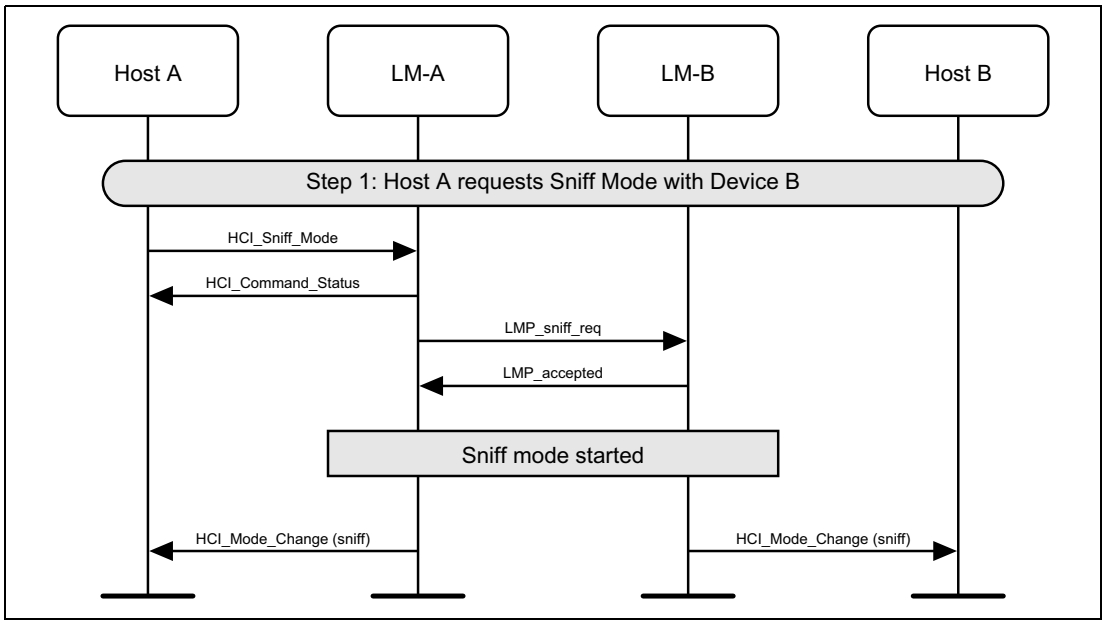

Figure 6.1: Sniff mode request

Step 2: Host requests to exit sniff mode. (See Figure 6.2.)

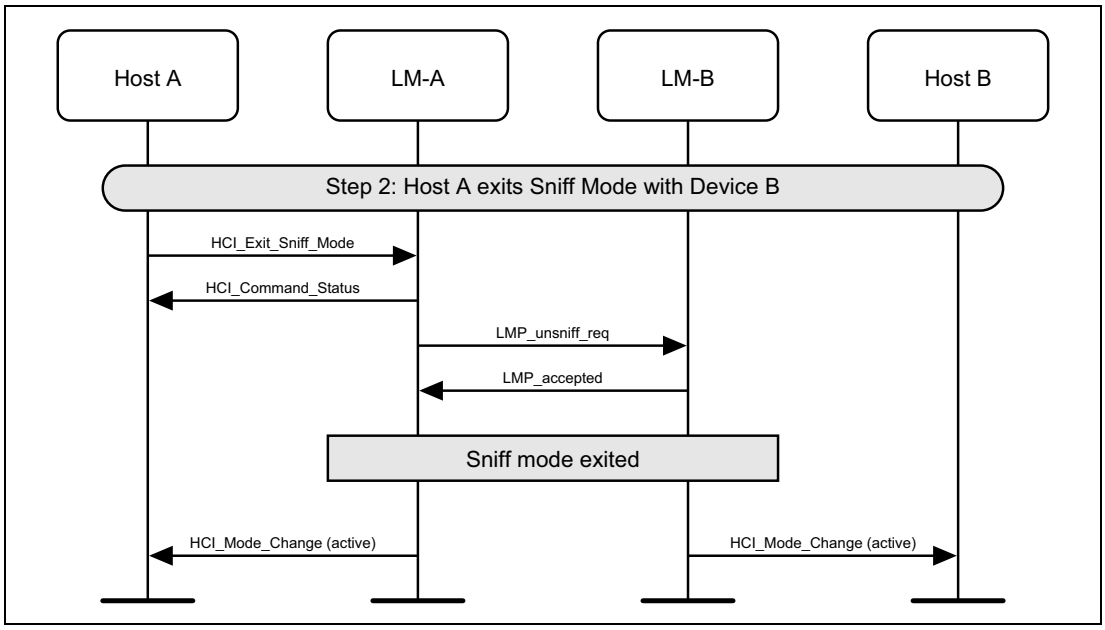

Figure 6.2: Exit sniff mode request

6.2 HOLD MODE

The HCI_Hold_Mode command can be used to place a device into hold mode. The Controller may do this by either negotiating the hold mode parameters or forcing hold mode. Hold mode will automatically end after the negotiated length of time.

Step 1a: A Host requests hold mode. (See Figure 6.3.)

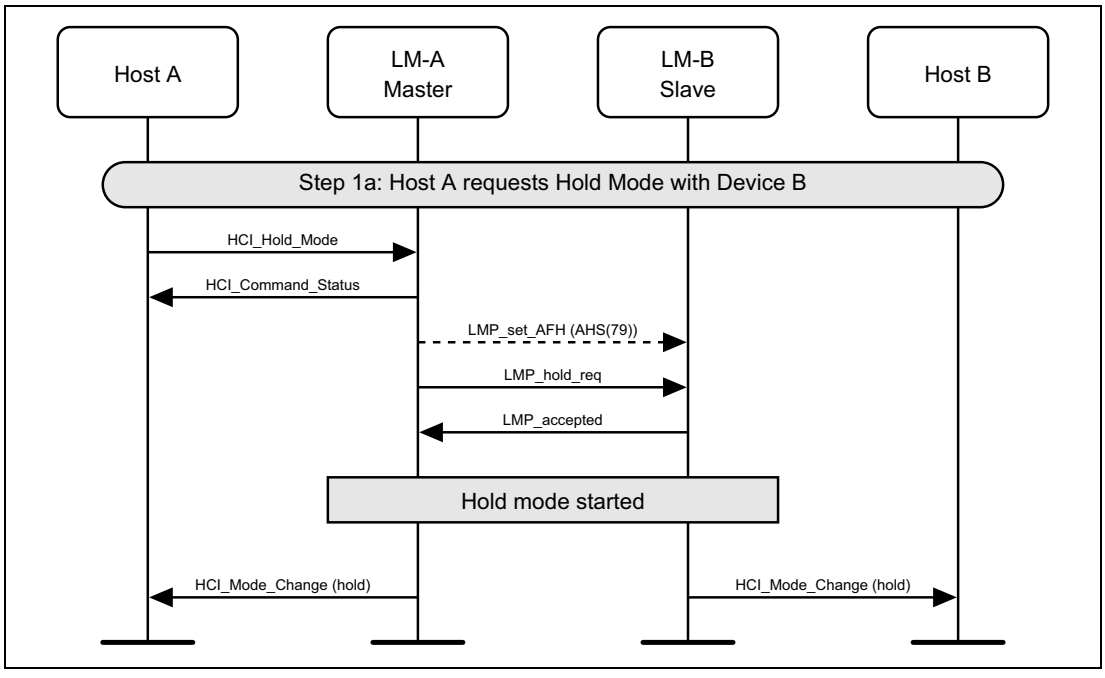

Figure 6.3: Hold request

Step 1b: A Host may force hold mode. (See Figure 6.4.)

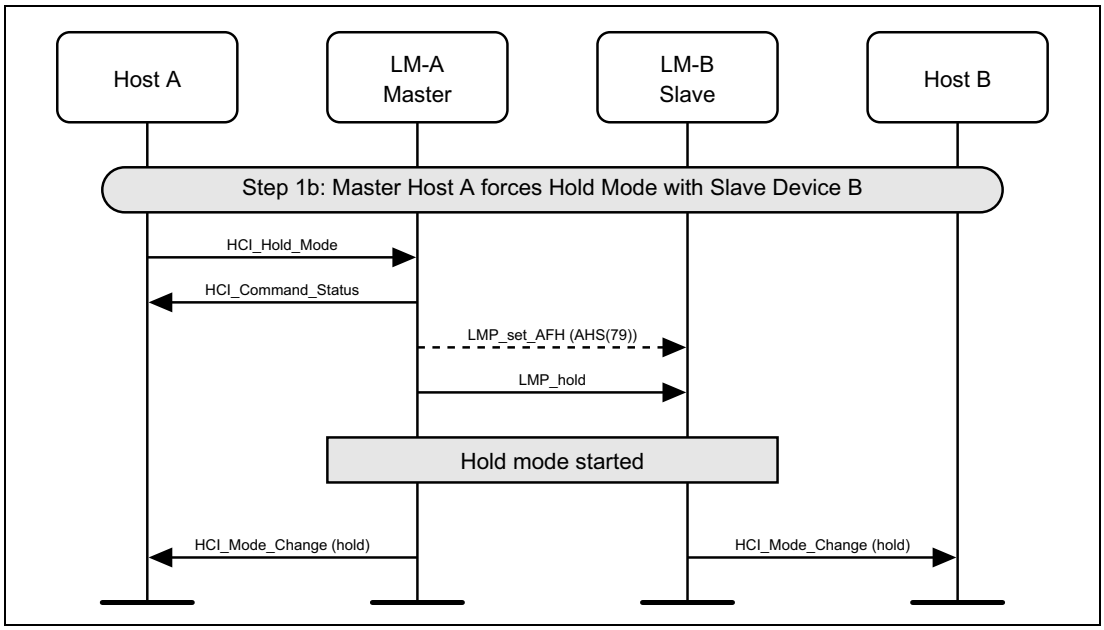

Figure 6.4: Master forces hold mode

Step 1c: A slave device requests hold mode. (See Figure 6.5.)

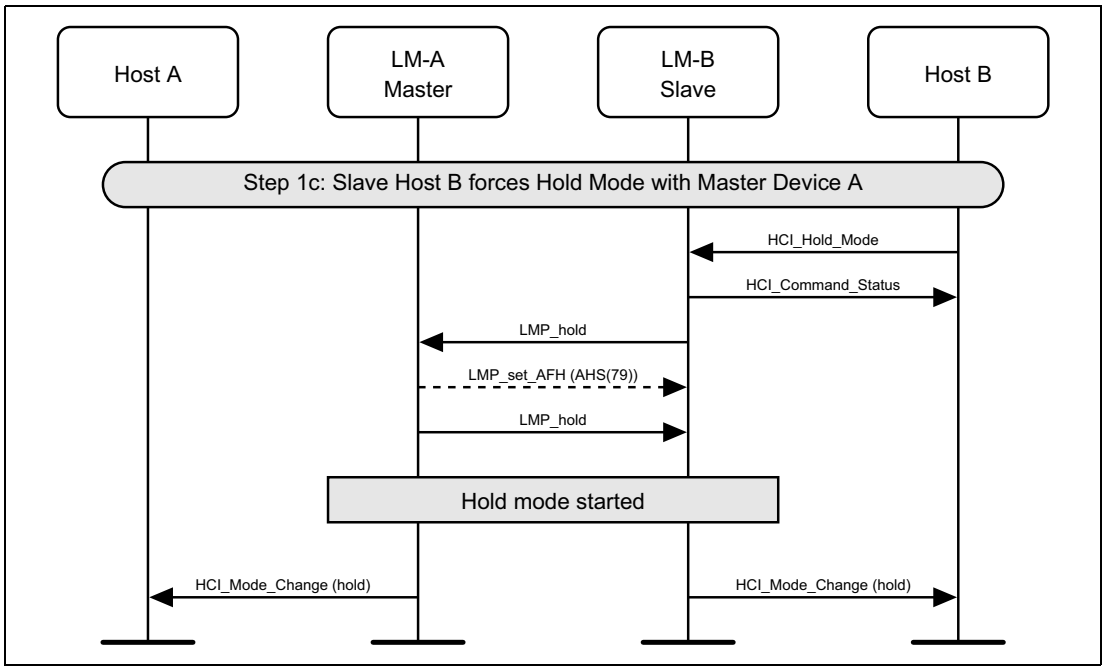

Figure 6.5: Slave forces hold mode

Step 2: When hold mode completes the Hosts are notified using the HCI_Mode_Change event. (See Figure 6.6.)

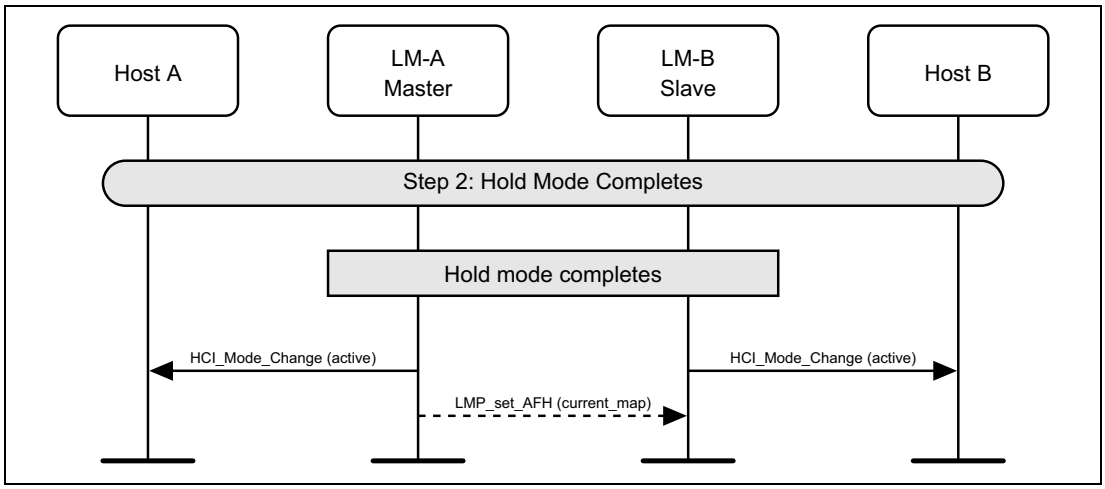

Figure 6.6: Hold mode completes

6.3 THIS SECTION NO LONGER USED

7 BUFFER MANAGEMENT, FLOW CONTROL

Buffer management is very important for resource limited devices. This can be achieved on the Host Controller Interface using the HCI_Read_Buffer_Size command, and the HCI_Number_Of_Completed_Packets event, and the HCI_Set_Host_Controller_To_Host_Flow_Control, HCI_Host_Buffer_Size and HCI_Host_Number_Of_Completed_Packets commands.

Step 1: During initialization, the Host reads the buffer sizes available in the Controller. When an HCI Data Packet has been transferred to the remote device, and a Baseband acknowledgment has been received for this data, then an HCI_Number_Of_Completed_Packets event will be generated.
(See Figure 7.1.)

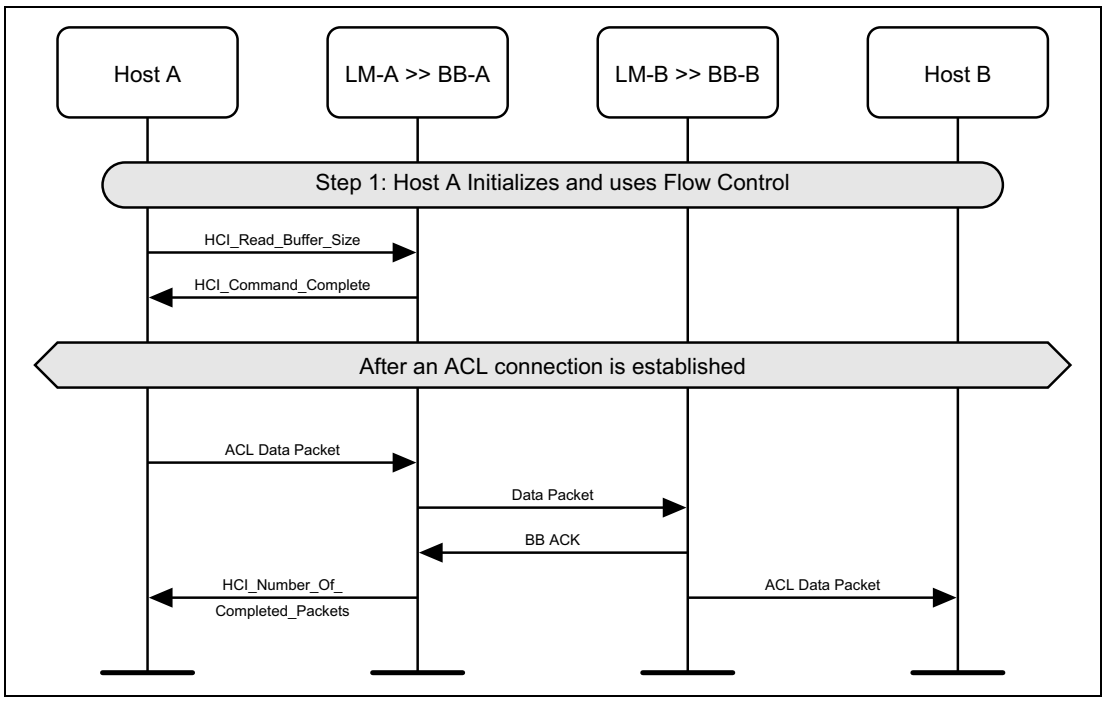

Figure 7.1: Host to Controller flow control

Step 2: During initialization, the Host notifies the Controller that Host flow control shall be used, and then the Host buffer sizes available. When a data packet has been received from a remote device, an HCI Data Packet is sent to the Host from the Controller, and the Host shall acknowledge its receipt by sending HCI_Host_Number_Of_Completed_Packets. (See Figure 7.2.)

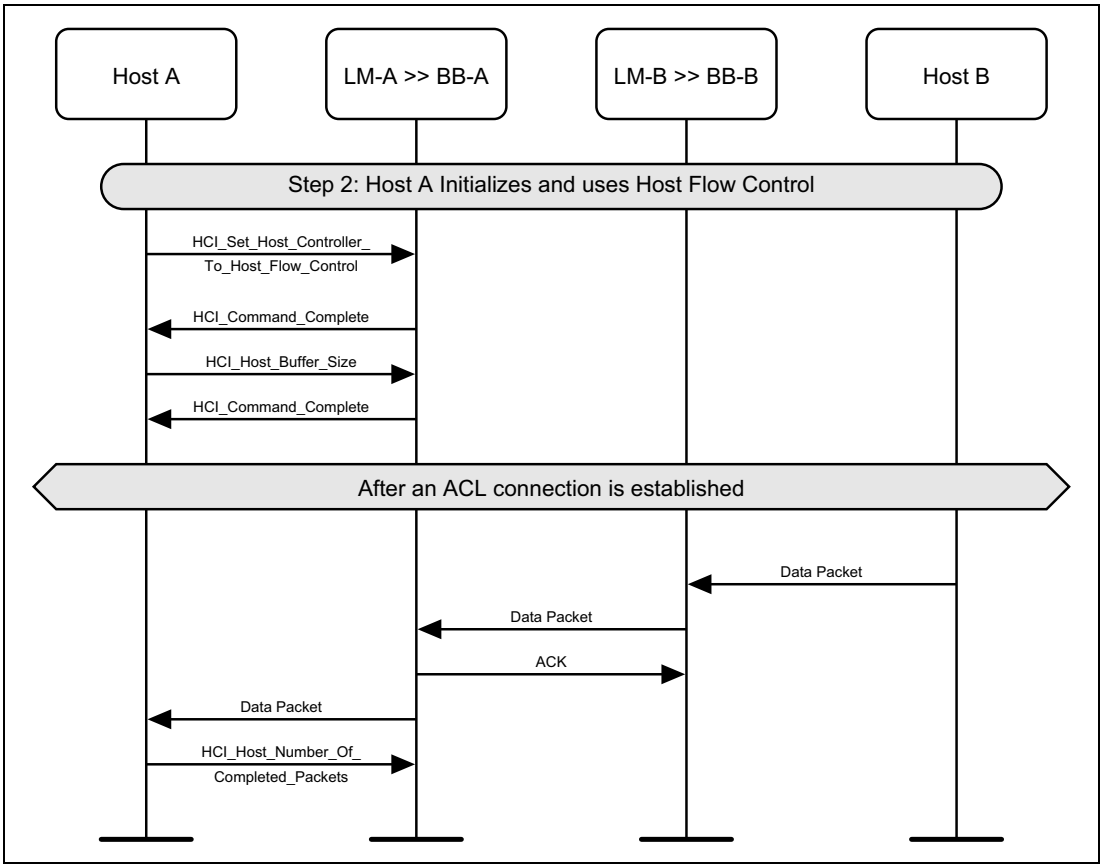

Figure 7.2: Controller to Host flow control

8 LOOPBACK MODE

The loopback modes are used for testing of a device only.

8.1 LOCAL LOOPBACK MODE

The local loopback mode is used to loopback received HCI Commands, and HCI ACL and HCI Synchronous packets sent from the Host to the Controller.

Step 1: The Host enters local loopback mode. Four connection complete events are generated and then a command complete event.
(See Figure 8.1.)

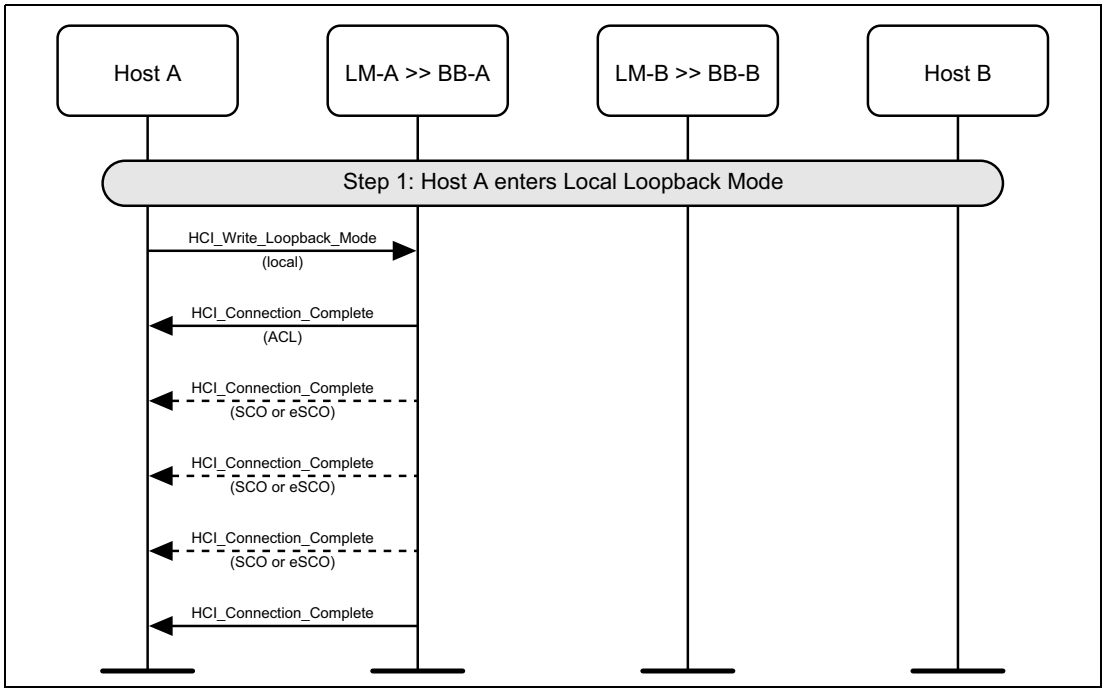

Figure 8.1: Entering local loopback mode

Step 2a: The Host sending HCI Data Packet will receive the exact same data back in HCI Data Packets from the Controller. (See Figure 8.2.)

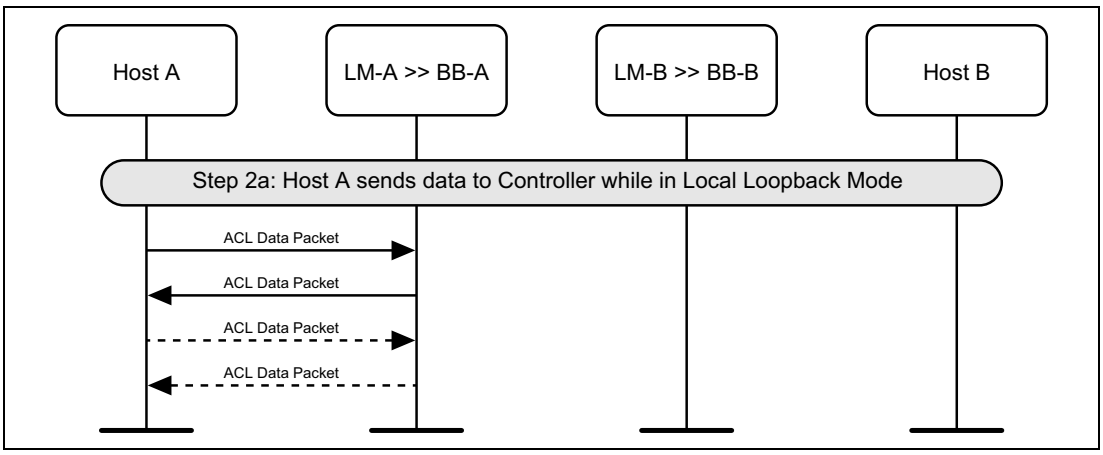

Figure 8.2: Looping back data in local loopback mode

Step 2b: The Host sending most HCI Command Packets to the Controller will receive an HCI_Loopback_Command event with the contents of the HCI Command Packet in the payload. (See Figure 8.3.)

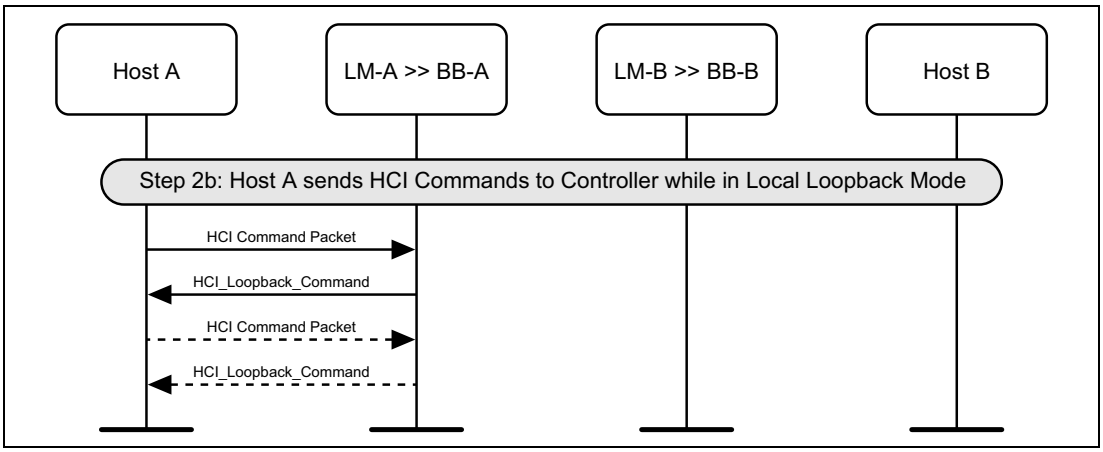

Figure 8.3: Looping back commands in local loopback mode

Step 3: The Host exits local loopback mode. Multiple disconnection complete events are generated before the command complete event. (See Figure 8.4.)

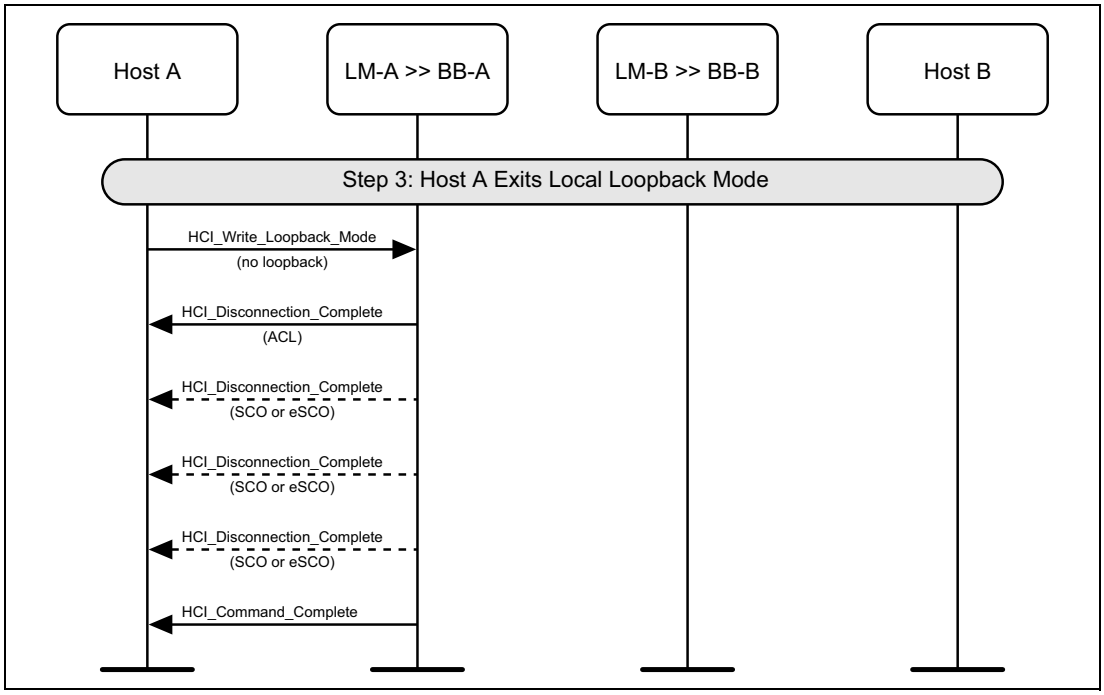

Figure 8.4: Exiting local loopback mode

8.2 REMOTE LOOPBACK MODE

The remote loopback mode is used to loopback data to a remote device over the air.

Step 1: The local device first enables remote loopback. The remote Host then sets up a connection to the local device. (See Figure 8.5.)

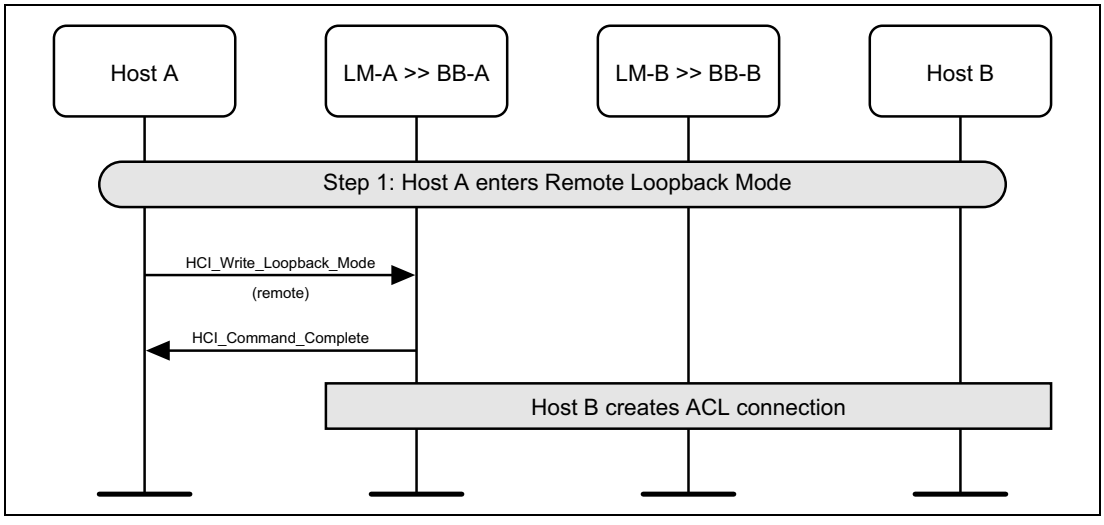

Figure 8.5: Entering remote loopback mode

Step 2: Any data received from the remote Host will be looped back in the Controller of the local device. (See Figure 8.6.)

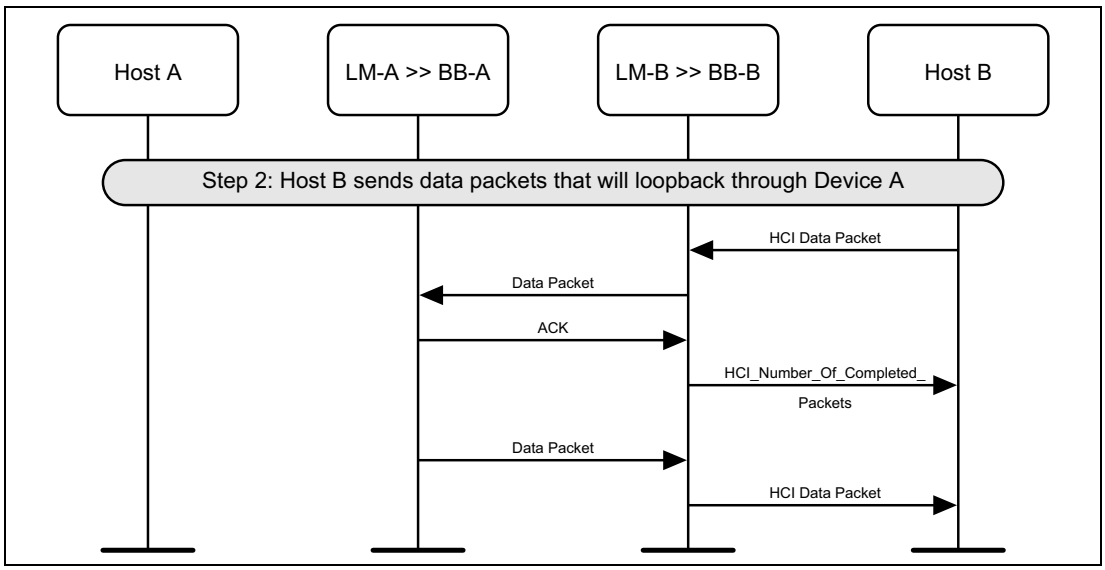

Figure 8.6: Looping back data in remote loopback mode

Step 3: The local Host exits remote loopback mode. Any connections can then be disconnected by the remote device. (See Figure 8.7.)

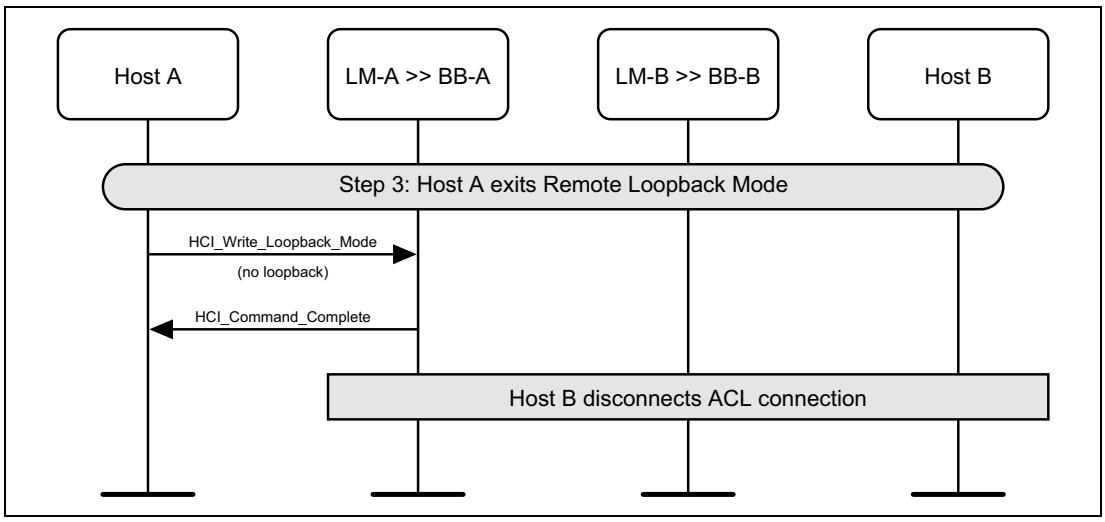

Figure 8.7: Exiting remote loopback mode

9 CONNECTIONLESS SLAVE BROADCAST SERVICES

Figure 9.1 illustrates the Truncated Page procedure.

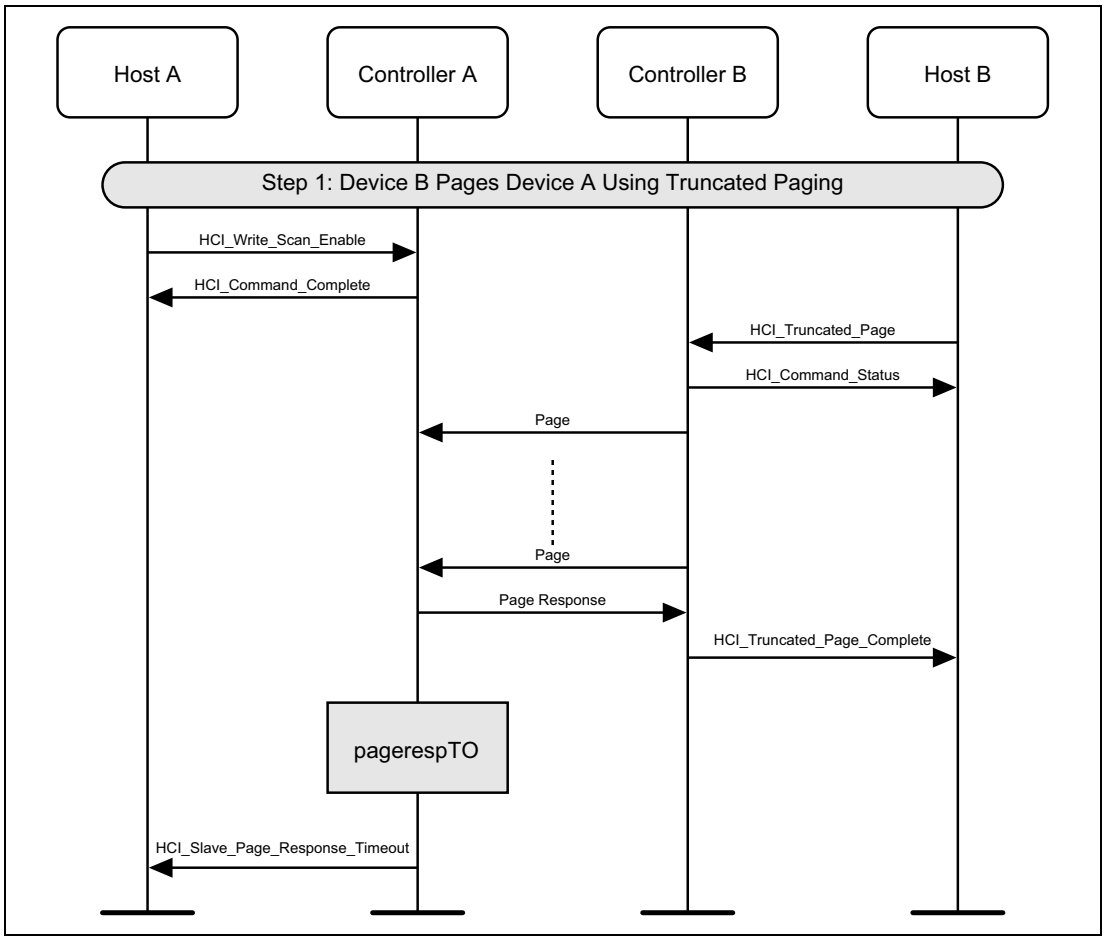

Figure 9.1: Truncated paging

Figure 9.2 illustrates how Device A starts transmitting Connectionless Slave Broadcast packets to Device B.

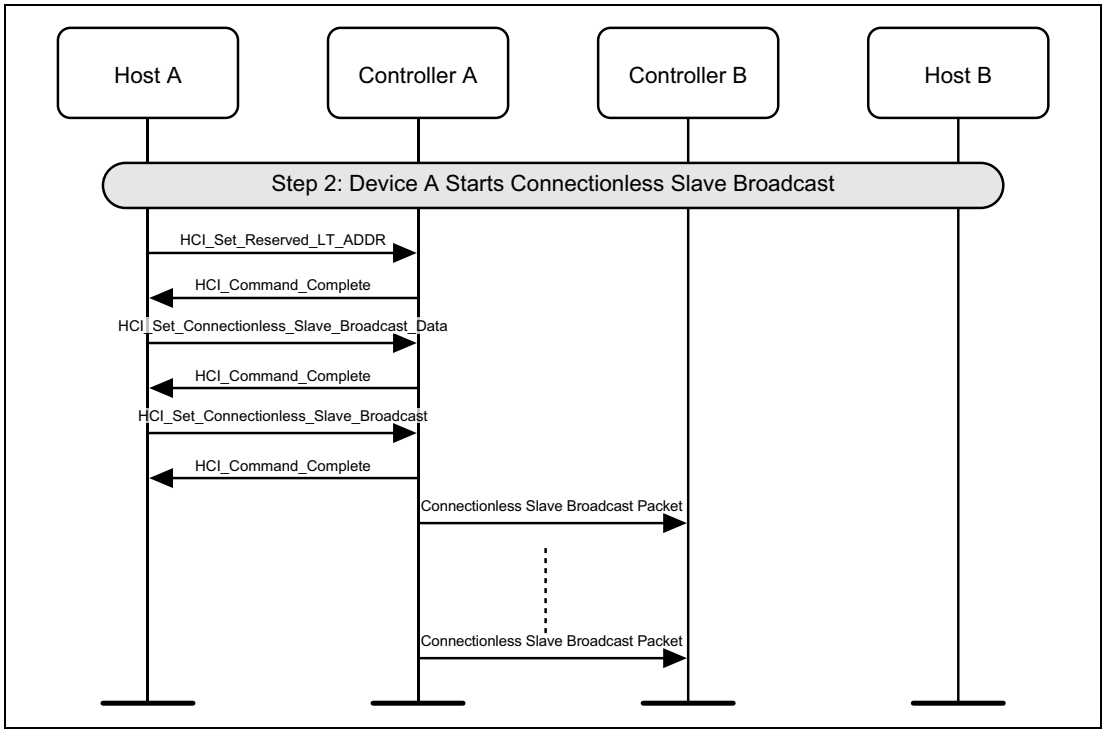

Figure 9.2: Connectionless slave broadcast transmitter start

Figure 9.3 shows the Synchronization Train feature. Device A is the Connectionless Slave Broadcast Transmitter. Device B is the Connectionless Slave Broadcast Receiver.

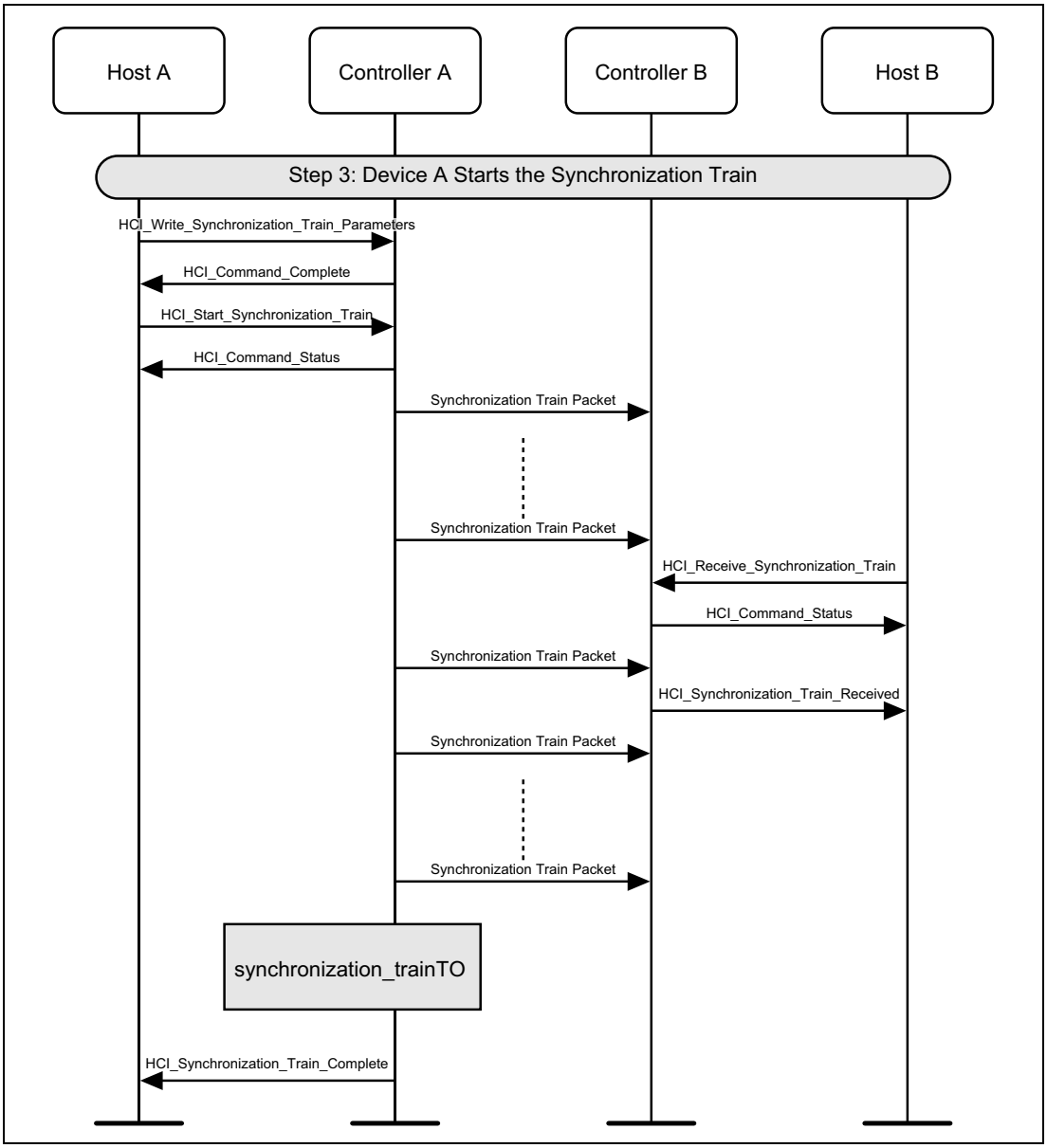

Figure 9.3: Synchronization train

Figure 9.4 illustrates how Device B starts receiving Connectionless Slave Broadcast packets from Device A.

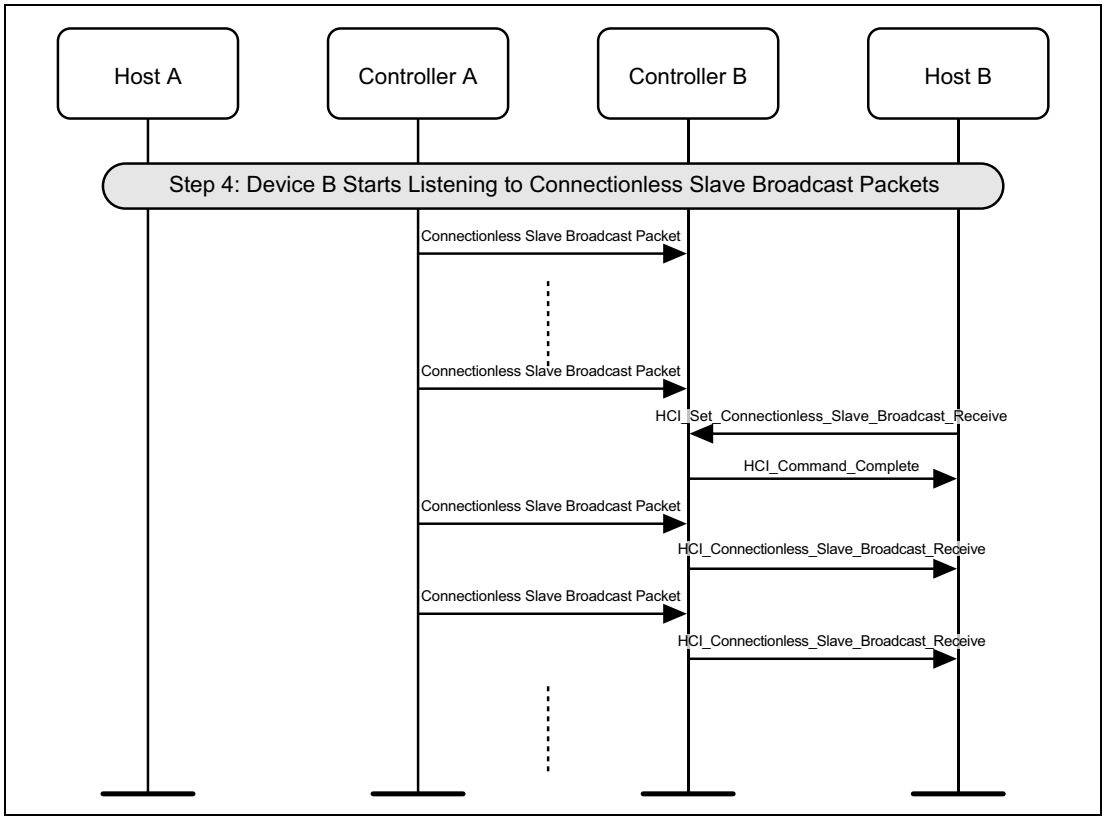

Figure 9.4: Connectionless slave broadcast receiver start

SAMPLE DATA

Sample data for various parts of the Bluetooth baseband specification. All sample data are provided for reference purpose only; they are intended as a complement to the definitions provided elsewhere in the specification. They can be used to check the behavior of an implementation and avoid misunderstandings. Fulfilling these sample data is a necessary but not sufficient condition for an implementation to be fully Bluetooth compliant.

CONTENTS

1 ENCRYPTION SAMPLE DATA

1.1 E0 ENCRYPTION SAMPLE DATA

This section contains four sets of sample data for the encryption process.

With respect to the functional description of the encryption engine in the Bluetooth baseband specification, the contents of registers and resulting concurrent values are listed as well. This by no means excludes different implementations (as far as they produce the same encryption stream) but is intended to describe the functional behavior.

In case of misunderstandings or inconsistencies, these sample data form the normative reference.

1.1.1 Generating Kc' from Kc

where Kc'(x) = g2(x)(Kc(x) mod g1(x)).

```
Note: All polynomials are in hexadecimal notation.
      'L' is the effective key length in bytes.
      The notation 'p: [m]' implies that deg(p(x)) = m.

                              MSB                                       LSB
L = 1
g1:                [8]        00000000 00000000 00000000 0000011d
g2:                [119]      00e275a0 abd218d4 cf928b9b bf6cb08f
Kc:                           a2b230a4 93f281bb 61a85b82 a9d4a30e
Kc mod g1:         [7]        00000000 00000000 00000000 0000009f
g2(Kc mod g1):     [126]      7aa16f39 59836ba3 22049a7b 87f1d8a5
------------------------------------------------------------
L = 2
g1:                [16]       00000000 00000000 00000000 0001003f
g2:                [112]      0001e3f6 3d7659b3 7f18c258 cff6efef
Kc:                           64e7df78 bb7ccaa4 61433123 5b3222ad
Kc mod g1:         [12]       00000000 00000000 00000000 00001ff0
g2(Kc mod g1):     [124]      142057bb 0bceac4c 58bd142e 1e710a50
------------------------------------------------------------
L = 3
g1:                [24]       00000000 00000000 00000000 010000db
g2:                [104]      000001be f66c6c3a b1030a5a 1919808b
Kc:                           575e5156 ba685dc6 112124ac edb2c179
Kc mod g1:         [23]       00000000 00000000 00000000 008ddbc8
g2(Kc mod g1):     [127]      d56d0adb 8216cb39 7fe3c591 1ff95618
------------------------------------------------------------
L = 4
g1:                [32]       00000000 00000000 00000001 000000af
g2:                [96]       00000001 6ab89969 de17467f d3736ad9
Kc:                           8917b4fc 403b6db2 1596b86d 1cb8adab
```

Sample Data

```
Kc mod g1:          [31]        00000000 00000000 00000000 aa1e78aa
g2(Kc mod g1):      [127]       91910128 b0e2f5ed a132a03e af3d8cda
------------------------------------------------------------
L = 5
g1:                 [40]        00000000 00000000 00000100 00000039
g2:                 [88]        00000000 01630632 91da50ec 55715247
Kc:                             785c915b dd25b9c6 0102ab00 b6cd2a68
Kc mod g1:          [38]        00000000 00000000 0000007f 13d44436
g2(Kc mod g1):      [126]       6fb5651c cb80c8d7 ea1ee56d f1ec5d02
------------------------------------------------------------
L = 6
g1:                 [48]        00000000 00000000 00010000 00000291
g2:                 [77]        00000000 00002c93 52aa6cc0 54468311
Kc:                             5e77d19f 55ccd7d5 798f9a32 3b83e5d8
Kc mod g1:          [47]        00000000 00000000 000082eb 4af213ed
g2(Kc mod g1):      [124]       16096bcb afcf8def 1d226a1b 4d3f9a3d
------------------------------------------------------------
```

Sample Data

```
L = 7
g1:                [56]        00000000 00000000 01000000 00000095
g2:                [71]        00000000 000000b3 f7fffce2 79f3a073
Kc:                            05454e03 8ddcfbe3 ed024b2d 92b7f54c
Kc mod g1:         [55]        00000000 00000000 0095b8a4 8eb816da
g2(Kc mod g1):     [126]       50f9c0d4 e3178da9 4a09fe0d 34f67b0e
------------------------------------------------------------
L = 8
g1:                [64]        00000000 00000001 00000000 0000001b
g2:                [63]        00000000 00000000 a1ab815b c7ec8025
Kc:                            7ce149fc f4b38ad7 2a5d8a41 eb15ba31
Kc mod g1:         [63]        00000000 00000000 8660806c 1865deec
g2(Kc mod g1):     [126]       532c36d4 5d0954e0 922989b6 826f78dc
------------------------------------------------------------
L = 9
g1:                [72]        00000000 00000100 00000000 00000609
g2:                [49]        00000000 00000000 0002c980 11d8b04d
Kc:                            5eeff7ca 84fc2782 9c051726 3df6f36e
Kc mod g1:         [71]        00000000 00000083 58ccb7d0 b95d3c71
g2(Kc mod g1):     [120]       016313f6 0d3771cf 7f8e4bb9 4aa6827d
------------------------------------------------------------
L = 10
g1:                [80]        00000000 00010000 00000000 00000215
g2:                [42]        00000000 00000000 0000058e 24f9a4bb
Kc:                            7b13846e 88beb4de 34e7160a fd44dc65
Kc mod g1:         [79]        00000000 0000b4de 34171767 f36981c3
g2(Kc mod g1):     [121]       023bc1ec 34a0029e f798dcfb 618ba58d
------------------------------------------------------------
L = 11
g1:                [88]        00000000 01000000 00000000 0000013b
g2:                [35]        00000000 00000000 0000000c a76024d7
Kc:                            bda6de6c 6e7d757e 8dfe2d49 9a181193
Kc mod g1:         [86]        00000000 007d757e 8dfe88aa 2fcee371
g2(Kc mod g1):     [121]       022e08a9 3aa51d8d 2f93fa78 85cc1f87
------------------------------------------------------------
L = 12
g1:                [96]        00000001 00000000 00000000 000000dd
g2:                [28]        00000000 00000000 00000000 1c9c26b9
Kc:                            e6483b1c 2cdb1040 9a658f97 c4efd90d
Kc mod g1:         [93]        00000000 2cdb1040 9a658fd7 5b562e41
g2(Kc mod g1):     [121]       030d752b 216fe29b b880275c d7e6f6f9
------------------------------------------------------------
L = 13
g1:                [104]       00000100 00000000 00000000 0000049d
g2:                [21]        00000000 00000000 00000000 0026d9e3
Kc:                            d79d281d a2266847 6b223c46 dc0ab9ee
Kc mod g1:         [100]       0000001d a2266847 6b223c45 e1fc5fa6
g2(Kc mod g1):     [121]       03f11138 9cebf919 00b93808 4ac158aa
------------------------------------------------------------
```

Sample Data

```
L = 14
g1:                [112]       00010000 00000000 00000000 0000014f
g2:                [14]        00000000 00000000 00000000 00004377
Kc:                            cad9a65b 9fca1c1d a2320fcf 7c4ae48e
Kc mod g1:         [111]       0000a65b 9fca1c1d a2320fcf 7cb6a909
g2(Kc mod g1):     [125]       284840fd f1305f3c 529f5703 76adf7cf
------------------------------------------------------------
L = 15
g1:                [120]       01000000 00000000 00000000 000000e7
g2:                [7]         00000000 00000000 00000000 00000089
Kc:                            21f0cc31 049b7163 d375e9e1 06029809
Kc mod g1:         [119]       00f0cc31 049b7163 d375e9e1 0602840e
g2(Kc mod g1):     [126]       7f10b53b 6df84b94 f22e566a 3754a37e
------------------------------------------------------------
L = 16
g1:                [128]       00000001 00000000 00000000 00000000 00000000
g2:                [0]         00000000 00000000 00000000 00000001
Kc:                            35ec8fc3 d50ccd32 5f2fd907 bde206de
Kc mod g1:         [125]       35ec8fc3 d50ccd32 5f2fd907 bde206de
g2(Kc mod g1):     [125]       35ec8fc3 d50ccd32 5f2fd907 bde206de
------------------------------------------------------------
```

1.1.2 First Set of Sample Data

```
Initial values for the key, pan address and clock

K'c1[0]   = 00   K'c1[1]   = 00    K'c1[2]   = 00    K'c1[3]  = 00
K'c1[4]   = 00   K'c1[5]   = 00    K'c1[6]   = 00    K'c1[7]  = 00
K'c1[8]   = 00   K'c1[9]   = 00    K'c1[10]  = 00    K'c1[11] = 00
K'c1[12]  = 00   K'c1[13]  = 00    K'c1[14]  = 00    K'c1[15] = 00

Addr1[0] = 00   Addr1[1] = 00    Addr1[2] = 00
Addr1[3] = 00   Addr1[4] = 00    Addr1[5] = 00

CL1[0]  = 00   CL1[1]  = 00    CL1[2]  = 00    CL1[3]  = 00


=============================================================================================
         Fill LFSRs with initial data
=============================================================================================

  t  clk#    LFSR1    LFSR2     LFSR3      LFSR4          X1 X2 X3 X4   Z  C[t+1] C[t] C[t-1]

  0     0    0000000* 00000000* 000000000* 0000000000*     0  0  0  0    0  00     00   00
  1     1    0000000* 00000001* 000000000* 0000000001*     0  0  0  0    0  00     00   00
  2     2    0000000* 00000002* 000000000* 0000000003*     0  0  0  0    0  00     00   00
  3     3    0000000* 00000004* 000000000* 0000000007*     0  0  0  0    0  00     00   00
  4     4    0000000* 00000008* 000000000* 000000000E*     0  0  0  0    0  00     00   00
  5     5    0000000* 00000010* 000000000* 000000001C*     0  0  0  0    0  00     00   00
  6     6    0000000* 00000020* 000000000* 0000000038*     0  0  0  0    0  00     00   00
```

Sample Data

7	7	0000000*	00000040*	000000000*	0000000070*	0	0	0	0	0	00	00	00
8	8	0000000*	00000080*	000000000*	00000000E0*	0	0	0	0	0	00	00	00
9	9	0000000*	00000100*	000000000*	00000001C0*	0	0	0	0	0	00	00	00
10	10	0000000*	00000200*	000000000*	0000000380*	0	0	0	0	0	00	00	00
11	11	0000000*	00000400*	000000000*	0000000700*	0	0	0	0	0	00	00	00
12	12	0000000*	00000800*	000000000*	0000000E00*	0	0	0	0	0	00	00	00
13	13	0000000*	00001000*	000000000*	0000001C00*	0	0	0	0	0	00	00	00
14	14	0000000*	00002000*	000000000*	0000003800*	0	0	0	0	0	00	00	00
15	15	0000000*	00004000*	000000000*	0000007000*	0	0	0	0	0	00	00	00
16	16	0000000*	00008000*	000000000*	000000E000*	0	0	0	0	0	00	00	00
17	17	0000000*	00010000*	000000000*	000001C000*	0	0	0	0	0	00	00	00
18	18	0000000*	00020000*	000000000*	0000038000*	0	0	0	0	0	00	00	00
19	19	0000000*	00040000*	000000000*	0000070000*	0	0	0	0	0	00	00	00
20	20	0000000*	00080000*	000000000*	00000E0000*	0	0	0	0	0	00	00	00
21	21	0000000*	00100000*	000000000*	00001C0000*	0	0	0	0	0	00	00	00
22	22	0000000*	00200000*	000000000*	0000380000*	0	0	0	0	0	00	00	00
23	23	0000000*	00400000*	000000000*	0000700000*	0	0	0	0	0	00	00	00
24	24	0000000*	00800000*	000000000*	0000E00000*	0	1	0	0	1	00	00	00
25	25	0000000*	01000000*	000000000*	0001C00000*	0	0	0	0	0	00	00	00
26	26	0000000	02000000*	000000000*	0003800000*	0	0	0	0	0	00	00	00
27	27	0000000	04000000*	000000000*	0007000000*	0	0	0	0	0	00	00	00
28	28	0000000	08000000*	000000000*	000E000000*	0	0	0	0	0	00	00	00
29	29	0000000	10000000*	000000000*	001C000000*	0	0	0	0	0	00	00	00
30	30	0000000	20000000*	000000000*	0038000000*	0	0	0	0	0	00	00	00
31	31	0000000	40000000*	000000000*	0070000000*	0	0	0	0	0	00	00	00
32	32	0000000	00000001	000000000*	00E0000000*	0	0	0	1	1	00	00	00
33	33	0000000	00000002	000000000*	01C0000000*	0	0	0	1	1	00	00	00
34	34	0000000	00000004	000000000	0380000000*	0	0	0	1	1	00	00	00
35	35	0000000	00000008	000000000	0700000000*	0	0	0	0	0	00	00	00
36	36	0000000	00000010	000000000	0E00000000*	0	0	0	0	0	00	00	00
37	37	0000000	00000020	000000000	1C00000000*	0	0	0	0	0	00	00	00
38	38	0000000	00000040	000000000	3800000000*	0	0	0	0	0	00	00	00
39	39	0000000	00000080	000000000	7000000000*	0	0	0	0	0	00	00	00

Start clocking Summation Combiner

40	1	0000000	00000100	000000000	6000000001	0	0	0	0	0	00	00	00
41	2	0000000	00000200	000000000	4000000003	0	0	0	0	0	00	00	00
42	3	0000000	00000400	000000000	0000000007	0	0	0	0	0	00	00	00
43	4	0000000	00000800	000000000	000000000E	0	0	0	0	0	00	00	00
44	5	0000000	00001001	000000000	000000001D	0	0	0	0	0	00	00	00
45	6	0000000	00002002	000000000	000000003B	0	0	0	0	0	00	00	00
46	7	0000000	00004004	000000000	0000000077	0	0	0	0	0	00	00	00
47	8	0000000	00008008	000000000	00000000EE	0	0	0	0	0	00	00	00
48	9	0000000	00010011	000000000	00000001DD	0	0	0	0	0	00	00	00
49	10	0000000	00020022	000000000	00000003BB	0	0	0	0	0	00	00	00
50	11	0000000	00040044	000000000	0000000777	0	0	0	0	0	00	00	00
51	12	0000000	00080088	000000000	0000000EEE	0	0	0	0	0	00	00	00
52	13	0000000	00100110	000000000	0000001DDD	0	0	0	0	0	00	00	00
53	14	0000000	00200220	000000000	0000003BBB	0	0	0	0	0	00	00	00
54	15	0000000	00400440	000000000	0000007777	0	0	0	0	0	00	00	00
55	16	0000000	00800880	000000000	000000EEEE	0	1	0	0	1	00	00	00
56	17	0000000	01001100	000000000	000001DDDD	0	0	0	0	0	00	00	00
57	18	0000000	02002200	000000000	000003BBBB	0	0	0	0	0	00	00	00
58	19	0000000	04004400	000000000	0000077777	0	0	0	0	0	00	00	00
59	20	0000000	08008800	000000000	00000EEEEE	0	0	0	0	0	00	00	00
60	21	0000000	10011000	000000000	00001DDDDD	0	0	0	0	0	00	00	00

Sample Data

61	22	0000000	20022000	000000000	00003BBBBB	0	0	0	0	0	00	00	00
62	23	0000000	40044000	000000000	0000777777	0	0	0	0	0	00	00	00
63	24	0000000	00088001	000000000	0000EEEEEE	0	0	0	0	0	00	00	00
64	25	0000000	00110003	000000000	0001DDDDDD	0	0	0	0	0	00	00	00
65	26	0000000	00220006	000000000	0003BBBBBB	0	0	0	0	0	00	00	00
66	27	0000000	0044000C	000000000	0007777777	0	0	0	0	0	00	00	00
67	28	0000000	00880018	000000000	000EEEEEEE	0	1	0	0	1	00	00	00
68	29	0000000	01100031	000000000	001DDDDDDC	0	0	0	0	0	00	00	00
69	30	0000000	02200062	000000000	003BBBBBB8	0	0	0	0	0	00	00	00
70	31	0000000	044000C4	000000000	0077777770	0	0	0	0	0	00	00	00
71	32	0000000	08800188	000000000	00EEEEEEE0	0	1	0	1	0	01	00	00
72	33	0000000	11000311	000000000	01DDDDDDC1	0	0	0	1	0	00	01	00
73	34	0000000	22000622	000000000	03BBBBBB83	0	0	0	1	1	11	00	01
74	35	0000000	44000C44	000000000	0777777707	0	0	0	0	1	10	11	00
75	36	0000000	08001888	000000000	0EEEEEEE0E	0	0	0	1	1	01	10	11
76	37	0000000	10003111	000000000	1DDDDDDC1D	0	0	0	1	0	01	01	10
77	38	0000000	20006222	000000000	3BBBBBB83B	0	0	0	1	0	11	01	01
78	39	0000000	4000C444	000000000	7777777077	0	0	0	0	1	01	11	01
79	40	0000000	00018888	000000000	6EEEEEE0EF	0	0	0	1	0	10	01	11
80	41	0000000	00031110	000000000	5DDDDDC1DE	0	0	0	1	1	00	10	01
81	42	0000000	00062220	000000000	3BBBBB83BC	0	0	0	1	1	01	00	10
82	43	0000000	000C4440	000000000	7777770779	0	0	0	0	1	01	01	00
83	44	0000000	00188880	000000000	6EEEEE0EF2	0	0	0	1	0	11	01	01
84	45	0000000	00311100	000000000	5DDDDC1DE5	0	0	0	1	0	10	11	01
85	46	0000000	00622200	000000000	3BBBB83BCB	0	0	0	1	1	01	10	11
86	47	0000000	00C44400	000000000	7777707797	0	1	0	0	0	01	01	10
87	48	0000000	01888801	000000000	6EEEE0EF2F	0	1	0	1	1	11	01	01
88	49	0000000	03111003	000000000	5DDDC1DE5E	0	0	0	1	0	10	11	01
89	50	0000000	06222006	000000000	3BBB83BCBC	0	0	0	1	1	01	10	11
90	51	0000000	0C44400C	000000000	7777077979	0	0	0	0	1	00	01	10
91	52	0000000	18888018	000000000	6EEE0EF2F2	0	1	0	1	0	10	00	01
92	53	0000000	31110030	000000000	5DDC1DE5E5	0	0	0	1	1	11	10	00
93	54	0000000	62220060	000000000	3BB83BCBCB	0	0	0	1	0	00	11	10
94	55	0000000	444400C1	000000000	7770779797	0	0	0	0	0	10	00	11
95	56	0000000	08880183	000000000	6EE0EF2F2F	0	1	0	1	0	00	10	00
96	57	0000000	11100307	000000000	5DC1DE5E5F	0	0	0	1	1	01	00	10
97	58	0000000	2220060E	000000000	3B83BCBCBF	0	0	0	1	0	00	01	00
98	59	0000000	44400C1C	000000000	770779797E	0	0	0	0	0	11	00	01
99	60	0000000	08801838	000000000	6E0EF2F2FC	0	1	0	0	0	01	11	00
100	61	0000000	11003070	000000000	5C1DE5E5F8	0	0	0	0	1	11	01	11
101	62	0000000	220060E0	000000000	383BCBCBF0	0	0	0	0	1	01	11	01
102	63	0000000	4400C1C0	000000000	70779797E0	0	0	0	0	1	11	01	11
103	64	0000000	08018380	000000000	60EF2F2FC1	0	0	0	1	0	10	11	01
104	65	0000000	10030701	000000000	41DE5E5F82	0	0	0	1	1	01	10	11
105	66	0000000	20060E02	000000000	03BCBCBF04	0	0	0	1	0	01	01	10
106	67	0000000	400C1C05	000000000	0779797E09	0	0	0	0	1	10	01	01
107	68	0000000	0018380A	000000000	0EF2F2FC12	0	0	0	1	1	00	10	01
108	69	0000000	00307015	000000000	1DE5E5F825	0	0	0	1	1	01	00	10
109	70	0000000	0060E02A	000000000	3BCBCBF04B	0	0	0	1	0	00	01	00
110	71	0000000	00C1C055	000000000	779797E097	0	1	0	1	0	10	00	01
111	72	0000000	018380AA	000000000	6F2F2FC12F	0	1	0	0	1	11	10	00
112	73	0000000	03070154	000000000	5E5E5F825E	0	0	0	0	1	11	11	10
113	74	0000000	060E02A8	000000000	3CBCBF04BC	0	0	0	1	0	11	11	11
114	75	0000000	0C1C0550	000000000	79797E0979	0	0	0	0	1	00	11	11
115	76	0000000	18380AA0	000000000	72F2FC12F2	0	0	0	1	1	10	00	11
116	77	0000000	30701541	000000000	65E5F825E5	0	0	0	1	1	11	10	00
117	78	0000000	60E02A82	000000000	4BCBF04BCB	0	1	0	1	1	00	11	10

Sample Data

118	79	0000000	41C05505	000000000	1797E09796	0	1	0	1	0	11	00	11
119	80	0000000	0380AA0A	000000000	2F2FC12F2C	0	1	0	0	0	01	11	00
120	81	0000000	07015415	000000000	5E5F825E59	0	0	0	0	1	11	01	11
121	82	0000000	0E02A82A	000000000	3CBF04BCB2	0	0	0	1	0	10	11	01
122	83	0000000	1C055054	000000000	797E097964	0	0	0	0	0	01	10	11
123	84	0000000	380AA0A8	000000000	72FC12F2C9	0	0	0	1	0	01	01	10
124	85	0000000	70154151	000000000	65F825E593	0	0	0	1	0	11	01	01
125	86	0000000	602A82A3	000000000	4BF04BCB26	0	0	0	1	0	10	11	01
126	87	0000000	40550546	000000000	17E097964C	0	0	0	1	1	01	10	11
127	88	0000000	00AA0A8D	000000000	2FC12F2C99	0	1	0	1	1	01	01	10
128	89	0000000	0154151A	000000000	5F825E5932	0	0	0	1	0	11	01	01
129	90	0000000	02A82A34	000000000	3F04BCB264	0	1	0	0	0	10	11	01
130	91	0000000	05505468	000000000	7E097964C9	0	0	0	0	0	01	10	11
131	92	0000000	0AA0A8D0	000000000	7C12F2C992	0	1	0	0	0	01	01	10
132	93	0000000	154151A1	000000000	7825E59324	0	0	0	0	1	10	01	01
133	94	0000000	2A82A342	000000000	704BCB2648	0	1	0	0	1	00	10	01
134	95	0000000	55054684	000000000	6097964C91	0	0	0	1	1	01	00	10
135	96	0000000	2A0A8D09	000000000	412F2C9923	0	0	0	0	1	01	01	00
136	97	0000000	54151A12	000000000	025E593246	0	0	0	0	1	10	01	01
137	98	0000000	282A3424	000000000	04BCB2648D	0	0	0	1	1	00	10	01
138	99	0000000	50546848	000000000	097964C91A	0	0	0	0	0	01	00	10
139	100	0000000	20A8D090	000000000	12F2C99235	0	1	0	1	1	00	01	00
140	101	0000000	4151A120	000000000	25E593246A	0	0	0	1	1	11	00	01
141	102	0000000	02A34240	000000000	4BCB2648D5	0	1	0	1	1	01	11	00
142	103	0000000	05468481	000000000	17964C91AB	0	0	0	1	0	10	01	11
143	104	0000000	0A8D0903	000000000	2F2C992357	0	1	0	0	1	00	10	01
144	105	0000000	151A1206	000000000	5E593246AE	0	0	0	0	0	01	00	10
145	106	0000000	2A34240C	000000000	3CB2648D5C	0	0	0	1	0	00	01	00
146	107	0000000	54684818	000000000	7964C91AB8	0	0	0	0	0	11	00	01
147	108	0000000	28D09030	000000000	72C9923571	0	1	0	1	1	01	11	00
148	109	0000000	51A12060	000000000	6593246AE2	0	1	0	1	1	10	01	11
149	110	0000000	234240C0	000000000	4B2648D5C5	0	0	0	0	0	00	10	01
150	111	0000000	46848180	000000000	164C91AB8A	0	1	0	0	1	01	00	10
151	112	0000000	0D090301	000000000	2C99235714	0	0	0	1	0	00	01	00
152	113	0000000	1A120602	000000000	593246AE28	0	0	0	0	0	11	00	01
153	114	0000000	34240C04	000000000	32648D5C51	0	0	0	0	1	10	11	00
154	115	0000000	68481809	000000000	64C91AB8A2	0	0	0	1	1	01	10	11
155	116	0000000	50903012	000000000	4992357144	0	1	0	1	1	01	01	10
156	117	0000000	21206024	000000000	13246AE288	0	0	0	0	1	10	01	01
157	118	0000000	4240C048	000000000	2648D5C511	0	0	0	0	0	00	10	01
158	119	0000000	04818090	000000000	4C91AB8A23	0	1	0	1	0	00	00	10
159	120	0000000	09030120	000000000	1923571446	0	0	0	0	0	00	00	00
160	121	0000000	12060240	000000000	3246AE288D	0	0	0	0	0	00	00	00
161	122	0000000	240C0480	000000000	648D5C511B	0	0	0	1	1	00	00	00
162	123	0000000	48180900	000000000	491AB8A237	0	0	0	0	0	00	00	00
163	124	0000000	10301200	000000000	123571446F	0	0	0	0	0	00	00	00
164	125	0000000	20602400	000000000	246AE288DF	0	0	0	0	0	00	00	00
165	126	0000000	40C04800	000000000	48D5C511BE	0	1	0	1	0	01	00	00
166	127	0000000	01809001	000000000	11AB8A237D	0	1	0	1	1	00	01	00
167	128	0000000	03012002	000000000	23571446FA	0	0	0	0	0	11	00	01
168	129	0000000	06024004	000000000	46AE288DF5	0	0	0	1	0	01	11	00
169	130	0000000	0C048008	000000000	0D5C511BEA	0	0	0	0	1	11	01	11
170	131	0000000	18090011	000000000	1AB8A237D5	0	0	0	1	0	10	11	01
171	132	0000000	30120022	000000000	3571446FAA	0	0	0	0	0	01	10	11
172	133	0000000	60240044	000000000	6AE288DF55	0	0	0	1	0	01	01	10
173	134	0000000	40480089	000000000	55C511BEAA	0	0	0	1	0	11	01	01
174	135	0000000	00900113	000000000	2B8A237D54	0	1	0	1	1	10	11	01

Sample Data

175	136	0000000	01200227	000000000	571446FAA8	0	0	0	0	0	01	10	11
176	137	0000000	0240044E	000000000	2E288DF550	0	0	0	0	1	00	01	10
177	138	0000000	0480089C	000000000	5C511BEAA0	0	1	0	0	1	11	00	01
178	139	0000000	09001138	000000000	38A237D540	0	0	0	1	0	01	11	00
179	140	0000000	12002270	000000000	71446FAA81	0	0	0	0	1	11	01	11
180	141	0000000	240044E0	000000000	6288DF5503	0	0	0	1	0	10	11	01
181	142	0000000	480089C0	000000000	4511BEAA06	0	0	0	0	0	01	10	11
182	143	0000000	10011381	000000000	0A237D540D	0	0	0	0	1	00	01	10
183	144	0000000	20022702	000000000	1446FAA81A	0	0	0	0	0	11	00	01
184	145	0000000	40044E04	000000000	288DF55035	0	0	0	1	0	01	11	00
185	146	0000000	00089C08	000000000	511BEAA06A	0	0	0	0	1	11	01	11
186	147	0000000	00113810	000000000	2237D540D5	0	0	0	0	1	01	11	01
187	148	0000000	00227021	000000000	446FAA81AA	0	0	0	0	1	11	01	11
188	149	0000000	0044E042	000000000	08DF550355	0	0	0	1	0	10	11	01
189	150	0000000	0089C085	000000000	11BEAA06AA	0	1	0	1	0	10	10	11
190	151	0000000	0113810A	000000000	237D540D54	0	0	0	0	0	10	10	10
191	152	0000000	02270215	000000000	46FAA81AA9	0	0	0	1	1	10	10	10
192	153	0000000	044E042A	000000000	0DF5503553	0	0	0	1	1	10	10	10
193	154	0000000	089C0854	000000000	1BEAA06AA7	0	1	0	1	0	01	10	10
194	155	0000000	113810A8	000000000	37D540D54E	0	0	0	1	0	01	01	10
195	156	0000000	22702150	000000000	6FAA81AA9D	0	0	0	1	0	11	01	01
196	157	0000000	44E042A0	000000000	5F5503553A	0	1	0	0	0	10	11	01
197	158	0000000	09C08540	000000000	3EAA06AA75	0	1	0	1	0	10	10	11
198	159	0000000	13810A80	000000000	7D540D54EA	0	1	0	0	1	10	10	10
199	160	0000000	27021500	000000000	7AA81AA9D5	0	0	0	1	1	10	10	10
200	161	0000000	4E042A00	000000000	75503553AB	0	0	0	0	0	10	10	10
201	162	0000000	1C085400	000000000	6AA06AA756	0	0	0	1	1	10	10	10
202	163	0000000	3810A800	000000000	5540D54EAC	0	0	0	0	0	10	10	10
203	164	0000000	70215000	000000000	2A81AA9D58	0	0	0	1	1	10	10	10
204	165	0000000	6042A001	000000000	5503553AB0	0	0	0	0	0	10	10	10
205	166	0000000	40854002	000000000	2A06AA7561	0	1	0	0	1	10	10	10
206	167	0000000	010A8004	000000000	540D54EAC3	0	0	0	0	0	10	10	10
207	168	0000000	02150009	000000000	281AA9D586	0	0	0	0	0	10	10	10
208	169	0000000	042A0012	000000000	503553AB0C	0	0	0	0	0	10	10	10
209	170	0000000	08540024	000000000	206AA75618	0	0	0	0	0	10	10	10
210	171	0000000	10A80048	000000000	40D54EAC30	0	1	0	1	0	01	10	10
211	172	0000000	21500091	000000000	01AA9D5861	0	0	0	1	0	01	01	10
212	173	0000000	42A00122	000000000	03553AB0C3	0	1	0	0	0	11	01	01
213	174	0000000	05400244	000000000	06AA756186	0	0	0	1	0	10	11	01
214	175	0000000	0A800488	000000000	0D54EAC30D	0	1	0	0	1	01	10	11
215	176	0000000	15000911	000000000	1AA9D5861A	0	0	0	1	0	01	01	10
216	177	0000000	2A001223	000000000	3553AB0C35	0	0	0	0	1	10	01	01
217	178	0000000	54002446	000000000	6AA756186A	0	0	0	1	1	00	10	01
218	179	0000000	2800488D	000000000	554EAC30D5	0	0	0	0	0	01	00	10
219	180	0000000	5000911B	000000000	2A9D5861AA	0	0	0	1	0	00	01	00
220	181	0000000	20012236	000000000	553AB0C355	0	0	0	0	0	11	00	01
221	182	0000000	4002446C	000000000	2A756186AA	0	0	0	0	1	10	11	00
222	183	0000000	000488D9	000000000	54EAC30D54	0	0	0	1	1	01	10	11
223	184	0000000	000911B2	000000000	29D5861AA8	0	0	0	1	0	01	01	10
224	185	0000000	00122364	000000000	53AB0C3550	0	0	0	1	0	11	01	01
225	186	0000000	002446C8	000000000	2756186AA0	0	0	0	0	1	01	11	01
226	187	0000000	00488D90	000000000	4EAC30D540	0	0	0	1	0	10	01	11
227	188	0000000	00911B20	000000000	1D5861AA81	0	1	0	0	1	00	10	01
228	189	0000000	01223640	000000000	3AB0C35502	0	0	0	1	1	01	00	10
229	190	0000000	02446C80	000000000	756186AA05	0	0	0	0	1	01	01	00
230	191	0000000	0488D901	000000000	6AC30D540B	0	1	0	1	1	11	01	01
231	192	0000000	0911B203	000000000	55861AA817	0	0	0	1	0	10	11	01

Sample Data

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232   193    0000000  12236407  000000000  2B0C35502F      0  0  0  0    0  01     10   11
233   194    0000000  2446C80E  000000000  56186AA05F      0  0  0  0    1  00     01   10
234   195    0000000  488D901C  000000000  2C30D540BF      0  1  0  0    1  11     00   01
235   196    0000000  111B2039  000000000  5861AA817E      0  0  0  0    1  10     11   00
236   197    0000000  22364072  000000000  30C35502FD      0  0  0  1    1  01     10   11
237   198    0000000  446C80E4  000000000  6186AA05FB      0  0  0  1    0  01     01   10
238   199    0000000  08D901C8  000000000  430D540BF6      0  1  0  0    0  11     01   01
239   200    0000000  11B20391  000000000  061AA817EC      0  1  0  0    0  10     11   01

Z[0]  = 3D
Z[1]  = C1
Z[2]  = F0
Z[3]  = BB
Z[4]  = 58
Z[5]  = 1E
Z[6]  = 42
Z[7]  = 42
Z[8]  = 4B
Z[9]  = 8E
Z[10] = C1
Z[11] = 2A
Z[12] = 40
Z[13] = 63
Z[14] = 7A
Z[15] = 1E

================================================================================================
         Reload this pattern into the LFSRs
         Hold content of Summation Combiner regs and calculate new C[t+1] and Z values
================================================================================================
LFSR1  <= 04B583D
LFSR2  <= 208E1EC1
LFSR3  <= 063C142F0
LFSR4  <= 0F7A2A42BB
C[t+1] <= 10

================================================================================================
         Generating 125 key symbols (encryption/decryption sequence)
================================================================================================
240     1    04B583D  208E1EC1  063C142F0  0F7A2A42BB      0  1  0  0    0  10     11   01
241     2    096B07A  411C3D82  0C78285E1  1EF4548577      1  0  1  1    1  10     10   11
242     3    12D60F4  02387B04  18F050BC3  3DE8A90AEF      0  0  1  1    0  01     10   10
243     4    05AC1E9  0470F609  11E0A1786  7BD15215DF      0  0  0  1    0  01     01   10
244     5    0B583D2  08E1EC13  03C142F0C  77A2A42BBF      1  1  0  1    0  00     01   01
245     6    16B07A5  11C3D827  078285E18  6F4548577E      0  1  0  0    1  11     00   01
246     7    0D60F4B  2387B04F  0F050BC30  5E8A90AEFD      1  1  1  1    1  00     11   00
247     8    1AC1E97  470F609E  1E0A17860  3D15215DFA      1  0  1  0    0  11     00   11
248     9    1583D2E  0E1EC13D  1C142F0C0  7A2A42BBF4      0  0  1  0    0  01     11   00
249    10    0B07A5D  1C3D827B  18285E181  74548577E9      1  0  1  0    1  10     01   11
250    11    160F4BB  387B04F7  1050BC302  68A90AEFD2      0  0  0  1    1  00     10   01
251    12    0C1E976  70F609EE  00A178605  515215DFA5      1  1  0  0    0  00     00   10
252    13    183D2ED  61EC13DD  0142F0C0B  22A42BBF4B      1  1  0  1    1  01     00   00
253    14    107A5DA  43D827BA  0285E1817  4548577E97      0  1  0  0    0  00     01   00
254    15    00F4BB4  07B04F74  050BC302F  0A90AEFD2E      0  1  0  1    0  10     00   01
255    16    01E9769  0F609EE8  0A178605E  15215DFA5C      0  0  1  0    1  11     10   00
256    17    03D2ED3  1EC13DD0  142F0C0BD  2A42BBF4B9      0  1  0  0    0  00     11   10
257    18    07A5DA7  3D827BA0  085E1817B  548577E972      0  1  1  1    1  11     00   11
```

Sample Data

258	19	0F4BB4F	7B04F740	10BC302F6	290AEFD2E5	1	0	0	0	0	01	11	00
259	20	1E9769F	7609EE80	0178605ED	5215DFA5CA	1	0	0	0	0	10	01	11
260	21	1D2ED3F	6C13DD01	02F0C0BDA	242BBF4B94	1	0	0	0	1	00	10	01
261	22	1A5DA7E	5827BA03	05E1817B4	48577E9729	1	0	0	0	1	01	00	10
262	23	14BB4FC	304F7407	0BC302F69	10AEFD2E53	0	0	1	1	1	00	01	00
263	24	09769F9	609EE80E	178605ED2	215DFA5CA7	1	1	0	0	0	10	00	01
264	25	12ED3F2	413DD01C	0F0C0BDA4	42BBF4B94F	0	0	1	1	0	00	10	00
265	26	05DA7E5	027BA038	1E1817B49	0577E9729F	0	0	1	0	1	01	00	10
266	27	0BB4FCA	04F74071	1C302F693	0AEFD2E53F	1	1	1	1	1	11	01	00
267	28	1769F95	09EE80E3	18605ED27	15DFA5CA7F	0	1	1	1	0	11	11	01
268	29	0ED3F2B	13DD01C6	10C0BDA4F	2BBF4B94FE	1	1	0	1	0	10	11	11
269	30	1DA7E56	27BA038D	01817B49F	577E9729FD	1	1	0	0	0	10	10	11
270	31	1B4FCAD	4F74071B	0302F693E	2EFD2E53FB	1	0	0	1	0	01	10	10
271	32	169F95B	1EE80E37	0605ED27D	5DFA5CA7F7	0	1	0	1	1	01	01	10
272	33	0D3F2B7	3DD01C6E	0C0BDA4FB	3BF4B94FEF	1	1	1	1	1	00	01	01
273	34	1A7E56F	7BA038DC	1817B49F6	77E9729FDE	1	1	1	1	0	01	00	01
274	35	14FCADF	774071B9	102F693ED	6FD2E53FBD	0	0	0	1	0	00	01	00
275	36	09F95BE	6E80E373	005ED27DB	5FA5CA7F7B	1	1	0	1	1	10	00	01
276	37	13F2B7C	5D01C6E7	00BDA4FB6	3F4B94FEF7	0	0	0	0	0	11	10	00
277	38	07E56F9	3A038DCE	017B49F6C	7E9729FDEE	0	0	0	1	0	00	11	10
278	39	0FCADF2	74071B9C	02F693ED8	7D2E53FBDD	1	0	0	0	1	10	00	11
279	40	1F95BE5	680E3738	05ED27DB0	7A5CA7F7BA	1	0	0	0	1	11	10	00
280	41	1F2B7CA	501C6E71	0BDA4FB60	74B94FEF74	1	0	1	1	0	01	11	10
281	42	1E56F94	2038DCE2	17B49F6C0	69729FDEE8	1	0	0	0	0	10	01	11
282	43	1CADF29	4071B9C4	0F693ED80	52E53FBDD1	1	0	1	1	1	11	10	01
283	44	195BE53	00E37389	1ED27DB01	25CA7F7BA3	1	1	1	1	1	01	11	10
284	45	12B7CA6	01C6E713	1DA4FB602	4B94FEF747	0	1	1	1	0	01	01	11
285	46	056F94C	038DCE26	1B49F6C04	1729FDEE8E	0	1	1	0	1	11	01	01
286	47	0ADF299	071B9C4D	1693ED808	2E53FBDD1C	1	0	0	0	0	10	11	01
287	48	15BE532	0E37389A	0D27DB011	5CA7F7BA38	0	0	1	1	0	10	10	11
288	49	0B7CA64	1C6E7135	1A4FB6022	394FEF7471	1	0	1	0	0	01	10	10
289	50	16F94C9	38DCE26A	149F6C044	729FDEE8E2	0	1	0	1	1	01	01	10
290	51	0DF2993	71B9C4D4	093ED8089	653FBDD1C4	1	1	1	0	0	00	01	01
291	52	1BE5327	637389A9	127DB0112	4A7F7BA388	1	0	0	0	1	11	00	01
292	53	17CA64E	46E71353	04FB60224	14FEF74710	0	1	0	1	1	01	11	00
293	54	0F94C9C	0DCE26A6	09F6C0448	29FDEE8E21	1	1	1	1	1	01	01	11
294	55	1F29939	1B9C4D4D	13ED80890	53FBDD1C42	1	1	0	1	0	00	01	01
295	56	1E53272	37389A9A	07DB01121	27F7BA3884	1	0	0	1	0	10	00	01
296	57	1CA64E5	6E713534	0FB602242	4FEF747108	1	0	1	1	1	00	10	00
297	58	194C9CB	5CE26A69	1F6C04485	1FDEE8E210	1	1	1	1	0	11	00	10
298	59	1299397	39C4D4D3	1ED80890A	3FBDD1C420	0	1	1	1	0	00	11	00
299	60	053272F	7389A9A6	1DB011214	7F7BA38840	0	1	1	0	0	11	00	11
300	61	0A64E5E	6713534C	1B6022428	7EF7471081	1	0	1	1	0	00	11	00
301	62	14C9CBD	4E26A699	16C044850	7DEE8E2102	0	0	0	1	1	10	00	11
302	63	099397A	1C4D4D32	0D80890A0	7BDD1C4205	1	0	1	1	1	00	10	00
303	64	13272F4	389A9A65	1B0112141	77BA38840B	0	1	1	1	1	00	00	10
304	65	064E5E8	713534CB	160224283	6F74710817	0	0	0	0	0	00	00	00
305	66	0C9CBD1	626A6997	0C0448507	5EE8E2102E	1	0	1	1	1	01	00	00
306	67	19397A3	44D4D32E	180890A0E	3DD1C4205C	1	1	1	1	1	11	01	00
307	68	1272F46	09A9A65D	10112141D	7BA38840B8	0	1	0	1	1	10	11	01
308	69	04E5E8C	13534CBA	00224283A	7747108171	0	0	0	0	0	01	10	11
309	70	09CBD19	26A69975	004485075	6E8E2102E3	1	1	0	1	0	10	01	10
310	71	1397A32	4D4D32EB	00890A0EA	5D1C4205C7	0	0	0	0	0	00	10	01
311	72	072F465	1A9A65D7	0112141D5	3A38840B8F	0	1	0	0	1	01	00	10
312	73	0E5E8CA	3534CBAF	0224283AA	747108171F	1	0	0	0	0	00	01	00
313	74	1CBD194	6A69975E	044850755	68E2102E3E	1	0	0	1	0	10	00	01
314	75	197A329	54D32EBC	0890A0EAB	51C4205C7D	1	1	1	1	0	01	10	00

Sample Data

315	76	12F4653	29A65D79	112141D56	238840B8FA	0	1	0	1	1	01	01	10
316	77	05E8CA6	534CBAF2	024283AAD	47108171F4	0	0	0	0	1	10	01	01
317	78	0BD194D	269975E5	04850755B	0E2102E3E9	1	1	0	0	0	11	10	01
318	79	17A329A	4D32EBCB	090A0EAB6	1C4205C7D2	0	0	1	0	0	00	11	10
319	80	0F46535	1A65D797	12141D56D	38840B8FA5	1	0	0	1	0	11	00	11
320	81	1E8CA6A	34CBAF2F	04283AADA	7108171F4B	1	1	0	0	1	01	11	00
321	82	1D194D5	69975E5F	0850755B4	62102E3E97	1	1	1	0	0	01	01	11
322	83	1A329AA	532EBCBF	10A0EAB68	44205C7D2F	1	0	0	0	0	11	01	01
323	84	1465355	265D797F	0141D56D1	0840B8FA5E	0	0	0	0	1	01	11	01
324	85	08CA6AB	4CBAF2FF	0283AADA2	108171F4BC	1	1	0	1	0	01	01	11
325	86	1194D56	1975E5FF	050755B45	2102E3E979	0	0	0	0	1	10	01	01
326	87	0329AAD	32EBCBFF	0A0EAB68A	4205C7D2F3	0	1	1	0	0	11	10	01
327	88	065355A	65D797FF	141D56D14	040B8FA5E7	0	1	0	0	0	00	11	10
328	89	0CA6AB4	4BAF2FFF	083AADA28	08171F4BCF	1	1	1	0	1	11	00	11
329	90	194D569	175E5FFF	10755B450	102E3E979E	1	0	0	0	0	01	11	00
330	91	129AAD3	2EBCBFFF	00EAB68A1	205C7D2F3C	0	1	0	0	0	10	01	11
331	92	05355A6	5D797FFF	01D56D142	40B8FA5E78	0	0	0	1	1	00	10	01
332	93	0A6AB4D	3AF2FFFE	03AADA285	0171F4BCF1	1	1	0	0	0	00	00	10
333	94	14D569B	75E5FFFD	0755B450A	02E3E979E2	0	1	0	1	0	01	00	00
334	95	09AAD37	6BCBFFFA	0EAB68A15	05C7D2F3C4	1	1	1	1	1	11	01	00
335	96	1355A6E	5797FFF4	1D56D142A	0B8FA5E788	0	1	1	1	0	11	11	01
336	97	06AB4DC	2F2FFFE8	1AADA2854	171F4BCF11	0	0	1	0	0	11	11	11
337	98	0D569B8	5E5FFFD0	155B450A9	2E3E979E23	1	0	0	0	0	11	11	11
338	99	1AAD370	3CBFFFA1	0AB68A153	5C7D2F3C46	1	1	1	0	0	10	11	11
339	100	155A6E0	797FFF43	156D142A7	38FA5E788D	0	0	0	1	1	01	10	11
340	101	0AB4DC0	72FFFE87	0ADA2854E	71F4BCF11B	1	1	1	1	1	10	01	10
341	102	1569B81	65FFFD0E	15B450A9D	63E979E236	0	1	0	1	0	11	10	01
342	103	0AD3703	4BFFFA1C	0B68A153B	47D2F3C46C	1	1	1	1	1	01	11	10
343	104	15A6E07	17FFF438	16D142A76	0FA5E788D8	0	1	0	1	1	10	01	11
344	105	0B4DC0F	2FFFE870	0DA2854EC	1F4BCF11B0	1	1	1	0	1	11	10	01
345	106	169B81F	5FFFD0E1	1B450A9D8	3E979E2360	0	1	1	1	0	01	11	10
346	107	0D3703F	3FFFA1C3	168A153B0	7D2F3C46C1	1	1	0	0	1	10	01	11
347	108	1A6E07E	7FFF4386	0D142A761	7A5E788D83	1	1	1	0	1	11	10	01
348	109	14DC0FD	7FFE870C	1A2854EC2	74BCF11B07	0	1	1	1	0	01	11	10
349	110	09B81FB	7FFD0E19	1450A9D84	6979E2360E	1	1	0	0	1	10	01	11
350	111	13703F6	7FFA1C33	08A153B09	52F3C46C1C	0	1	1	1	1	11	10	01
351	112	06E07EC	7FF43867	1142A7612	25E788D838	0	1	0	1	1	00	11	10
352	113	0DC0FD8	7FE870CF	02854EC25	4BCF11B071	1	1	0	1	1	11	00	11
353	114	1B81FB1	7FD0E19E	050A9D84B	179E2360E3	1	1	0	1	0	00	11	00
354	115	1703F62	7FA1C33D	0A153B096	2F3C46C1C7	0	1	1	0	0	11	00	11
355	116	0E07EC4	7F43867B	142A7612C	5E788D838E	1	0	0	0	0	01	11	00
356	117	1C0FD88	7E870CF6	0854EC259	3CF11B071C	1	1	1	1	1	01	01	11
357	118	181FB11	7D0E19ED	10A9D84B3	79E2360E38	1	0	0	1	1	11	01	01
358	119	103F622	7A1C33DA	0153B0967	73C46C1C71	0	0	0	1	0	10	11	01
359	120	007EC45	743867B5	02A7612CE	6788D838E3	0	0	0	1	1	01	10	11
360	121	00FD88B	6870CF6B	054EC259C	4F11B071C6	0	0	0	0	1	00	01	10
361	122	01FB117	50E19ED7	0A9D84B38	1E2360E38C	0	1	1	0	0	10	00	01
362	123	03F622F	21C33DAE	153B09671	3C46C1C718	0	1	0	0	1	11	10	00
363	124	07EC45F	43867B5C	0A7612CE2	788D838E30	0	1	1	1	0	01	11	10
364	125	0FD88BF	070CF6B9	14EC259C4	711B071C61	1	0	0	0	0	10	01	11

Sample Data

1.1.3 Second Set of Sample Data

```
Initial values for the key, BD_ADDR and clock

K'c2[0]   = 00   K'c2[1]   = 00    K'c2[2]   = 00    K'c2[3]  = 00
K'c2[4]   = 00   K'c2[5]   = 00    K'c2[6]   = 00    K'c2[7]  = 00
K'c2[8]   = 00   K'c2[9]   = 00    K'c2[10]  = 00    K'c2[11] = 00
K'c2[12]  = 00   K'c2[13]  = 00    K'c2[14]  = 00    K'c2[15] = 00

Addr2[0] = 00   Addr2[1] = 00    Addr2[2] = 00
Addr2[3] = 00   Addr2[4] = 00    Addr2[5] = 00

CL2[0]  = 00   CL2[1]  = 00    CL2[2]  = 00    CL2[3]  = 03


=============================================================================================
         Fill LFSRs with initial data
=============================================================================================

  t  clk#    LFSR1    LFSR2     LFSR3      LFSR4          X1 X2 X3 X4   Z  C[t+1] C[t] C[t-1]

  0     0    0000000* 00000000* 000000000* 0000000000*     0  0  0  0    0  00     00   00
  1     1    0000001* 00000001* 000000001* 0000000001*     0  0  0  0    0  00     00   00
  2     2    0000002* 00000002* 000000002* 0000000003*     0  0  0  0    0  00     00   00
  3     3    0000004* 00000004* 000000004* 0000000007*     0  0  0  0    0  00     00   00
  4     4    0000008* 00000008* 000000008* 000000000E*     0  0  0  0    0  00     00   00
  5     5    0000010* 00000010* 000000010* 000000001C*     0  0  0  0    0  00     00   00
  6     6    0000020* 00000020* 000000020* 0000000038*     0  0  0  0    0  00     00   00
  7     7    0000040* 00000040* 000000040* 0000000070*     0  0  0  0    0  00     00   00
  8     8    0000080* 00000080* 000000080* 00000000E0*     0  0  0  0    0  00     00   00
  9     9    0000100* 00000100* 000000100* 00000001C0*     0  0  0  0    0  00     00   00
 10    10    0000200* 00000200* 000000200* 0000000380*     0  0  0  0    0  00     00   00
 11    11    0000400* 00000400* 000000400* 0000000700*     0  0  0  0    0  00     00   00
 12    12    0000800* 00000800* 000000800* 0000000E00*     0  0  0  0    0  00     00   00
 13    13    0001000* 00001000* 000001000* 0000001C00*     0  0  0  0    0  00     00   00
 14    14    0002000* 00002000* 000002000* 0000003800*     0  0  0  0    0  00     00   00
 15    15    0004000* 00004000* 000004000* 0000007000*     0  0  0  0    0  00     00   00
 16    16    0008000* 00008000* 000008000* 000000E000*     0  0  0  0    0  00     00   00
 17    17    0010000* 00010000* 000010000* 000001C000*     0  0  0  0    0  00     00   00
 18    18    0020000* 00020000* 000020000* 0000038000*     0  0  0  0    0  00     00   00
 19    19    0040000* 00040000* 000040000* 0000070000*     0  0  0  0    0  00     00   00
 20    20    0080000* 00080000* 000080000* 00000E0000*     0  0  0  0    0  00     00   00
 21    21    0100000* 00100000* 000100000* 00001C0000*     0  0  0  0    0  00     00   00
 22    22    0200000* 00200000* 000200000* 0000380000*     0  0  0  0    0  00     00   00
 23    23    0400000* 00400000* 000400000* 0000700000*     0  0  0  0    0  00     00   00
 24    24    0800000* 00800000* 000800000* 0000E00000*     1  1  0  0    0  01     00   00
 25    25    1000000* 01000000* 001000000* 0001C00000*     0  0  0  0    0  00     00   00
 26    26    0000001  02000000* 002000000* 0003800000*     0  0  0  0    0  00     00   00
 27    27    0000002  04000000* 004000000* 0007000000*     0  0  0  0    0  00     00   00
 28    28    0000004  08000000* 008000000* 000E000000*     0  0  0  0    0  00     00   00
 29    29    0000008  10000000* 010000000* 001C000000*     0  0  0  0    0  00     00   00
 30    30    0000010  20000000* 020000000* 0038000000*     0  0  0  0    0  00     00   00
 31    31    0000020  40000000* 040000000* 0070000000*     0  0  0  0    0  00     00   00
 32    32    0000040  00000001  080000000* 00E0000000*     0  0  1  1    0  01     00   00
 33    33    0000080  00000002  100000000* 01C0000000*     0  0  0  1    1  00     00   00
 34    34    0000101  00000004  000000001  0380000000*     0  0  0  1    1  00     00   00
```

Sample Data

35	35	0000202	00000008	000000002	0700000000*	0	0	0	0	0	00	00	00
36	36	0000404	00000010	000000004	0E00000000*	0	0	0	0	0	00	00	00
37	37	0000808	00000020	000000008	1C00000000*	0	0	0	0	0	00	00	00
38	38	0001011	00000040	000000011	3800000000*	0	0	0	0	0	00	00	00
39	39	0002022	00000080	000000022	7000000000*	0	0	0	0	0	00	00	00

Start clocking Summation Combiner

40	1	0004044	00000100	000000044	6000000001	0	0	0	0	0	00	00	00
41	2	0008088	00000200	000000088	4000000003	0	0	0	0	0	00	00	00
42	3	0010111	00000400	000000111	0000000007	0	0	0	0	0	00	00	00
43	4	0020222	00000800	000000222	000000000E	0	0	0	0	0	00	00	00
44	5	0040444	00001001	000000444	000000001D	0	0	0	0	0	00	00	00
45	6	0080888	00002002	000000888	000000003B	0	0	0	0	0	00	00	00
46	7	0101111	00004004	000001111	0000000077	0	0	0	0	0	00	00	00
47	8	0202222	00008008	000002222	00000000EE	0	0	0	0	0	00	00	00
48	9	0404444	00010011	000004444	00000001DD	0	0	0	0	0	00	00	00
49	10	0808888	00020022	000008888	00000003BB	1	0	0	0	1	00	00	00
50	11	1011110	00040044	000011111	0000000777	0	0	0	0	0	00	00	00
51	12	0022221	00080088	000022222	0000000EEE	0	0	0	0	0	00	00	00
52	13	0044442	00100110	000044444	0000001DDD	0	0	0	0	0	00	00	00
53	14	0088884	00200220	000088888	0000003BBB	0	0	0	0	0	00	00	00
54	15	0111109	00400440	000111111	0000007777	0	0	0	0	0	00	00	00
55	16	0222212	00800880	000222222	000000EEEE	0	1	0	0	1	00	00	00
56	17	0444424	01001100	000444444	000001DDDD	0	0	0	0	0	00	00	00
57	18	0888848	02002200	000888888	000003BBBB	1	0	0	0	1	00	00	00
58	19	1111090	04004400	001111110	0000077777	0	0	0	0	0	00	00	00
59	20	0222120	08008800	002222220	00000EEEEE	0	0	0	0	0	00	00	00
60	21	0444240	10011000	004444440	00001DDDDD	0	0	0	0	0	00	00	00
61	22	0888480	20022000	008888880	00003BBBBB	1	0	0	0	1	00	00	00
62	23	1110900	40044000	011111100	0000777777	0	0	0	0	0	00	00	00
63	24	0221200	00088001	022222200	0000EEEEEE	0	0	0	0	0	00	00	00
64	25	0442400	00110003	044444400	0001DDDDDD	0	0	0	0	0	00	00	00
65	26	0884800	00220006	088888800	0003BBBBBB	1	0	1	0	0	01	00	00
66	27	1109000	0044000C	111111000	0007777777	0	0	0	0	1	01	01	00
67	28	0212001	00880018	022222001	000EEEEEEE	0	1	0	0	0	11	01	01
68	29	0424002	01100031	044444002	001DDDDDDC	0	0	0	0	1	01	11	01
69	30	0848004	02200062	088888004	003BBBBBB8	1	0	1	0	1	10	01	11
70	31	1090008	044000C4	111110008	0077777770	0	0	0	0	0	00	10	01
71	32	0120010	08800188	022220010	00EEEEEEE0	0	1	0	1	0	00	00	10
72	33	0240020	11000311	044440020	01DDDDDDC1	0	0	0	1	1	00	00	00
73	34	0480040	22000622	088880040	03BBBBBB83	0	0	1	1	0	01	00	00
74	35	0900081	44000C44	111100080	0777777707	1	0	0	0	0	00	01	00
75	36	1200103	08001888	022200101	0EEEEEEE0E	0	0	0	1	1	11	00	01
76	37	0400207	10003111	044400202	1DDDDDDC1D	0	0	0	1	0	01	11	00
77	38	080040E	20006222	088800404	3BBBBBB83B	1	0	1	1	0	01	01	11
78	39	100081C	4000C444	111000808	7777777077	0	0	0	0	1	10	01	01
79	40	0001038	00018888	022001010	6EEEEEE0EF	0	0	0	1	1	00	10	01
80	41	0002070	00031110	044002020	5DDDDDC1DE	0	0	0	1	1	01	00	10
81	42	00040E0	00062220	088004040	3BBBBB83BC	0	0	1	1	1	00	01	00
82	43	00081C1	000C4440	110008081	7777770779	0	0	0	0	0	11	00	01
83	44	0010383	00188880	020010103	6EEEEE0EF2	0	0	0	1	0	01	11	00
84	45	0020707	00311100	040020206	5DDDDC1DE5	0	0	0	1	0	10	01	11
85	46	0040E0E	00622200	08004040C	3BBBB83BCB	0	0	1	1	0	11	10	01
86	47	0081C1D	00C44400	100080819	7777707797	0	1	0	0	0	00	11	10
87	48	010383A	01888801	000101032	6EEEE0EF2F	0	1	0	1	0	11	00	11
88	49	0207075	03111003	000202064	5DDDC1DE5E	0	0	0	1	0	01	11	00

Sample Data

89	50	040E0EA	06222006	0004040C8	3BBB83BCBC	0	0	0	1	0	10	01	11
90	51	081C1D5	0C44400C	000808191	7777077979	1	0	0	0	1	00	10	01
91	52	10383AB	18888018	001010323	6EEE0EF2F2	0	1	0	1	0	00	00	10
92	53	0070756	31110030	002020646	5DDC1DE5E5	0	0	0	1	1	00	00	00
93	54	00E0EAC	62220060	004040C8C	3BB83BCBCB	0	0	0	1	1	00	00	00
94	55	01C1D59	444400C1	008081919	7770779797	0	0	0	0	0	00	00	00
95	56	0383AB2	08880183	010103232	6EE0EF2F2F	0	1	0	1	0	01	00	00
96	57	0707565	11100307	020206464	5DC1DE5E5F	0	0	0	1	0	00	01	00
97	58	0E0EACA	2220060E	04040C8C8	3B83BCBCBF	1	0	0	1	0	10	00	01
98	59	1C1D594	44400C1C	080819191	770779797E	1	0	1	0	0	00	10	00
99	60	183AB28	08801838	101032323	6E0EF2F2FC	1	1	0	0	0	00	00	10
100	61	1075650	11003070	002064647	5C1DE5E5F8	0	0	0	0	0	00	00	00
101	62	00EACA1	220060E0	0040C8C8E	383BCBCBF0	0	0	0	0	0	00	00	00
102	63	01D5943	4400C1C0	00819191D	70779797E0	0	0	0	0	0	00	00	00
103	64	03AB286	08018380	01032323A	60EF2F2FC1	0	0	0	1	1	00	00	00
104	65	075650C	10030701	020646475	41DE5E5F82	0	0	0	1	1	00	00	00
105	66	0EACA18	20060E02	040C8C8EA	03BCBCBF04	1	0	0	1	0	01	00	00
106	67	1D59430	400C1C05	0819191D4	0779797E09	1	0	1	0	1	00	01	00
107	68	1AB2861	0018380A	1032323A9	0EF2F2FC12	1	0	0	1	0	10	00	01
108	69	15650C3	00307015	006464752	1DE5E5F825	0	0	0	1	1	11	10	00
109	70	0ACA186	0060E02A	00C8C8EA4	3BCBCBF04B	1	0	0	1	1	00	11	10
110	71	159430C	00C1C055	019191D48	779797E097	0	1	0	1	0	11	00	11
111	72	0B28618	018380AA	032323A90	6F2F2FC12F	1	1	0	0	1	01	11	00
112	73	1650C30	03070154	064647520	5E5E5F825E	0	0	0	0	1	11	01	11
113	74	0CA1860	060E02A8	0C8C8EA40	3CBCBF04BC	1	0	1	1	0	11	11	01
114	75	19430C0	0C1C0550	19191D480	79797E0979	1	0	1	0	1	11	11	11
115	76	1286180	18380AA0	12323A900	72F2FC12F2	0	0	0	1	0	11	11	11
116	77	050C301	30701541	046475201	65E5F825E5	0	0	0	1	0	11	11	11
117	78	0A18602	60E02A82	08C8EA402	4BCBF04BCB	1	1	1	1	1	10	11	11
118	79	1430C04	41C05505	1191D4804	1797E09796	0	1	0	1	0	10	10	11
119	80	0861808	0380AA0A	0323A9008	2F2FC12F2C	1	1	0	0	0	01	10	10
120	81	10C3011	07015415	064752011	5E5F825E59	0	0	0	0	1	00	01	10
121	82	0186022	0E02A82A	0C8EA4022	3CBF04BCB2	0	0	1	1	0	10	00	01
122	83	030C045	1C055054	191D48044	797E097964	0	0	1	0	1	11	10	00
123	84	061808A	380AA0A8	123A90088	72FC12F2C9	0	0	0	1	0	00	11	10
124	85	0C30115	70154151	047520111	65F825E593	1	0	0	1	0	11	00	11
125	86	186022A	602A82A3	08EA40222	4BF04BCB26	1	0	1	1	0	00	11	00
126	87	10C0455	40550546	11D480444	17E097964C	0	0	0	1	1	10	00	11
127	88	01808AA	00AA0A8D	03A900888	2FC12F2C99	0	1	0	1	0	00	10	00
128	89	0301155	0154151A	075201111	5F825E5932	0	0	0	1	1	01	00	10
129	90	06022AA	02A82A34	0EA402222	3F04BCB264	0	1	1	0	1	00	01	00
130	91	0C04555	05505468	1D4804445	7E097964C9	1	0	1	0	0	10	00	01
131	92	1808AAA	0AA0A8D0	1A900888A	7C12F2C992	1	1	1	0	1	00	10	00
132	93	1011555	154151A1	152011115	7825E59324	0	0	0	0	0	01	00	10
133	94	0022AAB	2A82A342	0A402222B	704BCB2648	0	1	1	0	1	00	01	00
134	95	0045556	55054684	148044457	6097964C91	0	0	0	1	1	11	00	01
135	96	008AAAC	2A0A8D09	0900888AE	412F2C9923	0	0	1	0	0	01	11	00
136	97	0115559	54151A12	12011115D	025E593246	0	0	0	0	1	11	01	11
137	98	022AAB2	282A3424	0402222BA	04BCB2648D	0	0	0	1	0	10	11	01
138	99	0455564	50546848	080444575	097964C91A	0	0	1	0	1	01	10	11
139	100	08AAAC8	20A8D090	100888AEA	12F2C99235	1	1	0	1	0	10	01	10
140	101	1155591	4151A120	0011115D5	25E593246A	0	0	0	1	1	00	10	01
141	102	02AAB22	02A34240	002222BAA	4BCB2648D5	0	1	0	1	0	00	00	10
142	103	0555644	05468481	004445755	17964C91AB	0	0	0	1	1	00	00	00
143	104	0AAAC88	0A8D0903	00888AEAA	2F2C992357	1	1	0	0	0	01	00	00
144	105	1555911	151A1206	011115D55	5E593246AE	0	0	0	0	1	01	01	00
145	106	0AAB222	2A34240C	02222BAAA	3CB2648D5C	1	0	0	1	1	11	01	01

Sample Data

146	107	1556445	54684818	044457555	7964C91AB8	0	0	0	0	1	01	11	01
147	108	0AAC88B	28D09030	0888AEAAA	72C9923571	1	1	1	1	1	01	01	11
148	109	1559117	51A12060	11115D555	6593246AE2	0	1	0	1	1	11	01	01
149	110	0AB222F	234240C0	0222BAAAB	4B2648D5C5	1	0	0	0	0	10	11	01
150	111	156445F	46848180	044575557	164C91AB8A	0	1	0	0	1	01	10	11
151	112	0AC88BF	0D090301	088AEAAAE	2C99235714	1	0	1	1	0	10	01	10
152	113	159117F	1A120602	1115D555D	593246AE28	0	0	0	0	0	00	10	01
153	114	0B222FE	34240C04	022BAAABA	32648D5C51	1	0	0	0	1	01	00	10
154	115	16445FD	68481809	045755574	64C91AB8A2	0	0	0	1	0	00	01	00
155	116	0C88BFA	50903012	08AEAAAE8	4992357144	1	1	1	1	0	01	00	01
156	117	19117F5	21206024	115D555D1	13246AE288	1	0	0	0	0	00	01	00
157	118	1222FEA	4240C048	02BAAABA2	2648D5C511	0	0	0	0	0	11	00	01
158	119	0445FD5	04818090	057555744	4C91AB8A23	0	1	0	1	1	01	11	00
159	120	088BFAA	09030120	0AEAAAE88	1923571446	1	0	1	0	1	10	01	11
160	121	1117F55	12060240	15D555D11	3246AE288D	0	0	0	0	0	00	10	01
161	122	022FEAA	240C0480	0BAAABA22	648D5C511B	0	0	1	1	0	00	00	10
162	123	045FD54	48180900	175557444	491AB8A237	0	0	0	0	0	00	00	00
163	124	08BFAA9	10301200	0EAAAE889	123571446F	1	0	1	0	0	01	00	00
164	125	117F553	20602400	1D555D113	246AE288DF	0	0	1	0	0	00	01	00
165	126	02FEAA7	40C04800	1AAABA227	48D5C511BE	0	1	1	1	1	10	00	01
166	127	05FD54F	01809001	15557444F	11AB8A237D	0	1	0	1	0	00	10	00
167	128	0BFAA9F	03012002	0AAAE889E	23571446FA	1	0	1	0	0	00	00	10
168	129	17F553F	06024004	1555D113D	46AE288DF5	0	0	0	1	1	00	00	00
169	130	0FEAA7E	0C048008	0AABA227A	0D5C511BEA	1	0	1	0	0	01	00	00
170	131	1FD54FC	18090011	1557444F5	1AB8A237D5	1	0	0	1	1	00	01	00
171	132	1FAA9F9	30120022	0AAE889EB	3571446FAA	1	0	1	0	0	10	00	01
172	133	1F553F2	60240044	155D113D7	6AE288DF55	1	0	0	1	0	00	10	00
173	134	1EAA7E4	40480089	0ABA227AE	55C511BEAA	1	0	1	1	1	00	00	10
174	135	1D54FC9	00900113	157444F5D	2B8A237D54	1	1	0	1	1	01	00	00
175	136	1AA9F93	01200227	0AE889EBA	571446FAA8	1	0	1	0	1	00	01	00
176	137	1553F26	0240044E	15D113D75	2E288DF550	0	0	0	0	0	11	00	01
177	138	0AA7E4C	0480089C	0BA227AEA	5C511BEAA0	1	1	1	0	0	00	11	00
178	139	154FC98	09001138	17444F5D4	38A237D540	0	0	0	1	1	10	00	11
179	140	0A9F931	12002270	0E889EBA9	71446FAA81	1	0	1	0	0	00	10	00
180	141	153F262	240044E0	1D113D753	6288DF5503	0	0	1	1	0	00	00	10
181	142	0A7E4C5	480089C0	1A227AEA7	4511BEAA06	1	0	1	0	0	01	00	00
182	143	14FC98B	10011381	1444F5D4F	0A237D540D	0	0	0	0	1	01	01	00
183	144	09F9316	20022702	0889EBA9E	1446FAA81A	1	0	1	0	1	11	01	01
184	145	13F262D	40044E04	1113D753D	288DF55035	0	0	0	1	0	10	11	01
185	146	07E4C5A	00089C08	0227AEA7A	511BEAA06A	0	0	0	0	0	01	10	11
186	147	0FC98B4	00113810	044F5D4F5	2237D540D5	1	0	0	0	0	01	01	10
187	148	1F93169	00227021	089EBA9EB	446FAA81AA	1	0	1	0	1	11	01	01
188	149	1F262D2	0044E042	113D753D7	08DF550355	1	0	0	1	1	10	11	01
189	150	1E4C5A4	0089C085	027AEA7AE	11BEAA06AA	1	1	0	1	1	10	10	11
190	151	1C98B48	0113810A	04F5D4F5C	237D540D54	1	0	0	0	1	10	10	10
191	152	1931691	02270215	09EBA9EB8	46FAA81AA9	1	0	1	1	1	01	10	10
192	153	1262D22	044E042A	13D753D71	0DF5503553	0	0	0	1	0	01	01	10
193	154	04C5A44	089C0854	07AEA7AE2	1BEAA06AA7	0	1	0	1	1	11	01	01
194	155	098B488	113810A8	0F5D4F5C4	37D540D54E	1	0	1	1	0	11	11	01
195	156	1316910	22702150	1EBA9EB89	6FAA81AA9D	0	0	1	1	1	11	11	11
196	157	062D220	44E042A0	1D753D712	5F5503553A	0	1	1	0	1	11	11	11
197	158	0C5A440	09C08540	1AEA7AE25	3EAA06AA75	1	1	1	1	1	10	11	11
198	159	18B4880	13810A80	15D4F5C4B	7D540D54EA	1	1	0	0	0	10	10	11
199	160	1169100	27021500	0BA9EB897	7AA81AA9D5	0	0	1	1	0	01	10	10
200	161	02D2201	4E042A00	1753D712E	75503553AB	0	0	0	0	1	00	01	10
201	162	05A4403	1C085400	0EA7AE25C	6AA06AA756	0	0	1	1	0	10	00	01
202	163	0B48807	3810A800	1D4F5C4B8	5540D54EAC	1	0	1	0	0	00	10	00

Sample Data

203	164	169100F	70215000	1A9EB8971	2A81AA9D58	0	0	1	1	0	00	00	10
204	165	0D2201E	6042A001	153D712E3	5503553AB0	1	0	0	0	1	00	00	00
205	166	1A4403C	40854002	0A7AE25C6	2A06AA7561	1	1	1	0	1	01	00	00
206	167	1488079	010A8004	14F5C4B8D	540D54EAC3	0	0	0	0	1	01	01	00
207	168	09100F2	02150009	09EB8971B	281AA9D586	1	0	1	0	1	11	01	01
208	169	12201E5	042A0012	13D712E37	503553AB0C	0	0	0	0	1	01	11	01
209	170	04403CA	08540024	07AE25C6E	206AA75618	0	0	0	0	1	11	01	11
210	171	0880795	10A80048	0F5C4B8DD	40D54EAC30	1	1	1	1	1	11	11	01
211	172	1100F2A	21500091	1EB8971BA	01AA9D5861	0	0	1	1	1	11	11	11
212	173	0201E54	42A00122	1D712E374	03553AB0C3	0	1	1	0	1	11	11	11
213	174	0403CA9	05400244	1AE25C6E9	06AA756186	0	0	1	1	1	11	11	11
214	175	0807952	0A800488	15C4B8DD3	0D54EAC30D	1	1	0	0	1	11	11	11
215	176	100F2A5	15000911	0B8971BA6	1AA9D5861A	0	0	1	1	1	11	11	11
216	177	001E54A	2A001223	1712E374C	3553AB0C35	0	0	0	0	1	00	11	11
217	178	003CA94	54002446	0E25C6E98	6AA756186A	0	0	1	1	0	11	00	11
218	179	0079528	2800488D	1C4B8DD31	554EAC30D5	0	0	1	0	0	01	11	00
219	180	00F2A50	5000911B	18971BA62	2A9D5861AA	0	0	1	1	1	10	01	11
220	181	01E54A0	20012236	112E374C4	553AB0C355	0	0	0	0	0	00	10	01
221	182	03CA940	4002446C	025C6E988	2A756186AA	0	0	0	0	0	01	00	10
222	183	0795280	000488D9	04B8DD310	54EAC30D54	0	0	0	1	0	00	01	00
223	184	0F2A500	000911B2	0971BA620	29D5861AA8	1	0	1	1	1	10	00	01
224	185	1E54A00	00122364	12E374C40	53AB0C3550	1	0	0	1	0	00	10	00
225	186	1CA9400	002446C8	05C6E9880	2756186AA0	1	0	0	0	1	01	00	10
226	187	1952800	00488D90	0B8DD3101	4EAC30D540	1	0	1	1	0	11	01	00
227	188	12A5000	00911B20	171BA6202	1D5861AA81	0	1	0	0	0	10	11	01
228	189	054A000	01223640	0E374C404	3AB0C35502	0	0	1	1	0	10	10	11
229	190	0A94000	02446C80	1C6E98808	756186AA05	1	0	1	0	0	01	10	10
230	191	1528001	0488D901	18DD31011	6AC30D540B	0	1	1	1	0	10	01	10
231	192	0A50003	0911B203	11BA62023	55861AA817	1	0	0	1	0	11	10	01
232	193	14A0006	12236407	0374C4047	2B0C35502F	0	0	0	0	1	11	11	10
233	194	094000C	2446C80E	06E98808E	56186AA05F	1	0	0	0	0	11	11	11
234	195	1280018	488D901C	0DD31011D	2C30D540BF	0	1	1	0	1	11	11	11
235	196	0500030	111B2039	1BA62023A	5861AA817E	0	0	1	0	0	11	11	11
236	197	0A00060	22364072	174C40475	30C35502FD	1	0	0	1	1	11	11	11
237	198	14000C0	446C80E4	0E98808EA	6186AA05FB	0	0	1	1	1	11	11	11
238	199	0800180	08D901C8	1D31011D5	430D540BF6	1	1	1	0	0	10	11	11
239	200	1000301	11B20391	1A62023AB	061AA817EC	0	1	1	0	0	10	10	11

```
Z[0]  = 25
Z[1]  = 45
Z[2]  = 6B
Z[3]  = 55
Z[4]  = 5F
Z[5]  = C2
Z[6]  = 20
Z[7]  = E5
Z[8]  = C4
Z[9]  = F8
Z[10] = 3A
Z[11] = F1
Z[12] = FF
Z[13] = 89
Z[14] = 02
Z[15] = 35

================================================================================================
        Reload this pattern into the LFSRs
```

Sample Data

Hold content of Summation Combiner regs and calculate new C[t+1] and Z values

```
LFSR1  <= 1C45F25
LFSR2  <= 7FF8C245
LFSR3  <= 1893A206B
LFSR4  <= 1A02F1E555
C[t+1] <= 10
```

Generating 125 key symbols (encryption/decryption sequence)

240	1	1C45F25	7FF8C245	1893A206B	1A02F1E555	1	1	1	0	1	10	10	11
241	2	188BE4A	7FF1848B	1127440D7	3405E3CAAB	1	1	0	0	0	01	10	10
242	3	1117C95	7FE30917	024E881AF	680BC79557	0	1	0	0	0	01	01	10
243	4	022F92B	7FC6122F	049D1035E	50178F2AAF	0	1	0	0	0	11	01	01
244	5	045F257	7F8C245E	093A206BD	202F1E555E	0	1	1	0	1	10	11	01
245	6	08BE4AE	7F1848BC	127440D7A	405E3CAABC	1	0	0	0	1	01	10	11
246	7	117C95C	7E309178	04E881AF4	00BC795579	0	0	0	1	0	01	01	10
247	8	02F92B8	7C6122F0	09D1035E8	0178F2AAF2	0	0	1	0	0	11	01	01
248	9	05F2570	78C245E1	13A206BD0	02F1E555E5	0	1	0	1	1	10	11	01
249	10	0BE4AE1	71848BC2	07440D7A0	05E3CAABCA	1	1	0	1	1	10	10	11
250	11	17C95C3	63091784	0E881AF40	0BC7955795	0	0	1	1	0	01	10	10
251	12	0F92B87	46122F09	1D1035E80	178F2AAF2B	1	0	1	1	0	10	01	10
252	13	1F2570F	0C245E12	1A206BD01	2F1E555E56	1	0	1	0	0	11	10	01
253	14	1E4AE1F	1848BC25	1440D7A03	5E3CAABCAC	1	0	0	0	0	00	11	10
254	15	1C95C3E	3091784A	0881AF407	3C79557958	1	1	1	0	1	11	00	11
255	16	192B87D	6122F094	11035E80F	78F2AAF2B1	1	0	0	1	1	01	11	00
256	17	12570FA	4245E128	0206BD01E	71E555E562	0	0	0	1	0	10	01	11
257	18	04AE1F4	048BC250	040D7A03D	63CAABCAC5	0	1	0	1	0	11	10	01
258	19	095C3E8	091784A0	081AF407A	479557958A	1	0	1	1	0	01	11	10
259	20	12B87D1	122F0941	1035E80F4	0F2AAF2B14	0	0	0	0	1	11	01	11
260	21	0570FA3	245E1283	006BD01E9	1E555E5628	0	0	0	0	1	01	11	01
261	22	0AE1F46	48BC2506	00D7A03D2	3CAABCAC50	1	1	0	1	0	01	01	11
262	23	15C3E8C	11784A0C	01AF407A5	79557958A0	0	0	0	0	1	10	01	01
263	24	0B87D18	22F09419	035E80F4A	72AAF2B140	1	1	0	1	1	11	10	01
264	25	170FA30	45E12832	06BD01E94	6555E56280	0	1	0	0	0	00	11	10
265	26	0E1F460	0BC25065	0D7A03D28	4AABCAC501	1	1	1	1	0	00	00	11
266	27	1C3E8C0	1784A0CB	1AF407A50	1557958A03	1	1	1	0	1	01	00	00
267	28	187D181	2F094196	15E80F4A0	2AAF2B1406	1	0	0	1	1	00	01	00
268	29	10FA302	5E12832C	0BD01E941	555E56280C	0	0	1	0	1	11	00	01
269	30	01F4604	3C250658	17A03D283	2ABCAC5019	0	0	0	1	0	01	11	00
270	31	03E8C09	784A0CB0	0F407A506	557958A033	0	0	1	0	0	10	01	11
271	32	07D1812	70941960	1E80F4A0C	2AF2B14066	0	1	1	1	1	11	10	01
272	33	0FA3024	612832C1	1D01E9419	55E56280CD	1	0	1	1	0	01	11	10
273	34	1F46049	42506583	1A03D2832	2BCAC5019A	1	0	1	1	0	01	01	11
274	35	1E8C093	04A0CB07	1407A5065	57958A0335	1	1	0	1	0	00	01	01
275	36	1D18127	0941960F	080F4A0CB	2F2B14066B	1	0	1	0	0	10	00	01
276	37	1A3024F	12832C1F	101E94196	5E56280CD7	1	1	0	0	0	00	10	00
277	38	146049F	2506583E	003D2832C	3CAC5019AE	0	0	0	1	1	01	00	10
278	39	08C093E	4A0CB07D	007A50658	7958A0335D	1	0	0	0	0	00	01	00
279	40	118127C	141960FA	00F4A0CB0	72B14066BA	0	0	0	1	1	11	00	01
280	41	03024F8	2832C1F4	01E941961	656280CD74	0	0	0	0	1	10	11	00
281	42	06049F1	506583E9	03D2832C2	4AC5019AE9	0	0	0	1	1	01	10	11
282	43	0C093E2	20CB07D2	07A506585	158A0335D3	1	1	0	1	0	10	01	10
283	44	18127C5	41960FA5	0F4A0CB0B	2B14066BA7	1	1	1	0	1	11	10	01
284	45	1024F8A	032C1F4B	1E9419616	56280CD74F	0	0	1	0	0	00	11	10
285	46	0049F15	06583E97	1D2832C2C	2C5019AE9F	0	0	1	0	1	10	00	11

Sample Data

286	47	0093E2B	0CB07D2F	1A5065859	58A0335D3E	0	1	1	1	1	00	10	00
287	48	0127C56	1960FA5E	14A0CB0B2	314066BA7D	0	0	0	0	0	01	00	10
288	49	024F8AD	32C1F4BC	094196164	6280CD74FB	0	1	1	1	0	11	01	00
289	50	049F15A	6583E978	12832C2C8	45019AE9F6	0	1	0	0	0	10	11	01
290	51	093E2B5	4B07D2F0	050658591	0A0335D3ED	1	0	0	0	1	01	10	11
291	52	127C56B	160FA5E0	0A0CB0B22	14066BA7DA	0	0	1	0	0	01	01	10
292	53	04F8AD7	2C1F4BC1	141961645	280CD74FB5	0	0	0	0	1	10	01	01
293	54	09F15AF	583E9783	0832C2C8A	5019AE9F6A	1	0	1	0	0	11	10	01
294	55	13E2B5E	307D2F06	106585915	20335D3ED5	0	0	0	0	1	11	11	10
295	56	07C56BD	60FA5E0D	00CB0B22B	4066BA7DAA	0	1	0	0	0	11	11	11
296	57	0F8AD7A	41F4BC1B	019616457	00CD74FB54	1	1	0	1	0	10	11	11
297	58	1F15AF4	03E97836	032C2C8AF	019AE9F6A9	1	1	0	1	1	10	10	11
298	59	1E2B5E9	07D2F06C	06585915E	0335D3ED52	1	1	0	0	0	01	10	10
299	60	1C56BD2	0FA5E0D8	0CB0B22BC	066BA7DAA4	1	1	1	0	0	10	01	10
300	61	18AD7A5	1F4BC1B0	196164578	0CD74FB549	1	0	1	1	1	11	10	01
301	62	115AF4B	3E978361	12C2C8AF0	19AE9F6A92	0	1	0	1	1	00	11	10
302	63	02B5E96	7D2F06C2	0585915E0	335D3ED524	0	0	0	0	0	10	00	11
303	64	056BD2D	7A5E0D85	0B0B22BC1	66BA7DAA49	0	0	1	1	0	00	10	00
304	65	0AD7A5B	74BC1B0A	161645783	4D74FB5493	1	1	0	0	0	00	00	10
305	66	15AF4B6	69783615	0C2C8AF07	1AE9F6A926	0	0	1	1	0	01	00	00
306	67	0B5E96D	52F06C2B	185915E0F	35D3ED524C	1	1	1	1	1	11	01	00
307	68	16BD2DB	25E0D857	10B22BC1F	6BA7DAA499	0	1	0	1	1	10	11	01
308	69	0D7A5B7	4BC1B0AF	01645783F	574FB54933	1	1	0	0	0	10	10	11
309	70	1AF4B6F	1783615F	02C8AF07F	2E9F6A9266	1	1	0	1	1	01	10	10
310	71	15E96DF	2F06C2BF	05915E0FF	5D3ED524CC	0	0	0	0	1	00	01	10
311	72	0BD2DBF	5E0D857F	0B22BC1FE	3A7DAA4998	1	0	1	0	0	10	00	01
312	73	17A5B7F	3C1B0AFE	1645783FD	74FB549331	0	0	0	1	1	11	10	00
313	74	0F4B6FF	783615FD	0C8AF07FA	69F6A92662	1	0	1	1	0	01	11	10
314	75	1E96DFF	706C2BFB	1915E0FF5	53ED524CC4	1	0	1	1	0	01	01	11
315	76	1D2DBFE	60D857F6	122BC1FEB	27DAA49988	1	1	0	1	0	00	01	01
316	77	1A5B7FD	41B0AFEC	045783FD7	4FB5493310	1	1	0	1	1	10	00	01
317	78	14B6FFA	03615FD8	08AF07FAE	1F6A926620	0	0	1	0	1	11	10	00
318	79	096DFF4	06C2BFB1	115E0FF5D	3ED524CC40	1	1	0	1	0	01	11	10
319	80	12DBFE8	0D857F63	02BC1FEBB	7DAA499881	0	1	0	1	1	10	01	11
320	81	05B7FD0	1B0AFEC6	05783FD77	7B54933103	0	0	0	0	0	00	10	01
321	82	0B6FFA1	3615FD8C	0AF07FAEF	76A9266206	1	0	1	1	1	00	00	10
322	83	16DFF42	6C2BFB18	15E0FF5DE	6D524CC40C	0	0	0	0	0	00	00	00
323	84	0DBFE85	5857F631	0BC1FEBBD	5AA4998819	1	0	1	1	1	01	00	00
324	85	1B7FD0B	30AFEC62	1783FD77A	3549331033	1	1	0	0	1	00	01	00
325	86	16FFA16	615FD8C5	0F07FAEF5	6A92662067	0	0	1	1	0	10	00	01
326	87	0DFF42D	42BFB18B	1E0FF5DEA	5524CC40CE	1	1	1	0	1	00	10	00
327	88	1BFE85B	057F6317	1C1FEBBD5	2A4998819C	1	0	1	0	0	00	00	10
328	89	17FD0B7	0AFEC62E	183FD77AA	5493310339	0	1	1	1	1	01	00	00
329	90	0FFA16F	15FD8C5C	107FAEF55	2926620672	1	1	0	0	1	00	01	00
330	91	1FF42DF	2BFB18B9	00FF5DEAA	524CC40CE5	1	1	0	0	0	10	00	01
331	92	1FE85BF	57F63172	01FEBBD55	24998819CA	1	1	0	1	1	00	10	00
332	93	1FD0B7F	2FEC62E4	03FD77AAA	4933103394	1	1	0	0	0	00	00	10
333	94	1FA16FF	5FD8C5C9	07FAEF555	1266206728	1	1	0	0	0	01	00	00
334	95	1F42DFF	3FB18B93	0FF5DEAAA	24CC40CE51	1	1	1	1	1	11	01	00
335	96	1E85BFF	7F631727	1FEBBD554	4998819CA3	1	0	1	1	0	11	11	01
336	97	1D0B7FE	7EC62E4F	1FD77AAA9	1331033947	1	1	1	0	0	10	11	11
337	98	1A16FFC	7D8C5C9F	1FAEF5553	266206728E	1	1	1	0	1	10	10	11
338	99	142DFF9	7B18B93F	1F5DEAAA7	4CC40CE51D	0	0	1	1	0	01	10	10
339	100	085BFF3	7631727F	1EBBD554E	198819CA3B	1	0	1	1	0	10	01	10
340	101	10B7FE6	6C62E4FF	1D77AAA9C	3310339477	0	0	1	0	1	00	10	01
341	102	016FFCC	58C5C9FE	1AEF55538	66206728EE	0	1	1	0	0	00	00	10
342	103	02DFF98	318B93FC	15DEAAA70	4C40CE51DC	0	1	0	0	1	00	00	00

Sample Data

343	104	05BFF31	631727F8	0BBD554E1	18819CA3B9	0	0	1	1	0	01	00	00
344	105	0B7FE62	462E4FF1	177AAA9C2	3103394772	1	0	0	0	0	00	01	00
345	106	16FFCC5	0C5C9FE2	0EF555384	6206728EE4	0	0	1	0	1	11	00	01
346	107	0DFF98A	18B93FC4	1DEAAA709	440CE51DC9	1	1	1	0	0	00	11	00
347	108	1BFF315	31727F88	1BD554E12	0819CA3B93	1	0	1	0	0	11	00	11
348	109	17FE62A	62E4FF11	17AAA9C24	1033947726	0	1	0	0	0	01	11	00
349	110	0FFCC54	45C9FE22	0F5553849	206728EE4C	1	1	1	0	0	01	01	11
350	111	1FF98A8	0B93FC44	1EAAA7093	40CE51DC99	1	1	1	1	1	00	01	01
351	112	1FF3150	1727F889	1D554E127	019CA3B933	1	0	1	1	1	10	00	01
352	113	1FE62A0	2E4FF112	1AAA9C24F	0339477267	1	0	1	0	0	00	10	00
353	114	1FCC541	5C9FE225	15553849E	06728EE4CF	1	1	0	0	0	00	00	10
354	115	1F98A82	393FC44B	0AAA7093C	0CE51DC99F	1	0	1	1	1	01	00	00
355	116	1F31504	727F8897	1554E1279	19CA3B933E	1	0	0	1	1	00	01	00
356	117	1E62A09	64FF112F	0AA9C24F2	339477267D	1	1	1	1	0	01	00	01
357	118	1CC5412	49FE225E	1553849E4	6728EE4CFB	1	1	0	0	1	00	01	00
358	119	198A824	13FC44BC	0AA7093C9	4E51DC99F7	1	1	1	0	1	10	00	01
359	120	1315049	27F88979	154E12792	1CA3B933EE	0	1	0	1	0	00	10	00
360	121	062A093	4FF112F3	0A9C24F24	39477267DC	0	1	1	0	0	00	00	10
361	122	0C54127	1FE225E6	153849E48	728EE4CFB8	1	1	0	1	1	01	00	00
362	123	18A824E	3FC44BCD	0A7093C91	651DC99F71	1	1	1	0	0	11	01	00
363	124	115049C	7F88979A	14E127922	4A3B933EE2	0	1	0	0	0	10	11	01
364	125	02A0938	7F112F35	09C24F244	1477267DC5	0	0	1	0	1	01	10	11

Sample Data

1.1.4 Third Set of Samples

```
Initial values for the key, pan address and clock

K'c3[0]   = FF   K'c3[1]   = FF    K'c3[2]   = FF    K'c3[3]  = FF
K'c3[4]   = FF   K'c3[5]   = FF    K'c3[6]   = FF    K'c3[7]  = FF
K'c3[8]   = FF   K'c3[9]   = FF    K'c3[10]  = FF    K'c3[11] = FF
K'c3[12]  = FF   K'c3[13]  = FF    K'c3[14]  = FF    K'c3[15] = FF

Addr3[0] = FF   Addr3[1] = FF    Addr3[2] = FF
Addr3[3] = FF   Addr3[4] = FF    Addr3[5] = FF

CL3[0]  = FF   CL3[1]  = FF    CL3[2]  = FF    CL3[3]  = 03


=============================================================================================
         Fill LFSRs with initial data
=============================================================================================

  t  clk#    LFSR1    LFSR2     LFSR3      LFSR4          X1 X2 X3 X4   Z  C[t+1] C[t] C[t-1]

  0     0    0000000* 00000000* 000000000* 0000000000*     0  0  0  0    0  00     00   00
  1     1    0000001* 00000001* 000000001* 0000000001*     0  0  0  0    0  00     00   00
  2     2    0000003* 00000002* 000000003* 0000000003*     0  0  0  0    0  00     00   00
  3     3    0000007* 00000004* 000000007* 0000000007*     0  0  0  0    0  00     00   00
  4     4    000000F* 00000009* 00000000F* 000000000F*     0  0  0  0    0  00     00   00
  5     5    000001F* 00000013* 00000001F* 000000001F*     0  0  0  0    0  00     00   00
  6     6    000003F* 00000027* 00000003F* 000000003F*     0  0  0  0    0  00     00   00
  7     7    000007F* 0000004F* 00000007F* 000000007F*     0  0  0  0    0  00     00   00
  8     8    00000FF* 0000009F* 0000000FF* 00000000FF*     0  0  0  0    0  00     00   00
  9     9    00001FF* 0000013F* 0000001FF* 00000001FF*     0  0  0  0    0  00     00   00
 10    10    00003FF* 0000027F* 0000003FF* 00000003FF*     0  0  0  0    0  00     00   00
 11    11    00007FF* 000004FF* 0000007FF* 00000007FF*     0  0  0  0    0  00     00   00
 12    12    0000FFF* 000009FF* 000000FFF* 0000000FFF*     0  0  0  0    0  00     00   00
 13    13    0001FFF* 000013FF* 000001FFF* 0000001FFF*     0  0  0  0    0  00     00   00
 14    14    0003FFF* 000027FF* 000003FFF* 0000003FFF*     0  0  0  0    0  00     00   00
 15    15    0007FFF* 00004FFF* 000007FFF* 0000007FFF*     0  0  0  0    0  00     00   00
 16    16    000FFFF* 00009FFF* 00000FFFF* 000000FFFF*     0  0  0  0    0  00     00   00
 17    17    001FFFF* 00013FFF* 00001FFFF* 000001FFFF*     0  0  0  0    0  00     00   00
 18    18    003FFFF* 00027FFF* 00003FFFF* 000003FFFF*     0  0  0  0    0  00     00   00
 19    19    007FFFF* 0004FFFF* 00007FFFF* 000007FFFF*     0  0  0  0    0  00     00   00
 20    20    00FFFFF* 0009FFFF* 0000FFFFF* 00000FFFFF*     0  0  0  0    0  00     00   00
 21    21    01FFFFF* 0013FFFF* 0001FFFFF* 00001FFFFF*     0  0  0  0    0  00     00   00
 22    22    03FFFFF* 0027FFFF* 0003FFFFF* 00003FFFFF*     0  0  0  0    0  00     00   00
 23    23    07FFFFF* 004FFFFF* 0007FFFFF* 00007FFFFF*     0  0  0  0    0  00     00   00
 24    24    0FFFFFF* 009FFFFF* 000FFFFFF* 0000FFFFFF*     1  1  0  0    0  01     00   00
 25    25    1FFFFFF* 013FFFFF* 001FFFFFF* 0001FFFFFF*     1  0  0  0    1  00     00   00
 26    26    1FFFFFF  027FFFFF* 003FFFFFF* 0003FFFFFF*     1  0  0  0    1  00     00   00
 27    27    1FFFFFF  04FFFFFF* 007FFFFFF* 0007FFFFFF*     1  1  0  0    0  01     00   00
 28    28    1FFFFFF  09FFFFFF* 00FFFFFFF* 000FFFFFFF*     1  1  0  0    0  01     00   00
 29    29    1FFFFFF  13FFFFFF* 01FFFFFFF* 001FFFFFFF*     1  1  0  0    0  01     00   00
 30    30    1FFFFFF  27FFFFFF* 03FFFFFFF* 003FFFFFFF*     1  1  0  0    0  01     00   00
 31    31    1FFFFFF  4FFFFFFF* 07FFFFFFF* 007FFFFFFF*     1  1  0  0    0  01     00   00
 32    32    1FFFFFF  1FFFFFFF  0FFFFFFFF* 00FFFFFFFF*     1  1  1  1    0  10     00   00
 33    33    1FFFFFF  3FFFFFFE  1FFFFFFFF* 01FFFFFFFF*     1  1  1  1    0  10     00   00
 34    34    1FFFFFF  7FFFFFFC  1FFFFFFFF  03FFFFFFFF*     1  1  1  1    0  10     00   00
```

Sample Data

35	35	1FFFFFF	7FFFFFF9	1FFFFFFFF	07FFFFFFF*	1	1	1	1	0	10	00	00
36	36	1FFFFFF	7FFFFFF3	1FFFFFFFF	0FFFFFFFF*	1	1	1	1	0	10	00	00
37	37	1FFFFFF	7FFFFFE7	1FFFFFFFF	1FFFFFFFF*	1	1	1	1	0	10	00	00
38	38	1FFFFFF	7FFFFFCF	1FFFFFFFF	3FFFFFFFF*	1	1	1	1	0	10	00	00
39	39	1FFFFFF	7FFFFF9F	1FFFFFFFF	7FFFFFFFF*	1	1	1	1	0	10	00	00

Start clocking Summation Combiner

40	1	1FFFFFF	7FFFFF3F	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	01	10	00
41	2	1FFFFFF	7FFFFE7F	1FFFFFFFF	7FFFFFFFF	1	1	1	1	1	10	01	10
42	3	1FFFFFF	7FFFFCFF	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	10	10	01
43	4	1FFFFFF	7FFFF9FF	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	00	10	10
44	5	1FFFFFF	7FFFF3FF	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	11	00	10
45	6	1FFFFFF	7FFFE7FE	1FFFFFFFF	7FFFFFFFF	1	1	1	1	1	00	11	00
46	7	1FFFFFF	7FFFCFFC	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	00	00	11
47	8	1FFFFFF	7FFF9FF9	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	10	00	00
48	9	1FFFFFF	7FFF3FF3	1FFFFFFFF	7FFFFFFFF	1	1	1	1	0	01	10	00
49	10	1FFFFFF	7FFE7FE6	1FFFFFFFF	7FFFFFFFF	1	1	1	1	1	10	01	10
50	11	1FFFFFE	7FFCFFCC	1FFFFFFFE	7FFFFFFFF	1	1	1	1	0	10	10	01
51	12	1FFFFFC	7FF9FF99	1FFFFFFFC	7FFFFFFFF	1	1	1	1	0	00	10	10
52	13	1FFFFF8	7FF3FF33	1FFFFFFF8	7FFFFFFFF	1	1	1	1	0	11	00	10
53	14	1FFFFF0	7FE7FE67	1FFFFFFF0	7FFFFFFFF	1	1	1	1	1	00	11	00
54	15	1FFFFE0	7FCFFCCF	1FFFFFFE1	7FFFFFFFF	1	1	1	1	0	00	00	11
55	16	1FFFFC0	7F9FF99F	1FFFFFFC3	7FFFFFFFF	1	1	1	1	0	10	00	00
56	17	1FFFF80	7F3FF33E	1FFFFFF87	7FFFFFFFE	1	0	1	1	1	00	10	00
57	18	1FFFF00	7E7FE67C	1FFFFFF0F	7FFFFFFFC	1	0	1	1	1	00	00	10
58	19	1FFFE01	7CFFCCF8	1FFFFFE1E	7FFFFFFF8	1	1	1	1	0	10	00	00
59	20	1FFFC03	79FF99F0	1FFFFFC3C	7FFFFFFF0	1	1	1	1	0	01	10	00
60	21	1FFF807	73FF33E0	1FFFFF878	7FFFFFFE1	1	1	1	1	1	10	01	10
61	22	1FFF00F	67FE67C0	1FFFFF0F0	7FFFFFFC3	1	1	1	1	0	10	10	01
62	23	1FFE01E	4FFCCF80	1FFFFE1E1	7FFFFFF87	1	1	1	1	0	00	10	10
63	24	1FFC03C	1FF99F00	1FFFFC3C3	7FFFFFF0F	1	1	1	1	0	11	00	10
64	25	1FF8078	3FF33E01	1FFFF8787	7FFFFFE1E	1	1	1	1	1	00	11	00
65	26	1FF00F0	7FE67C02	1FFFF0F0F	7FFFFFC3C	1	1	1	1	0	00	00	11
66	27	1FE01E1	7FCCF805	1FFFE1E1E	7FFFFF878	1	1	1	1	0	10	00	00
67	28	1FC03C3	7F99F00A	1FFFC3C3C	7FFFFF0F0	1	1	1	1	0	01	10	00
68	29	1F80787	7F33E015	1FFF87878	7FFFFE1E1	1	0	1	1	0	10	01	10
69	30	1F00F0F	7E67C02A	1FFF0F0F0	7FFFFC3C3	1	0	1	1	1	11	10	01
70	31	1E01E1E	7CCF8054	1FFE1E1E1	7FFFF8787	1	1	1	1	1	01	11	10
71	32	1C03C3C	799F00A9	1FFC3C3C3	7FFFF0F0F	1	1	1	1	1	01	01	11
72	33	1807878	733E0152	1FF878787	7FFFE1E1E	1	0	1	1	0	00	01	01
73	34	100F0F0	667C02A5	1FF0F0F0F	7FFFC3C3C	0	0	1	1	0	10	00	01
74	35	001E1E0	4CF8054B	1FE1E1E1F	7FFFF87878	0	1	1	1	1	00	10	00
75	36	003C3C1	19F00A96	1FC3C3C3F	7FFFF0F0F0	0	1	1	1	1	00	00	10
76	37	0078783	33E0152C	1F878787F	7FFFE1E1E1	0	1	1	1	1	01	00	00
77	38	00F0F07	67C02A59	1F0F0F0FF	7FFFC3C3C3	0	1	1	1	0	11	01	00
78	39	01E1E0E	4F8054B3	1E1E1E1FF	7FFF878787	0	1	1	1	0	11	11	01
79	40	03C3C1C	1F00A966	1C3C3C3FF	7FFF0F0F0F	0	0	1	1	1	11	11	11
80	41	0787838	3E0152CC	1878787FF	7FFE1E1E1E	0	0	1	1	1	11	11	11
81	42	0F0F070	7C02A598	10F0F0FFF	7FFC3C3C3C	1	0	0	1	1	11	11	11
82	43	1E1E0E0	78054B30	01E1E1FFF	7FF8787878	1	0	0	1	1	11	11	11
83	44	1C3C1C0	700A9660	03C3C3FFE	7FF0F0F0F0	1	0	0	1	1	11	11	11
84	45	1878380	60152CC0	078787FFC	7FE1E1E1E0	1	0	0	1	1	11	11	11
85	46	10F0700	402A5980	0F0F0FFF8	7FC3C3C3C0	0	0	1	1	1	11	11	11
86	47	01E0E00	0054B300	1E1E1FFF0	7F87878780	0	0	1	1	1	11	11	11
87	48	03C1C00	00A96601	1C3C3FFE0	7F0F0F0F00	0	1	1	0	1	11	11	11
88	49	0783800	0152CC03	18787FFC0	7E1E1E1E01	0	0	1	0	0	11	11	11

Sample Data

89	50	0F07000	02A59806	10F0FFF80	7C3C3C3C03	1	1	0	0	1	11	11	11
90	51	1E0E000	054B300D	01E1FFF00	7878787807	1	0	0	0	0	11	11	11
91	52	1C1C001	0A96601A	03C3FFE01	70F0F0F00F	1	1	0	1	0	10	11	11
92	53	1838003	152CC035	0787FFC03	61E1E1E01E	1	0	0	1	0	10	10	11
93	54	1070007	2A59806B	0F0FFF807	43C3C3C03C	0	0	1	1	0	01	10	10
94	55	00E000F	54B300D7	1E1FFF00F	0787878078	0	1	1	1	0	10	01	10
95	56	01C001F	296601AE	1C3FFE01F	0F0F0F00F1	0	0	1	0	1	00	10	01
96	57	038003F	52CC035C	187FFC03F	1E1E1E01E2	0	1	1	0	0	00	00	10
97	58	070007F	259806B8	10FFF807F	3C3C3C03C4	0	1	0	0	1	00	00	00
98	59	0E000FE	4B300D71	01FFF00FE	7878780788	1	0	0	0	1	00	00	00
99	60	1C001FD	16601AE2	03FFE01FD	70F0F00F10	1	0	0	1	0	01	00	00
100	61	18003FA	2CC035C5	07FFC03FB	61E1E01E21	1	1	0	1	0	11	01	00
101	62	10007F4	59806B8B	0FFF807F7	43C3C03C43	0	1	1	1	0	11	11	01
102	63	0000FE8	3300D717	1FFF00FEE	0787807887	0	0	1	1	1	11	11	11
103	64	0001FD0	6601AE2F	1FFE01FDC	0F0F00F10E	0	0	1	0	0	11	11	11
104	65	0003FA0	4C035C5F	1FFC03FB8	1E1E01E21D	0	0	1	0	0	11	11	11
105	66	0007F40	1806B8BE	1FF807F70	3C3C03C43B	0	0	1	0	0	11	11	11
106	67	000FE81	300D717C	1FF00FEE1	7878078877	0	0	1	0	0	11	11	11
107	68	001FD02	601AE2F8	1FE01FDC2	70F00F10EF	0	0	1	1	1	11	11	11
108	69	003FA05	4035C5F0	1FC03FB84	61E01E21DE	0	0	1	1	1	11	11	11
109	70	007F40B	006B8BE0	1F807F708	43C03C43BC	0	0	1	1	1	11	11	11
110	71	00FE816	00D717C0	1F00FEE11	0780788778	0	1	1	1	0	10	11	11
111	72	01FD02C	01AE2F81	1E01FDC23	0F00F10EF1	0	1	1	0	0	10	10	11
112	73	03FA059	035C5F02	1C03FB847	1E01E21DE3	0	0	1	0	1	10	10	10
113	74	07F40B3	06B8BE05	1807F708F	3C03C43BC7	0	1	1	0	0	01	10	10
114	75	0FE8166	0D717C0B	100FEE11E	780788778F	1	0	0	0	0	01	01	10
115	76	1FD02CD	1AE2F817	001FDC23D	700F10EF1F	1	1	0	0	1	11	01	01
116	77	1FA059B	35C5F02F	003FB847A	601E21DE3F	1	1	0	0	1	10	11	01
117	78	1F40B37	6B8BE05E	007F708F4	403C43BC7F	1	1	0	0	0	10	10	11
118	79	1E8166E	5717C0BD	00FEE11E9	00788778FF	1	0	0	0	1	10	10	10
119	80	1D02CDC	2E2F817A	01FDC23D3	00F10EF1FE	1	0	0	1	0	01	10	10
120	81	1A059B9	5C5F02F5	03FB847A6	01E21DE3FD	1	0	0	1	1	01	01	10
121	82	140B373	38BE05EB	07F708F4C	03C43BC7FB	0	1	0	1	1	11	01	01
122	83	08166E7	717C0BD7	0FEE11E98	0788778FF7	1	0	1	1	0	11	11	01
123	84	102CDCF	62F817AE	1FDC23D31	0F10EF1FEF	0	1	1	0	1	11	11	11
124	85	0059B9F	45F02F5C	1FB847A63	1E21DE3FDE	0	1	1	0	1	11	11	11
125	86	00B373E	0BE05EB9	1F708F4C7	3C43BC7FBC	0	1	1	0	1	11	11	11
126	87	0166E7D	17C0BD72	1EE11E98F	788778FF78	0	1	1	1	0	10	11	11
127	88	02CDCFB	2F817AE5	1DC23D31F	710EF1FEF1	0	1	1	0	0	10	10	11
128	89	059B9F7	5F02F5CA	1B847A63F	621DE3FDE2	0	0	1	0	1	10	10	10
129	90	0B373EF	3E05EB94	1708F4C7F	443BC7FBC4	1	0	0	0	1	10	10	10
130	91	166E7DF	7C0BD728	0E11E98FF	08778FF788	0	0	1	0	1	10	10	10
131	92	0CDCFBE	7817AE50	1C23D31FF	10EF1FEF10	1	0	1	1	1	01	10	10
132	93	19B9F7D	702F5CA1	1847A63FE	21DE3FDE21	1	0	1	1	0	10	01	10
133	94	1373EFB	605EB942	108F4C7FC	43BC7FBC43	0	0	0	1	1	00	10	01
134	95	06E7DF7	40BD7285	011E98FF8	0778FF7886	0	1	0	0	1	01	00	10
135	96	0DCFBEF	017AE50A	023D31FF0	0EF1FEF10D	1	0	0	1	1	00	01	00
136	97	1B9F7DF	02F5CA15	047A63FE1	1DE3FDE21A	1	1	0	1	1	10	00	01
137	98	173EFBF	05EB942B	08F4C7FC3	3BC7FBC434	0	1	1	1	1	00	10	00
138	99	0E7DF7F	0BD72856	11E98FF87	778FF78869	1	1	0	1	1	00	00	10
139	100	1CFBEFF	17AE50AC	03D31FF0F	6F1FEF10D3	1	1	0	0	0	01	00	00
140	101	19F7DFE	2F5CA159	07A63FE1E	5E3FDE21A7	1	0	0	0	0	00	01	00
141	102	13EFBFC	5EB942B3	0F4C7FC3C	3C7FBC434F	0	1	1	0	0	10	00	01
142	103	07DF7F8	3D728566	1E98FF878	78FF78869F	0	0	1	1	0	00	10	00
143	104	0FBEFF0	7AE50ACD	1D31FF0F0	71FEF10D3E	1	1	1	1	0	11	00	10
144	105	1F7DFE1	75CA159B	1A63FE1E1	63FDE21A7D	1	1	1	1	1	00	11	00
145	106	1EFBFC3	6B942B36	14C7FC3C3	47FBC434FB	1	1	0	1	1	11	00	11

Sample Data

146	107	1DF7F86	5728566D	098FF8786	0FF78869F7	1	0	1	1	0	00	11	00
147	108	1BEFF0C	2E50ACDB	131FF0F0C	1FEF10D3EF	1	0	0	1	0	11	00	11
148	109	17DFE19	5CA159B6	063FE1E19	3FDE21A7DF	0	1	0	1	1	01	11	00
149	110	0FBFC33	3942B36D	0C7FC3C32	7FBC434FBF	1	0	1	1	0	01	01	11
150	111	1F7F866	728566DB	18FF87865	7F78869F7E	1	1	1	0	0	00	01	01
151	112	1EFF0CC	650ACDB6	11FF0F0CB	7EF10D3EFC	1	0	0	1	0	10	00	01
152	113	1DFE199	4A159B6D	03FE1E196	7DE21A7DF9	1	0	0	1	0	00	10	00
153	114	1BFC333	142B36DB	07FC3C32C	7BC434FBF3	1	0	0	1	0	00	00	10
154	115	17F8666	28566DB6	0FF878659	778869F7E6	0	0	1	1	0	01	00	00
155	116	0FF0CCC	50ACDB6D	1FF0F0CB3	6F10D3EFCC	1	1	1	0	0	11	01	00
156	117	1FE1999	2159B6DA	1FE1E1966	5E21A7DF99	1	0	1	0	1	10	11	01
157	118	1FC3332	42B36DB5	1FC3C32CC	3C434FBF33	1	1	1	0	1	10	10	11
158	119	1F86664	0566DB6B	1F8786599	78869F7E67	1	0	1	1	1	01	10	10
159	120	1F0CCC8	0ACDB6D6	1F0F0CB33	710D3EFCCE	1	1	1	0	0	10	01	10
160	121	1E19991	159B6DAC	1E1E19666	621A7DF99D	1	1	1	0	1	11	10	01
161	122	1C33323	2B36DB58	1C3C32CCC	4434FBF33B	1	0	1	0	1	00	11	10
162	123	1866647	566DB6B0	187865999	0869F7E676	1	0	1	0	0	11	00	11
163	124	10CCC8F	2CDB6D60	10F0CB333	10D3EFCCEC	0	1	0	1	1	01	11	00
164	125	019991E	59B6DAC0	01E196666	21A7DF99D9	0	1	0	1	1	10	01	11
165	126	033323C	336DB580	03C32CCCD	434FBF33B3	0	0	0	0	0	00	10	01
166	127	0666478	66DB6B01	07865999A	069F7E6766	0	1	0	1	0	00	00	10
167	128	0CCC8F0	4DB6D603	0F0CB3334	0D3EFCCECD	1	1	1	0	1	01	00	00
168	129	19991E1	1B6DAC07	1E1966669	1A7DF99D9B	1	0	1	0	1	00	01	00
169	130	13323C3	36DB580E	1C32CCCD3	34FBF33B37	0	1	1	1	1	10	00	01
170	131	0664786	6DB6B01C	1865999A7	69F7E6766F	0	1	1	1	1	00	10	00
171	132	0CC8F0D	5B6D6039	10CB3334F	53EFCCECDF	1	0	0	1	0	00	00	10
172	133	1991E1A	36DAC073	01966669E	27DF99D9BF	1	1	0	1	1	01	00	00
173	134	1323C35	6DB580E6	032CCCD3C	4FBF33B37E	0	1	0	1	1	00	01	00
174	135	064786A	5B6B01CD	065999A78	1F7E6766FC	0	0	0	0	0	11	00	01
175	136	0C8F0D5	36D6039B	0CB3334F0	3EFCCECDF9	1	1	1	1	1	00	11	00
176	137	191E1AA	6DAC0737	1966669E1	7DF99D9BF3	1	1	1	1	0	00	00	11
177	138	123C354	5B580E6E	12CCCD3C3	7BF33B37E7	0	0	0	1	1	00	00	00
178	139	04786A9	36B01CDC	05999A787	77E6766FCE	0	1	0	1	0	01	00	00
179	140	08F0D53	6D6039B8	0B3334F0E	6FCCECDF9C	1	0	1	1	0	11	01	00
180	141	11E1AA6	5AC07370	166669E1D	5F99D9BF38	0	1	0	1	1	10	11	01
181	142	03C354C	3580E6E0	0CCCD3C3A	3F33B37E70	0	1	1	0	0	10	10	11
182	143	0786A99	6B01CDC0	1999A7875	7E6766FCE1	0	0	1	0	1	10	10	10
183	144	0F0D533	56039B81	13334F0EB	7CCECDF9C2	1	0	0	1	0	01	10	10
184	145	1E1AA66	2C073703	06669E1D6	799D9BF385	1	0	0	1	1	01	01	10
185	146	1C354CC	580E6E06	0CCD3C3AC	733B37E70B	1	0	1	0	1	11	01	01
186	147	186A998	301CDC0C	199A78759	66766FCE17	1	0	1	0	1	10	11	01
187	148	10D5331	6039B818	1334F0EB2	4CECDF9C2F	0	0	0	1	1	01	10	11
188	149	01AA662	40737031	0669E1D65	19D9BF385E	0	0	0	1	0	01	01	10
189	150	0354CC5	00E6E063	0CD3C3ACB	33B37E70BD	0	1	1	1	0	00	01	01
190	151	06A998A	01CDC0C6	19A787596	6766FCE17B	0	1	1	0	0	10	00	01
191	152	0D53315	039B818C	134F0EB2C	4ECDF9C2F6	1	1	0	1	1	00	10	00
192	153	1AA662A	07370318	069E1D659	1D9BF385ED	1	0	0	1	0	00	00	10
193	154	154CC54	0E6E0630	0D3C3ACB3	3B37E70BDB	0	0	1	0	1	00	00	00
194	155	0A998A8	1CDC0C60	1A7875967	766FCE17B6	1	1	1	0	1	01	00	00
195	156	1533151	39B818C0	14F0EB2CE	6CDF9C2F6C	0	1	0	1	1	00	01	00
196	157	0A662A3	73703180	09E1D659D	59BF385ED8	1	0	1	1	1	10	00	01
197	158	14CC547	66E06301	13C3ACB3A	337E70BDB0	0	1	0	0	1	11	10	00
198	159	0998A8E	4DC0C602	078759675	66FCE17B61	1	1	0	1	0	01	11	10
199	160	133151D	1B818C05	0F0EB2CEB	4DF9C2F6C2	0	1	1	1	0	01	01	11
200	161	0662A3B	3703180B	1E1D659D6	1BF385ED85	0	0	1	1	1	11	01	01
201	162	0CC5477	6E063017	1C3ACB3AC	37E70BDB0B	1	0	1	1	0	11	11	01
202	163	198A8EF	5C0C602F	187596759	6FCE17B617	1	0	1	1	0	10	11	11

Sample Data

203	164	13151DE	3818C05F	10EB2CEB2	5F9C2F6C2F	0	0	0	1	1	01	10	11
204	165	062A3BC	703180BF	01D659D65	3F385ED85E	0	0	0	0	1	00	01	10
205	166	0C54779	6063017E	03ACB3ACB	7E70BDB0BD	1	0	0	0	1	11	00	01
206	167	18A8EF2	40C602FD	075967597	7CE17B617B	1	1	0	1	0	00	11	00
207	168	1151DE4	018C05FA	0EB2CEB2F	79C2F6C2F7	0	1	1	1	1	11	00	11
208	169	02A3BC9	03180BF5	1D659D65E	7385ED85EE	0	0	1	1	1	01	11	00
209	170	0547793	063017EB	1ACB3ACBC	670BDB0BDC	0	0	1	0	0	10	01	11
210	171	0A8EF27	0C602FD6	159675978	4E17B617B9	1	0	0	0	1	00	10	01
211	172	151DE4E	18C05FAD	0B2CEB2F1	1C2F6C2F73	0	1	1	0	0	00	00	10
212	173	0A3BC9C	3180BF5A	1659D65E3	385ED85EE6	1	1	0	0	0	01	00	00
213	174	1477938	63017EB5	0CB3ACBC6	70BDB0BDCC	0	0	1	1	1	00	01	00
214	175	08EF270	4602FD6A	19675978D	617B617B99	1	0	1	0	0	10	00	01
215	176	11DE4E1	0C05FAD5	12CEB2F1A	42F6C2F733	0	0	0	1	1	11	10	00
216	177	03BC9C3	180BF5AA	059D65E34	05ED85EE67	0	0	0	1	0	00	11	10
217	178	0779387	3017EB55	0B3ACBC68	0BDB0BDCCF	0	0	1	1	0	11	00	11
218	179	0EF270F	602FD6AA	1675978D0	17B617B99F	1	0	0	1	1	01	11	00
219	180	1DE4E1F	405FAD54	0CEB2F1A1	2F6C2F733F	1	0	1	0	1	10	01	11
220	181	1BC9C3F	00BF5AA9	19D65E342	5ED85EE67F	1	1	1	1	0	10	10	01
221	182	179387F	017EB552	13ACBC684	3DB0BDCCFE	0	0	0	1	1	10	10	10
222	183	0F270FF	02FD6AA5	075978D09	7B617B99FC	1	1	0	0	0	01	10	10
223	184	1E4E1FF	05FAD54A	0EB2F1A12	76C2F733F9	1	1	1	1	1	10	01	10
224	185	1C9C3FE	0BF5AA94	1D65E3425	6D85EE67F2	1	1	1	1	0	10	10	01
225	186	19387FD	17EB5529	1ACBC684B	5B0BDCCFE4	1	1	1	0	1	01	10	10
226	187	1270FFA	2FD6AA53	15978D096	3617B99FC9	0	1	0	0	0	01	01	10
227	188	04E1FF5	5FAD54A7	0B2F1A12C	6C2F733F93	0	1	1	0	1	11	01	01
228	189	09C3FEB	3F5AA94E	165E34258	585EE67F27	1	0	0	0	0	10	11	01
229	190	1387FD7	7EB5529C	0CBC684B1	30BDCCFE4F	0	1	1	1	1	10	10	11
230	191	070FFAE	7D6AA538	1978D0962	617B99FC9E	0	0	1	0	1	10	10	10
231	192	0E1FF5C	7AD54A70	12F1A12C4	42F733F93D	1	1	0	1	1	01	10	10
232	193	1C3FEB9	75AA94E1	05E342588	05EE67F27A	1	1	0	1	0	10	01	10
233	194	187FD73	6B5529C3	0BC684B10	0BDCCFE4F4	1	0	1	1	1	11	10	01
234	195	10FFAE6	56AA5386	178D09621	17B99FC9E8	0	1	0	1	1	00	11	10
235	196	01FF5CC	2D54A70C	0F1A12C43	2F733F93D0	0	0	1	0	1	10	00	11
236	197	03FEB98	5AA94E19	1E3425887	5EE67F27A1	0	1	1	1	1	00	10	00
237	198	07FD731	35529C33	1C684B10F	3DCCFE4F42	0	0	1	1	0	00	00	10
238	199	0FFAE63	6AA53866	18D09621F	7B99FC9E84	1	1	1	1	0	10	00	00
239	200	1FF5CC6	554A70CD	11A12C43F	7733F93D09	1	0	0	0	1	11	10	00

```
Z[0]  = 59
Z[1]  = 3B
Z[2]  = EF
Z[3]  = 07
Z[4]  = 13
Z[5]  = 70
Z[6]  = 9B
Z[7]  = B7
Z[8]  = 52
Z[9]  = 8F
Z[10] = 3E
Z[11] = B9
Z[12] = A5
Z[13] = AC
Z[14] = EA
Z[15] = 9E
```

Sample Data

```
================================================================================================
         Reload this pattern into the LFSRs
         Hold content of Summation Combiner regs and calculate new C[t+1] and Z values
================================================================================================
LFSR1  <= 1521359
LFSR2  <= 528F703B
LFSR3  <= 0AC3E9BEF
LFSR4  <= 4FEAB9B707
C[t+1] <= 00

================================================================================================
         Generating 125 key symbols (encryption/decryption sequence)
================================================================================================
```

240	1	1521359	528F703B	0AC3E9BEF	4FEAB9B707	0	1	1	1	1	00	10	00
241	2	0A426B3	251EE076	1587D37DE	1FD5736E0F	1	0	0	1	0	00	00	10
242	3	1484D67	4A3DC0ED	0B0FA6FBD	3FAAE6DC1E	0	0	1	1	0	01	00	00
243	4	0909ACF	147B81DA	161F4DF7A	7F55CDB83D	1	0	0	0	0	00	01	00
244	5	121359E	28F703B5	0C3E9BEF5	7EAB9B707B	0	1	1	1	1	10	00	01
245	6	0426B3C	51EE076B	187D37DEB	7D5736E0F6	0	1	1	0	0	00	10	00
246	7	084D679	23DC0ED6	10FA6FBD7	7AAE6DC1EC	1	1	0	1	1	00	00	10
247	8	109ACF2	47B81DAC	01F4DF7AF	755CDB83D8	0	1	0	0	1	00	00	00
248	9	01359E4	0F703B59	03E9BEF5E	6AB9B707B1	0	0	0	1	1	00	00	00
249	10	026B3C8	1EE076B3	07D37DEBD	55736E0F63	0	1	0	0	1	00	00	00
250	11	04D6791	3DC0ED67	0FA6FBD7A	2AE6DC1EC7	0	1	1	1	1	01	00	00
251	12	09ACF22	7B81DACF	1F4DF7AF4	55CDB83D8F	1	1	1	1	1	11	01	00
252	13	1359E44	7703B59E	1E9BEF5E8	2B9B707B1F	0	0	1	1	1	10	11	01
253	14	06B3C88	6E076B3C	1D37DEBD0	5736E0F63F	0	0	1	0	1	01	10	11
254	15	0D67911	5C0ED678	1A6FBD7A1	2E6DC1EC7E	1	0	1	0	1	01	01	10
255	16	1ACF223	381DACF0	14DF7AF42	5CDB83D8FD	1	0	0	1	1	11	01	01
256	17	159E446	703B59E0	09BEF5E85	39B707B1FA	0	0	1	1	1	10	11	01
257	18	0B3C88C	6076B3C0	137DEBD0A	736E0F63F4	1	0	0	0	1	01	10	11
258	19	1679118	40ED6780	06FBD7A15	66DC1EC7E8	0	1	0	1	1	01	01	10
259	20	0CF2231	01DACF00	0DF7AF42A	4DB83D8FD1	1	1	1	1	1	00	01	01
260	21	19E4463	03B59E01	1BEF5E854	1B707B1FA3	1	1	1	0	1	10	00	01
261	22	13C88C6	076B3C03	17DEBD0A9	36E0F63F47	0	0	0	1	1	11	10	00
262	23	079118C	0ED67807	0FBD7A152	6DC1EC7E8E	0	1	1	1	0	01	11	10
263	24	0F22318	1DACF00E	1F7AF42A4	5B83D8FD1D	1	1	1	1	1	01	01	11
264	25	1E44630	3B59E01C	1EF5E8548	3707B1FA3B	1	0	1	0	1	11	01	01
265	26	1C88C61	76B3C039	1DEBD0A91	6E0F63F477	1	1	1	0	0	11	11	01
266	27	19118C3	6D678073	1BD7A1523	5C1EC7E8EF	1	0	1	0	1	11	11	11
267	28	1223187	5ACF00E6	17AF42A46	383D8FD1DE	0	1	0	0	0	11	11	11
268	29	044630E	359E01CC	0F5E8548D	707B1FA3BD	0	1	1	0	1	11	11	11
269	30	088C61C	6B3C0399	1EBD0A91A	60F63F477B	1	0	1	1	0	10	11	11
270	31	1118C39	56780733	1D7A15234	41EC7E8EF6	0	0	1	1	0	10	10	11
271	32	0231872	2CF00E67	1AF42A468	03D8FD1DEC	0	1	1	1	1	01	10	10
272	33	04630E5	59E01CCE	15E8548D1	07B1FA3BD8	0	1	0	1	1	01	01	10
273	34	08C61CB	33C0399D	0BD0A91A3	0F63F477B1	1	1	1	0	0	00	01	01
274	35	118C396	6780733A	17A152347	1EC7E8EF63	0	1	0	1	0	10	00	01
275	36	031872D	4F00E674	0F42A468E	3D8FD1DEC7	0	0	1	1	0	00	10	00
276	37	0630E5A	1E01CCE8	1E8548D1D	7B1FA3BD8E	0	0	1	0	1	01	00	10
277	38	0C61CB5	3C0399D0	1D0A91A3B	763F477B1C	1	0	1	0	1	00	01	00
278	39	18C396A	780733A0	1A1523477	6C7E8EF639	1	0	1	0	0	10	00	01
279	40	11872D5	700E6741	142A468EF	58FD1DEC72	0	0	0	1	1	11	10	00
280	41	030E5AB	601CCE83	08548D1DF	31FA3BD8E5	0	0	1	1	1	00	11	10
281	42	061CB57	40399D07	10A91A3BF	63F477B1CB	0	0	0	1	1	10	00	11
282	43	0C396AF	00733A0F	01523477E	47E8EF6396	1	0	0	1	0	00	10	00
283	44	1872D5F	00E6741F	02A468EFD	0FD1DEC72C	1	1	0	1	1	00	00	10

Sample Data

284	45	10E5ABE	01CCE83F	0548D1DFA	1FA3BD8E58	0	1	0	1	0	01	00	00
285	46	01CB57C	0399D07F	0A91A3BF4	3F477B1CB0	0	1	1	0	1	00	01	00
286	47	0396AF9	0733A0FE	1523477E9	7E8EF63961	0	0	0	1	1	11	00	01
287	48	072D5F3	0E6741FD	0A468EFD2	7D1DEC72C3	0	0	1	0	0	01	11	00
288	49	0E5ABE7	1CCE83FA	148D1DFA4	7A3BD8E587	1	1	0	0	1	10	01	11
289	50	1CB57CE	399D07F4	091A3BF49	7477B1CB0F	1	1	1	0	1	11	10	01
290	51	196AF9D	733A0FE9	123477E92	68EF63961E	1	0	0	1	1	00	11	10
291	52	12D5F3B	66741FD2	0468EFD25	51DEC72C3C	0	0	0	1	1	10	00	11
292	53	05ABE77	4CE83FA4	08D1DFA4B	23BD8E5879	0	1	1	1	1	00	10	00
293	54	0B57CEE	19D07F49	11A3BF496	477B1CB0F2	1	1	0	0	0	00	00	10
294	55	16AF9DC	33A0FE92	03477E92C	0EF63961E4	0	1	0	1	0	01	00	00
295	56	0D5F3B8	6741FD25	068EFD259	1DEC72C3C9	1	0	0	1	1	00	01	00
296	57	1ABE771	4E83FA4B	0D1DFA4B3	3BD8E58793	1	1	1	1	0	01	00	01
297	58	157CEE2	1D07F496	1A3BF4967	77B1CB0F26	0	0	1	1	1	00	01	00
298	59	0AF9DC5	3A0FE92D	1477E92CE	6F63961E4D	1	0	0	0	1	11	00	01
299	60	15F3B8B	741FD25A	08EFD259C	5EC72C3C9B	0	0	1	1	1	01	11	00
300	61	0BE7716	683FA4B4	11DFA4B39	3D8E587937	1	0	0	1	1	10	01	11
301	62	17CEE2D	507F4968	03BF49672	7B1CB0F26E	0	0	0	0	0	00	10	01
302	63	0F9DC5B	20FE92D0	077E92CE4	763961E4DC	1	1	0	0	0	00	00	10
303	64	1F3B8B6	41FD25A0	0EFD259C9	6C72C3C9B9	1	1	1	0	1	01	00	00
304	65	1E7716D	03FA4B40	1DFA4B393	58E5879373	1	1	1	1	1	11	01	00
305	66	1CEE2DB	07F49680	1BF496727	31CB0F26E6	1	1	1	1	1	11	11	01
306	67	19DC5B7	0FE92D00	17E92CE4E	63961E4DCD	1	1	0	1	0	10	11	11
307	68	13B8B6F	1FD25A00	0FD259C9C	472C3C9B9A	0	1	1	0	0	10	10	11
308	69	07716DF	3FA4B400	1FA4B3938	0E58793735	0	1	1	0	0	01	10	10
309	70	0EE2DBF	7F496800	1F4967271	1CB0F26E6A	1	0	1	1	0	10	01	10
310	71	1DC5B7F	7E92D000	1E92CE4E2	3961E4DCD4	1	1	1	0	1	11	10	01
311	72	1B8B6FF	7D25A001	1D259C9C4	72C3C9B9A9	1	0	1	1	0	01	11	10
312	73	1716DFF	7A4B4002	1A4B39389	6587937352	0	0	1	1	1	10	01	11
313	74	0E2DBFF	74968005	149672713	4B0F26E6A5	1	1	0	0	0	11	10	01
314	75	1C5B7FE	692D000B	092CE4E26	161E4DCD4B	1	0	1	0	1	00	11	10
315	76	18B6FFC	525A0017	1259C9C4D	2C3C9B9A96	1	0	0	0	1	10	00	11
316	77	116DFF8	24B4002F	04B39389B	587937352C	0	1	0	0	1	11	10	00
317	78	02DBFF1	4968005F	096727136	30F26E6A58	0	0	1	1	1	00	11	10
318	79	05B7FE3	12D000BF	12CE4E26C	61E4DCD4B1	0	1	0	1	0	11	00	11
319	80	0B6FFC7	25A0017F	059C9C4D8	43C9B9A963	1	1	0	1	0	00	11	00
320	81	16DFF8E	4B4002FF	0B39389B1	07937352C6	0	0	1	1	0	11	00	11
321	82	0DBFF1C	168005FF	167271363	0F26E6A58C	1	1	0	0	1	01	11	00
322	83	1B7FE38	2D000BFF	0CE4E26C7	1E4DCD4B18	1	0	1	0	1	10	01	11
323	84	16FFC70	5A0017FF	19C9C4D8F	3C9B9A9631	0	0	1	1	0	11	10	01
324	85	0DFF8E1	34002FFF	139389B1E	7937352C62	1	0	0	0	0	00	11	10
325	86	1BFF1C3	68005FFF	07271363D	726E6A58C4	1	0	0	0	1	10	00	11
326	87	17FE387	5000BFFE	0E4E26C7B	64DCD4B188	0	0	1	1	0	00	10	00
327	88	0FFC70F	20017FFD	1C9C4D8F6	49B9A96311	1	0	1	1	1	00	00	10
328	89	1FF8E1F	4002FFFB	19389B1ED	137352C623	1	0	1	0	0	01	00	00
329	90	1FF1C3F	0005FFF7	1271363DB	26E6A58C46	1	0	0	1	1	00	01	00
330	91	1FE387F	000BFFEE	04E26C7B6	4DCD4B188C	1	0	0	1	0	10	00	01
331	92	1FC70FF	0017FFDC	09C4D8F6D	1B9A963118	1	0	1	1	1	00	10	00
332	93	1F8E1FF	002FFFB8	1389B1EDA	37352C6231	1	0	0	0	1	01	00	10
333	94	1F1C3FF	005FFF70	071363DB4	6E6A58C462	1	0	0	0	0	00	01	00
334	95	1E387FE	00BFFEE0	0E26C7B68	5CD4B188C5	1	1	1	1	0	01	00	01
335	96	1C70FFC	017FFDC1	1C4D8F6D1	39A963118A	1	0	1	1	0	11	01	00
336	97	18E1FF9	02FFFB82	189B1EDA2	7352C62315	1	1	1	0	0	11	11	01
337	98	11C3FF2	05FFF705	11363DB45	66A58C462B	0	1	0	1	1	11	11	11
338	99	0387FE4	0BFFEE0A	026C7B68B	4D4B188C56	0	1	0	0	0	11	11	11
339	100	070FFC9	17FFDC15	04D8F6D16	1A963118AD	0	1	0	1	1	11	11	11
340	101	0E1FF92	2FFFB82B	09B1EDA2C	352C62315A	1	1	1	0	0	10	11	11

Sample Data

341	102	1C3FF24	5FFF7057	1363DB458	6A58C462B4	1	1	0	0	0	10	10	11
342	103	187FE48	3FFEE0AE	06C7B68B0	54B188C569	1	1	0	1	1	01	10	10
343	104	10FFC90	7FFDC15C	0D8F6D161	2963118AD2	0	1	1	0	1	01	01	10
344	105	01FF920	7FFB82B9	1B1EDA2C2	52C62315A5	0	1	1	1	0	00	01	01
345	106	03FF240	7FF70573	163DB4584	258C462B4B	0	1	0	1	0	10	00	01
346	107	07FE481	7FEE0AE6	0C7B68B08	4B188C5696	0	1	1	0	0	00	10	00
347	108	0FFC902	7FDC15CD	18F6D1610	163118AD2D	1	1	1	0	1	00	00	10
348	109	1FF9204	7FB82B9A	11EDA2C20	2C62315A5B	1	1	0	0	0	01	00	00
349	110	1FF2408	7F705735	03DB45841	58C462B4B6	1	0	0	1	1	00	01	00
350	111	1FE4810	7EE0AE6B	07B68B082	3188C5696C	1	1	0	1	1	10	00	01
351	112	1FC9021	7DC15CD6	0F6D16105	63118AD2D8	1	1	1	0	1	00	10	00
352	113	1F92042	7B82B9AD	1EDA2C20B	462315A5B0	1	1	1	0	1	00	00	10
353	114	1F24084	7705735A	1DB458416	0C462B4B61	1	0	1	0	0	01	00	00
354	115	1E48108	6E0AE6B5	1B68B082C	188C5696C3	1	0	1	1	0	11	01	00
355	116	1C90211	5C15CD6A	16D161059	3118AD2D86	1	0	0	0	0	10	11	01
356	117	1920422	382B9AD5	0DA2C20B3	62315A5B0D	1	0	1	0	0	10	10	11
357	118	1240845	705735AA	1B4584167	4462B4B61A	0	0	1	0	1	10	10	10
358	119	048108A	60AE6B55	168B082CF	08C5696C34	0	1	0	1	0	01	10	10
359	120	0902114	415CD6AB	0D161059E	118AD2D869	1	0	1	1	0	10	01	10
360	121	1204228	02B9AD56	1A2C20B3D	2315A5B0D2	0	1	1	0	0	11	10	01
361	122	0408451	05735AAD	14584167B	462B4B61A4	0	0	0	0	1	11	11	10
362	123	08108A2	0AE6B55B	08B082CF7	0C5696C348	1	1	1	0	0	10	11	11
363	124	1021144	15CD6AB6	1161059EF	18AD2D8690	0	1	0	1	0	10	10	11
364	125	0042289	2B9AD56C	02C20B3DE	315A5B0D20	0	1	0	0	1	10	10	10

Sample Data

1.1.5 Fourth Set of Samples

```
Initial values for the key, pan address and clock

K'c4[0]   = 21   K'c4[1]   = 87    K'c4[2]   = F0    K'c4[3]  = 4A
K'c4[4]   = BA   K'c4[5]   = 90    K'c4[6]   = 31    K'c4[7]  = D0
K'c4[8]   = 78   K'c4[9]   = 0D    K'c4[10]  = 4C    K'c4[11] = 53
K'c4[12]  = E0   K'c4[13]  = 15    K'c4[14]  = 3A    K'c4[15] = 63

Addr4[0] = 2C   Addr4[1] = 7F    Addr4[2] = 94
Addr4[3] = 56   Addr4[4] = 0F    Addr4[5] = 1B

CL4[0]  = 5F   CL4[1]  = 1A    CL4[2]  = 00    CL4[3]  = 02


=============================================================================================
         Fill LFSRs with initial data
=============================================================================================

  t  clk#    LFSR1    LFSR2     LFSR3      LFSR4          X1 X2 X3 X4   Z  C[t+1] C[t] C[t-1]

  0     0    0000000* 00000000* 000000000* 0000000000*     0  0  0  0    0  00     00   00
  1     1    0000000* 00000001* 000000001* 0000000001*     0  0  0  0    0  00     00   00
  2     2    0000001* 00000002* 000000002* 0000000003*     0  0  0  0    0  00     00   00
  3     3    0000002* 00000004* 000000004* 0000000007*     0  0  0  0    0  00     00   00
  4     4    0000004* 00000009* 000000008* 000000000F*     0  0  0  0    0  00     00   00
  5     5    0000008* 00000013* 000000010* 000000001E*     0  0  0  0    0  00     00   00
  6     6    0000010* 00000027* 000000021* 000000003D*     0  0  0  0    0  00     00   00
  7     7    0000021* 0000004F* 000000043* 000000007A*     0  0  0  0    0  00     00   00
  8     8    0000042* 0000009F* 000000087* 00000000F4*     0  0  0  0    0  00     00   00
  9     9    0000084* 0000013F* 00000010F* 00000001E9*     0  0  0  0    0  00     00   00
 10    10    0000108* 0000027F* 00000021F* 00000003D2*     0  0  0  0    0  00     00   00
 11    11    0000211* 000004FE* 00000043E* 00000007A5*     0  0  0  0    0  00     00   00
 12    12    0000422* 000009FC* 00000087C* 0000000F4A*     0  0  0  0    0  00     00   00
 13    13    0000845* 000013F8* 0000010F8* 0000001E94*     0  0  0  0    0  00     00   00
 14    14    000108B* 000027F0* 0000021F1* 0000003D29*     0  0  0  0    0  00     00   00
 15    15    0002117* 00004FE1* 0000043E3* 0000007A52*     0  0  0  0    0  00     00   00
 16    16    000422E* 00009FC2* 0000087C6* 000000F4A4*     0  0  0  0    0  00     00   00
 17    17    000845D* 00013F84* 000010F8C* 000001E948*     0  0  0  0    0  00     00   00
 18    18    00108BA* 00027F08* 000021F18* 000003D290*     0  0  0  0    0  00     00   00
 19    19    0021174* 0004FE10* 000043E30* 000007A520*     0  0  0  0    0  00     00   00
 20    20    00422E8* 0009FC21* 000087C61* 00000F4A41*     0  0  0  0    0  00     00   00
 21    21    00845D1* 0013F842* 00010F8C3* 00001E9482*     0  0  0  0    0  00     00   00
 22    22    0108BA3* 0027F084* 00021F186* 00003D2905*     0  0  0  0    0  00     00   00
 23    23    0211747* 004FE109* 00043E30C* 00007A520B*     0  0  0  0    0  00     00   00
 24    24    0422E8F* 009FC213* 00087C619* 0000F4A417*     0  1  0  0    1  00     00   00
 25    25    0845D1E* 013F8426* 0010F8C32* 0001E9482F*     1  0  0  0    1  00     00   00
 26    26    108BA3D  027F084D* 0021F1864* 0003D2905E*     0  0  0  0    0  00     00   00
 27    27    011747B  04FE109B* 0043E30C9* 0007A520BC*     0  1  0  0    1  00     00   00
 28    28    022E8F6  09FC2136* 0087C6192* 000F4A4179*     0  1  0  0    1  00     00   00
 29    29    045D1EC  13F8426C* 010F8C325* 001E9482F2*     0  1  0  0    1  00     00   00
 30    30    08BA3D9  27F084D8* 021F1864B* 003D2905E5*     1  1  0  0    0  01     00   00
 31    31    11747B3  4FE109B0* 043E30C97* 007A520BCA*     0  1  0  0    1  00     00   00
 32    32    02E8F67  1FC21360  087C6192E* 00F4A41795*     0  1  1  1    1  01     00   00
 33    33    05D1ECF  3F8426C1  10F8C325C* 01E9482F2B*     0  1  0  1    0  01     00   00
 34    34    0BA3D9F  7F084D82  01F1864B8  03D2905E56*     1  0  0  1    0  01     00   00
```

Sample Data

35	35	1747B3E	7E109B04	03E30C970	07A520BCAC*	0	0	0	1	1	00	00	00
36	36	0E8F67C	7C213608	07C6192E1	0F4A417958*	1	0	0	0	1	00	00	00
37	37	1D1ECF8	78426C11	0F8C325C3	1E9482F2B1*	1	0	1	1	1	01	00	00
38	38	1A3D9F0	7084D822	1F1864B86	3D2905E563*	1	1	1	0	1	01	00	00
39	39	147B3E1	6109B044	1E30C970C	7A520BCAC6*	0	0	1	0	1	00	00	00

Start clocking Summation Combiner

40	1	08F67C2	42136088	1C6192E18	74A417958D	1	0	1	1	1	01	00	00
41	2	11ECF84	0426C111	18C325C30	69482F2B1B	0	0	1	0	0	00	01	00
42	3	03D9F08	084D8222	11864B861	52905E5637	0	0	0	1	1	11	00	01
43	4	07B3E10	109B0444	030C970C3	2520BCAC6E	0	1	0	0	0	01	11	00
44	5	0F67C21	21360889	06192E186	4A417958DC	1	0	0	0	0	10	01	11
45	6	1ECF843	426C1112	0C325C30C	1482F2B1B8	1	0	1	1	1	11	10	01
46	7	1D9F086	04D82225	1864B8619	2905E56370	1	1	1	0	0	01	11	10
47	8	1B3E10D	09B0444B	10C970C32	520BCAC6E1	1	1	0	0	1	10	01	11
48	9	167C21B	13608897	0192E1865	2417958DC3	0	0	0	0	0	00	10	01
49	10	0CF8436	26C1112F	0325C30CB	482F2B1B87	1	1	0	0	0	00	00	10
50	11	19F086D	4D82225E	064B86197	105E56370F	1	1	0	0	0	01	00	00
51	12	13E10DB	1B0444BC	0C970C32F	20BCAC6E1F	0	0	1	1	1	00	01	00
52	13	07C21B7	36088979	192E1865E	417958DC3F	0	0	1	0	1	11	00	01
53	14	0F8436E	6C1112F2	125C30CBD	02F2B1B87F	1	0	0	1	1	01	11	00
54	15	1F086DD	582225E4	04B86197B	05E56370FF	1	0	0	1	1	10	01	11
55	16	1E10DBA	30444BC9	0970C32F7	0BCAC6E1FF	1	0	1	1	1	11	10	01
56	17	1C21B75	60889793	12E1865EE	17958DC3FF	1	1	0	1	0	01	11	10
57	18	18436EA	41112F27	05C30CBDD	2F2B1B87FF	1	0	0	0	0	10	01	11
58	19	1086DD4	02225E4E	0B86197BA	5E56370FFF	0	0	1	0	1	00	10	01
59	20	010DBA8	0444BC9D	170C32F74	3CAC6E1FFF	0	0	0	1	1	01	00	10
60	21	021B750	0889793A	0E1865EE8	7958DC3FFF	0	1	1	0	1	00	01	00
61	22	0436EA0	1112F274	1C30CBDD0	72B1B87FFE	0	0	1	1	0	10	00	01
62	23	086DD40	2225E4E9	186197BA1	656370FFFC	1	0	1	0	0	00	10	00
63	24	10DBA81	444BC9D3	10C32F743	4AC6E1FFF8	0	0	0	1	1	01	00	10
64	25	01B7502	089793A7	01865EE86	158DC3FFF1	0	1	0	1	1	00	01	00
65	26	036EA05	112F274E	030CBDD0D	2B1B87FFE3	0	0	0	0	0	11	00	01
66	27	06DD40B	225E4E9C	06197BA1A	56370FFFC6	0	0	0	0	1	10	11	00
67	28	0DBA817	44BC9D39	0C32F7434	2C6E1FFF8D	1	1	1	0	1	10	10	11
68	29	1B7502E	09793A72	1865EE868	58DC3FFF1B	1	0	1	1	1	01	10	10
69	30	16EA05D	12F274E5	10CBDD0D0	31B87FFE36	0	1	0	1	1	01	01	10
70	31	0DD40BA	25E4E9CB	0197BA1A1	6370FFFC6D	1	1	0	0	1	11	01	01
71	32	1BA8174	4BC9D397	032F74343	46E1FFF8DA	1	1	0	1	0	11	11	01
72	33	17502E8	1793A72F	065EE8687	0DC3FFF1B4	0	1	0	1	1	11	11	11
73	34	0EA05D0	2F274E5E	0CBDD0D0F	1B87FFE369	1	0	1	1	0	10	11	11
74	35	1D40BA0	5E4E9CBD	197BA1A1F	370FFFC6D2	1	0	1	0	0	10	10	11
75	36	1A81741	3C9D397B	12F74343F	6E1FFF8DA5	1	1	0	0	0	01	10	10
76	37	1502E82	793A72F6	05EE8687F	5C3FFF1B4B	0	0	0	0	1	00	01	10
77	38	0A05D05	7274E5ED	0BDD0D0FF	387FFE3696	1	0	1	0	0	10	00	01
78	39	140BA0B	64E9CBDA	17BA1A1FF	70FFFC6D2C	0	1	0	1	0	00	10	00
79	40	0817416	49D397B4	0F74343FE	61FFF8DA59	1	1	1	1	0	11	00	10
80	41	102E82C	13A72F69	1EE8687FD	43FFF1B4B3	0	1	1	1	0	00	11	00
81	42	005D058	274E5ED2	1DD0D0FFA	07FFE36966	0	0	1	1	0	11	00	11
82	43	00BA0B0	4E9CBDA5	1BA1A1FF5	0FFFC6D2CD	0	1	1	1	0	00	11	00
83	44	0174160	1D397B4A	174343FEA	1FFF8DA59B	0	0	0	1	1	10	00	11
84	45	02E82C0	3A72F695	0E8687FD4	3FFF1B4B37	0	0	1	1	0	00	10	00
85	46	05D0580	74E5ED2B	1D0D0FFA9	7FFE36966E	0	1	1	1	1	00	00	10
86	47	0BA0B00	69CBDA56	1A1A1FF53	7FFC6D2CDC	1	1	1	1	0	10	00	00
87	48	1741600	5397B4AC	14343FEA6	7FF8DA59B8	0	1	0	1	0	00	10	00
88	49	0E82C01	272F6959	08687FD4D	7FF1B4B370	1	0	1	1	1	00	00	10

Sample Data

89	50	1D05802	4E5ED2B3	10D0FFA9A	7FE36966E0	1	0	0	1	0	01	00	00
90	51	1A0B004	1CBDA566	01A1FF535	7FC6D2CDC0	1	1	0	1	0	11	01	00
91	52	1416009	397B4ACC	0343FEA6B	7F8DA59B80	0	0	0	1	0	10	11	01
92	53	082C013	72F69599	0687FD4D7	7F1B4B3701	1	1	0	0	0	10	10	11
93	54	1058026	65ED2B33	0D0FFA9AF	7E36966E03	0	1	1	0	0	01	10	10
94	55	00B004D	4BDA5667	1A1FF535E	7C6D2CDC06	0	1	1	0	1	01	01	10
95	56	016009B	17B4ACCE	143FEA6BD	78DA59B80D	0	1	0	1	1	11	01	01
96	57	02C0137	2F69599D	087FD4D7B	71B4B3701A	0	0	1	1	1	10	11	01
97	58	058026F	5ED2B33B	10FFA9AF6	636966E034	0	1	0	0	1	01	10	11
98	59	0B004DF	3DA56677	01FF535ED	46D2CDC068	1	1	0	1	0	10	01	10
99	60	16009BF	7B4ACCEF	03FEA6BDB	0DA59B80D0	0	0	0	1	1	00	10	01
100	61	0C0137F	769599DF	07FD4D7B7	1B4B3701A1	1	1	0	0	0	00	00	10
101	62	18026FE	6D2B33BE	0FFA9AF6E	36966E0342	1	0	1	1	1	01	00	00
102	63	1004DFC	5A56677D	1FF535EDD	6D2CDC0684	0	0	1	0	0	00	01	00
103	64	0009BF9	34ACCEFB	1FEA6BDBB	5A59B80D09	0	1	1	0	0	10	00	01
104	65	00137F2	69599DF7	1FD4D7B76	34B3701A12	0	0	1	1	0	00	10	00
105	66	0026FE5	52B33BEF	1FA9AF6EC	6966E03424	0	1	1	0	0	00	00	10
106	67	004DFCA	256677DF	1F535EDD8	52CDC06848	0	0	1	1	0	01	00	00
107	68	009BF94	4ACCEFBE	1EA6BDBB0	259B80D091	0	1	1	1	0	11	01	00
108	69	0137F29	1599DF7C	1D4D7B760	4B3701A123	0	1	1	0	1	10	11	01
109	70	026FE53	2B33BEF9	1A9AF6EC0	166E034246	0	0	1	0	1	01	10	11
110	71	04DFCA7	56677DF2	1535EDD81	2CDC06848D	0	0	0	1	0	01	01	10
111	72	09BF94F	2CCEFBE4	0A6BDBB03	59B80D091B	1	1	1	1	1	00	01	01
112	73	137F29E	599DF7C9	14D7B7607	33701A1236	0	1	0	0	1	11	00	01
113	74	06FE53C	333BEF93	09AF6EC0E	66E034246C	0	0	1	1	1	01	11	00
114	75	0DFCA79	6677DF26	135EDD81D	4DC06848D8	1	0	0	1	1	10	01	11
115	76	1BF94F2	4CEFBE4D	06BDBB03B	1B80D091B1	1	1	0	1	1	11	10	01
116	77	17F29E5	19DF7C9A	0D7B76077	3701A12363	0	1	1	0	1	00	11	10
117	78	0FE53CA	33BEF934	1AF6EC0EF	6E034246C6	1	1	1	0	1	11	00	11
118	79	1FCA794	677DF269	15EDD81DF	5C06848D8C	1	0	0	0	0	01	11	00
119	80	1F94F29	4EFBE4D2	0BDBB03BE	380D091B19	1	1	1	0	0	01	01	11
120	81	1F29E53	1DF7C9A5	17B76077D	701A123633	1	1	0	0	1	11	01	01
121	82	1E53CA6	3BEF934B	0F6EC0EFB	6034246C66	1	1	1	0	0	11	11	01
122	83	1CA794D	77DF2696	1EDD81DF6	406848D8CD	1	1	1	0	0	10	11	11
123	84	194F29B	6FBE4D2C	1DBB03BED	00D091B19B	1	1	1	1	0	11	10	11
124	85	129E536	5F7C9A59	1B76077DA	01A1236337	0	0	1	1	1	00	11	10
125	86	053CA6C	3EF934B3	16EC0EFB4	034246C66E	0	1	0	0	1	10	00	11
126	87	0A794D9	7DF26967	0DD81DF69	06848D8CDD	1	1	1	1	0	01	10	00
127	88	14F29B3	7BE4D2CF	1BB03BED3	0D091B19BB	0	1	1	0	1	01	01	10
128	89	09E5366	77C9A59F	176077DA6	1A12363377	1	1	0	0	1	11	01	01
129	90	13CA6CD	6F934B3F	0EC0EFB4D	34246C66EF	0	1	1	0	1	10	11	01
130	91	0794D9B	5F26967F	1D81DF69A	6848D8CDDF	0	0	1	0	1	01	10	11
131	92	0F29B37	3E4D2CFE	1B03BED35	5091B19BBE	1	0	1	1	0	10	01	10
132	93	1E5366F	7C9A59FD	16077DA6B	212363377C	1	1	0	0	0	11	10	01
133	94	1CA6CDF	7934B3FB	0C0EFB4D6	4246C66EF9	1	0	1	0	1	00	11	10
134	95	194D9BE	726967F6	181DF69AD	048D8CDDF2	1	0	1	1	1	11	00	11
135	96	129B37D	64D2CFED	103BED35B	091B19BBE5	0	1	0	0	0	01	11	00
136	97	05366FA	49A59FDA	0077DA6B7	12363377CA	0	1	0	0	0	10	01	11
137	98	0A6CDF5	134B3FB4	00EFB4D6E	246C66EF95	1	0	0	0	1	00	10	01
138	99	14D9BEA	26967F69	01DF69ADD	48D8CDDF2B	0	1	0	1	0	00	00	10
139	100	09B37D4	4D2CFED2	03BED35BB	11B19BBE56	1	0	0	1	0	01	00	00
140	101	1366FA8	1A59FDA5	077DA6B77	2363377CAC	0	0	0	0	1	01	01	00
141	102	06CDF51	34B3FB4A	0EFB4D6EF	46C66EF959	0	1	1	1	0	00	01	01
142	103	0D9BEA2	6967F695	1DF69ADDF	0D8CDDF2B2	1	0	1	1	1	10	00	01
143	104	1B37D45	52CFED2A	1BED35BBF	1B19BBE564	1	1	1	0	1	00	10	00
144	105	166FA8A	259FDA54	17DA6B77E	363377CAC8	0	1	0	0	1	01	00	10
145	106	0CDF515	4B3FB4A9	0FB4D6EFC	6C66EF9591	1	0	1	0	1	00	01	00

Sample Data

146	107	19BEA2B	167F6952	1F69ADDF8	58CDDF2B22	1	0	1	1	1	10	00	01
147	108	137D457	2CFED2A5	1ED35BBF1	319BBE5645	0	1	1	1	1	00	10	00
148	109	06FA8AF	59FDA54A	1DA6B77E2	63377CAC8B	0	1	1	0	0	00	00	10
149	110	0DF515F	33FB4A95	1B4D6EFC4	466EF95916	1	1	1	0	1	01	00	00
150	111	1BEA2BF	67F6952A	169ADDF88	0CDDF2B22C	1	1	0	1	0	11	01	00
151	112	17D457F	4FED2A55	0D35BBF10	19BBE56459	0	1	1	1	0	11	11	01
152	113	0FA8AFE	1FDA54AB	1A6B77E20	3377CAC8B3	1	1	1	0	0	10	11	11
153	114	1F515FD	3FB4A957	14D6EFC40	66EF959166	1	1	0	1	1	10	10	11
154	115	1EA2BFA	7F6952AF	09ADDF880	4DDF2B22CC	1	0	1	1	1	01	10	10
155	116	1D457F4	7ED2A55F	135BBF100	1BBE564598	1	1	0	1	0	10	01	10
156	117	1A8AFE8	7DA54ABF	06B77E200	377CAC8B31	1	1	0	0	0	11	10	01
157	118	1515FD0	7B4A957F	0D6EFC401	6EF9591663	0	0	1	1	1	00	11	10
158	119	0A2BFA1	76952AFE	1ADDF8803	5DF2B22CC7	1	1	1	1	0	00	00	11
159	120	1457F42	6D2A55FD	15BBF1007	3BE564598E	0	0	0	1	1	00	00	00
160	121	08AFE84	5A54ABFB	0B77E200F	77CAC8B31C	1	0	1	1	1	01	00	00
161	122	115FD09	34A957F7	16EFC401F	6F95916639	0	1	0	1	1	00	01	00
162	123	02BFA12	6952AFEF	0DDF8803E	5F2B22CC73	0	0	1	0	1	11	00	01
163	124	057F424	52A55FDF	1BBF1007D	3E564598E7	0	1	1	0	1	01	11	00
164	125	0AFE848	254ABFBF	177E200FA	7CAC8B31CF	1	0	0	1	1	10	01	11
165	126	15FD090	4A957F7E	0EFC401F5	795916639E	0	1	1	0	0	11	10	01
166	127	0BFA121	152AFEFD	1DF8803EA	72B22CC73C	1	0	1	1	0	01	11	10
167	128	17F4243	2A55FDFA	1BF1007D4	6564598E78	0	0	1	0	0	10	01	11
168	129	0FE8486	54ABFBF4	17E200FA8	4AC8B31CF0	1	1	0	1	1	11	10	01
169	130	1FD090C	2957F7E8	0FC401F51	15916639E1	1	0	1	1	0	01	11	10
170	131	1FA1219	52AFEFD1	1F8803EA3	2B22CC73C2	1	1	1	0	0	01	01	11
171	132	1F42432	255FDFA2	1F1007D47	564598E785	1	0	1	0	1	11	01	01
172	133	1E84865	4ABFBF44	1E200FA8F	2C8B31CF0B	1	1	1	1	1	11	11	01
173	134	1D090CB	157F7E88	1C401F51E	5916639E17	1	0	1	0	1	11	11	11
174	135	1A12196	2AFEFD11	18803EA3C	322CC73C2E	1	1	1	0	0	10	11	11
175	136	142432C	55FDFA23	11007D479	64598E785C	0	1	0	0	1	01	10	11
176	137	0848659	2BFBF446	0200FA8F2	48B31CF0B9	1	1	0	1	0	10	01	10
177	138	1090CB2	57F7E88C	0401F51E4	116639E173	0	1	0	0	1	00	10	01
178	139	0121964	2FEFD118	0803EA3C8	22CC73C2E6	0	1	1	1	1	00	00	10
179	140	02432C9	5FDFA230	1007D4791	4598E785CD	0	1	0	1	0	01	00	00
180	141	0486593	3FBF4461	000FA8F23	0B31CF0B9B	0	1	0	0	0	00	01	00
181	142	090CB26	7F7E88C3	001F51E47	16639E1736	1	0	0	0	1	11	00	01
182	143	121964D	7EFD1187	003EA3C8F	2CC73C2E6C	0	1	0	1	1	01	11	00
183	144	0432C9B	7DFA230E	007D4791E	598E785CD8	0	1	0	1	1	10	01	11
184	145	0865936	7BF4461C	00FA8F23C	331CF0B9B0	1	1	0	0	0	11	10	01
185	146	10CB26D	77E88C38	01F51E479	6639E17361	0	1	0	0	0	00	11	10
186	147	01964DA	6FD11870	03EA3C8F2	4C73C2E6C2	0	1	0	0	1	10	00	11
187	148	032C9B4	5FA230E1	07D4791E4	18E785CD84	0	1	0	1	0	00	10	00
188	149	0659368	3F4461C2	0FA8F23C9	31CF0B9B09	0	0	1	1	0	00	00	10
189	150	0CB26D0	7E88C384	1F51E4793	639E173612	1	1	1	1	0	10	00	00
190	151	1964DA0	7D118709	1EA3C8F27	473C2E6C24	1	0	1	0	0	00	10	00
191	152	12C9B41	7A230E12	1D4791E4E	0E785CD848	0	0	1	0	1	01	00	10
192	153	0593683	74461C24	1A8F23C9C	1CF0B9B091	0	0	1	1	1	00	01	00
193	154	0B26D06	688C3848	151E47938	39E1736123	1	1	0	1	1	10	00	01
194	155	164DA0D	51187091	0A3C8F271	73C2E6C247	0	0	1	1	0	00	10	00
195	156	0C9B41A	2230E123	14791E4E3	6785CD848F	1	0	0	1	0	00	00	10
196	157	1936835	4461C247	08F23C9C6	4F0B9B091E	1	0	1	0	0	01	00	00
197	158	126D06A	08C3848E	11E47938D	1E1736123C	0	1	0	0	0	00	01	00
198	159	04DA0D5	1187091C	03C8F271B	3C2E6C2478	0	1	0	0	1	11	00	01
199	160	09B41AA	230E1238	0791E4E37	785CD848F1	1	0	0	0	0	01	11	00
200	161	1368354	461C2470	0F23C9C6F	70B9B091E3	0	0	1	1	1	10	01	11
201	162	06D06A9	0C3848E1	1E47938DF	61736123C6	0	0	1	0	1	00	10	01
202	163	0DA0D52	187091C3	1C8F271BE	42E6C2478D	1	0	1	1	1	00	00	10

Sample Data

203	164	1B41AA4	30E12387	191E4E37C	05CD848F1A	1	1	1	1	0	10	00	00
204	165	1683549	61C2470F	123C9C6F9	0B9B091E34	0	1	0	1	0	00	10	00
205	166	0D06A92	43848E1E	047938DF3	1736123C68	1	1	0	0	0	00	00	10
206	167	1A0D524	07091C3C	08F271BE7	2E6C2478D1	1	0	1	0	0	01	00	00
207	168	141AA49	0E123879	11E4E37CF	5CD848F1A2	0	0	0	1	0	00	01	00
208	169	0835492	1C2470F3	03C9C6F9F	39B091E345	1	0	0	1	0	10	00	01
209	170	106A925	3848E1E6	07938DF3F	736123C68B	0	0	0	0	0	11	10	00
210	171	00D524A	7091C3CD	0F271BE7E	66C2478D16	0	1	1	1	0	01	11	10
211	172	01AA495	6123879B	1E4E37CFD	4D848F1A2D	0	0	1	1	1	10	01	11
212	173	035492A	42470F36	1C9C6F9FB	1B091E345B	0	0	1	0	1	00	10	01
213	174	06A9255	048E1E6C	1938DF3F6	36123C68B7	0	1	1	0	0	00	00	10
214	175	0D524AB	091C3CD8	1271BE7EC	6C2478D16E	1	0	0	0	1	00	00	00
215	176	1AA4957	123879B1	04E37CFD8	5848F1A2DD	1	0	0	0	1	00	00	00
216	177	15492AF	2470F363	09C6F9FB0	3091E345BA	0	0	1	1	0	01	00	00
217	178	0A9255E	48E1E6C7	138DF3F61	6123C68B75	1	1	0	0	1	00	01	00
218	179	1524ABD	11C3CD8F	071BE7EC3	42478D16EB	0	1	0	0	1	11	00	01
219	180	0A4957B	23879B1F	0E37CFD87	048F1A2DD6	1	1	1	1	1	00	11	00
220	181	1492AF6	470F363F	1C6F9FB0E	091E345BAD	0	0	1	0	1	10	00	11
221	182	09255EC	0E1E6C7F	18DF3F61D	123C68B75B	1	0	1	0	0	00	10	00
222	183	124ABD9	1C3CD8FF	11BE7EC3A	2478D16EB6	0	0	0	0	0	01	00	10
223	184	04957B3	3879B1FE	037CFD874	48F1A2DD6D	0	0	0	1	0	00	01	00
224	185	092AF66	70F363FD	06F9FB0E9	11E345BADB	1	1	0	1	1	10	00	01
225	186	1255ECD	61E6C7FA	0DF3F61D3	23C68B75B7	0	1	1	1	1	00	10	00
226	187	04ABD9B	43CD8FF5	1BE7EC3A7	478D16EB6E	0	1	1	1	1	00	00	10
227	188	0957B37	079B1FEA	17CFD874E	0F1A2DD6DD	1	1	0	0	0	01	00	00
228	189	12AF66F	0F363FD4	0F9FB0E9C	1E345BADBB	0	0	1	0	0	00	01	00
229	190	055ECDE	1E6C7FA9	1F3F61D39	3C68B75B76	0	0	1	0	1	11	00	01
230	191	0ABD9BC	3CD8FF53	1E7EC3A73	78D16EB6EC	1	1	1	1	1	00	11	00
231	192	157B379	79B1FEA7	1CFD874E6	71A2DD6DD9	0	1	1	1	1	11	00	11
232	193	0AF66F3	7363FD4E	19FB0E9CD	6345BADBB2	1	0	1	0	1	01	11	00
233	194	15ECDE6	66C7FA9D	13F61D39A	468B75B765	0	1	0	1	1	10	01	11
234	195	0BD9BCC	4D8FF53A	07EC3A735	0D16EB6ECA	1	1	0	0	0	11	10	01
235	196	17B3799	1B1FEA75	0FD874E6A	1A2DD6DD94	0	0	1	0	0	00	11	10
236	197	0F66F33	363FD4EA	1FB0E9CD5	345BADBB28	1	0	1	0	0	11	00	11
237	198	1ECDE67	6C7FA9D5	1F61D39AA	68B75B7650	1	0	1	1	0	00	11	00
238	199	1D9BCCF	58FF53AB	1EC3A7354	516EB6ECA0	1	1	1	0	1	11	00	11
239	200	1B3799E	31FEA756	1D874E6A8	22DD6DD940	1	1	1	1	1	00	11	00

```
Z[0]  = 3F
Z[1]  = B1
Z[2]  = 67
Z[3]  = D2
Z[4]  = 2F
Z[5]  = A6
Z[6]  = 1F
Z[7]  = B9
Z[8]  = E6
Z[9]  = 84
Z[10] = 43
Z[11] = 07
Z[12] = D8
Z[13] = 1E
Z[14] = E7
Z[15] = C3
```

Sample Data

```
================================================================================================
         Reload this pattern into the LFSRs
         Hold content of Summation Combiner regs and calculate new C[t+1] and Z values
================================================================================================
LFSR1  <= 0E62F3F
LFSR2  <= 6C84A6B1
LFSR3  <= 11E431F67
LFSR4  <= 61E707B9D2
C[t+1] <= 00

================================================================================================
         Generating 125 key symbols (encryption/decryption sequence)
================================================================================================
```

240	1	0E62F3F	6C84A6B1	11E431F67	61E707B9D2	1	1	0	1	0	00	11	00
241	2	1CC5E7F	59094D63	03C863ECE	43CE0F73A5	1	0	0	1	0	11	00	11
242	3	198BCFF	32129AC6	0790C7D9D	079C1EE74A	1	0	0	1	1	01	11	00
243	4	13179FE	6425358C	0F218FB3A	0F383DCE94	0	0	1	0	0	10	01	11
244	5	062F3FD	484A6B19	1E431F675	1E707B9D28	0	0	1	0	1	00	10	01
245	6	0C5E7FB	1094D632	1C863ECEB	3CE0F73A50	1	1	1	1	0	11	00	10
246	7	18BCFF7	2129AC64	190C7D9D7	79C1EE74A1	1	0	1	1	0	00	11	00
247	8	1179FEE	425358C8	1218FB3AE	7383DCE942	0	0	0	1	1	10	00	11
248	9	02F3FDD	04A6B190	0431F675D	6707B9D285	0	1	0	0	1	11	10	00
249	10	05E7FBB	094D6320	0863ECEBB	4E0F73A50B	0	0	1	0	0	00	11	10
250	11	0BCFF77	129AC640	10C7D9D77	1C1EE74A16	1	1	0	0	0	11	00	11
251	12	179FEEE	25358C80	018FB3AEE	383DCE942C	0	0	0	0	1	10	11	00
252	13	0F3FDDC	4A6B1900	031F675DD	707B9D2859	1	0	0	0	1	01	10	11
253	14	1E7FBB8	14D63200	063ECEBBA	60F73A50B3	1	1	0	1	0	10	01	10
254	15	1CFF771	29AC6401	0C7D9D774	41EE74A167	1	1	1	1	0	10	10	01
255	16	19FEEE2	5358C803	18FB3AEE9	03DCE942CE	1	0	1	1	1	01	10	10
256	17	13FDDC4	26B19007	11F675DD2	07B9D2859C	0	1	0	1	1	01	01	10
257	18	07FBB88	4D63200E	03ECEBBA4	0F73A50B38	0	0	0	0	1	10	01	01
258	19	0FF7711	1AC6401D	07D9D7748	1EE74A1670	1	1	0	1	1	11	10	01
259	20	1FEEE23	358C803B	0FB3AEE91	3DCE942CE1	1	1	1	1	1	01	11	10
260	21	1FDDC47	6B190076	1F675DD23	7B9D2859C2	1	0	1	1	0	01	01	11
261	22	1FBB88F	563200ED	1ECEBBA47	773A50B385	1	0	1	0	1	11	01	01
262	23	1F7711E	2C6401DB	1D9D7748F	6E74A1670A	1	0	1	0	1	10	11	01
263	24	1EEE23D	58C803B6	1B3AEE91E	5CE942CE15	1	1	1	1	0	11	10	11
264	25	1DDC47A	3190076C	1675DD23D	39D2859C2B	1	1	0	1	0	01	11	10
265	26	1BB88F4	63200ED9	0CEBBA47A	73A50B3856	1	0	1	1	0	01	01	11
266	27	17711E8	46401DB2	19D7748F5	674A1670AD	0	0	1	0	0	11	01	01
267	28	0EE23D0	0C803B64	13AEE91EA	4E942CE15B	1	1	0	1	0	11	11	01
268	29	1DC47A0	190076C8	075DD23D4	1D2859C2B7	1	0	0	0	0	11	11	11
269	30	1B88F41	3200ED90	0EBBA47A9	3A50B3856E	1	0	1	0	1	11	11	11
270	31	1711E83	6401DB20	1D7748F53	74A1670ADC	0	0	1	1	1	11	11	11
271	32	0E23D07	4803B641	1AEE91EA7	6942CE15B8	1	0	1	0	1	11	11	11
272	33	1C47A0F	10076C82	15DD23D4F	52859C2B71	1	0	0	1	1	11	11	11
273	34	188F41E	200ED905	0BBA47A9E	250B3856E3	1	0	1	0	1	11	11	11
274	35	111E83C	401DB20A	17748F53D	4A1670ADC7	0	0	0	0	1	00	11	11
275	36	023D078	003B6414	0EE91EA7A	142CE15B8E	0	0	1	0	1	10	00	11
276	37	047A0F0	0076C828	1DD23D4F5	2859C2B71C	0	0	1	0	1	11	10	00
277	38	08F41E1	00ED9050	1BA47A9EA	50B3856E39	1	1	1	1	1	01	11	10
278	39	11E83C2	01DB20A0	1748F53D5	21670ADC72	0	1	0	0	0	10	01	11
279	40	03D0785	03B64141	0E91EA7AA	42CE15B8E4	0	1	1	1	1	11	10	01
280	41	07A0F0A	076C8283	1D23D4F54	059C2B71C8	0	0	1	1	1	00	11	10
281	42	0F41E14	0ED90507	1A47A9EA9	0B3856E390	1	1	1	0	1	11	00	11
282	43	1E83C29	1DB20A0F	148F53D52	1670ADC720	1	1	0	0	1	01	11	00
283	44	1D07853	3B64141E	091EA7AA5	2CE15B8E40	1	0	1	1	0	01	01	11

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284	45	1A0F0A6	76C8283C	123D4F54B	59C2B71C81	1	1	0	1	0	00	01	01
285	46	141E14C	6D905079	047A9EA97	33856E3902	0	1	0	1	0	10	00	01
286	47	083C299	5B20A0F2	08F53D52F	670ADC7204	1	0	1	0	0	00	10	00
287	48	1078533	364141E4	11EA7AA5E	4E15B8E408	0	0	0	0	0	01	00	10
288	49	00F0A67	6C8283C8	03D4F54BC	1C2B71C811	0	1	0	0	0	00	01	00
289	50	01E14CE	59050791	07A9EA978	3856E39022	0	0	0	0	0	11	00	01
290	51	03C299C	320A0F23	0F53D52F1	70ADC72045	0	0	1	1	1	01	11	00
291	52	0785339	64141E47	1EA7AA5E2	615B8E408A	0	0	1	0	0	10	01	11
292	53	0F0A673	48283C8E	1D4F54BC4	42B71C8115	1	0	1	1	1	11	10	01
293	54	1E14CE6	1050791C	1A9EA9788	056E39022B	1	0	1	0	1	00	11	10
294	55	1C299CD	20A0F239	153D52F10	0ADC720456	1	1	0	1	1	11	00	11
295	56	185339B	4141E472	0A7AA5E20	15B8E408AC	1	0	1	1	0	00	11	00
296	57	10A6736	0283C8E4	14F54BC41	2B71C81158	0	1	0	0	1	10	00	11
297	58	014CE6C	050791C9	09EA97882	56E39022B0	0	0	1	1	0	00	10	00
298	59	0299CD9	0A0F2393	13D52F104	2DC7204561	0	0	0	1	1	01	00	10
299	60	05339B3	141E4726	07AA5E208	5B8E408AC3	0	0	0	1	0	00	01	00
300	61	0A67366	283C8E4C	0F54BC411	371C811587	1	0	1	0	0	10	00	01
301	62	14CE6CC	50791C98	1EA978822	6E39022B0F	0	0	1	0	1	11	10	00
302	63	099CD99	20F23930	1D52F1045	5C7204561E	1	1	1	0	0	01	11	10
303	64	1339B33	41E47260	1AA5E208B	38E408AC3D	0	1	1	1	0	01	01	11
304	65	0673666	03C8E4C0	154BC4117	71C811587A	0	1	0	1	1	11	01	01
305	66	0CE6CCC	0791C980	0A978822E	639022B0F5	1	1	1	1	1	11	11	01
306	67	19CD999	0F239301	152F1045C	47204561EB	1	0	0	0	0	11	11	11
307	68	139B332	1E472603	0A5E208B9	0E408AC3D6	0	0	1	0	0	11	11	11
308	69	0736664	3C8E4C06	14BC41172	1C811587AD	0	1	0	1	1	11	11	11
309	70	0E6CCC8	791C980C	0978822E5	39022B0F5A	1	0	1	0	1	11	11	11
310	71	1CD9990	72393019	12F1045CB	7204561EB4	1	0	0	0	0	11	11	11
311	72	19B3320	64726033	05E208B97	6408AC3D69	1	0	0	0	0	11	11	11
312	73	1366640	48E4C067	0BC41172F	4811587AD3	0	1	1	0	1	11	11	11
313	74	06CCC81	11C980CF	178822E5E	1022B0F5A6	0	1	0	0	0	11	11	11
314	75	0D99903	2393019E	0F1045CBC	204561EB4C	1	1	1	0	0	10	11	11
315	76	1B33206	4726033D	1E208B979	408AC3D699	1	0	1	1	1	10	10	11
316	77	166640D	0E4C067B	1C41172F2	011587AD33	0	0	1	0	1	10	10	10
317	78	0CCC81B	1C980CF6	18822E5E5	022B0F5A66	1	1	1	0	1	01	10	10
318	79	1999036	393019EC	11045CBCA	04561EB4CD	1	0	0	0	0	01	01	10
319	80	133206C	726033D9	0208B9794	08AC3D699B	0	0	0	1	0	11	01	01
320	81	06640D9	64C067B3	041172F29	11587AD337	0	1	0	0	0	10	11	01
321	82	0CC81B3	4980CF66	0822E5E53	22B0F5A66F	1	1	1	1	0	11	10	11
322	83	1990366	13019ECC	1045CBCA6	4561EB4CDF	1	0	0	0	0	00	11	10
323	84	13206CC	26033D98	008B9794D	0AC3D699BE	0	0	0	1	1	10	00	11
324	85	0640D98	4C067B31	01172F29B	1587AD337C	0	0	0	1	1	11	10	00
325	86	0C81B30	180CF662	022E5E537	2B0F5A66F9	1	0	0	0	0	00	11	10
326	87	1903660	3019ECC5	045CBCA6F	561EB4CDF3	1	0	0	0	1	10	00	11
327	88	1206CC1	6033D98A	08B9794DE	2C3D699BE6	0	0	1	0	1	11	10	00
328	89	040D983	4067B315	1172F29BD	587AD337CC	0	0	0	0	1	11	11	10
329	90	081B306	00CF662A	02E5E537A	30F5A66F98	1	1	0	1	0	10	11	11
330	91	103660C	019ECC55	05CBCA6F4	61EB4CDF31	0	1	0	1	0	10	10	11
331	92	006CC19	033D98AB	0B9794DE8	43D699BE62	0	0	1	1	0	01	10	10
332	93	00D9833	067B3156	172F29BD0	07AD337CC5	0	0	0	1	0	01	01	10
333	94	01B3066	0CF662AC	0E5E537A0	0F5A66F98B	0	1	1	0	1	11	01	01
334	95	03660CD	19ECC559	1CBCA6F41	1EB4CDF317	0	1	1	1	0	11	11	01
335	96	06CC19B	33D98AB2	19794DE83	3D699BE62F	0	1	1	0	1	11	11	11
336	97	0D98336	67B31565	12F29BD06	7AD337CC5F	1	1	0	1	0	10	11	11
337	98	1B3066D	4F662ACA	05E537A0C	75A66F98BF	1	0	0	1	0	10	10	11
338	99	1660CDB	1ECC5594	0BCA6F418	6B4CDF317E	0	1	1	0	0	01	10	10
339	100	0CC19B7	3D98AB29	1794DE831	5699BE62FC	1	1	0	1	0	10	01	10
340	101	198336F	7B315653	0F29BD062	2D337CC5F9	1	0	1	0	0	11	10	01

Sample Data

341	102	13066DE	7662ACA7	1E537A0C5	5A66F98BF2	0	0	1	0	0	00	11	10
342	103	060CDBC	6CC5594F	1CA6F418B	34CDF317E4	0	1	1	1	1	11	00	11
343	104	0C19B78	598AB29F	194DE8317	699BE62FC9	1	1	1	1	1	00	11	00
344	105	18336F1	3315653F	129BD062E	5337CC5F92	1	0	0	0	1	10	00	11
345	106	1066DE2	662ACA7E	0537A0C5C	266F98BF25	0	0	0	0	0	11	10	00
346	107	00CDBC5	4C5594FD	0A6F418B9	4CDF317E4B	0	0	1	1	1	00	11	10
347	108	019B78B	18AB29FA	14DE83172	19BE62FC96	0	1	0	1	0	11	00	11
348	109	0336F16	315653F4	09BD062E5	337CC5F92C	0	0	1	0	0	01	11	00
349	110	066DE2D	62ACA7E8	137A0C5CA	66F98BF258	0	1	0	1	1	10	01	11
350	111	0CDBC5B	45594FD1	06F418B95	4DF317E4B1	1	0	0	1	0	11	10	01
351	112	19B78B6	0AB29FA2	0DE83172B	1BE62FC962	1	1	1	1	1	01	11	10
352	113	136F16C	15653F45	1BD062E57	37CC5F92C5	0	0	1	1	1	10	01	11
353	114	06DE2D9	2ACA7E8B	17A0C5CAE	6F98BF258B	0	1	0	1	0	11	10	01
354	115	0DBC5B2	5594FD16	0F418B95D	5F317E4B16	1	1	1	0	0	01	11	10
355	116	1B78B64	2B29FA2C	1E83172BB	3E62FC962C	1	0	1	0	1	10	01	11
356	117	16F16C8	5653F458	1D062E577	7CC5F92C58	0	0	1	1	0	11	10	01
357	118	0DE2D91	2CA7E8B0	1A0C5CAEF	798BF258B1	1	1	1	1	1	01	11	10
358	119	1BC5B23	594FD161	1418B95DF	7317E4B163	1	0	0	0	0	10	01	11
359	120	178B647	329FA2C2	083172BBF	662FC962C7	0	1	1	0	0	11	10	01
360	121	0F16C8E	653F4584	1062E577F	4C5F92C58E	1	0	0	0	0	00	11	10
361	122	1E2D91C	4A7E8B09	00C5CAEFE	18BF258B1C	1	0	0	1	0	11	00	11
362	123	1C5B238	14FD1613	018B95DFC	317E4B1639	1	1	0	0	1	01	11	00
363	124	18B6471	29FA2C27	03172BBF9	62FC962C72	1	1	0	1	0	01	01	11
364	125	116C8E2	53F4584E	062E577F3	45F92C58E4	0	1	0	1	1	11	01	01

1.2 AES-CCM ENCRYPTION SAMPLE DATA

```
All values below are hexadecimal and follow notation of AES-CCM:
MSbyte to LSbyte & msbit to lsbit.

(0 byte DM1, M --> S)
(8 byte DM1, M --> S)
(8 byte DM1, S --> M)
(17 byte DM1, M --> S)
(17 byte DM1, S --> M)
(20 byte DH1, M --> S)
(20 byte DH1, S --> M)
(27 byte DH1, M --> S)
(27 byte DH1, S --> M)
(367 byte 2-DH3, M --> S)
(367 byte 2-DH3, S --> M)
(1021 byte 3-DH5, M --> S)
(1021 byte 3-DH5, S --> M)
```

1.2.1 Sample Data 1 (DM1, M --> S)

```
Payload byte length: 00
K: 89678967 89678967 45234523 45234523
Payload counter: 0000bc614e
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 66778899 aabbccdd
LT_ADDR: 1
Packet Type: 3
LLID: 2
Payload:

B0: 494e61bc 0000ddcc bbaa9988 77660000
B1: 00190200 00000000 00000000 00000000

Y0: bb01f0c5 16dfd7b5 0d0cccb8 eaebb347
Y1: a9adf6e6 7876cf95 118a09d5 ac3f216e


T: a9adf6e6

CTR0: 014e61bc 0000ddcc bbaa9988 77660000

S0: b90f2b23 f63717d3 38e0559d 1e7e785e

MIC: 10a2ddc5
Encrypted payload:
```

Sample Data

1.2.2 Sample Data 2 (DM1, M --> S)

```
Payload byte length: 08
K: 89678967 89678967 45234523 45234523
Payload counter: 0000bc614e
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 66778899 aabbccdd
LT_ADDR: 1
Packet Type: 3
LLID: 2
Payload: 68696a6b 6c6d6e6f

B0: 494e61bc 0000ddcc bbaa9988 77660008
B1: 00190200 00000000 00000000 00000000
B2: 68696a6b 6c6d6e6f 00000000 00000000

Y0: 95ddc3d4 2c9a70f1 61a28ee2 c08271ab
Y1: 418635ff 54615443 8aceca41 fe274779
Y2: 08d78b32 9d78ed33 b285fc42 e178d781

T: 08d78b32

CTR0: 014e61bc 0000ddcc bbaa9988 77660000
CTR1: 014e61bc 0000ddcc bbaa9988 77660001

S0: b90f2b23 f63717d3 38e0559d 1e7e785e
S1: d8c7e3e1 02050abb 025d0895 17cbe5fb

MIC: b1d8a011
Encrypted payload: b0ae898a 6e6864d4
```

1.2.3 Sample Data 3 (DM1, S --> M)

```
Payload byte length: 08
K: 89678967 89678967 45234523 45234523
Payload counter: 0000bc614e
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 66778899 aabbccdd
LT_ADDR: 1
Packet Type: 3
LLID: 2
Payload: 68696a6b 6c6d6e6f

B0: 494e61bc 0020ddcc bbaa9988 77660008
B1: 00190200 00000000 00000000 00000000
B2: 68696a6b 6c6d6e6f 00000000 00000000

Y0: 31081122 b1cca37a 5f04d238 897b9bc8
Y1: 02ee3065 95c5d55a d0a030a3 3bee507b
Y2: 7382a2ba aa874418 14eafbef 41f57180

T: 7382a2ba

CTR0: 014e61bc 0020ddcc bbaa9988 77660000
CTR1: 014e61bc 0020ddcc bbaa9988 77660001

S0: 2a4d408d 2035b058 cc2fbf3b 8de15c73
S1: 9c89f68f b31bf4b5 7fbc7e83 123bd8a8

MIC: 59cfe237
Encrypted payload: f4e09ce4 df769ada
```

1.2.4 Sample Data 4 (DM1, M --> S)

```
Payload byte length: 11
K: ce2ad11b a11456bd bd9d8b1f 848322fc
Payload counter: 00bdb3be95
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 82b8b727 5bf92769
LT_ADDR: 1
Packet Type: 3
LLID: 2
Payload: 86126da5 dbb39164 9ba1cac4 60917233
         05

B0: 4995beb3 bd006927 f95b27b7 b8820011
B1: 00190200 00000000 00000000 00000000
B2: 86126da5 dbb39164 9ba1cac4 60917233
B3: 05000000 00000000 00000000 00000000

Y0: ab182b6f e8bca0a9 7cc306e0 eab19e84
Y1: c198f821 49061035 977a5aae 60c51726
Y2: 45dd4181 40facb43 0f73f71b 49ea36ae
Y3: 7b112114 38d06bc2 98cb22db c5218041
```

```
T: 7b112114

CTR0: 0195beb3 bd006927 f95b27b7 b8820000
CTR1: 0195beb3 bd006927 f95b27b7 b8820001
CTR2: 0195beb3 bd006927 f95b27b7 b8820002

S0: bd3d1368 1478c30c 62b734ac e8e00c6e
S1: bfaa326d 8d84d8f6 e4518d12 20babe4f
S2: fc4a6327 776a3136 604a1ab8 20836505

MIC: c62c327c
Encrypted payload: 39b85fc8 56374992 7ff047d6 402bcc7c
                   f9
```

1.2.5 Sample Data 5 (DM1, S --> M)

```
Payload byte length: 11
K: ce2ad11b a11456bd bd9d8b1f 848322fc
Payload counter: 00bdb3be95
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 82b8b727 5bf92769
LT_ADDR: 1
Packet Type: 3
LLID: 2
Payload: 86126da5 dbb39164 9ba1cac4 60917233
         05

B0: 4995beb3 bd206927 f95b27b7 b8820011
B1: 00190200 00000000 00000000 00000000
B2: 86126da5 dbb39164 9ba1cac4 60917233
B3: 05000000 00000000 00000000 00000000

Y0: 2c317af0 b12026df 8400f84e aa8e53e7
Y1: 1ec2c0c5 74e2cad3 3e143b2b 9d63095d
Y2: e7f08f4b d7c24c04 651434d8 a84f8ae9
Y3: d6f08416 0d556004 6c9b850b 1b579614

T: d6f08416

CTR0: 0195beb3 bd206927 f95b27b7 b8820000
CTR1: 0195beb3 bd206927 f95b27b7 b8820001
CTR2: 0195beb3 bd206927 f95b27b7 b8820002

S0: d8bc791d b48ea182 ef438e70 ee0f50e1
S1: c5e90ff5 6e1e06b3 4d6b699c 9fb72e3d
S2: b68f4956 19bea370 0a1f118e a5dd6aff

MIC: 0e4cfd0b
Encrypted payload: 43fb6250 b5ad97d7 d6caa358 ff265c0e
                   b3
```

1.2.6 Sample Data 6 (DH1, M --> S)

```
Payload byte length: 14
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: 4
LLID: 2
Payload: 9bb3a2bd dd043b3a 904cc247 0a1d545f
         b2095e3d

B0: 498bf767 62006f98 36b1e858 ca740014
B1: 00210200 00000000 00000000 00000000
B2: 9bb3a2bd dd043b3a 904cc247 0a1d545f
B3: b2095e3d 00000000 00000000 00000000

Y0: ae691727 39e614a3 e0be3227 ac9afd99
Y1: 47b13424 8ff2f5f7 eaea4fdd 0fab9d92
Y2: 36154960 3c1fc026 4509902e de57dfc3
Y3: 1d45d8f7 950a39c3 9779bb7c d1b3fe17

T: 1d45d8f7

CTR0: 018bf767 62006f98 36b1e858 ca740000
CTR1: 018bf767 62006f98 36b1e858 ca740001
CTR2: 018bf767 62006f98 36b1e858 ca740002

S0: 254593c4 cd12c6a7 d9dec572 95524b75
S1: af492e65 ca391b26 e8ce9653 498ed0de
S2: 869271ed ac79c1bc 3cf0f959 c2711f3b

MIC: 38004b33
Encrypted payload: 34fa8cd8 173d201c 78825414 43938481
                   349b2fd0
```

1.2.7 Sample Data 7 (DH1, S --> M)

```
Payload byte length: 14
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: 4
LLID: 2
Payload: 9bb3a2bd dd043b3a 904cc247 0a1d545f
         b2095e3d

B0: 498bf767 62206f98 36b1e858 ca740014
B1: 00210200 00000000 00000000 00000000
B2: 9bb3a2bd dd043b3a 904cc247 0a1d545f
B3: b2095e3d 00000000 00000000 00000000

Y0: 55410490 6f3a5827 e5a04a60 7cf19ad5
Y1: 000cc95c c0d099ca b15b244b d3440c24
Y2: bd1d9815 96438c28 eebfd508 6cf80d34
Y3: 8c227888 d0725a21 ffba99b2 38043d5e

T: 8c227888

CTR0: 018bf767 62206f98 36b1e858 ca740000
CTR1: 018bf767 62206f98 36b1e858 ca740001
CTR2: 018bf767 62206f98 36b1e858 ca740002

S0: 1404487a 919e16c8 b3245d80 2b364231
S1: 82082cbc 57038db7 4823be9a 34e0a8d7
S2: 1b5f7526 d26fe763 7669dfee 63743d3a

MIC: 982630f2
Encrypted payload: 19bb8e01 8a07b68d d86f7cdd 3efdfc88
                   a9562b1b
```

1.2.8 Sample Data 8 (DH1, M --> S)

```
Payload byte length: 1b
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: 4
LLID: 2
Payload: 8f11d05e e0e749b5 eeda42f9 2b184502
         95388ce5 872916b4 bf7260

B0: 498bf767 62006f98 36b1e858 ca74001b
B1: 00210200 00000000 00000000 00000000
B2: 8f11d05e e0e749b5 eeda42f9 2b184502
B3: 95388ce5 872916b4 bf726000 00000000

Y0: 28015834 f3117a84 904800f7 ebd4b0d4
Y1: 15c4a61e b7ae954e 2c9d1b19 3ba2a9e5
Y2: 832c185d 1effc0ee 94d3a26e 23aca8e6
Y3: dcef7067 fc38a84e 893670a6 fb9e069b

T: dcef7067

CTR0: 018bf767 62006f98 36b1e858 ca740000
CTR1: 018bf767 62006f98 36b1e858 ca740001
CTR2: 018bf767 62006f98 36b1e858 ca740002

S0: 254593c4 cd12c6a7 d9dec572 95524b75
S1: af492e65 ca391b26 e8ce9653 498ed0de
S2: 869271ed ac79c1bc 3cf0f959 c2711f3b

MIC: f9aae3a3
Encrypted payload: 2058fe3b 2ade5293 0614d4aa 629695dc
                   13aafd08 2b50d708 838299
```

1.2.9 Sample Data 9 (DH1, S --> M)

```
Payload byte length: 1b
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: 4
LLID: 2
Payload: 8f11d05e e0e749b5 eeda42f9 2b184502
         95388ce5 872916b4 bf7260

B0: 498bf767 62206f98 36b1e858 ca74001b
B1: 00210200 00000000 00000000 00000000
B2: 8f11d05e e0e749b5 eeda42f9 2b184502
B3: 95388ce5 872916b4 bf726000 00000000

Y0: feb39b06 54b486da bf1cec46 b5c5ec2a
Y1: eeda0fc3 4057d94e 3572448d 67b640f4
Y2: 48461729 ec1c7060 3b0f88ce becef21a
Y3: b1ff4755 658c2aa2 862952a5 1ca041a1

T: b1ff4755

CTR0: 018bf767 62206f98 36b1e858 ca740000
CTR1: 018bf767 62206f98 36b1e858 ca740001
CTR2: 018bf767 62206f98 36b1e858 ca740002

S0: 1404487a 919e16c8 b3245d80 2b364231
S1: 82082cbc 57038db7 4823be9a 34e0a8d7
S2: 1b5f7526 d26fe763 7669dfee 63743d3a

MIC: a5fb0f2f
Encrypted payload: 0d19fce2 b7e4c402 a6f9fc63 1ff8edd5
                   8e67f9c3 5546f1d7 c91bbf
```

Sample Data

1.2.10 Sample Data 10 (2-DH3, M --> S)

```
Payload byte length: 16f
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: a
LLID: 2
Payload: 969b0972 549738ea 89120710 55797f19
         631dd8e7 219308a0 836e8d6b a55ec08f
         42604406 543c2f96 60c261c3 1c3d8826
         73aab82e bd5a8278 93625aa8 b9a4c5b3
         bc310174 e4d6436e 2e44aa08 1d64e751
         b5501222 dcc34270 6aefd398 1e10b2e2
         56e20d95 1e4e68cc 3fdd4b5c 8e93809a
         ff008232 3b6a864e b8556219 e94fbdd2
         500550e9 939e6108 43a375ab a75d1f6d
         a0304656 b45f488c 0ba40259 4e1ee6a1
         c59301e8 f1507906 40dc0c24 330120c0
         ac7f6707 e7f00d4a ea6c0577 a31abbb6
         4f9b6bab 47bfa387 c89bbbe1 6d8cbd49
         4a9c452f 9d46ab05 dcf0f434 f4c27bce
         2e0e177d 1aba438d 64a8cd72 ca0c170c
         9fa6e227 992fe354 98c94581 f1d869ee
         b07ffcf2 c19b35c8 5e22939e b54c772c
         2c4c0963 f51a653d 777879f2 d1ab67fc
         ba300c9e fa3ba62e 9f70e4b9 1a996f81
         7a9dff0b 56fd15c2 e9858db3 9b33e8c2
         254df11b 64b9ac36 409f2406 5c9e478a
         fc3b8161 b32d1b56 9236e631 23ed2a53
         89d4c4e0 8a799f0a 370e7310 734c9f

B0: 498bf767 62006f98 36b1e858 ca74016f
B1: 00510200 00000000 00000000 00000000
B2: 969b0972 549738ea 89120710 55797f19
B3: 631dd8e7 219308a0 836e8d6b a55ec08f
B4: 42604406 543c2f96 60c261c3 1c3d8826
B5: 73aab82e bd5a8278 93625aa8 b9a4c5b3
B6: bc310174 e4d6436e 2e44aa08 1d64e751
B7: b5501222 dcc34270 6aefd398 1e10b2e2
B8: 56e20d95 1e4e68cc 3fdd4b5c 8e93809a
B9: ff008232 3b6a864e b8556219 e94fbdd2
B10: 500550e9 939e6108 43a375ab a75d1f6d
B11: a0304656 b45f488c 0ba40259 4e1ee6a1
B12: c59301e8 f1507906 40dc0c24 330120c0
B13: ac7f6707 e7f00d4a ea6c0577 a31abbb6
B14: 4f9b6bab 47bfa387 c89bbbe1 6d8cbd49
B15: 4a9c452f 9d46ab05 dcf0f434 f4c27bce
B16: 2e0e177d 1aba438d 64a8cd72 ca0c170c
B17: 9fa6e227 992fe354 98c94581 f1d869ee
B18: b07ffcf2 c19b35c8 5e22939e b54c772c
B19: 2c4c0963 f51a653d 777879f2 d1ab67fc
B20: ba300c9e fa3ba62e 9f70e4b9 1a996f81
```

Sample Data

```
B21: 7a9dff0b 56fd15c2 e9858db3 9b33e8c2
B22: 254df11b 64b9ac36 409f2406 5c9e478a
B23: fc3b8161 b32d1b56 9236e631 23ed2a53
B24: 89d4c4e0 8a799f0a 370e7310 734c9f00

Y0: 29d89cd3 f2a1cf11 de30fb32 7e036fd8
Y1: 969453f9 b7ed6ed5 0bb166ac ad84b447
Y2: 29c1dbe6 569d3bcd 517acede fdf9b2a3
Y3: 87ae6d80 ceb1d9ae e7e009f3 0564b2b4
Y4: f7b4d9bf a1fa7bba 484cba56 f72c649c
Y5: 7cff7307 318bed9a 94c81c3f 7fa87554
Y6: ccf442c7 832413c6 1387b50f 1d6af991
Y7: fda7fb71 83c5a785 a798814c d0a4f4ef
Y8: ca85d795 514e510a e715b603 ad7fd821
Y9: 65527777 4efa23ca d5124e05 0597d5ff
Y10: b17f66c4 8a523b41 950f09c0 fc3a2a15
Y11: 886ec25e ed7cd1af 44de48bf fde11c40
Y12: cd685d0d 10a34a2f 2fa75fee c8a36979
Y13: d7486efa 056ebad9 0f6fe2ac f9871d36
Y14: c28103ad 2fe40cb6 42337daa fee66a03
Y15: c4a313af aad33282 8db4432c 73550d1c
Y16: e29b7baa b3c83223 72fc11d5 b15c01bb
Y17: 22737a00 4e7f26b9 c9f368e1 a90843ae
Y18: 11f9a9f7 997119fb ebad9814 230e9f11
Y19: 026c4112 d016c255 9595bdc9 a8b14e95
Y20: dfe4c01a b101dfca 4bd2ca7e 4342d595
Y21: 5a128313 b4180f77 80a029cc 23a0c1fc
Y22: b4df1ace 2e0a3a2a 968d45e4 7a11a3cf
Y23: d2fb23c5 4849439d 80e8fed4 7ee0e5cb
Y24: da1c4547 7eab6f64 b771cf1e 8ca278ad

T: da1c4547

CTR0: 018bf767 62006f98 36b1e858 ca740000
CTR1: 018bf767 62006f98 36b1e858 ca740001
CTR2: 018bf767 62006f98 36b1e858 ca740002
CTR3: 018bf767 62006f98 36b1e858 ca740003
CTR4: 018bf767 62006f98 36b1e858 ca740004
CTR5: 018bf767 62006f98 36b1e858 ca740005
CTR6: 018bf767 62006f98 36b1e858 ca740006
CTR7: 018bf767 62006f98 36b1e858 ca740007
CTR8: 018bf767 62006f98 36b1e858 ca740008
CTR9: 018bf767 62006f98 36b1e858 ca740009
CTR10: 018bf767 62006f98 36b1e858 ca74000a
CTR11: 018bf767 62006f98 36b1e858 ca74000b
CTR12: 018bf767 62006f98 36b1e858 ca74000c
CTR13: 018bf767 62006f98 36b1e858 ca74000d
CTR14: 018bf767 62006f98 36b1e858 ca74000e
CTR15: 018bf767 62006f98 36b1e858 ca74000f
CTR16: 018bf767 62006f98 36b1e858 ca740010
CTR17: 018bf767 62006f98 36b1e858 ca740011
CTR18: 018bf767 62006f98 36b1e858 ca740012
CTR19: 018bf767 62006f98 36b1e858 ca740013
CTR20: 018bf767 62006f98 36b1e858 ca740014
CTR21: 018bf767 62006f98 36b1e858 ca740015
CTR22: 018bf767 62006f98 36b1e858 ca740016
CTR23: 018bf767 62006f98 36b1e858 ca740017
```

Sample Data

```
S0: 254593c4 cd12c6a7 d9dec572 95524b75
S1: af492e65 ca391b26 e8ce9653 498ed0de
S2: 869271ed ac79c1bc 3cf0f959 c2711f3b
S3: 31554cb7 aa9b1dfb 24ba8b26 eab59ad8
S4: 7cb39415 9dce80e6 0ac0e5e0 9667747e
S5: 9727b319 ccbcc251 d539fd08 497942c8
S6: bd972408 212a147c 3eb66687 1488e2d9
S7: aef3e149 6b4e615b 309a7f93 53ca2981
S8: 6b276914 1d957bec 4c87e76d ee681e76
S9: a2df383f eece9b0d 4553f2e8 6f8b6035
S10: 11dac6bc c4177830 c7038ee1 e6cb0579
S11: 30bfd1cf 7fa95155 7c0757bf f14840a0
S12: 2315682b 1f4cb1f6 10fd4365 4d9b6155
S13: 7f4aa2fd 211bbc18 9ff3dcd7 c8102220
S14: a072aa38 70e32a62 f7214fb1 97dbfbfd
S15: f7c2b622 96a1f9e1 d3e7837f 293f6e86
S16: e63dc9fd 830944d5 b9fa2257 b0e19402
S17: eceef697 e76f671f 5e7e8c6e ae43f63b
S18: a9bccd3a 4ae6b498 40a6ead6 cd6200a8
S19: 2b624b6b f923eb0f 110ff341 4b1ab902
S20: a47db290 f068ca62 c9236eec ddb431f4
S21: a4ad3dc5 7e324250 1938950e 7b3827fd
S22: 364c32d8 35f63c05 5c8f32dd e560cc8f
S23: f2fd81dc cd12d0cc 2e4f7834 43a74630

MIC: ff59d683
Encrypted payload: 39d22717 9eae23cc 61dc9143 1cf7afc7
                   e58fa90a 8deac91c bf9e7432 672fdfb4
                   733508b1 fea7326d 4478eae5 f68812fe
                   0f192c3b 2094029e 99a2bf48 2fc3b1cd
                   2b16b26d 286a813f fb7d5700 541da599
                   08c7362a fde9560c 5459b51f 0a98503b
                   f811ecdc 75000997 0f4734cf dd59a91b
                   9427eb26 26fffda2 f4d28574 0727a3a4
                   f2da68d6 7d50fa05 06f08743 c8d67f58
                   b1ea80ea 704830bc cca78cb8 a8d5e3d8
                   f52cd027 8ef92853 3cdb5b9b c2496060
                   8f6a0f2c f8bcbcbc fa914612 ee81dae3
                   30d1c956 66a41f9f 57686736 a59c9f69
                   eaeeef17 eda58167 2bd1bb85 63198033
                   d9cca15f 8c1bba6c b74f4e0d e333798a
                   799b2bda 1a26a781 213367d6 4139fdec
                   5c910a65 26f452d7 005c1ff0 1b0f8117
                   85f0c459 bffcd1a5 37de9324 1cc96754
                   915247f5 03184d21 8e7f17f8 5183d683
                   dee04d9b a695dfa0 20a6e35f 4687d936
                   81e0ccde 1a8bee66 59a7b108 27a66077
                   ca77b3b9 86db2753 ceb9d4ec c68de6dc
                   7b29453c 476b4fc6 19410b24 30ebd9
```

1.2.11 Sample Data 11 (2-DH3, S --> M)

```
Payload byte length: 16f
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: a
LLID: 2
Payload: 969b0972 549738ea 89120710 55797f19
         631dd8e7 219308a0 836e8d6b a55ec08f
         42604406 543c2f96 60c261c3 1c3d8826
         73aab82e bd5a8278 93625aa8 b9a4c5b3
         bc310174 e4d6436e 2e44aa08 1d64e751
         b5501222 dcc34270 6aefd398 1e10b2e2
         56e20d95 1e4e68cc 3fdd4b5c 8e93809a
         ff008232 3b6a864e b8556219 e94fbdd2
         500550e9 939e6108 43a375ab a75d1f6d
         a0304656 b45f488c 0ba40259 4e1ee6a1
         c59301e8 f1507906 40dc0c24 330120c0
         ac7f6707 e7f00d4a ea6c0577 a31abbb6
         4f9b6bab 47bfa387 c89bbbe1 6d8cbd49
         4a9c452f 9d46ab05 dcf0f434 f4c27bce
         2e0e177d 1aba438d 64a8cd72 ca0c170c
         9fa6e227 992fe354 98c94581 f1d869ee
         b07ffcf2 c19b35c8 5e22939e b54c772c
         2c4c0963 f51a653d 777879f2 d1ab67fc
         ba300c9e fa3ba62e 9f70e4b9 1a996f81
         7a9dff0b 56fd15c2 e9858db3 9b33e8c2
         254df11b 64b9ac36 409f2406 5c9e478a
         fc3b8161 b32d1b56 9236e631 23ed2a53
         89d4c4e0 8a799f0a 370e7310 734c9f

B0: 498bf767 62206f98 36b1e858 ca74016f
B1: 00510200 00000000 00000000 00000000
B2: 969b0972 549738ea 89120710 55797f19
B3: 631dd8e7 219308a0 836e8d6b a55ec08f
B4: 42604406 543c2f96 60c261c3 1c3d8826
B5: 73aab82e bd5a8278 93625aa8 b9a4c5b3
B6: bc310174 e4d6436e 2e44aa08 1d64e751
B7: b5501222 dcc34270 6aefd398 1e10b2e2
B8: 56e20d95 1e4e68cc 3fdd4b5c 8e93809a
B9: ff008232 3b6a864e b8556219 e94fbdd2
B10: 500550e9 939e6108 43a375ab a75d1f6d
B11: a0304656 b45f488c 0ba40259 4e1ee6a1
B12: c59301e8 f1507906 40dc0c24 330120c0
B13: ac7f6707 e7f00d4a ea6c0577 a31abbb6
B14: 4f9b6bab 47bfa387 c89bbbe1 6d8cbd49
B15: 4a9c452f 9d46ab05 dcf0f434 f4c27bce
B16: 2e0e177d 1aba438d 64a8cd72 ca0c170c
B17: 9fa6e227 992fe354 98c94581 f1d869ee
B18: b07ffcf2 c19b35c8 5e22939e b54c772c
B19: 2c4c0963 f51a653d 777879f2 d1ab67fc
B20: ba300c9e fa3ba62e 9f70e4b9 1a996f81
```

Sample Data

```
B21: 7a9dff0b 56fd15c2 e9858db3 9b33e8c2
B22: 254df11b 64b9ac36 409f2406 5c9e478a
B23: fc3b8161 b32d1b56 9236e631 23ed2a53
B24: 89d4c4e0 8a799f0a 370e7310 734c9f00

Y0: 34969012 2648722b fb7771dd b1b38b1b
Y1: 8c511978 793004c6 975e5f19 93c19d99
Y2: 482014e5 39ddbbd4 0833c079 5bab45ef
Y3: b994181f a79795ce a6968237 28ad1659
Y4: 7b8fea33 1c4c8c50 d8ae584b bfc65033
Y5: e185c7b7 dd9831f5 2e0d2140 95368c09
Y6: d598bb23 fb4d4e82 a8b74b2b c95b5b71
Y7: 6c5c7fc1 8cc70897 3bb594a8 39541943
Y8: c7f822e8 7546115f 80d57035 7960abb8
Y9: a430ddc8 58f529f1 97bebcb7 e9160550
Y10: c9bf7627 33253b87 1490fbd7 353a3175
Y11: 1d93c403 de2c3b76 62e6ea6e cbf757c0
Y12: 0d607c00 af5502d9 2d56d483 745f6855
Y13: e27bdc66 de323cff a3a1620d 1637310e
Y14: 840d6d95 6785fead 710de246 e944bf2e
Y15: 806b9eb6 6517c4f8 1d55f260 e08f455b
Y16: 36883866 2f7275ab 6ba45111 2431882d
Y17: e5b4f1f6 cbbcc363 33ef1b05 94b5385e
Y18: e8d47695 67be9d89 04445e73 8a45e019
Y19: 77639b94 f0f9907c db541ef0 c8d45e4b
Y20: a2bd914a 281e1d5f 0c9b8de4 3fcb6565
Y21: 6c1072e6 5581e658 7d7a0561 e8a85ddf
Y22: 8256c105 5c932ba8 bb71936b c727d10f
Y23: 2f4cc66a d568be7e 500a7448 6c2278ad
Y24: 2ca06cb0 0009e3c3 9e123a8a 2c2869dc

T: 2ca06cb0

CTR0: 018bf767 62206f98 36b1e858 ca740000
CTR1: 018bf767 62206f98 36b1e858 ca740001
CTR2: 018bf767 62206f98 36b1e858 ca740002
CTR3: 018bf767 62206f98 36b1e858 ca740003
CTR4: 018bf767 62206f98 36b1e858 ca740004
CTR5: 018bf767 62206f98 36b1e858 ca740005
CTR6: 018bf767 62206f98 36b1e858 ca740006
CTR7: 018bf767 62206f98 36b1e858 ca740007
CTR8: 018bf767 62206f98 36b1e858 ca740008
CTR9: 018bf767 62206f98 36b1e858 ca740009
CTR10: 018bf767 62206f98 36b1e858 ca74000a
CTR11: 018bf767 62206f98 36b1e858 ca74000b
CTR12: 018bf767 62206f98 36b1e858 ca74000c
CTR13: 018bf767 62206f98 36b1e858 ca74000d
CTR14: 018bf767 62206f98 36b1e858 ca74000e
CTR15: 018bf767 62206f98 36b1e858 ca74000f
CTR16: 018bf767 62206f98 36b1e858 ca740010
CTR17: 018bf767 62206f98 36b1e858 ca740011
CTR18: 018bf767 62206f98 36b1e858 ca740012
CTR19: 018bf767 62206f98 36b1e858 ca740013
CTR20: 018bf767 62206f98 36b1e858 ca740014
CTR21: 018bf767 62206f98 36b1e858 ca740015
CTR22: 018bf767 62206f98 36b1e858 ca740016
CTR23: 018bf767 62206f98 36b1e858 ca740017
```

Sample Data

```
S0: 1404487a 919e16c8 b3245d80 2b364231
S1: 82082cbc 57038db7 4823be9a 34e0a8d7
S2: 1b5f7526 d26fe763 7669dfee 63743d3a
S3: a3673258 5020c6cd d72bf517 accb632d
S4: 8a60ebb6 59c59ac1 a45a1ffd f54f7cd7
S5: 036f35c7 130c8a30 25e9da14 706df5bc
S6: e328cbb0 09c91d56 f010b40e e0fc5c3f
S7: 626d3d67 b53eb139 e155c9a2 df407b17
S8: d94e430b 829c7caf 289d2898 3c68aa5a
S9: d6343452 d92cb1ac b3fde90b e2f0789f
S10: 8ab8413c 0df18adf ae07a74f 82b3c91f
S11: 61bfac52 125b8fc4 eaac30f7 5a543821
S12: 68899f8f 2892931d 88b08926 7fa3cfc9
S13: 86b668c5 4ef24455 22a45f42 61aea816
S14: f57b4941 8332f0b3 7749ea30 53a711ee
S15: 593562a8 45c75a7c 70030f08 6fedd965
S16: f85e742f a743f353 6a22b384 be1dabdc
S17: ed7e317b 635deed3 e8b619f2 9bc65eb0
S18: 2035622d 94718ad6 c1631fa2 755883f4
S19: 40f50638 ad826c4a 3ca4fb88 467445ae
S20: e27eb632 0c2aee5c 9210b1c7 736fb897
S21: 711a9be3 c7054fa5 82ec70b6 028489e7
S22: 7b543081 c52e2cba 26400e6b 46642d0d
S23: d9564733 01fa7fae 7cfac2a7 239639e2

MIC: 38a424ca
Encrypted payload: 149325ce 0394b55d c131b98a 6199d7ce
                   7842adc1 f3fcefc3 f5075285 c62afdb5
                   e107765e 041ce95b b7e994d4 b0f6eb0b
                   f9ca5398 e49f18b9 37384555 4cebb964
                   bf5e34b3 f7dac95e 0bad701c 6d0912ed
                   5678d992 d50a5f26 9aff6796 feeceedd
                   348f30f2 ab70d9f5 de8882fe 51d3fb8d
                   264ec139 b9f6fae1 90c84a81 d5271788
                   863164bb 4ab2d0a4 f05e9ca0 45ad67f2
                   2a88076a b9aec253 a5a3a516 ccad2fbe
                   a42cadba e30bf6c2 aa703cd3 695518e1
                   c4f6f888 cf629e57 62dc8c51 dcb9747f
                   c92d036e 094de7d2 ea3fe4a3 0c22155f
                   bfe70c6e 1e745bb6 abb91e04 a7656a20
                   773b75d5 5f7d19f1 14abc27a a5e1ce69
                   67f89608 3e6c1007 f2ebf605 4fc5c232
                   5d01cd89 a2c6db1b b6948a6c 2e8a299c
                   0c796b4e 616befeb b61b6650 a4f3e408
                   fac50aa6 57b9ca64 a3d41f31 5ced2a2f
                   98e34939 5ad7fb9e 7b953c74 e85c5055
                   54576af8 a3bce393 c27354b0 5e1ace6d
                   876fb1e0 760337ec b476e85a 6589075e
                   508283d3 8b83e0a4 4bf4b1b7 50daa6
```

1.2.12 Sample Data 12 (3-DH5, M --> S)

```
Payload byte length: 3fd
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 0
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: f
LLID: 2
Payload: 6d42614c 50694940 209c8bd5 5be57733
         3ec1066a 76cb602e a58ced25 f98ceb94
         58bc3db4 e7c46bb9 e23f9220 68bfca00
         c1da8f08 1c10e526 0ea37fab 3d91be9f
         3a4e68e9 006cca11 fdc76c59 1e20769d
         e1e34385 af105dab 4d44eda7 eacd1974
         5414d5a9 568d67af c05aedd9 6726a130
         7ebe31fd 81881237 c953d2a5 42c57c3b
         019691ef 911953fb 39264712 c61e3e5e
         21286421 85891af5 bf8ca291 59c30596
         11bbe5cd 8f88a7bb b8afd34a 4211eed5
         850ca781 cc9cf5b9 06d5fced 79d35981
         39a1a239 2965b0d5 c6c03a9f e22433ba
         08e7aac7 7d207392 b3486ead dd5c81c6
         5454d575 edd91892 0a2f0fe9 f6d5c037
         fec1272e f22c9aa0 d02b3412 81f60847
         887cd303 a82937cf ded4be2d 139342ce
         bd09041a f5eaa675 4307eb2d 20a60f7b
         1b944afe e3ae1a6f 476021c7 d30d300e
         44f9eaa2 42e8cb7a 6d74d5b5 0f2d6c1b
         d436f44f 1ddf8579 70821a65 117e1200
         e0270f00 7cbe6bb2 020ec332 bc464299
         20131eb1 e8864206 3b4a8324 522cfe0a
         a5209fd7 3f11a1e0 da00c945 835b6b5f
         ec9eaea9 9d177dc0 cbd2efe8 21b388c3
         78b2e137 c84f37a4 5599ffc0 a9106204
         5ed1439f 7e67ea1d 6ab024f7 247e85df
         bf15d19c b0f488d2 cb06bed9 644ec34c
         2e69f752 4af38319 81c7556e 359bfaf5
         22a00878 4ce3e7e2 362698ea 6c00001d
         fdf0936d 2cf7a318 ed4f0447 ad506cdd
         c2fcf8b7 328bb527 063859b5 f60819d3
         eebdd291 0a12c6af 1c670a30 38fd9e2c
         4a6a3ad7 a51982bd 8d4fabf5 a8c16517
         831661b0 09405052 9fba337b 2b3544cf
         6811a761 093afd66 8b154a21 a5941b88
         a482c5ce f04b18c1 c2e67d7d f90c3a4d
         d4ee12fe 4b734174 d3ee8b0c 1ade74eb
         237710da 4694764b 7cce26c4 7a2570bf
         30bb18c7 6571ab05 26892de7 b5d62840
         7f300971 14d6014b 2ca566b3 d6ad1ef5
         96e552e6 defc287e 6a5a5c16 be31d26a
         392e1570 a9f9e0b3 32d223e5 b15407f3
         41cc55f8 3296f3f5 175ebece 580a3f24
         49494406 fa75e051 c829441b ce7cba98
```

Sample Data

```
          cb7ea85d 8031787d 9495b971 c6925f64
          2726ef05 932d3f1a 14a9bd1a d88a9b31
          6f54d80e 9fe31dcf c94c1f6a 92cc2c82
          60bd9296 e075b884 2976b667 041800df
          520e7a28 e5b9314a 0bb93966 1aba4643
          829544e2 d69f255c ce5bfa89 9a4704f3
          be803081 fbc36f5c 65fb13c8 69fc770a
          07cbc8ff 50b8dbe3 b171e9f9 ebc8cf22
          49127607 32973806 95979b3c d75a3f8f
          f933a408 d4945f63 96755d6e 493b554b
          58e78f5b a21d31b3 bbcddf62 83e94233
          15a3bea8 3a6ff73f f02809da 3c6d8208
          acfd6f05 b62bb5a5 91f1e4d5 4b84d357
          2f00672a 3e3c434c 1736072b 45f6370c
          bb46706b 56a57e86 3ed2217a 816e5c09
          1e2895f7 89b57c5e c0a67011 d5f2f69d
          6dac3941 3bc897dc cb42d3bc ffda31e0
          e961f3fb e4f40041 69e86cc0 530e891c
  7665902a 1ce0804c 921780ae e2

B0: 498bf767 62006f98 36b1e858 ca7403fd
B1: 00790200 00000000 00000000 00000000
B2: 6d42614c 50694940 209c8bd5 5be57733
B3: 3ec1066a 76cb602e a58ced25 f98ceb94
B4: 58bc3db4 e7c46bb9 e23f9220 68bfca00
B5: c1da8f08 1c10e526 0ea37fab 3d91be9f
B6: 3a4e68e9 006cca11 fdc76c59 1e20769d
B7: e1e34385 af105dab 4d44eda7 eacd1974
B8: 5414d5a9 568d67af c05aedd9 6726a130
B9: 7ebe31fd 81881237 c953d2a5 42c57c3b
B10: 019691ef 911953fb 39264712 c61e3e5e
B11: 21286421 85891af5 bf8ca291 59c30596
B12: 11bbe5cd 8f88a7bb b8afd34a 4211eed5
B13: 850ca781 cc9cf5b9 06d5fced 79d35981
B14: 39a1a239 2965b0d5 c6c03a9f e22433ba
B15: 08e7aac7 7d207392 b3486ead dd5c81c6
B16: 5454d575 edd91892 0a2f0fe9 f6d5c037
B17: fec1272e f22c9aa0 d02b3412 81f60847
B18: 887cd303 a82937cf ded4be2d 139342ce
B19: bd09041a f5eaa675 4307eb2d 20a60f7b
B20: 1b944afe e3ae1a6f 476021c7 d30d300e
B21: 44f9eaa2 42e8cb7a 6d74d5b5 0f2d6c1b
B22: d436f44f 1ddf8579 70821a65 117e1200
B23: e0270f00 7cbe6bb2 020ec332 bc464299
B24: 20131eb1 e8864206 3b4a8324 522cfe0a
B25: a5209fd7 3f11a1e0 da00c945 835b6b5f
B26: ec9eaea9 9d177dc0 cbd2efe8 21b388c3
B27: 78b2e137 c84f37a4 5599ffc0 a9106204
B28: 5ed1439f 7e67ea1d 6ab024f7 247e85df
B29: bf15d19c b0f488d2 cb06bed9 644ec34c
B30: 2e69f752 4af38319 81c7556e 359bfaf5
B31: 22a00878 4ce3e7e2 362698ea 6c00001d
B32: fdf0936d 2cf7a318 ed4f0447 ad506cdd
B33: c2fcf8b7 328bb527 063859b5 f60819d3
B34: eebdd291 0a12c6af 1c670a30 38fd9e2c
B35: 4a6a3ad7 a51982bd 8d4fabf5 a8c16517
B36: 831661b0 09405052 9fba337b 2b3544cf
```

Sample Data

```
B37: 6811a761 093afd66 8b154a21 a5941b88
B38: a482c5ce f04b18c1 c2e67d7d f90c3a4d
B39: d4ee12fe 4b734174 d3ee8b0c 1ade74eb
B40: 237710da 4694764b 7cce26c4 7a2570bf
B41: 30bb18c7 6571ab05 26892de7 b5d62840
B42: 7f300971 14d6014b 2ca566b3 d6ad1ef5
B43: 96e552e6 defc287e 6a5a5c16 be31d26a
B44: 392e1570 a9f9e0b3 32d223e5 b15407f3
B45: 41cc55f8 3296f3f5 175ebece 580a3f24
B46: 49494406 fa75e051 c829441b ce7cba98
B47: cb7ea85d 8031787d 9495b971 c6925f64
B48: 2726ef05 932d3f1a 14a9bd1a d88a9b31
B49: 6f54d80e 9fe31dcf c94c1f6a 92cc2c82
B50: 60bd9296 e075b884 2976b667 041800df
B51: 520e7a28 e5b9314a 0bb93966 1aba4643
B52: 829544e2 d69f255c ce5bfa89 9a4704f3
B53: be803081 fbc36f5c 65fb13c8 69fc770a
B54: 07cbc8ff 50b8dbe3 b171e9f9 ebc8cf22
B55: 49127607 32973806 95979b3c d75a3f8f
B56: f933a408 d4945f63 96755d6e 493b554b
B57: 58e78f5b a21d31b3 bbcddf62 83e94233
B58: 15a3bea8 3a6ff73f f02809da 3c6d8208
B59: acfd6f05 b62bb5a5 91f1e4d5 4b84d357
B60: 2f00672a 3e3c434c 1736072b 45f6370c
B61: bb46706b 56a57e86 3ed2217a 816e5c09
B62: 1e2895f7 89b57c5e c0a67011 d5f2f69d
B63: 6dac3941 3bc897dc cb42d3bc ffda31e0
B64: e961f3fb e4f40041 69e86cc0 530e891c
B65: 7665902a 1ce0804c 921780ae e2000000

Y0: ebe10d25 4ab27e31 1ea87d16 867d7904
Y1: 99b84ef8 a25d519e 700f76f1 85a74583
Y2: 23fd3478 f96bddd9 dd2e7ded 25f2515e
Y3: 5659d15b 1b569b1f 298f4430 7459cbe0
Y4: d0e6d2f8 939e7c9d 3774cf46 642295ce
Y5: 7e6662bc 99ec7ecc d985ddd4 d2365187
Y6: 421bb569 a5f4d07a 5157fed4 db03f630
Y7: 9fa62969 f43263b1 ac3e269f 15b844ff
Y8: a36e0d50 b75b2feb 45d8c9ee 052f33e4
Y9: 6245ece7 0ad0e314 2ce6ad6b f406b745
Y10: 41ff1de6 e1b3ccec eb6cfb07 fd150751
Y11: 43cae883 dd43266d 2f717cd4 b7c777ba
Y12: 92e3f4b7 bc4b8613 38c0043b 6885fbfb
Y13: b1595644 ec0a8e4e 803994e6 f3d284c5
Y14: e9f7ec01 c4f11349 a5f0a3aa efe88c98
Y15: 8c48cadc 7483c350 c11b6cb4 b8f32b25
Y16: b76f72f5 d54da8e0 b70bcaae 0727f4ed
Y17: b700d8e8 585256f8 38530196 ef3a4a6e
Y18: e0a0f7f0 8f252298 48f8e404 ff4d9f93
Y19: aea86952 8f028974 d890f4e5 52e6da13
Y20: 36566635 1c0a0078 9ee4499b d30ac682
Y21: 886e6fcb 9e9fe3e8 dbfa13ae 7d1e44a7
Y22: 43c5285e de2846da 266a4720 cbd3713e
Y23: 52c47b3e d9a6666e 566eaba7 9275a90f
Y24: ac04ee00 56922a78 5f48347a 3a2360f7
Y25: 33b5496f 546e71f0 80272f6a d189898a
Y26: 5519cbaf ff8fe542 4934f09a 39584456
```

Sample Data

```
Y27: 913a3746 5e6ad4c1 7fce844c f72dc1d8
Y28: 46cef034 a103a8f4 ac13040c 6c466b4b
Y29: 6cbffa5e 2dff5b95 87ba863b 26eab593
Y30: f3dbf258 03f21f71 4d03c4a2 7be84598
Y31: b3c7f849 ab6e9612 e9ece9d5 57c4c813
Y32: 39043423 c60f8fd8 2c108055 6f387c76
Y33: f9dd8872 1fa6f4f4 e5345613 fd5495fd
Y34: cf3d7135 63d2ccfd 41507bd0 fe759830
Y35: 8215cff7 93ae5d92 446fb102 632b4fb8
Y36: 8b02ecb6 fcc063f6 fb41e34a 19afdb3a
Y37: 982e82d3 171d9fb0 ab5b8fbf 17dc00d2
Y38: 2dc18652 f4818748 e3c5fe0e 36b47716
Y39: e6eaef36 46e56552 8ed8c309 ea46ba7f
Y40: 40842220 827424b0 b2f7d5cf b201b5e4
Y41: 5153e29d bc85bafb 36dea69c ec1f1a43
Y42: 08614ff3 44d96b3a f5b9e763 5600b69c
Y43: 2550a964 b17af58b 1843199b 1394de57
Y44: 11cda830 619505fa 49d971c9 c8051abb
Y45: d73824df 17b8ccc2 b52ba9ea ff6f6097
Y46: 100d3219 3486065d 9e7e7ebd 235c34c1
Y47: 440e8fbf e2af1797 2fa75056 2e1941d4
Y48: 91eb5850 4d92d2b8 a64b0e8e 34cf38ef
Y49: 715b4924 0a081cee 2509e363 c746ba6b
Y50: 1cc42047 e5fa2dfb 1c0901f0 a01676c5
Y51: 2634d6db 62d0d5b7 328c5278 6d44b7b1
Y52: 79a0548c 8589f663 323c1604 6af753a8
Y53: e0ba54a0 412e68c1 13c5daf1 8a6e275a
Y54: a1a5e608 3359873b cfb66476 052fcb79
Y55: ce70f15c f2971ebe 7c2d1e3c a288f591
Y56: d9a64946 58968fda 4756668d a5b82b89
Y57: 0c2d5786 6ae786a6 03c6db95 6d26186a
Y58: 00732c24 192905a4 3edaeb0d cc3d4a95
Y59: ae9a2e1c 042112df 4578395b cba685b1
Y60: 50fdc48d 0af8812c b3e64e85 3316b083
Y61: d2c14e67 888a7401 85bd5b91 37d6977a
Y62: 4b882e82 ca8338bb 2278c4d3 8d07f474
Y63: 4bf051e5 19bc961e 38c52cae 50e61d87
Y64: 657025a1 064ec7d6 e1d16bc0 049931bf
Y65: 6de9dbe8 c5a2ed24 66701ea3 4caee13e

T: 6de9dbe8

CTR0: 018bf767 62006f98 36b1e858 ca740000
CTR1: 018bf767 62006f98 36b1e858 ca740001
CTR2: 018bf767 62006f98 36b1e858 ca740002
CTR3: 018bf767 62006f98 36b1e858 ca740003
CTR4: 018bf767 62006f98 36b1e858 ca740004
CTR5: 018bf767 62006f98 36b1e858 ca740005
CTR6: 018bf767 62006f98 36b1e858 ca740006
CTR7: 018bf767 62006f98 36b1e858 ca740007
CTR8: 018bf767 62006f98 36b1e858 ca740008
CTR9: 018bf767 62006f98 36b1e858 ca740009
CTR10: 018bf767 62006f98 36b1e858 ca74000a
CTR11: 018bf767 62006f98 36b1e858 ca74000b
CTR12: 018bf767 62006f98 36b1e858 ca74000c
CTR13: 018bf767 62006f98 36b1e858 ca74000d
CTR14: 018bf767 62006f98 36b1e858 ca74000e
```

Sample Data

```
CTR15: 018bf767 62006f98 36b1e858 ca74000f
CTR16: 018bf767 62006f98 36b1e858 ca740010
CTR17: 018bf767 62006f98 36b1e858 ca740011
CTR18: 018bf767 62006f98 36b1e858 ca740012
CTR19: 018bf767 62006f98 36b1e858 ca740013
CTR20: 018bf767 62006f98 36b1e858 ca740014
CTR21: 018bf767 62006f98 36b1e858 ca740015
CTR22: 018bf767 62006f98 36b1e858 ca740016
CTR23: 018bf767 62006f98 36b1e858 ca740017
CTR24: 018bf767 62006f98 36b1e858 ca740018
CTR25: 018bf767 62006f98 36b1e858 ca740019
CTR26: 018bf767 62006f98 36b1e858 ca74001a

CTR27: 018bf767 62006f98 36b1e858 ca74001b
CTR28: 018bf767 62006f98 36b1e858 ca74001c
CTR29: 018bf767 62006f98 36b1e858 ca74001d
CTR30: 018bf767 62006f98 36b1e858 ca74001e
CTR31: 018bf767 62006f98 36b1e858 ca74001f
CTR32: 018bf767 62006f98 36b1e858 ca740020
CTR33: 018bf767 62006f98 36b1e858 ca740021
CTR34: 018bf767 62006f98 36b1e858 ca740022
CTR35: 018bf767 62006f98 36b1e858 ca740023
CTR36: 018bf767 62006f98 36b1e858 ca740024
CTR37: 018bf767 62006f98 36b1e858 ca740025
CTR38: 018bf767 62006f98 36b1e858 ca740026
CTR39: 018bf767 62006f98 36b1e858 ca740027
CTR40: 018bf767 62006f98 36b1e858 ca740028
CTR41: 018bf767 62006f98 36b1e858 ca740029
CTR42: 018bf767 62006f98 36b1e858 ca74002a
CTR43: 018bf767 62006f98 36b1e858 ca74002b
CTR44: 018bf767 62006f98 36b1e858 ca74002c
CTR45: 018bf767 62006f98 36b1e858 ca74002d
CTR46: 018bf767 62006f98 36b1e858 ca74002e
CTR47: 018bf767 62006f98 36b1e858 ca74002f
CTR48: 018bf767 62006f98 36b1e858 ca740030
CTR49: 018bf767 62006f98 36b1e858 ca740031
CTR50: 018bf767 62006f98 36b1e858 ca740032
CTR51: 018bf767 62006f98 36b1e858 ca740033
CTR52: 018bf767 62006f98 36b1e858 ca740034
CTR53: 018bf767 62006f98 36b1e858 ca740035
CTR54: 018bf767 62006f98 36b1e858 ca740036
CTR55: 018bf767 62006f98 36b1e858 ca740037
CTR56: 018bf767 62006f98 36b1e858 ca740038
CTR57: 018bf767 62006f98 36b1e858 ca740039
CTR58: 018bf767 62006f98 36b1e858 ca74003a
CTR59: 018bf767 62006f98 36b1e858 ca74003b
CTR60: 018bf767 62006f98 36b1e858 ca74003c
CTR61: 018bf767 62006f98 36b1e858 ca74003d
CTR62: 018bf767 62006f98 36b1e858 ca74003e
CTR63: 018bf767 62006f98 36b1e858 ca74003f
CTR64: 018bf767 62006f98 36b1e858 ca740040

S0: 254593c4 cd12c6a7 d9dec572 95524b75
S1: af492e65 ca391b26 e8ce9653 498ed0de
S2: 869271ed ac79c1bc 3cf0f959 c2711f3b
S3: 31554cb7 aa9b1dfb 24ba8b26 eab59ad8
S4: 7cb39415 9dce80e6 0ac0e5e0 9667747e
```

Sample Data

```
S5: 9727b319 ccbcc251 d539fd08 497942c8
S6: bd972408 212a147c 3eb66687 1488e2d9
S7: aef3e149 6b4e615b 309a7f93 53ca2981
S8: 6b276914 1d957bec 4c87e76d ee681e76
S9: a2df383f eece9b0d 4553f2e8 6f8b6035
S10: 11dac6bc c4177830 c7038ee1 e6cb0579
S11: 30bfd1cf 7fa95155 7c0757bf f14840a0
S12: 2315682b 1f4cb1f6 10fd4365 4d9b6155
S13: 7f4aa2fd 211bbc18 9ff3dcd7 c8102220
S14: a072aa38 70e32a62 f7214fb1 97dbfbfd
S15: f7c2b622 96a1f9e1 d3e7837f 293f6e86
S16: e63dc9fd 830944d5 b9fa2257 b0e19402
S17: eceef697 e76f671f 5e7e8c6e ae43f63b
S18: a9bccd3a 4ae6b498 40a6ead6 cd6200a8
S19: 2b624b6b f923eb0f 110ff341 4b1ab902
S20: a47db290 f068ca62 c9236eec ddb431f4
S21: a4ad3dc5 7e324250 1938950e 7b3827fd
S22: 364c32d8 35f63c05 5c8f32dd e560cc8f
S23: f2fd81dc cd12d0cc 2e4f7834 43a74630
S24: 7875bf58 8a162375 b25069d6 b82f4f36
S25: a66bb2d0 43870301 47dbe7f1 92f04b34
S26: 52b87f3e 796b208e 5a0f57c1 6de88c53
S27: 312e84cd 8f627142 ffa9b6cd 56ce3c59
S28: 6695a4dd 1e85cb05 c2070e7c fa16dd90
S29: 10df7734 8a106a97 3b37c508 e54fc157
S30: 54abd840 17756b69 0b7e187b ef5c8ea5
S31: 0bf5f442 c3fecabd 64b313ca 9787f134
S32: aaed31c5 98d1b73a ceaf242d 37b08fd4
S33: 37946570 fcf94220 77cf63da 4781771b
S34: ab5dd397 a7c0d893 7b17c1d2 eb9bc233
S35: 7367b29c 0ecc6a76 1a3c5602 40ca2ca2
S36: 6b593c6d f7485995 f36f1169 089c0be9
S37: ffca503f cfb8848c 73e37041 508128a3
S38: 444e1461 b95ef61a 90c93236 5aaa9fa8
S39: 4099c123 717f86df 23e16eaf 7ed015df
S40: 730217d1 28fa1af8 720864ad 99430469
S41: 43e6b844 95068645 5aca15ed 1bc668a6
S42: 9ee17b6a 65f56326 42e4b829 b5348945
S43: acf20ec7 151b75f0 dd4023ba d099b71c
S44: 41880777 e033c519 79eee51e 14a9246d
S45: 02bb2b01 4981e028 ddb66c67 a7077a1b
S46: db90a526 db75c631 d31af69d ef7b9082
S47: fddfda45 35a30553 78f655cb eae4d1d3
S48: 3472e976 3205e39b e8295a5d 9be10244
S49: fbe961bd 23f25c70 c87cac28 157b55d1
S50: 20a9174a 8da17e48 167086fd 5201ccbb
S51: 390a62b8 90a669c1 b89476ac a46ee788
S52: e354ab7f bd3afd7d 02361116 91afbf21
S53: cbe14419 ab1a4841 3155aaab e1d41a64
S54: cf8fd9f8 8d63ce6a c4c81f7b 852a081f
S55: c6abaae1 44875175 f239963a 194565d1
S56: 8f420880 95982bda d1317139 e9ca663b
S57: 5c7e5c2e 9a457be9 325620ed e0465cf7
S58: f9eb32f4 e1804702 eaff74d1 dea8a295
S59: eb66a965 5551f198 b13495a8 2200509c
S60: a0ee623d 5562b3a6 2cea2c8d f60eb0d8
S61: e7562630 9f7d5b7b 4da8effc e4a1e015
```

Sample Data

```
S62: fa1a5da9 7cdfed2b efd7b409 e065c33e
S63: 238ac0b6 f00d1b5b 77b091cc f4a4ffc4
S64: 533e37d7 b179b943 53511492 e4f58248

MIC: 48ac482c
Encrypted payload: c20b4f29 9a505266 c8521d86 126ba7ed
                   b8537787 dab2a192 997c147c 3bfdf4af
                   69e97103 4d5f7642 c6851906 820a50d8
                   bd691b1d 81de65c0 04639a4b abf6cae1
                   ad69dbf0 ccd00840 28fe9151 57593455
                   5c74678d 8e3a49d7 73f28b20 fe45fbad
                   fae734e0 3dc306f4 f0c0924a 34ec88b1
                   159958e9 9c1d69db 85d435c8 acad624d
                   a349a9d0 7fd7c8f6 7c75b5fa a9955e6b
                   30f2a29d 419e62c5 788f2c70 bf0800ef
                   21043402 f021f6ee c4a884f5 b359ae75
                   a619cfaa d3d0444f 1628bf88 344838d4
                   46eb00c4 087e0ccd 5933e648 2a34119a
                   a89500ff 0dc359f0 4469211c 4a877a3b
                   a3966357 7b78e173 d9c88c96 dfeaaeb1
                   18fceed3 7125de75 69d11645 31179c45
                   64922594 4f4650d0 80aa3243 bdd0b4f5
                   14b5c920 bf0c12ed 03a101fb edc40fd3
                   30f60195 1a8df160 566fd286 9817890c
                   e0845832 b2800118 a457bb59 d2995def
                   709bc98a 63edc729 69ba8f6b 6a4635fd
                   d66b3dd8 494857b7 5e81f1ef 59268e16
                   d2ee9f6d 259492ca 1505fb10 118bb83a
                   dd55208f b5078295 6850a093 3b742469
                   4af51c79 de907ec1 8c090819 b343c3f7
                   2a0a9e09 b124172a 0f96a801 c4f8ee57
                   6fffc752 f1059b5f 9519923a 72b0b986
                   d9807541 ae7143d7 0901b0a5 9e581edc
                   3eb68066 c0e3e98e baf09066 d0d43ba2
                   760bd038 5b968c8b 3d588091 835c8eb8
                   f605672f ef0969a5 89fc178d 3ad79de9
                   6811c972 aa5a021d c8977d98 c1b89607
                   d929b7e1 f6eb848f 6ba869ea 7f7ce937
                   e137e940 02d95a2e f6586a27 435aa724
                   f071d32c 078c3a24 85866579 6bff686d
                   03489b0c fe72a4f3 787a5b48 ad081061
                   5b4895f1 3ff39c4d b1050d3c a98d12ee
                   90a0069f f22db76e 4327b93a 4074eb43
                   63eed1f9 37ebf094 5f2f486b 04f56560
                   43b90f16 4d8bb1fd 5481494a 2c952c29
                   3cd6b135 81d0870e 766f735e cd6b7653
                   0804298c bb094b58 28bee43f 0b055b2f
                   95dc1bb7 bce29543 ef92005f 61cdb0ef
                   0044528f d2a536ec 6eb05bd0 4ca31b49
                   4bf26f07 b3f40079 159f287c 697bc083
                   10ee0d7b 5b44be4c 478f4fec 29e9cfe6
                   daf93540 a68e3a49 6c5fe8d1 326e4ae2
                   5b263178 ade6fe54 21654537 092d2ec6
                   9b54f32b c387e4f4 e10a1a4f 1163550e
                   72a76d62 68184f02 1dc9bf9b 48bb8af8
                   bb9f265a 46394c9d 76cf8c25 3e29e37b
                   5dd49bfe 46f99221 67cd02de f853c82b
```

```
cc2a8ce6 fba293a2 80244352 0a1cd546
869dafff bff4f66c 515f8447 52703790
3f980ee9 90130e16 644ccb54 507e309a
d7a587db 37851a69 6afcae5b 6a232408
49dde286 a02a8cd6 c27e2937 dc2bdeff
55165df1 57abf2a7 7b0e9004 952c71c2
c466ce4f 6b6db2d4 a6029283 67f66790
1ba81256 03c7cd20 12380df7 7760ecd1
f97eb3c7 16c82725 8d0e9fed 31531688
97b664e8 47177af7 249567b5 1fbff2de
caeb334d 14f91b1a 1e58fd0c a7aa76d8
255ba7fd ad99390f c146943c 06
```

1.2.13 Sample Data 13 (3-DH5, S --> M)

```
Payload byte length: 3fd
K: 7b04934f d9d25294 ef1a014d a094f0b5
Payload counter: 006267f78b
Zero-length ACL-U Continuation: 0
Direction: 1
Initialization vector: 74ca58e8 b136986f
LT_ADDR: 1
Packet Type: f
LLID: 2
Payload: 6d42614c 50694940 209c8bd5 5be57733
         3ec1066a 76cb602e a58ced25 f98ceb94
         58bc3db4 e7c46bb9 e23f9220 68bfca00
         c1da8f08 1c10e526 0ea37fab 3d91be9f
         3a4e68e9 006cca11 fdc76c59 1e20769d
         e1e34385 af105dab 4d44eda7 eacd1974
         5414d5a9 568d67af c05aedd9 6726a130
         7ebe31fd 81881237 c953d2a5 42c57c3b
         019691ef 911953fb 39264712 c61e3e5e
         21286421 85891af5 bf8ca291 59c30596
         11bbe5cd 8f88a7bb b8afd34a 4211eed5
         850ca781 cc9cf5b9 06d5fced 79d35981
         39a1a239 2965b0d5 c6c03a9f e22433ba
         08e7aac7 7d207392 b3486ead dd5c81c6
         5454d575 edd91892 0a2f0fe9 f6d5c037
         fec1272e f22c9aa0 d02b3412 81f60847
         887cd303 a82937cf ded4be2d 139342ce
         bd09041a f5eaa675 4307eb2d 20a60f7b
         1b944afe e3ae1a6f 476021c7 d30d300e
         44f9eaa2 42e8cb7a 6d74d5b5 0f2d6c1b
         d436f44f 1ddf8579 70821a65 117e1200
         e0270f00 7cbe6bb2 020ec332 bc464299
         20131eb1 e8864206 3b4a8324 522cfe0a
         a5209fd7 3f11a1e0 da00c945 835b6b5f
         ec9eaea9 9d177dc0 cbd2efe8 21b388c3
         78b2e137 c84f37a4 5599ffc0 a9106204
         5ed1439f 7e67ea1d 6ab024f7 247e85df
         bf15d19c b0f488d2 cb06bed9 644ec34c
         2e69f752 4af38319 81c7556e 359bfaf5
         22a00878 4ce3e7e2 362698ea 6c00001d
         fdf0936d 2cf7a318 ed4f0447 ad506cdd
```

Sample Data

```
          c2fcf8b7 328bb527 063859b5 f60819d3
          eebdd291 0a12c6af 1c670a30 38fd9e2c
          4a6a3ad7 a51982bd 8d4fabf5 a8c16517
          831661b0 09405052 9fba337b 2b3544cf
          6811a761 093afd66 8b154a21 a5941b88
          a482c5ce f04b18c1 c2e67d7d f90c3a4d
          d4ee12fe 4b734174 d3ee8b0c 1ade74eb
          237710da 4694764b 7cce26c4 7a2570bf
          30bb18c7 6571ab05 26892de7 b5d62840
          7f300971 14d6014b 2ca566b3 d6ad1ef5
          96e552e6 defc287e 6a5a5c16 be31d26a
          392e1570 a9f9e0b3 32d223e5 b15407f3
          41cc55f8 3296f3f5 175ebece 580a3f24
          49494406 fa75e051 c829441b ce7cba98
          cb7ea85d 8031787d 9495b971 c6925f64
          2726ef05 932d3f1a 14a9bd1a d88a9b31
          6f54d80e 9fe31dcf c94c1f6a 92cc2c82
          60bd9296 e075b884 2976b667 041800df
          520e7a28 e5b9314a 0bb93966 1aba4643
          829544e2 d69f255c ce5bfa89 9a4704f3
          be803081 fbc36f5c 65fb13c8 69fc770a
          07cbc8ff 50b8dbe3 b171e9f9 ebc8cf22
          49127607 32973806 95979b3c d75a3f8f
          f933a408 d4945f63 96755d6e 493b554b
          58e78f5b a21d31b3 bbcddf62 83e94233
          15a3bea8 3a6ff73f f02809da 3c6d8208
          acfd6f05 b62bb5a5 91f1e4d5 4b84d357
          2f00672a 3e3c434c 1736072b 45f6370c
          bb46706b 56a57e86 3ed2217a 816e5c09
          1e2895f7 89b57c5e c0a67011 d5f2f69d
          6dac3941 3bc897dc cb42d3bc ffda31e0
          e961f3fb e4f40041 69e86cc0 530e891c
          7665902a 1ce0804c 921780ae e2

B0: 498bf767 62206f98 36b1e858 ca7403fd
B1: 00790200 00000000 00000000 00000000
B2: 6d42614c 50694940 209c8bd5 5be57733
B3: 3ec1066a 76cb602e a58ced25 f98ceb94
B4: 58bc3db4 e7c46bb9 e23f9220 68bfca00
B5: c1da8f08 1c10e526 0ea37fab 3d91be9f
B6: 3a4e68e9 006cca11 fdc76c59 1e20769d
B7: e1e34385 af105dab 4d44eda7 eacd1974
B8: 5414d5a9 568d67af c05aedd9 6726a130
B9: 7ebe31fd 81881237 c953d2a5 42c57c3b
B10: 019691ef 911953fb 39264712 c61e3e5e
B11: 21286421 85891af5 bf8ca291 59c30596
B12: 11bbe5cd 8f88a7bb b8afd34a 4211eed5
B13: 850ca781 cc9cf5b9 06d5fced 79d35981
B14: 39a1a239 2965b0d5 c6c03a9f e22433ba
B15: 08e7aac7 7d207392 b3486ead dd5c81c6
B16: 5454d575 edd91892 0a2f0fe9 f6d5c037
B17: fec1272e f22c9aa0 d02b3412 81f60847
B18: 887cd303 a82937cf ded4be2d 139342ce
B19: bd09041a f5eaa675 4307eb2d 20a60f7b
B20: 1b944afe e3ae1a6f 476021c7 d30d300e
B21: 44f9eaa2 42e8cb7a 6d74d5b5 0f2d6c1b
B22: d436f44f 1ddf8579 70821a65 117e1200
```

Sample Data

```
B23: e0270f00 7cbe6bb2 020ec332 bc464299
B24: 20131eb1 e8864206 3b4a8324 522cfe0a
B25: a5209fd7 3f11a1e0 da00c945 835b6b5f
B26: ec9eaea9 9d177dc0 cbd2efe8 21b388c3
B27: 78b2e137 c84f37a4 5599ffc0 a9106204
B28: 5ed1439f 7e67ea1d 6ab024f7 247e85df
B29: bf15d19c b0f488d2 cb06bed9 644ec34c
B30: 2e69f752 4af38319 81c7556e 359bfaf5
B31: 22a00878 4ce3e7e2 362698ea 6c00001d
B32: fdf0936d 2cf7a318 ed4f0447 ad506cdd
B33: c2fcf8b7 328bb527 063859b5 f60819d3
B34: eebdd291 0a12c6af 1c670a30 38fd9e2c
B35: 4a6a3ad7 a51982bd 8d4fabf5 a8c16517
B36: 831661b0 09405052 9fba337b 2b3544cf
B37: 6811a761 093afd66 8b154a21 a5941b88
B38: a482c5ce f04b18c1 c2e67d7d f90c3a4d
B39: d4ee12fe 4b734174 d3ee8b0c 1ade74eb
B40: 237710da 4694764b 7cce26c4 7a2570bf
B41: 30bb18c7 6571ab05 26892de7 b5d62840
B42: 7f300971 14d6014b 2ca566b3 d6ad1ef5
B43: 96e552e6 defc287e 6a5a5c16 be31d26a
B44: 392e1570 a9f9e0b3 32d223e5 b15407f3
B45: 41cc55f8 3296f3f5 175ebece 580a3f24
B46: 49494406 fa75e051 c829441b ce7cba98
B47: cb7ea85d 8031787d 9495b971 c6925f64
B48: 2726ef05 932d3f1a 14a9bd1a d88a9b31
B49: 6f54d80e 9fe31dcf c94c1f6a 92cc2c82
B50: 60bd9296 e075b884 2976b667 041800df
B51: 520e7a28 e5b9314a 0bb93966 1aba4643
B52: 829544e2 d69f255c ce5bfa89 9a4704f3
B53: be803081 fbc36f5c 65fb13c8 69fc770a
B54: 07cbc8ff 50b8dbe3 b171e9f9 ebc8cf22
B55: 49127607 32973806 95979b3c d75a3f8f
B56: f933a408 d4945f63 96755d6e 493b554b
B57: 58e78f5b a21d31b3 bbcddf62 83e94233
B58: 15a3bea8 3a6ff73f f02809da 3c6d8208
B59: acfd6f05 b62bb5a5 91f1e4d5 4b84d357
B60: 2f00672a 3e3c434c 1736072b 45f6370c
B61: bb46706b 56a57e86 3ed2217a 816e5c09
B62: 1e2895f7 89b57c5e c0a67011 d5f2f69d
B63: 6dac3941 3bc897dc cb42d3bc ffda31e0
B64: e961f3fb e4f40041 69e86cc0 530e891c
B65: 7665902a 1ce0804c 921780ae e2000000

Y0: b7b63a11 d2ff710c 5d821353 120fe064
Y1: 31635446 16989968 dbd392df 77ab44b2
Y2: fe667b06 7ef88846 a74b5119 476c5ca9
Y3: 03db41e6 902e40ff fa6d86e6 92a2c630
Y4: 0a1c2366 e55a2cd0 701fe43d 34becee0
Y5: 8e8c6fd4 dfb9071b 3feb7938 defa835e
Y6: 61b2fe53 6f876519 43698e8d f7ca327e
Y7: 3705a0c3 39989f81 377afb1b d9f01569
Y8: d96211f1 959c7a64 3ee0a727 b4ad2ae2
Y9: 7cdc85ed d204d4ce 33665710 bcd4f7f1
Y10: 9a6d0fed cfde263e 62eddf28 fab38c98
Y11: 98915f60 f70cc4df 74ac9931 1a4f2990
Y12: 4a88113a 754243af c00324ef 117678f7
```

Sample Data

```
Y13: a0f620c0 b3a903fa 648210ef 63eef46f
Y14: f526db99 20291004 225a762f 129e58ff
Y15: 8ee96b03 494a8b18 1e1194b7 babb8a27
Y16: 59b69b74 0455f2ac 65f9c651 34ceae70
Y17: 9c0a2ee9 64e57ffb 57bcd10d f3c8a567
Y18: ee339202 c09ff61a 72fc2a2f 183b370e
Y19: 57b1bac2 63769a7b db0eac84 6b49aca4
Y20: 20e3786a e9526a50 cdc9dcc5 c579a3bf
Y21: 6bc61121 214dd538 aa3cc0a3 9abab72a
Y22: 5a42d758 fb854450 55199e78 ba42ca62
Y23: fc9cf1f6 58691ce8 01ca2501 25223403
Y24: cfa5ab4f 90431bc8 f832f148 db633e8e
Y25: 7254ae54 60a7dcbd 3470df60 7af3c1ca
Y26: 436205c4 763e68ab 390907e2 da236e8d
Y27: 6738b5db e1b8b739 d5eccc0d 47ab511c
Y28: 65a1dd1e f661d376 1c917ea7 f171dc7e
Y29: 55a82897 a7d19703 87e783cd 52ddecd8
Y30: 7e0ae507 5c9b8dc1 e4981e02 377472b5
Y31: 035d4dd3 493a84b5 0c2bd3ae 2f9f728b
Y32: 34441d1c cd9400d9 164c74b3 5021a97e
Y33: 4c5c3051 0c1d8571 782993c0 3a7a9e13
Y34: 63453300 3bc6cc3d 53a36db3 79f2b047
Y35: e3630826 7ac4040c b087d657 953a4560
Y36: 967ef5bd bf821572 466bf00f aefd751b
Y37: 4f19c371 c5da0b9f 4bc55452 05dab223
Y38: 6fa54807 d40a41ca 3c41bf6a 890d56c9
Y39: fb2d42e7 013c1e0d 17aa1e01 090fe190
Y40: f6104499 02efdc76 6cae97b7 f27d8765
Y41: 5d9ebc6d 22b48c7c 276b9670 636433cb
Y42: d85fb261 60c02b6d 348e6616 8d79f268
Y43: c66ab5e0 7fc159dd 07f41e8d 511989d0
Y44: e18f58b0 c831550b 2aa0f002 51899793
Y45: c36620e2 7a396916 74cc358f 36d4ae68
Y46: 6b1cb137 b69d021f 764150fd 5b29744f
Y47: cc3b7f27 a69a9666 6919d755 6893a18f
Y48: b1e1c8f8 936c88d1 b2540bf8 e82032d9
Y49: 045ad0f2 638df0e6 79357e37 0240dd8a
Y50: 455f563e 5cf94329 a4efbede ac30d09f
Y51: f6e8f947 ec78897c 96fe5879 a1519ede
Y52: f2a0a601 d7765bb7 0a41a0b6 fae10c36
Y53: 86bcc098 bcd1e930 7b008ec5 6c027ccb
Y54: 8f0f380b c973be6a c88d8a4d 45f86b0c
Y55: 2b5ca348 5bb4015a e9b907f6 1cc77400
Y56: a2755ca8 2c52702b ed08736d ef68938a
Y57: d92292d5 0a0cf7cd 79d95799 6c6dff88
Y58: 469d1262 83afb58c 9810c732 a4a36a79
Y59: bb563499 7ca1c960 8357c393 60148fff
Y60: 83e8dbc7 67e501de 080aac2d 0501b9ec
Y61: 956f13a2 c14f9476 d268896c f24ed47a
Y62: 1dfcb90c 4b088e40 830784fe f9dbe7c6
Y63: e7c8898d 9c033db9 117191d0 57d0d5cb
Y64: 6a187312 e7bc05cc bd8e8199 e9e7348d
Y65: 682ec5d4 8fec944f 0e02eeb0 bcf11786

T: 682ec5d4

CTR0: 018bf767 62206f98 36b1e858 ca740000
```

Sample Data

```
CTR1: 018bf767 62206f98 36b1e858 ca740001
CTR2: 018bf767 62206f98 36b1e858 ca740002
CTR3: 018bf767 62206f98 36b1e858 ca740003
CTR4: 018bf767 62206f98 36b1e858 ca740004
CTR5: 018bf767 62206f98 36b1e858 ca740005
CTR6: 018bf767 62206f98 36b1e858 ca740006
CTR7: 018bf767 62206f98 36b1e858 ca740007
CTR8: 018bf767 62206f98 36b1e858 ca740008
CTR9: 018bf767 62206f98 36b1e858 ca740009
CTR10: 018bf767 62206f98 36b1e858 ca74000a
CTR11: 018bf767 62206f98 36b1e858 ca74000b
CTR12: 018bf767 62206f98 36b1e858 ca74000c
CTR13: 018bf767 62206f98 36b1e858 ca74000d
CTR14: 018bf767 62206f98 36b1e858 ca74000e
CTR15: 018bf767 62206f98 36b1e858 ca74000f
CTR16: 018bf767 62206f98 36b1e858 ca740010
CTR17: 018bf767 62206f98 36b1e858 ca740011
CTR18: 018bf767 62206f98 36b1e858 ca740012
CTR19: 018bf767 62206f98 36b1e858 ca740013
CTR20: 018bf767 62206f98 36b1e858 ca740014
CTR21: 018bf767 62206f98 36b1e858 ca740015
CTR22: 018bf767 62206f98 36b1e858 ca740016
CTR23: 018bf767 62206f98 36b1e858 ca740017
CTR24: 018bf767 62206f98 36b1e858 ca740018
CTR25: 018bf767 62206f98 36b1e858 ca740019
CTR26: 018bf767 62206f98 36b1e858 ca74001a
CTR27: 018bf767 62206f98 36b1e858 ca74001b
CTR28: 018bf767 62206f98 36b1e858 ca74001c
CTR29: 018bf767 62206f98 36b1e858 ca74001d
CTR30: 018bf767 62206f98 36b1e858 ca74001e
CTR31: 018bf767 62206f98 36b1e858 ca74001f
CTR32: 018bf767 62206f98 36b1e858 ca740020
CTR33: 018bf767 62206f98 36b1e858 ca740021
CTR34: 018bf767 62206f98 36b1e858 ca740022
CTR35: 018bf767 62206f98 36b1e858 ca740023
CTR36: 018bf767 62206f98 36b1e858 ca740024
CTR37: 018bf767 62206f98 36b1e858 ca740025
CTR38: 018bf767 62206f98 36b1e858 ca740026
CTR39: 018bf767 62206f98 36b1e858 ca740027
CTR40: 018bf767 62206f98 36b1e858 ca740028
CTR41: 018bf767 62206f98 36b1e858 ca740029
CTR42: 018bf767 62206f98 36b1e858 ca74002a
CTR43: 018bf767 62206f98 36b1e858 ca74002b
CTR44: 018bf767 62206f98 36b1e858 ca74002c
CTR45: 018bf767 62206f98 36b1e858 ca74002d
CTR46: 018bf767 62206f98 36b1e858 ca74002e
CTR47: 018bf767 62206f98 36b1e858 ca74002f
CTR48: 018bf767 62206f98 36b1e858 ca740030
CTR49: 018bf767 62206f98 36b1e858 ca740031
CTR50: 018bf767 62206f98 36b1e858 ca740032
CTR51: 018bf767 62206f98 36b1e858 ca740033
CTR52: 018bf767 62206f98 36b1e858 ca740034
CTR53: 018bf767 62206f98 36b1e858 ca740035
CTR54: 018bf767 62206f98 36b1e858 ca740036
CTR55: 018bf767 62206f98 36b1e858 ca740037
CTR56: 018bf767 62206f98 36b1e858 ca740038
CTR57: 018bf767 62206f98 36b1e858 ca740039
```

Sample Data

```
CTR58: 018bf767 62206f98 36b1e858 ca74003a
CTR59: 018bf767 62206f98 36b1e858 ca74003b
CTR60: 018bf767 62206f98 36b1e858 ca74003c
CTR61: 018bf767 62206f98 36b1e858 ca74003d
CTR62: 018bf767 62206f98 36b1e858 ca74003e
CTR63: 018bf767 62206f98 36b1e858 ca74003f
CTR64: 018bf767 62206f98 36b1e858 ca740040

S0: 1404487a 919e16c8 b3245d80 2b364231
S1: 82082cbc 57038db7 4823be9a 34e0a8d7
S2: 1b5f7526 d26fe763 7669dfee 63743d3a
S3: a3673258 5020c6cd d72bf517 accb632d
S4: 8a60ebb6 59c59ac1 a45a1ffd f54f7cd7
S5: 036f35c7 130c8a30 25e9da14 706df5bc
S6: e328cbb0 09c91d56 f010b40e e0fc5c3f
S7: 626d3d67 b53eb139 e155c9a2 df407b17
S8: d94e430b 829c7caf 289d2898 3c68aa5a
S9: d6343452 d92cb1ac b3fde90b e2f0789f
S10: 8ab8413c 0df18adf ae07a74f 82b3c91f
S11: 61bfac52 125b8fc4 eaac30f7 5a543821
S12: 68899f8f 2892931d 88b08926 7fa3cfc9
S13: 86b668c5 4ef24455 22a45f42 61aea816
S14: f57b4941 8332f0b3 7749ea30 53a711ee
S15: 593562a8 45c75a7c 70030f08 6fedd965
S16: f85e742f a743f353 6a22b384 be1dabdc
S17: ed7e317b 635deed3 e8b619f2 9bc65eb0
S18: 2035622d 94718ad6 c1631fa2 755883f4
S19: 40f50638 ad826c4a 3ca4fb88 467445ae
S20: e27eb632 0c2aee5c 9210b1c7 736fb897
S21: 711a9be3 c7054fa5 82ec70b6 028489e7
S22: 7b543081 c52e2cba 26400e6b 46642d0d
S23: d9564733 01fa7fae 7cfac2a7 239639e2
S24: 202ed696 6fbc2ecf f0982979 25bef3ea
S25: e2148e71 5935e2a5 bd175ee9 a799a549
S26: 77310821 6671e6dc 3a121369 a557aa4f
S27: 6d6c2659 06036f0c 1cec57ed 4a36158d
S28: b216aab3 be06fde0 262ae2ea e81cd2e5
S29: 0b56812e 52b653f9 0e27362e dd7dcbd4
S30: df590fb5 d38ea1cd f8eb2d5b 3d474253
S31: 6493924c 073da4bf d5658181 48b52d76
S32: e8491efc f7d18b0a 027f656e c6886a7d
S33: eb26ca54 5d221211 73a037ec e43053e9
S34: fa2f9edf 4e9d9c1c aa6e786c e743c1c0
S35: cf833d58 0d508e0e da69560a 66d3c03b
S36: f5922c3b 4382f00f 9b64ebb1 b2accbb0
S37: 9a3faeeb 69fdb9e1 3a025f2d 299c177e
S38: 376d0236 76cfe2b1 1c0e342a afe6418b
S39: 1d2a5ab1 7dc816ee 6c37e855 07f11bd7
S40: c33e7e9f 7669ad90 44625f47 1155c411
S41: bae0615e 9d48b215 0b9e7065 04b09ef7
S42: 606e0db2 17e5251d ba08c3db f20915fd
S43: f28282de b65b5dcc 0b88f0d0 20fa4810
S44: 701e67ab aa5af6c2 1bf15c6f ea339a58
S45: bd5176ce 91b3298f fe989ff0 c6ff991f
S46: 9eb857c4 bfec9af6 b1c78acd f3aabd69
S47: 7acfb2d7 217154f8 09cd5f4c 9728c6cc
S48: 66b07ebe 3665809d 7b855491 4bf90528
```

Sample Data

```
S49: 91a82a7d f3744bd0 7fc8850c 08554c8d
S50: 0fa45385 3cca72db eaa031b2 65c9d590
S51: 2bf70aa1 dab678d7 f8d8a2b2 88dc22da
S52: 1633856d aacda2bb 94f1d66b 0f4ad876
S53: b09b906a ff48f724 b9524495 409a0a62
S54: 7cda29ed 1e6f903d b7a9f4c5 26c28530
S55: f5338a50 74e0c5ed 214c4380 70886009
S56: 9cd2fb3c f8e8d55f 93a10ccd f288eead
S57: 9f1b72ba 2e506062 9dcc02a2 a3536e0e
S58: ea50be8b e9ffe171 c6f64b44 1357e68e
S59: 5d3c94b8 ef4051ff 79cd4200 3d9a3208
S60: 14267f84 ee8d7e71 df5d46ec 361f1648
S61: 7871fd55 dbcbcf6c 20c2902d 58935861
S62: 33b892d6 63807bf4 ddc0cc2b 3e037547
S63: 611a7ca9 85d3571a 1b6a0917 40795e7c
S64: ef6adb06 6b6cb075 5ac5a39a 08ae7e7b

MIC: 7c2a8dae
Encrypted payload: ef4a4df0 076ac4f7 68bf354f 6f05dfe4
                   259e734c a4a4874d d3e532cb 9af8d6ae
                   fbdb0fec b7e4ad74 35146737 c474a92d
                   4bba64be 45d57fe7 aaf96056 c8dec248
                   39215d2e 13604021 d82eb64d 6e4d8321
                   02cb8835 a6d940fd bd5459a9 0a31454b
                   3679e8ce e3b3d696 210f247b b866da27
                   a7f072f6 03146e98 e1cefa3d 7eadd661
                   d7a2a5bd 4835e257 8adbae19 24ee46c1
                   ab90251d 8878902a 118b05de db70cc89
                   7004499f 9dd3287f 5203e3bd 1845d6f4
                   ed85380e e40e66a4 8e6575cb 06709648
                   bf17cafc 6797f480 e46465dd 838a9bac
                   fd9ce386 fe128321 c401849d 8efb9028
                   0d61b7dd a81e42ee 7a2c00e1 99381952
                   069f5301 556f69f3 ba098796 3feba39b
                   6502e278 cb74d91c 3662a7df 88551c7e
                   9d3c6637 619b2ca3 8264f48f 55fe8c8f
                   5b614cc6 4e2c7625 7bc4da4f 957975a0
                   a6875c90 4ec22526 ff646472 7c42d48c
                   a52c6fac dadacadc f26e6ad3 13fa9be7
                   9b733f81 b9904708 244ecd59 fa226f94
                   f9455982 e97c3da8 47b04183 71bac7e8
                   850e4941 50ad8f2f 2a98e03c a6e598b5
                   0e8a20d8 c4229f65 76c5b101 862a2d8a
                   0f83e916 ae3ed178 6f8beca9 0c47c84b
                   33bd65c6 78648511 765c731a 6e489052
                   0d037b2f 0ef27532 ed2c5c33 8c5211a9
                   253f767c 1845d0e0 8fe06340 e8e63121
                   fdf907cd 9f6d462f cecdb5b1 5147424e
                   99630121 2bca07a7 382a85c6 e5e541ab
                   2ab5e64b c55a3e2d 04473cdb 308073ae
                   059b18c5 5730d4be 6fc73ddc dccdcdc5
                   b045a408 eb841ea1 2721d399 4f82a4d7
                   4c955ce8 0410de5c 45d36571 4de684f4
                   9d838b5a 4ab80d69 1071a190 1738d038
                   3ebd6b25 99b6a120 f8e42250 d0902d33
                   e38310c8 3dbca3c5 cfe0bf26 b5383560
                   3e5d4a6b 3b5c60a5 10f9ce91 7dd46b68
```

```
f3856658 13180695 62eb72a0 a483ec51
c5d0682f 899eb35e 273b16d6 d21d8002
f68b5f54 c9190d63 d0529fcd 4c38c797
cbac97ae 1fa2bd7f 395ad335 91ae4fe3
31d23253 98cc0537 0cafe2a1 b239a57c
f41832c8 6bc6c9de 36b1dbeb 08832387
55c6ff99 3fdde28b 255233bc 3538e20d
5de95dd2 b25c6be2 1d64e256 4fa25dfd
09e4a6b0 a9869d52 b2c94bfb d93529aa
f115b8eb 1301f354 56be336b 0c4d4c52
5daa29ad d9734391 e11908d4 7f7393d3
a9624e43 0c295d8b 3683583b 129b2629
a8b3b5ec 510ecde7 f10ac5a3 66b6af7c
b7505895 aff02cc7 0823ad6c ab52c540
35c85fea 2cf8a83b 223e6ff9 f198babf
0c002e58 a0749a8e b7391eee 39b33542
c4357467 5af5e4ec 286cd3af 7161ac9e
8ab8cc12 143f975d 6de40b78 9f3eec06
46add18e 5fd454d4 5707af91 58d335d9
723cf392 d17c12b3 6efb452b 786c0504
af600fef b82800f7 e18f6796 b7714a41
665968a2 527eb332 e064e03c 8d61aefc
5e14ab97 5848ec28 16821f97 c1d944a7
887b8f52 6127575b 728265d7 1377d760
990f4b2c 778c3039 c8d22334 ea
```

1.2.14 Sample Data 14 (EV3)

```
Payload byte length: 1e
K: 972b7dcd be8942b7 d8fdc356 a5590aca
CLK[27:1]: 030b5a8f
dayCounter: 061a
Initialization vector: 70b690bd dfe9630f
LT_ADDR: 1
Packet Type: 7
Payload: 4625f778 578290f9 0ee83576 b3f8a898
         faff3fe4 5db812b2 e189297a fd89

CTR0: 018f5a0b d3700f63 e9dfbd90 b6700000
CTR1: 018f5a0b d3700f63 e9dfbd90 b6700001
CTR2: 018f5a0b d3700f63 e9dfbd90 b6700002

Encrypted payload: 76637937 69b2ba4c 41704100 d6c4602a
                   dbae2a87 f77a9fdb a0c56d2c b532
```

2 FREQUENCY HOPPING SAMPLE DATA

The section contains three sets of sample data showing the basic and adapted hopping schemes for different combinations of addresses and initial clock values.

Sample Data

2.1 FIRST SET

```
Hop sequence {k} for PAGE SCAN/INQUIRY SCAN SUBSTATE:
CLKN start:      0x0000000
UAP / LAP:       0x00000000
#ticks:          0000 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 |
                 -----------------------------------------------------
0x0000000:          0 |    2 |    4 |    6 |    8 |   10 |   12 |   14 |
0x0008000:         16 |   18 |   20 |   22 |   24 |   26 |   28 |   30 |
0x0010000:         32 |   34 |   36 |   38 |   40 |   42 |   44 |   46 |
0x0018000:         48 |   50 |   52 |   54 |   56 |   58 |   60 |   62 |
0x0020000:          0 |    2 |    4 |    6 |    8 |   10 |   12 |   14 |
0x0028000:         16 |   18 |   20 |   22 |   24 |   26 |   28 |   30 |
0x0030000:         32 |   34 |   36 |   38 |   40 |   42 |   44 |   46 |
0x0038000:         48 |   50 |   52 |   54 |   56 |   58 |   60 |   62 |

Hop sequence {k} for PAGE STATE/INQUIRY SUBSTATE:
CLKE start:      0x0000000
UAP / LAP:       0x00000000
#ticks:          00 01 02 03 | 04 05 06 07 | 08 09 0a 0b | 0c 0d 0e 0f |
                 -----------------------------------------------------
0x0000000:       48 50 09 13 | 52 54 41 45 | 56 58 11 15 | 60 62 43 47 |
0x0000010:       00 02 64 68 | 04 06 17 21 | 08 10 66 70 | 12 14 19 23 |
0x0000020:       48 50 09 13 | 52 54 41 45 | 56 58 11 15 | 60 62 43 47 |
0x0000030:       00 02 64 68 | 04 06 17 21 | 08 10 66 70 | 12 14 19 23 |
...
0x0001000:       48 18 09 05 | 20 22 33 37 | 24 26 03 07 | 28 30 35 39 |
0x0001010:       32 34 72 76 | 36 38 25 29 | 40 42 74 78 | 44 46 27 31 |
0x0001020:       48 18 09 05 | 20 22 33 37 | 24 26 03 07 | 28 30 35 39 |
0x0001030:       32 34 72 76 | 36 38 25 29 | 40 42 74 78 | 44 46 27 31 |
...
0x0002000:       16 18 01 05 | 52 54 41 45 | 56 58 11 15 | 60 62 43 47 |
0x0002010:       00 02 64 68 | 04 06 17 21 | 08 10 66 70 | 12 14 19 23 |
0x0002020:       16 18 01 05 | 52 54 41 45 | 56 58 11 15 | 60 62 43 47 |
0x0002030:       00 02 64 68 | 04 06 17 21 | 08 10 66 70 | 12 14 19 23 |
...
0x0003000:       48 50 09 13 | 52 22 41 37 | 24 26 03 07 | 28 30 35 39 |
0x0003010:       32 34 72 76 | 36 38 25 29 | 40 42 74 78 | 44 46 27 31 |
0x0003020:       48 50 09 13 | 52 22 41 37 | 24 26 03 07 | 28 30 35 39 |
0x0003030:       32 34 72 76 | 36 38 25 29 | 40 42 74 78 | 44 46 27 31 |

Hop sequence {k} for SLAVE PAGE RESPONSE SUBSTATE:
CLKN* =          0x0000010
UAP / LAP:       0x00000000
#ticks:          00 | 02 04 | 06 08 | 0a 0c | 0e 10 | 12 14 | 16 18 | 1a 1c | 1e
                 ---------------------------------------------------------------
0x0000012:       64 | 02 68 | 04 17 | 06 21 | 08 66 | 10 70 | 12 19 | 14 23 | 16
0x0000032:       01 | 18 05 | 20 33 | 22 37 | 24 03 | 26 07 | 28 35 | 30 39 | 32
0x0000052:       72 | 34 76 | 36 25 | 38 29 | 40 74 | 42 78 | 44 27 | 46 31 | 48
0x0000072:       09 | 50 13 | 52 41 | 54 45 | 56 11 | 58 15 | 60 43 | 62 47 | 00

Hop sequence {k} for MASTER PAGE RESPONSE SUBSTATE:
Offset value:    24
CLKE* =          0x0000012
UAP / LAP:       0x00000000
#ticks:          00 02 | 04 06 | 08 0a | 0c 0e | 10 12 | 14 16 | 18 1a | 1c 1e |
                 -----------------------------------------------------------------
0x0000014:       02 68 | 04 17 | 06 21 | 08 66 | 10 70 | 12 19 | 14 23 | 16 01 |
0x0000034:       18 05 | 20 33 | 22 37 | 24 03 | 26 07 | 28 35 | 30 39 | 32 72 |
0x0000054:       34 76 | 36 25 | 38 29 | 40 74 | 42 78 | 44 27 | 46 31 | 48 09 |
0x0000074:       50 13 | 52 41 | 54 45 | 56 11 | 58 15 | 60 43 | 62 47 | 00 64 |
```

Sample Data

Hop sequence {k} for CONNECTION STATE (Basic channel hopping sequence; ie, non-AFH):
CLK start: 0x0000010
UAP/LAP: 0x00000000

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010:	08 66	10 70	12 19	14 23	16 01	18 05	20 33	22 37
0x0000030:	24 03	26 07	28 35	30 39	32 72	34 76	36 25	38 29
0x0000050:	40 74	42 78	44 27	46 31	48 09	50 13	52 41	54 45
0x0000070:	56 11	58 15	60 43	62 47	32 17	36 19	34 49	38 51
0x0000090:	40 21	44 23	42 53	46 55	48 33	52 35	50 65	54 67
0x00000b0:	56 37	60 39	58 69	62 71	64 25	68 27	66 57	70 59
0x00000d0:	72 29	76 31	74 61	78 63	01 41	05 43	03 73	07 75
0x00000f0:	09 45	13 47	11 77	15 00	64 49	66 53	68 02	70 06
0x0000110:	01 51	03 55	05 04	07 08	72 57	74 61	76 10	78 14
0x0000130:	09 59	11 63	13 12	15 16	17 65	19 69	21 18	23 22
0x0000150:	33 67	35 71	37 20	39 24	25 73	27 77	29 26	31 30
0x0000170:	41 75	43 00	45 28	47 32	17 02	21 04	19 34	23 36
0x0000190:	33 06	37 08	35 38	39 40	25 10	29 12	27 42	31 44
0x00001b0:	41 14	45 16	43 46	47 48	49 18	53 20	51 50	55 52
0x00001d0:	65 22	69 24	67 54	71 56	57 26	61 28	59 58	63 60
0x00001f0:	73 30	77 32	75 62	00 64	49 34	51 42	57 66	59 74
0x0000210:	53 36	55 44	61 68	63 76	65 50	67 58	73 03	75 11
0x0000230:	69 52	71 60	77 05	00 13	02 38	04 46	10 70	12 78
0x0000250:	06 40	08 48	14 72	16 01	18 54	20 62	26 07	28 15
0x0000270:	22 56	24 64	30 09	32 17	02 66	06 74	10 19	14 27
0x0000290:	04 70	08 78	12 23	16 31	18 03	22 11	26 35	30 43
0x00002b0:	20 07	24 15	28 39	32 47	34 68	38 76	42 21	46 29
0x00002d0:	36 72	40 01	44 25	48 33	50 05	54 13	58 37	62 45
0x00002f0:	52 09	56 17	60 41	64 49	34 19	36 35	50 51	52 67
0x0000310:	38 21	40 37	54 53	56 69	42 27	44 43	58 59	60 75
0x0000330:	46 29	48 45	62 61	64 77	66 23	68 39	03 55	05 71
0x0000350:	70 25	72 41	07 57	09 73	74 31	76 47	11 63	13 00
0x0000370:	78 33	01 49	15 65	17 02	66 51	70 67	03 04	07 20
0x0000390:	68 55	72 71	05 08	09 24	74 59	78 75	11 12	15 28
0x00003b0:	76 63	01 00	13 16	17 32	19 53	23 69	35 06	39 22
0x00003d0:	21 57	25 73	37 10	41 26	27 61	31 77	43 14	47 30
0x00003f0:	29 65	33 02	45 18	49 34	19 04	21 08	23 20	25 24

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with all channel used; ie, AFH(79)):

CLK start: 0x0000010

ULAP: 0x00000000

Used Channels:0x7fffffffffffffffffff

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	08 08	10 10	12 12	14 14	16 16	18 18	20 20	22 22
0x0000030	24 24	26 26	28 28	30 30	32 32	34 34	36 36	38 38
0x0000050	40 40	42 42	44 44	46 46	48 48	50 50	52 52	54 54
0x0000070	56 56	58 58	60 60	62 62	32 32	36 36	34 34	38 38
0x0000090	40 40	44 44	42 42	46 46	48 48	52 52	50 50	54 54
0x00000b0	56 56	60 60	58 58	62 62	64 64	68 68	66 66	70 70
0x00000d0	72 72	76 76	74 74	78 78	01 01	05 05	03 03	07 07
0x00000f0	09 09	13 13	11 11	15 15	64 64	66 66	68 68	70 70
0x0000110	01 01	03 03	05 05	07 07	72 72	74 74	76 76	78 78
0x0000130	09 09	11 11	13 13	15 15	17 17	19 19	21 21	23 23
0x0000150	33 33	35 35	37 37	39 39	25 25	27 27	29 29	31 31
0x0000170	41 41	43 43	45 45	47 47	17 17	21 21	19 19	23 23
0x0000190	33 33	37 37	35 35	39 39	25 25	29 29	27 27	31 31
0x00001b0	41 41	45 45	43 43	47 47	49 49	53 53	51 51	55 55
0x00001d0	65 65	69 69	67 67	71 71	57 57	61 61	59 59	63 63
0x00001f0	73 73	77 77	75 75	00 00	49 49	51 51	57 57	59 59
0x0000210	53 53	55 55	61 61	63 63	65 65	67 67	73 73	75 75
0x0000230	69 69	71 71	77 77	00 00	02 02	04 04	10 10	12 12
0x0000250	06 06	08 08	14 14	16 16	18 18	20 20	26 26	28 28
0x0000270	22 22	24 24	30 30	32 32	02 02	06 06	10 10	14 14
0x0000290	04 04	08 08	12 12	16 16	18 18	22 22	26 26	30 30
0x00002b0	20 20	24 24	28 28	32 32	34 34	38 38	42 42	46 46
0x00002d0	36 36	40 40	44 44	48 48	50 50	54 54	58 58	62 62
0x00002f0	52 52	56 56	60 60	64 64	34 34	36 36	50 50	52 52
0x0000310	38 38	40 40	54 54	56 56	42 42	44 44	58 58	60 60
0x0000330	46 46	48 48	62 62	64 64	66 66	68 68	03 03	05 05
0x0000350	70 70	72 72	07 07	09 09	74 74	76 76	11 11	13 13
0x0000370	78 78	01 01	15 15	17 17	66 66	70 70	03 03	07 07
0x0000390	68 68	72 72	05 05	09 09	74 74	78 78	11 11	15 15
0x00003b0	76 76	01 01	13 13	17 17	19 19	23 23	35 35	39 39
0x00003d0	21 21	25 25	37 37	41 41	27 27	31 31	43 43	47 47
0x00003f0	29 29	33 33	45 45	49 49	19 19	21 21	23 23	25 25

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with channels 0 to 21 unused):

CLK start: 0x0000010

ULAP: 0x00000000

Used Channels:0x7ffffffffffffc00000

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	30 30	32 32	34 34	36 36	38 38	40 40	42 42	22 22
0x0000030	24 24	26 26	28 28	30 30	32 32	34 34	36 36	38 38
0x0000050	40 40	42 42	44 44	46 46	48 48	50 50	52 52	54 54
0x0000070	56 56	58 58	60 60	62 62	32 32	36 36	34 34	38 38
0x0000090	40 40	44 44	42 42	46 46	48 48	52 52	50 50	54 54
0x00000b0	56 56	60 60	58 58	62 62	64 64	68 68	66 66	70 70
0x00000d0	72 72	76 76	74 74	78 78	45 45	49 49	47 47	51 51
0x00000f0	53 53	57 57	55 55	59 59	64 64	66 66	68 68	70 70
0x0000110	45 45	47 47	49 49	51 51	72 72	74 74	76 76	78 78
0x0000130	53 53	55 55	57 57	59 59	61 61	63 63	65 65	23 23
0x0000150	33 33	35 35	37 37	39 39	25 25	27 27	29 29	31 31
0x0000170	41 41	43 43	45 45	47 47	61 61	65 65	63 63	23 23
0x0000190	33 33	37 37	35 35	39 39	25 25	29 29	27 27	31 31
0x00001b0	41 41	45 45	43 43	47 47	49 49	53 53	51 51	55 55
0x00001d0	65 65	69 69	67 67	71 71	57 57	61 61	59 59	63 63
0x00001f0	73 73	77 77	75 75	66 66	49 49	51 51	57 57	59 59
0x0000210	53 53	55 55	61 61	63 63	65 65	67 67	73 73	75 75
0x0000230	69 69	71 71	77 77	66 66	68 68	70 70	76 76	78 78
0x0000250	72 72	74 74	23 23	25 25	27 27	29 29	26 26	28 28
0x0000270	22 22	24 24	30 30	32 32	68 68	72 72	76 76	23 23
0x0000290	70 70	74 74	78 78	25 25	27 27	22 22	26 26	30 30
0x00002b0	29 29	24 24	28 28	32 32	34 34	38 38	42 42	46 46
0x00002d0	36 36	40 40	44 44	48 48	50 50	54 54	58 58	62 62
0x00002f0	52 52	56 56	60 60	64 64	34 34	36 36	50 50	52 52
0x0000310	38 38	40 40	54 54	56 56	42 42	44 44	58 58	60 60
0x0000330	46 46	48 48	62 62	64 64	66 66	68 68	34 34	36 36
0x0000350	70 70	72 72	38 38	40 40	74 74	76 76	42 42	44 44
0x0000370	78 78	32 32	46 46	48 48	66 66	70 70	34 34	38 38
0x0000390	68 68	72 72	36 36	40 40	74 74	78 78	42 42	46 46
0x00003b0	76 76	32 32	44 44	48 48	50 50	23 23	35 35	39 39
0x00003d0	52 52	25 25	37 37	41 41	27 27	31 31	43 43	47 47
0x00003f0	29 29	33 33	45 45	49 49	50 50	52 52	23 23	25 25

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with even channels used):

CLK start: 0x0000010

ULAP: 0x00000000

Used Channels:0x55555555555555555

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	08 08	10 10	12 12	14 14	16 16	18 18	20 20	22 22
0x0000030	24 24	26 26	28 28	30 30	32 32	34 34	36 36	38 38
0x0000050	40 40	42 42	44 44	46 46	48 48	50 50	52 52	54 54
0x0000070	56 56	58 58	60 60	62 62	32 32	36 36	34 34	38 38
0x0000090	40 40	44 44	42 42	46 46	48 48	52 52	50 50	54 54
0x00000b0	56 56	60 60	58 58	62 62	64 64	68 68	66 66	70 70
0x00000d0	72 72	76 76	74 74	78 78	00 00	04 04	02 02	06 06
0x00000f0	08 08	12 12	10 10	14 14	64 64	66 66	68 68	70 70
0x0000110	00 00	02 02	04 04	06 06	72 72	74 74	76 76	78 78
0x0000130	08 08	10 10	12 12	14 14	16 16	18 18	20 20	22 22
0x0000150	32 32	34 34	36 36	38 38	24 24	26 26	28 28	30 30
0x0000170	40 40	42 42	44 44	46 46	16 16	20 20	18 18	22 22
0x0000190	32 32	36 36	34 34	38 38	24 24	28 28	26 26	30 30
0x00001b0	40 40	44 44	42 42	46 46	48 48	52 52	50 50	54 54
0x00001d0	64 64	68 68	66 66	70 70	56 56	60 60	58 58	62 62
0x00001f0	72 72	76 76	74 74	00 00	48 48	50 50	56 56	58 58
0x0000210	52 52	54 54	60 60	62 62	64 64	66 66	72 72	74 74
0x0000230	68 68	70 70	76 76	00 00	02 02	04 04	10 10	12 12
0x0000250	06 06	08 08	14 14	16 16	18 18	20 20	26 26	28 28
0x0000270	22 22	24 24	30 30	32 32	02 02	06 06	10 10	14 14
0x0000290	04 04	08 08	12 12	16 16	18 18	22 22	26 26	30 30
0x00002b0	20 20	24 24	28 28	32 32	34 34	38 38	42 42	46 46
0x00002d0	36 36	40 40	44 44	48 48	50 50	54 54	58 58	62 62
0x00002f0	52 52	56 56	60 60	64 64	34 34	36 36	50 50	52 52
0x0000310	38 38	40 40	54 54	56 56	42 42	44 44	58 58	60 60
0x0000330	46 46	48 48	62 62	64 64	66 66	68 68	00 00	02 02
0x0000350	70 70	72 72	04 04	06 06	74 74	76 76	08 08	10 10
0x0000370	78 78	78 78	12 12	14 14	66 66	70 70	00 00	04 04
0x0000390	68 68	72 72	02 02	06 06	74 74	78 78	08 08	12 12
0x00003b0	76 76	78 78	10 10	14 14	16 16	20 20	32 32	36 36
0x00003d0	18 18	22 22	34 34	38 38	24 24	28 28	40 40	44 44
0x00003f0	26 26	30 30	42 42	46 46	16 16	18 18	20 20	22 22

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with odd channels used):

CLK start: 0x0000010

ULAP: 0x00000000

Used Channels:0x2aaaaaaaaaaaaaaaaaaa

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	09 09	11 11	13 13	15 15	17 17	19 19	21 21	23 23
0x0000030	25 25	27 27	29 29	31 31	33 33	35 35	37 37	39 39
0x0000050	41 41	43 43	45 45	47 47	49 49	51 51	53 53	55 55
0x0000070	57 57	59 59	61 61	63 63	33 33	37 37	35 35	39 39
0x0000090	41 41	45 45	43 43	47 47	49 49	53 53	51 51	55 55
0x00000b0	57 57	61 61	59 59	63 63	65 65	69 69	67 67	71 71
0x00000d0	73 73	77 77	75 75	01 01	01 01	05 05	03 03	07 07
0x00000f0	09 09	13 13	11 11	15 15	65 65	67 67	69 69	71 71
0x0000110	01 01	03 03	05 05	07 07	73 73	75 75	77 77	01 01
0x0000130	09 09	11 11	13 13	15 15	17 17	19 19	21 21	23 23
0x0000150	33 33	35 35	37 37	39 39	25 25	27 27	29 29	31 31
0x0000170	41 41	43 43	45 45	47 47	17 17	21 21	19 19	23 23
0x0000190	33 33	37 37	35 35	39 39	25 25	29 29	27 27	31 31
0x00001b0	41 41	45 45	43 43	47 47	49 49	53 53	51 51	55 55
0x00001d0	65 65	69 69	67 67	71 71	57 57	61 61	59 59	63 63
0x00001f0	73 73	77 77	75 75	03 03	49 49	51 51	57 57	59 59
0x0000210	53 53	55 55	61 61	63 63	65 65	67 67	73 73	75 75
0x0000230	69 69	71 71	77 77	03 03	05 05	07 07	13 13	15 15
0x0000250	09 09	11 11	17 17	19 19	21 21	23 23	29 29	31 31
0x0000270	25 25	27 27	33 33	35 35	05 05	09 09	13 13	17 17
0x0000290	07 07	11 11	15 15	19 19	21 21	25 25	29 29	33 33
0x00002b0	23 23	27 27	31 31	35 35	37 37	41 41	45 45	49 49
0x00002d0	39 39	43 43	47 47	51 51	53 53	57 57	61 61	65 65
0x00002f0	55 55	59 59	63 63	67 67	37 37	39 39	53 53	55 55
0x0000310	41 41	43 43	57 57	59 59	45 45	47 47	61 61	63 63
0x0000330	49 49	51 51	65 65	67 67	69 69	71 71	03 03	05 05
0x0000350	73 73	75 75	07 07	09 09	77 77	01 01	11 11	13 13
0x0000370	03 03	01 01	15 15	17 17	69 69	73 73	03 03	07 07
0x0000390	71 71	75 75	05 05	09 09	77 77	03 03	11 11	15 15
0x00003b0	01 01	01 01	13 13	17 17	19 19	23 23	35 35	39 39
0x00003d0	21 21	25 25	37 37	41 41	27 27	31 31	43 43	47 47
0x00003f0	29 29	33 33	45 45	49 49	19 19	21 21	23 23	25 25

Sample Data

2.2 SECOND SET

```
Hop sequence {k} for PAGE SCAN/INQUIRY SCAN SUBSTATE:
CLKN start:      0x0000000
ULAP:            0x2a96ef25
#ticks:          0000 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 |
                 -----------------------------------------------------
0x0000000:         49 |   13 |   17 |   51 |   55 |   19 |   23 |   53 |
0x0008000:         57 |   21 |   25 |   27 |   31 |   74 |   78 |   29 |
0x0010000:         33 |   76 |    1 |   35 |   39 |    3 |    7 |   37 |
0x0018000:         41 |    5 |    9 |   43 |   47 |   11 |   15 |   45 |
0x0020000:         49 |   13 |   17 |   51 |   55 |   19 |   23 |   53 |
0x0028000:         57 |   21 |   25 |   27 |   31 |   74 |   78 |   29 |
0x0030000:         33 |   76 |    1 |   35 |   39 |    3 |    7 |   37 |
0x0038000:         41 |    5 |    9 |   43 |   47 |   11 |   15 |   45 |

Hop sequence {k} for PAGE STATE/INQUIRY SUBSTATE:
CLKE start:      0x0000000
ULAP:            0x2a96ef25
#ticks:          00 01 02 03 | 04 05 06 07 | 08 09 0a 0b | 0c 0d 0e 0f |
                 -----------------------------------------------------
0x0000000:       41 05 10 04 | 09 43 06 16 | 47 11 18 12 | 15 45 14 32 |
0x0000010:       49 13 34 28 | 17 51 30 24 | 55 19 26 20 | 23 53 22 40 |
0x0000020:       41 05 10 04 | 09 43 06 16 | 47 11 18 12 | 15 45 14 32 |
0x0000030:       49 13 34 28 | 17 51 30 24 | 55 19 26 20 | 23 53 22 40 |
...
0x0001000:       41 21 10 36 | 25 27 38 63 | 31 74 65 59 | 78 29 61 00 |
0x0001010:       33 76 02 75 | 01 35 77 71 | 39 03 73 67 | 07 37 69 08 |
0x0001020:       41 21 10 36 | 25 27 38 63 | 31 74 65 59 | 78 29 61 00 |
0x0001030:       33 76 02 75 | 01 35 77 71 | 39 03 73 67 | 07 37 69 08 |
...
0x0002000:       57 21 42 36 | 09 43 06 16 | 47 11 18 12 | 15 45 14 32 |
0x0002010:       49 13 34 28 | 17 51 30 24 | 55 19 26 20 | 23 53 22 40 |
0x0002020:       57 21 42 36 | 09 43 06 16 | 47 11 18 12 | 15 45 14 32 |
0x0002030:       49 13 34 28 | 17 51 30 24 | 55 19 26 20 | 23 53 22 40 |
...
0x0003000:       41 05 10 04 | 09 27 06 63 | 31 74 65 59 | 78 29 61 00 |
0x0003010:       33 76 02 75 | 01 35 77 71 | 39 03 73 67 | 07 37 69 08 |
0x0003020:       41 05 10 04 | 09 27 06 63 | 31 74 65 59 | 78 29 61 00 |
0x0003030:       33 76 02 75 | 01 35 77 71 | 39 03 73 67 | 07 37 69 08 |

Hop sequence {k} for SLAVE PAGE RESPONSE SUBSTATE:
CLKN* =          0x0000010
ULAP:            0x2a96ef25
#ticks:          00 | 02 04 | 06 08 | 0a 0c | 0e 10 | 12 14 | 16 18 | 1a
                 -----------------------------------------------------
0x0000012:       34 | 13 28 | 17 30 | 51 24 | 55 26 | 19 20 | 23 22 | 53
0x0000032:       42 | 21 36 | 25 38 | 27 63 | 31 65 | 74 59 | 78 61 | 29
0x0000052:       02 | 76 75 | 01 77 | 35 71 | 39 73 | 03 67 | 07 69 | 37
0x0000072:       10 | 05 04 | 09 06 | 43 16 | 47 18 | 11 12 | 15 14 | 45

Hop sequence {k} for MASTER PAGE RESPONSE SUBSTATE:
Offset value:    24
CLKE* =          0x0000012
ULAP:            0x2a96ef25
#ticks:          00 02 | 04 06 | 08 0a | 0c 0e | 10 12 | 14 16 | 18 1a |
                 -----------------------------------------------------
0x0000014:       13 28 | 17 30 | 51 24 | 55 26 | 19 20 | 23 22 | 53 40 |
0x0000034:       21 36 | 25 38 | 27 63 | 31 65 | 74 59 | 78 61 | 29 00 |
0x0000054:       76 75 | 01 77 | 35 71 | 39 73 | 03 67 | 07 69 | 37 08 |
0x0000074:       05 04 | 09 06 | 43 16 | 47 18 | 11 12 | 15 14 | 45 32 |
```

Sample Data

Hop sequence {k} for CONNECTION STATE (Basic channel hopping sequence; ie, non-AFH):
CLK start: 0x0000010
ULAP: 0x2a96ef25

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010:	55 26	19 20	23 22	53 40	57 42	21 36	25 38	27 63
0x0000030:	31 65	74 59	78 61	29 00	33 02	76 75	01 77	35 71
0x0000050:	39 73	03 67	07 69	37 08	41 10	05 04	09 06	43 16
0x0000070:	47 18	11 12	15 14	45 32	02 66	47 60	49 64	04 54
0x0000090:	06 58	51 52	53 56	08 70	10 74	55 68	57 72	59 14
0x00000b0:	61 18	27 12	29 16	63 30	65 34	31 28	33 32	67 22
0x00000d0:	69 26	35 20	37 24	71 38	73 42	39 36	41 40	75 46
0x00000f0:	77 50	43 44	45 48	00 62	26 11	69 05	73 07	36 17
0x0000110:	40 19	04 13	08 15	38 25	42 27	06 21	10 23	12 48
0x0000130:	16 50	59 44	63 46	14 56	18 58	61 52	65 54	28 64
0x0000150:	32 66	75 60	00 62	30 72	34 74	77 68	02 70	20 01
0x0000170:	24 03	67 76	71 78	22 09	58 43	24 37	26 41	68 47
0x0000190:	70 51	36 45	38 49	72 55	74 59	40 53	42 57	44 78
0x00001b0:	46 03	12 76	14 01	48 07	50 11	16 05	18 09	60 15
0x00001d0:	62 19	28 13	30 17	64 23	66 27	32 21	34 25	52 31
0x00001f0:	54 35	20 29	22 33	56 39	19 04	62 63	66 00	07 73
0x0000210:	11 10	54 69	58 06	23 75	27 12	70 71	74 08	76 33
0x0000230:	01 49	44 29	48 45	13 35	17 51	60 31	64 47	05 41
0x0000250:	09 57	52 37	56 53	21 43	25 59	68 39	72 55	78 65
0x0000270:	03 02	46 61	50 77	15 67	51 36	17 18	19 34	41 24
0x0000290:	43 40	09 22	11 38	57 28	59 44	25 26	27 42	29 63
0x00002b0:	31 00	76 61	78 77	45 67	47 04	13 65	15 02	37 71
0x00002d0:	39 08	05 69	07 06	53 75	55 12	21 73	23 10	33 16
0x00002f0:	35 32	01 14	03 30	49 20	75 60	39 48	43 56	00 66
0x0000310:	04 74	47 62	51 70	08 68	12 76	55 64	59 72	61 18
0x0000330:	65 26	29 14	33 22	69 20	73 28	37 16	41 24	77 34
0x0000350:	02 42	45 30	49 38	06 36	10 44	53 32	57 40	63 50
0x0000370:	67 58	31 46	35 54	71 52	28 13	73 03	75 11	34 17
0x0000390:	36 25	02 15	04 23	42 21	44 29	10 19	12 27	14 48
0x00003b0:	16 56	61 46	63 54	22 52	24 60	69 50	71 58	30 64
0x00003d0:	32 72	77 62	00 70	38 68	40 76	06 66	08 74	18 01
0x00003f0:	20 09	65 78	67 07	26 05	44 29	32 23	36 25	70 43

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with all channel used; ie, AFH(79)):

CLK start: 0x0000010

ULAP: 0x2a96ef25

Used Channels:0x7fffffffffffffffffff

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	55 55	19 19	23 23	53 53	57 57	21 21	25 25	27 27
0x0000030	31 31	74 74	78 78	29 29	33 33	76 76	01 01	35 35
0x0000050	39 39	03 03	07 07	37 37	41 41	05 05	09 09	43 43
0x0000070	47 47	11 11	15 15	45 45	02 02	47 47	49 49	04 04
0x0000090	06 06	51 51	53 53	08 08	10 10	55 55	57 57	59 59
0x00000b0	61 61	27 27	29 29	63 63	65 65	31 31	33 33	67 67
0x00000d0	69 69	35 35	37 37	71 71	73 73	39 39	41 41	75 75
0x00000f0	77 77	43 43	45 45	00 00	26 26	69 69	73 73	36 36
0x0000110	40 40	04 04	08 08	38 38	42 42	06 06	10 10	12 12
0x0000130	16 16	59 59	63 63	14 14	18 18	61 61	65 65	28 28
0x0000150	32 32	75 75	00 00	30 30	34 34	77 77	02 02	20 20
0x0000170	24 24	67 67	71 71	22 22	58 58	24 24	26 26	68 68
0x0000190	70 70	36 36	38 38	72 72	74 74	40 40	42 42	44 44
0x00001b0	46 46	12 12	14 14	48 48	50 50	16 16	18 18	60 60
0x00001d0	62 62	28 28	30 30	64 64	66 66	32 32	34 34	52 52
0x00001f0	54 54	20 20	22 22	56 56	19 19	62 62	66 66	07 07
0x0000210	11 11	54 54	58 58	23 23	27 27	70 70	74 74	76 76
0x0000230	01 01	44 44	48 48	13 13	17 17	60 60	64 64	05 05
0x0000250	09 09	52 52	56 56	21 21	25 25	68 68	72 72	78 78
0x0000270	03 03	46 46	50 50	15 15	51 51	17 17	19 19	41 41
0x0000290	43 43	09 09	11 11	57 57	59 59	25 25	27 27	29 29
0x00002b0	31 31	76 76	78 78	45 45	47 47	13 13	15 15	37 37
0x00002d0	39 39	05 05	07 07	53 53	55 55	21 21	23 23	33 33
0x00002f0	35 35	01 01	03 03	49 49	75 75	39 39	43 43	00 00
0x0000310	04 04	47 47	51 51	08 08	12 12	55 55	59 59	61 61
0x0000330	65 65	29 29	33 33	69 69	73 73	37 37	41 41	77 77
0x0000350	02 02	45 45	49 49	06 06	10 10	53 53	57 57	63 63
0x0000370	67 67	31 31	35 35	71 71	28 28	73 73	75 75	34 34
0x0000390	36 36	02 02	04 04	42 42	44 44	10 10	12 12	14 14
0x00003b0	16 16	61 61	63 63	22 22	24 24	69 69	71 71	30 30
0x00003d0	32 32	77 77	00 00	38 38	40 40	06 06	08 08	18 18
0x00003f0	20 20	65 65	67 67	26 26	44 44	32 32	36 36	70 70

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with channels 0 to 21 unused):

CLK start: 0x0000010

ULAP: 0x2a96ef25

Used Channels:0x7fffffffffffc00000

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	55 55	50 50	23 23	53 53	57 57	52 52	25 25	27 27
0x0000030	31 31	74 74	78 78	29 29	33 33	76 76	32 32	35 35
0x0000050	39 39	34 34	38 38	37 37	41 41	36 36	40 40	43 43
0x0000070	47 47	42 42	46 46	45 45	55 55	47 47	49 49	57 57
0x0000090	59 59	51 51	53 53	61 61	63 63	55 55	57 57	59 59
0x00000b0	61 61	27 27	29 29	63 63	65 65	31 31	33 33	67 67
0x00000d0	69 69	35 35	37 37	71 71	73 73	39 39	41 41	75 75
0x00000f0	77 77	43 43	45 45	53 53	26 26	69 69	73 73	36 36
0x0000110	40 40	57 57	61 61	38 38	42 42	59 59	63 63	65 65
0x0000130	69 69	59 59	63 63	67 67	71 71	61 61	65 65	28 28
0x0000150	32 32	75 75	53 53	30 30	34 34	77 77	55 55	73 73
0x0000170	24 24	67 67	71 71	22 22	58 58	24 24	26 26	68 68
0x0000190	70 70	36 36	38 38	72 72	74 74	40 40	42 42	44 44
0x00001b0	46 46	65 65	67 67	48 48	50 50	69 69	71 71	60 60
0x00001d0	62 62	28 28	30 30	64 64	66 66	32 32	34 34	52 52
0x00001f0	54 54	73 73	22 22	56 56	37 37	62 62	66 66	25 25
0x0000210	29 29	54 54	58 58	23 23	27 27	70 70	74 74	76 76
0x0000230	76 76	44 44	48 48	31 31	35 35	60 60	64 64	23 23
0x0000250	27 27	52 52	56 56	39 39	25 25	68 68	72 72	78 78
0x0000270	78 78	46 46	50 50	33 33	51 51	35 35	37 37	41 41
0x0000290	43 43	27 27	29 29	57 57	59 59	25 25	27 27	29 29
0x00002b0	31 31	76 76	78 78	45 45	47 47	31 31	33 33	37 37
0x00002d0	39 39	23 23	25 25	53 53	55 55	39 39	23 23	33 33
0x00002f0	35 35	76 76	78 78	49 49	75 75	39 39	43 43	40 40
0x0000310	44 44	47 47	51 51	48 48	52 52	55 55	59 59	61 61
0x0000330	65 65	29 29	33 33	69 69	73 73	37 37	41 41	77 77
0x0000350	42 42	45 45	49 49	46 46	50 50	53 53	57 57	63 63
0x0000370	67 67	31 31	35 35	71 71	28 28	73 73	75 75	34 34
0x0000390	36 36	42 42	44 44	42 42	44 44	50 50	52 52	54 54
0x00003b0	56 56	61 61	63 63	22 22	24 24	69 69	71 71	30 30
0x00003d0	32 32	77 77	40 40	38 38	40 40	46 46	48 48	58 58
0x00003f0	60 60	65 65	67 67	26 26	44 44	32 32	36 36	70 70

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with even channels used):

CLK start: 0x0000010

ULAP: 0x2a96ef25

Used Channels:0x55555555555555555

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	52 52	16 16	20 20	50 50	54 54	18 18	22 22	24 24
0x0000030	28 28	74 74	78 78	26 26	30 30	76 76	78 78	32 32
0x0000050	36 36	00 00	04 04	34 34	38 38	02 02	06 06	40 40
0x0000070	44 44	08 08	12 12	42 42	02 02	44 44	46 46	04 04
0x0000090	06 06	48 48	50 50	08 08	10 10	52 52	54 54	56 56
0x00000b0	58 58	24 24	26 26	60 60	62 62	28 28	30 30	64 64
0x00000d0	66 66	32 32	34 34	68 68	70 70	36 36	38 38	72 72
0x00000f0	74 74	40 40	42 42	00 00	26 26	66 66	70 70	36 36
0x0000110	40 40	04 04	08 08	38 38	42 42	06 06	10 10	12 12
0x0000130	16 16	56 56	60 60	14 14	18 18	58 58	62 62	28 28
0x0000150	32 32	72 72	00 00	30 30	34 34	74 74	02 02	20 20
0x0000170	24 24	64 64	68 68	22 22	58 58	24 24	26 26	68 68
0x0000190	70 70	36 36	38 38	72 72	74 74	40 40	42 42	44 44
0x00001b0	46 46	12 12	14 14	48 48	50 50	16 16	18 18	60 60
0x00001d0	62 62	28 28	30 30	64 64	66 66	32 32	34 34	52 52
0x00001f0	54 54	20 20	22 22	56 56	14 14	62 62	66 66	02 02
0x0000210	06 06	54 54	58 58	18 18	22 22	70 70	74 74	76 76
0x0000230	76 76	44 44	48 48	08 08	12 12	60 60	64 64	00 00
0x0000250	04 04	52 52	56 56	16 16	20 20	68 68	72 72	78 78
0x0000270	78 78	46 46	50 50	10 10	46 46	12 12	14 14	36 36
0x0000290	38 38	04 04	06 06	52 52	54 54	20 20	22 22	24 24
0x00002b0	26 26	76 76	78 78	40 40	42 42	08 08	10 10	32 32
0x00002d0	34 34	00 00	02 02	48 48	50 50	16 16	18 18	28 28
0x00002f0	30 30	76 76	78 78	44 44	70 70	34 34	38 38	00 00
0x0000310	04 04	42 42	46 46	08 08	12 12	50 50	54 54	56 56
0x0000330	60 60	24 24	28 28	64 64	68 68	32 32	36 36	72 72
0x0000350	02 02	40 40	44 44	06 06	10 10	48 48	52 52	58 58
0x0000370	62 62	26 26	30 30	66 66	28 28	68 68	70 70	34 34
0x0000390	36 36	02 02	04 04	42 42	44 44	10 10	12 12	14 14
0x00003b0	16 16	56 56	58 58	22 22	24 24	64 64	66 66	30 30
0x00003d0	32 32	72 72	00 00	38 38	40 40	06 06	08 08	18 18
0x00003f0	20 20	60 60	62 62	26 26	44 44	32 32	36 36	70 70

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with odd channels used):

CLK start: 0x0000010

ULAP: 0x2a96ef25

Used Channels:0x2aaaaaaaaaaaaaaaaaaa

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	55 55	19 19	23 23	53 53	57 57	21 21	25 25	27 27
0x0000030	31 31	77 77	03 03	29 29	33 33	01 01	01 01	35 35
0x0000050	39 39	03 03	07 07	37 37	41 41	05 05	09 09	43 43
0x0000070	47 47	11 11	15 15	45 45	07 07	47 47	49 49	09 09
0x0000090	11 11	51 51	53 53	13 13	15 15	55 55	57 57	59 59
0x00000b0	61 61	27 27	29 29	63 63	65 65	31 31	33 33	67 67
0x00000d0	69 69	35 35	37 37	71 71	73 73	39 39	41 41	75 75
0x00000f0	77 77	43 43	45 45	05 05	31 31	69 69	73 73	41 41
0x0000110	45 45	09 09	13 13	43 43	47 47	11 11	15 15	17 17
0x0000130	21 21	59 59	63 63	19 19	23 23	61 61	65 65	33 33
0x0000150	37 37	75 75	05 05	35 35	39 39	77 77	07 07	25 25
0x0000170	29 29	67 67	71 71	27 27	63 63	29 29	31 31	73 73
0x0000190	75 75	41 41	43 43	77 77	01 01	45 45	47 47	49 49
0x00001b0	51 51	17 17	19 19	53 53	55 55	21 21	23 23	65 65
0x00001d0	67 67	33 33	35 35	69 69	71 71	37 37	39 39	57 57
0x00001f0	59 59	25 25	27 27	61 61	19 19	67 67	71 71	07 07
0x0000210	11 11	59 59	63 63	23 23	27 27	75 75	01 01	03 03
0x0000230	01 01	49 49	53 53	13 13	17 17	65 65	69 69	05 05
0x0000250	09 09	57 57	61 61	21 21	25 25	73 73	77 77	05 05
0x0000270	03 03	51 51	55 55	15 15	51 51	17 17	19 19	41 41
0x0000290	43 43	09 09	11 11	57 57	59 59	25 25	27 27	29 29
0x00002b0	31 31	03 03	05 05	45 45	47 47	13 13	15 15	37 37
0x00002d0	39 39	05 05	07 07	53 53	55 55	21 21	23 23	33 33
0x00002f0	35 35	01 01	03 03	49 49	75 75	39 39	43 43	07 07
0x0000310	11 11	47 47	51 51	15 15	19 19	55 55	59 59	61 61
0x0000330	65 65	29 29	33 33	69 69	73 73	37 37	41 41	77 77
0x0000350	09 09	45 45	49 49	13 13	17 17	53 53	57 57	63 63
0x0000370	67 67	31 31	35 35	71 71	35 35	73 73	75 75	41 41
0x0000390	43 43	09 09	11 11	49 49	51 51	17 17	19 19	21 21
0x00003b0	23 23	61 61	63 63	29 29	31 31	69 69	71 71	37 37
0x00003d0	39 39	77 77	07 07	45 45	47 47	13 13	15 15	25 25
0x00003f0	27 27	65 65	67 67	33 33	51 51	39 39	43 43	77 77

Sample Data

2.3 THIRD SET

```
Hop sequence {k} for PAGE SCAN/INQUIRY SCAN SUBSTATE:
CLKN start:      0x0000000
ULAP:            0x6587cba9
#ticks:          0000 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 |
                 -------------------------------------------------------
0x0000000:         16 |   65 |   67 |   18 |   20 |   53 |   55 |    6 |
0x0008000:          8 |   57 |   59 |   10 |   12 |   69 |   71 |   22 |
0x0010000:         24 |   73 |   75 |   26 |   28 |   45 |   47 |   77 |
0x0018000:          0 |   49 |   51 |    2 |    4 |   61 |   63 |   14 |
0x0020000:         16 |   65 |   67 |   18 |   20 |   53 |   55 |    6 |
0x0028000:          8 |   57 |   59 |   10 |   12 |   69 |   71 |   22 |
0x0030000:         24 |   73 |   75 |   26 |   28 |   45 |   47 |   77 |
0x0038000:          0 |   49 |   51 |    2 |    4 |   61 |   63 |   14 |

Hop sequence {k} for PAGE STATE/INQUIRY SUBSTATE:
CLKE start:      0x0000000
ULAP:            0x6587cba9
#ticks:          00 01 02 03 | 04 05 06 07 | 08 09 0a 0b | 0c 0d 0e 0f |
                 -----------------------------------------------------
0x0000000:       00 49 36 38 | 51 02 42 40 | 04 61 44 46 | 63 14 50 48 |
0x0000010:       16 65 52 54 | 67 18 58 56 | 20 53 60 62 | 55 06 66 64 |
0x0000020:       00 49 36 38 | 51 02 42 40 | 04 61 44 46 | 63 14 50 48 |
0x0000030:       16 65 52 54 | 67 18 58 56 | 20 53 60 62 | 55 06 66 64 |
...
0x0001000:       00 57 36 70 | 59 10 74 72 | 12 69 76 78 | 71 22 03 01 |
0x0001010:       24 73 05 07 | 75 26 11 09 | 28 45 13 30 | 47 77 34 32 |
0x0001020:       00 57 36 70 | 59 10 74 72 | 12 69 76 78 | 71 22 03 01 |
0x0001030:       24 73 05 07 | 75 26 11 09 | 28 45 13 30 | 47 77 34 32 |
...
0x0002000:       08 57 68 70 | 51 02 42 40 | 04 61 44 46 | 63 14 50 48 |
0x0002010:       16 65 52 54 | 67 18 58 56 | 20 53 60 62 | 55 06 66 64 |
0x0002020:       08 57 68 70 | 51 02 42 40 | 04 61 44 46 | 63 14 50 48 |
0x0002030:       16 65 52 54 | 67 18 58 56 | 20 53 60 62 | 55 06 66 64 |
...
0x0003000:       00 49 36 38 | 51 10 42 72 | 12 69 76 78 | 71 22 03 01 |
0x0003010:       24 73 05 07 | 75 26 11 09 | 28 45 13 30 | 47 77 34 32 |
0x0003020:       00 49 36 38 | 51 10 42 72 | 12 69 76 78 | 71 22 03 01 |
0x0003030:       24 73 05 07 | 75 26 11 09 | 28 45 13 30 | 47 77 34 32 |

Hop sequence {k} for SLAVE PAGE RESPONSE SUBSTATE:
CLKN* =          0x0000010
ULAP:            0x6587cba9
#ticks:          00 | 02 04 | 06 08 | 0a 0c | 0e 10 | 12 14 | 16 18 | 1a 1c | 1e
                 ---------------------------------------------------------------
0x0000012:       52 | 65 54 | 67 58 | 18 56 | 20 60 | 53 62 | 55 66 | 06 64 | 08
0x0000032:       68 | 57 70 | 59 74 | 10 72 | 12 76 | 69 78 | 71 03 | 22 01 | 24
0x0000052:       05 | 73 07 | 75 11 | 26 09 | 28 13 | 45 30 | 47 34 | 77 32 | 00
0x0000072:       36 | 49 38 | 51 42 | 02 40 | 04 44 | 61 46 | 63 50 | 14 48 | 16

Hop sequence {k} for MASTER PAGE RESPONSE SUBSTATE:
Offset value:    24
CLKE* =          0x0000012
ULAP:            0x6587cba9
#ticks:          00 02 | 04 06 | 08 0a | 0c 0e | 10 12 | 14 16 | 18 1a | 1c 1e |
                 -----------------------------------------------------------------
0x0000014:       65 54 | 67 58 | 18 56 | 20 60 | 53 62 | 55 66 | 06 64 | 08 68 |
0x0000034:       57 70 | 59 74 | 10 72 | 12 76 | 69 78 | 71 03 | 22 01 | 24 05 |
0x0000054:       73 07 | 75 11 | 26 09 | 28 13 | 45 30 | 47 34 | 77 32 | 00 36 |
0x0000074:       49 38 | 51 42 | 02 40 | 04 44 | 61 46 | 63 50 | 14 48 | 16 52 |
```

Sample Data

Hop sequence {k} for CONNECTION STATE (Basic channel hopping sequence; ie, non-AFH):
CLK start: 0x0000010
ULAP: 0x6587cba9

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010:	20 60	53 62	55 66	06 64	08 68	57 70	59 74	10 72
0x0000030:	12 76	69 78	71 03	22 01	24 05	73 07	75 11	26 09
0x0000050:	28 13	45 30	47 34	77 32	00 36	49 38	51 42	02 40
0x0000070:	04 44	61 46	63 50	14 48	50 05	16 07	20 09	48 11
0x0000090:	52 13	06 15	10 17	38 19	42 21	08 23	12 25	40 27
0x00000b0:	44 29	22 31	26 33	54 35	58 37	24 39	28 41	56 43
0x00000d0:	60 45	77 62	02 64	30 66	34 68	00 70	04 72	32 74
0x00000f0:	36 76	14 78	18 01	46 03	72 29	42 39	44 43	74 41
0x0000110:	76 45	46 47	48 51	78 49	01 53	50 63	52 67	03 65
0x0000130:	05 69	54 55	56 59	07 57	09 61	58 71	60 75	11 73
0x0000150:	13 77	30 15	32 19	62 17	64 21	34 31	36 35	66 33
0x0000170:	68 37	38 23	40 27	70 25	27 61	72 71	76 73	25 75
0x0000190:	29 77	78 00	03 02	31 04	35 06	01 16	05 18	33 20
0x00001b0:	37 22	07 08	11 10	39 12	43 14	09 24	13 26	41 28
0x00001d0:	45 30	62 47	66 49	15 51	19 53	64 63	68 65	17 67
0x00001f0:	21 69	70 55	74 57	23 59	53 22	35 12	37 28	67 14
0x0000210:	69 30	23 32	25 48	55 34	57 50	39 40	41 56	71 42
0x0000230:	73 58	27 36	29 52	59 38	61 54	43 44	45 60	75 46
0x0000250:	77 62	15 00	17 16	47 02	49 18	31 08	33 24	63 10
0x0000270:	65 26	19 04	21 20	51 06	06 54	65 42	69 58	18 46
0x0000290:	22 62	55 64	59 01	08 68	12 05	71 72	75 09	24 76
0x00002b0:	28 13	57 66	61 03	10 70	14 07	73 74	77 11	26 78
0x00002d0:	30 15	47 32	51 48	00 36	04 52	63 40	67 56	16 44
0x00002f0:	20 60	49 34	53 50	02 38	38 78	12 05	14 13	44 07
0x0000310:	46 15	16 17	18 25	48 19	50 27	24 33	26 41	56 35
0x0000330:	58 43	20 21	22 29	52 23	54 31	28 37	30 45	60 39
0x0000350:	62 47	00 64	02 72	32 66	34 74	08 01	10 09	40 03
0x0000370:	42 11	04 68	06 76	36 70	70 31	42 35	46 43	74 39
0x0000390:	78 47	48 49	52 57	01 53	05 61	56 65	60 73	09 69
0x00003b0:	13 77	50 51	54 59	03 55	07 63	58 67	62 75	11 71
0x00003d0:	15 00	32 17	36 25	64 21	68 29	40 33	44 41	72 37
0x00003f0:	76 45	34 19	38 27	66 23	11 71	05 18	07 22	13 20

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with all channel used; ie, AFH(79)):

CLK start: 0x0000010

ULAP: 0x6587cba9

Used Channels:0x7fffffffffffffffffff

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	20 20	53 53	55 55	06 06	08 08	57 57	59 59	10 10
0x0000030	12 12	69 69	71 71	22 22	24 24	73 73	75 75	26 26
0x0000050	28 28	45 45	47 47	77 77	00 00	49 49	51 51	02 02
0x0000070	04 04	61 61	63 63	14 14	50 50	16 16	20 20	48 48
0x0000090	52 52	06 06	10 10	38 38	42 42	08 08	12 12	40 40
0x00000b0	44 44	22 22	26 26	54 54	58 58	24 24	28 28	56 56
0x00000d0	60 60	77 77	02 02	30 30	34 34	00 00	04 04	32 32
0x00000f0	36 36	14 14	18 18	46 46	72 72	42 42	44 44	74 74
0x0000110	76 76	46 46	48 48	78 78	01 01	50 50	52 52	03 03
0x0000130	05 05	54 54	56 56	07 07	09 09	58 58	60 60	11 11
0x0000150	13 13	30 30	32 32	62 62	64 64	34 34	36 36	66 66
0x0000170	68 68	38 38	40 40	70 70	27 27	72 72	76 76	25 25
0x0000190	29 29	78 78	03 03	31 31	35 35	01 01	05 05	33 33
0x00001b0	37 37	07 07	11 11	39 39	43 43	09 09	13 13	41 41
0x00001d0	45 45	62 62	66 66	15 15	19 19	64 64	68 68	17 17
0x00001f0	21 21	70 70	74 74	23 23	53 53	35 35	37 37	67 67
0x0000210	69 69	23 23	25 25	55 55	57 57	39 39	41 41	71 71
0x0000230	73 73	27 27	29 29	59 59	61 61	43 43	45 45	75 75
0x0000250	77 77	15 15	17 17	47 47	49 49	31 31	33 33	63 63
0x0000270	65 65	19 19	21 21	51 51	06 06	65 65	69 69	18 18
0x0000290	22 22	55 55	59 59	08 08	12 12	71 71	75 75	24 24
0x00002b0	28 28	57 57	61 61	10 10	14 14	73 73	77 77	26 26
0x00002d0	30 30	47 47	51 51	00 00	04 04	63 63	67 67	16 16
0x00002f0	20 20	49 49	53 53	02 02	38 38	12 12	14 14	44 44
0x0000310	46 46	16 16	18 18	48 48	50 50	24 24	26 26	56 56
0x0000330	58 58	20 20	22 22	52 52	54 54	28 28	30 30	60 60
0x0000350	62 62	00 00	02 02	32 32	34 34	08 08	10 10	40 40
0x0000370	42 42	04 04	06 06	36 36	70 70	42 42	46 46	74 74
0x0000390	78 78	48 48	52 52	01 01	05 05	56 56	60 60	09 09
0x00003b0	13 13	50 50	54 54	03 03	07 07	58 58	62 62	11 11
0x00003d0	15 15	32 32	36 36	64 64	68 68	40 40	44 44	72 72
0x00003f0	76 76	34 34	38 38	66 66	11 11	05 05	07 07	13 13

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with channels 0 to 21 unused):

CLK start: 0x0000010

ULAP: 0x6587cba9

Used Channels:0x7ffffffffffffc00000

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	29 29	53 53	55 55	72 72	74 74	57 57	59 59	76 76
0x0000030	78 78	69 69	71 71	22 22	24 24	73 73	75 75	26 26
0x0000050	28 28	45 45	47 47	77 77	66 66	49 49	51 51	68 68
0x0000070	70 70	61 61	63 63	23 23	50 50	25 25	29 29	48 48
0x0000090	52 52	72 72	76 76	38 38	42 42	74 74	78 78	40 40
0x00000b0	44 44	22 22	26 26	54 54	58 58	24 24	28 28	56 56
0x00000d0	60 60	77 77	68 68	30 30	34 34	66 66	70 70	32 32
0x00000f0	36 36	23 23	27 27	46 46	72 72	42 42	44 44	74 74
0x0000110	76 76	46 46	48 48	78 78	32 32	50 50	52 52	34 34
0x0000130	36 36	54 54	56 56	38 38	40 40	58 58	60 60	42 42
0x0000150	44 44	30 30	32 32	62 62	64 64	34 34	36 36	66 66
0x0000170	68 68	38 38	40 40	70 70	27 27	72 72	76 76	25 25
0x0000190	29 29	78 78	34 34	31 31	35 35	32 32	36 36	33 33
0x00001b0	37 37	38 38	42 42	39 39	43 43	40 40	44 44	41 41
0x00001d0	45 45	62 62	66 66	46 46	50 50	64 64	68 68	48 48
0x00001f0	52 52	70 70	74 74	23 23	53 53	35 35	37 37	67 67
0x0000210	69 69	23 23	25 25	55 55	57 57	39 39	41 41	71 71
0x0000230	73 73	27 27	29 29	59 59	61 61	43 43	45 45	75 75
0x0000250	77 77	46 46	48 48	47 47	49 49	31 31	33 33	63 63
0x0000270	65 65	50 50	52 52	51 51	59 59	65 65	69 69	71 71
0x0000290	22 22	55 55	59 59	61 61	65 65	71 71	75 75	24 24
0x00002b0	28 28	57 57	61 61	63 63	67 67	73 73	77 77	26 26
0x00002d0	30 30	47 47	51 51	53 53	57 57	63 63	67 67	69 69
0x00002f0	73 73	49 49	53 53	55 55	38 38	65 65	67 67	44 44
0x0000310	46 46	69 69	71 71	48 48	50 50	24 24	26 26	56 56
0x0000330	58 58	73 73	22 22	52 52	54 54	28 28	30 30	60 60
0x0000350	62 62	53 53	55 55	32 32	34 34	61 61	63 63	40 40
0x0000370	42 42	57 57	59 59	36 36	70 70	42 42	46 46	74 74
0x0000390	78 78	48 48	52 52	76 76	23 23	56 56	60 60	27 27
0x00003b0	31 31	50 50	54 54	78 78	25 25	58 58	62 62	29 29
0x00003d0	33 33	32 32	36 36	64 64	68 68	40 40	44 44	72 72
0x00003f0	76 76	34 34	38 38	66 66	29 29	23 23	25 25	31 31

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with even channels used):

CLK start: 0x0000010

ULAP: 0x6587cba9

Used Channels:0x55555555555555555555

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	20 20	52 52	54 54	06 06	08 08	56 56	58 58	10 10
0x0000030	12 12	68 68	70 70	22 22	24 24	72 72	74 74	26 26
0x0000050	28 28	44 44	46 46	76 76	00 00	48 48	50 50	02 02
0x0000070	04 04	60 60	62 62	14 14	50 50	16 16	20 20	48 48
0x0000090	52 52	06 06	10 10	38 38	42 42	08 08	12 12	40 40
0x00000b0	44 44	22 22	26 26	54 54	58 58	24 24	28 28	56 56
0x00000d0	60 60	76 76	02 02	30 30	34 34	00 00	04 04	32 32
0x00000f0	36 36	14 14	18 18	46 46	72 72	42 42	44 44	74 74
0x0000110	76 76	46 46	48 48	78 78	78 78	50 50	52 52	00 00
0x0000130	02 02	54 54	56 56	04 04	06 06	58 58	60 60	08 08
0x0000150	10 10	30 30	32 32	62 62	64 64	34 34	36 36	66 66
0x0000170	68 68	38 38	40 40	70 70	24 24	72 72	76 76	22 22
0x0000190	26 26	78 78	00 00	28 28	32 32	78 78	02 02	30 30
0x00001b0	34 34	04 04	08 08	36 36	40 40	06 06	10 10	38 38
0x00001d0	42 42	62 62	66 66	12 12	16 16	64 64	68 68	14 14
0x00001f0	18 18	70 70	74 74	20 20	50 50	32 32	34 34	64 64
0x0000210	66 66	20 20	22 22	52 52	54 54	36 36	38 38	68 68
0x0000230	70 70	24 24	26 26	56 56	58 58	40 40	42 42	72 72
0x0000250	74 74	12 12	14 14	44 44	46 46	28 28	30 30	60 60
0x0000270	62 62	16 16	18 18	48 48	06 06	62 62	66 66	18 18
0x0000290	22 22	52 52	56 56	08 08	12 12	68 68	72 72	24 24
0x00002b0	28 28	54 54	58 58	10 10	14 14	70 70	74 74	26 26
0x00002d0	30 30	44 44	48 48	00 00	04 04	60 60	64 64	16 16
0x00002f0	20 20	46 46	50 50	02 02	38 38	12 12	14 14	44 44
0x0000310	46 46	16 16	18 18	48 48	50 50	24 24	26 26	56 56
0x0000330	58 58	20 20	22 22	52 52	54 54	28 28	30 30	60 60
0x0000350	62 62	00 00	02 02	32 32	34 34	08 08	10 10	40 40
0x0000370	42 42	04 04	06 06	36 36	70 70	42 42	46 46	74 74
0x0000390	78 78	48 48	52 52	76 76	00 00	56 56	60 60	04 04
0x00003b0	08 08	50 50	54 54	78 78	02 02	58 58	62 62	06 06
0x00003d0	10 10	32 32	36 36	64 64	68 68	40 40	44 44	72 72
0x00003f0	76 76	34 34	38 38	66 66	06 06	00 00	02 02	08 08

Sample Data

Hop Sequence {k} for CONNECTION STATE (Adapted channel hopping sequence with odd channels used):

CLK start: 0x0000010

ULAP: 0x6587cba9

Used Channels:0x2aaaaaaaaaaaaaaaaaaa

#ticks:	00 02	04 06	08 0a	0c 0e	10 12	14 16	18 1a	1c 1e
0x0000010	23 23	53 53	55 55	09 09	11 11	57 57	59 59	13 13
0x0000030	15 15	69 69	71 71	25 25	27 27	73 73	75 75	29 29
0x0000050	31 31	45 45	47 47	77 77	03 03	49 49	51 51	05 05
0x0000070	07 07	61 61	63 63	17 17	53 53	19 19	23 23	51 51
0x0000090	55 55	09 09	13 13	41 41	45 45	11 11	15 15	43 43
0x00000b0	47 47	25 25	29 29	57 57	61 61	27 27	31 31	59 59
0x00000d0	63 63	77 77	05 05	33 33	37 37	03 03	07 07	35 35
0x00000f0	39 39	17 17	21 21	49 49	75 75	45 45	47 47	77 77
0x0000110	01 01	49 49	51 51	03 03	01 01	53 53	55 55	03 03
0x0000130	05 05	57 57	59 59	07 07	09 09	61 61	63 63	11 11
0x0000150	13 13	33 33	35 35	65 65	67 67	37 37	39 39	69 69
0x0000170	71 71	41 41	43 43	73 73	27 27	75 75	01 01	25 25
0x0000190	29 29	03 03	03 03	31 31	35 35	01 01	05 05	33 33
0x00001b0	37 37	07 07	11 11	39 39	43 43	09 09	13 13	41 41
0x00001d0	45 45	65 65	69 69	15 15	19 19	67 67	71 71	17 17
0x00001f0	21 21	73 73	77 77	23 23	53 53	35 35	37 37	67 67
0x0000210	69 69	23 23	25 25	55 55	57 57	39 39	41 41	71 71
0x0000230	73 73	27 27	29 29	59 59	61 61	43 43	45 45	75 75
0x0000250	77 77	15 15	17 17	47 47	49 49	31 31	33 33	63 63
0x0000270	65 65	19 19	21 21	51 51	11 11	65 65	69 69	23 23
0x0000290	27 27	55 55	59 59	13 13	17 17	71 71	75 75	29 29
0x00002b0	33 33	57 57	61 61	15 15	19 19	73 73	77 77	31 31
0x00002d0	35 35	47 47	51 51	05 05	09 09	63 63	67 67	21 21
0x00002f0	25 25	49 49	53 53	07 07	43 43	17 17	19 19	49 49
0x0000310	51 51	21 21	23 23	53 53	55 55	29 29	31 31	61 61
0x0000330	63 63	25 25	27 27	57 57	59 59	33 33	35 35	65 65
0x0000350	67 67	05 05	07 07	37 37	39 39	13 13	15 15	45 45
0x0000370	47 47	09 09	11 11	41 41	75 75	47 47	51 51	01 01
0x0000390	05 05	53 53	57 57	01 01	05 05	61 61	65 65	09 09
0x00003b0	13 13	55 55	59 59	03 03	07 07	63 63	67 67	11 11
0x00003d0	15 15	37 37	41 41	69 69	73 73	45 45	49 49	77 77
0x00003f0	03 03	39 39	43 43	71 71	11 11	05 05	07 07	13 13

3 ACCESS CODE SAMPLE DATA

Different access codes (GIAC, DIACs, others...)

LAP with LSB as rightmost bit.

```
                  Bit transmit order on air
               --------------------------------->
LAP:        | Preamble:| Sync word:      | Trailer: |
-------------------------------------------------
000000      |   5    | 7e7041e3 4000000d |    5     |
ffffff      |   a    | e758b522 7ffffff2 |    a     |
9e8b33      |   5    | 475c58cc 73345e72 |    a     |
9e8b34      |   5    | 28ed3c34 cb345e72 |    a     |
9e8b36      |   5    | 62337b64 1b345e72 |    a     |
9e8b39      |   a    | c05747b9 e7345e72 |    a     |
9e8b3d      |   5    | 7084eab0 2f345e72 |    a     |
9e8b42      |   5    | 64c86d2b 90b45e72 |    a     |
9e8b48      |   a    | e3c3725e 04b45e72 |    a     |
9e8b4f      |   a    | 8c7216a6 bcb45e72 |    a     |
9e8b57      |   a    | b2f16c30 fab45e72 |    a     |
9e8b60      |   5    | 57bd3b22 c1b45e72 |    a     |
9e8b6a      |   a    | d0b62457 55b45e72 |    a     |
9e8b75      |   a    | 81843a39 abb45e72 |    a     |
9e8b81      |   5    | 0ca96681 e0745e72 |    a     |
9e8b8e      |   a    | aecd5a5c 1c745e72 |    a     |
9e8b9c      |   5    | 17453fbf ce745e72 |    a     |
9e8bab      |   a    | f20968ad f5745e72 |    a     |
9e8bbb      |   5    | 015f4a1e f7745e72 |    a     |
9e8bcc      |   a    | d8c695a0 0cf45e72 |    a     |
9e8bde      |   5    | 614ef043 def45e72 |    a     |
9e8bf1      |   a    | ba81ddc7 a3f45e72 |    a     |
9e8c05      |   5    | 64a7dc4f 680c5e72 |    a     |
9e8c1a      |   5    | 3595c221 960c5e72 |    a     |
9e8c30      |   a    | cb35cc0d 830c5e72 |    a     |
9e8c47      |   5    | 12ac13b3 788c5e72 |    a     |
9e8c5f      |   5    | 2c2f6925 3e8c5e72 |    a     |
9e8c78      |   5    | 3a351c84 078c5e72 |    a     |
9e8c92      |   5    | 7396d0f3 124c5e72 |    a     |
9e8cad      |   5    | 5b0fdfc4 6d4c5e72 |    a     |
9e8cc9      |   a    | aea2eb38 e4cc5e72 |    a     |
9e8ce6      |   5    | 756dc6bc 99cc5e72 |    a     |
9e8d04      |   5    | 214cf934 882c5e72 |    a     |
9e8d23      |   5    | 37568c95 b12c5e72 |    a     |
9e8d43      |   5    | 72281560 f0ac5e72 |    a     |
9e8d64      |   5    | 643260c1 c9ac5e72 |    a     |
9e8d86      |   a    | e044f493 986c5e72 |    a     |
9e8da9      |   5    | 3b8bd917 e56c5e72 |    a     |
9e8dcd      |   a    | ce26edeb 6cec5e72 |    a     |
9e8df2      |   a    | e6bfe2dc 13ec5e72 |    a     |
9e8e18      |   a    | 82dcde3d c61c5e72 |    a     |
9e8e3f      |   a    | 94c6ab9c ff1c5e72 |    a     |
```

Sample Data

9e8e67	a	969059a6 799c5e72	a
9e8e90	a	c4dfccef 425c5e72	a
9e8eba	5	3a7fc2c3 575c5e72	a
9e8ee5	5	57985401 69dc5e72	a
9e8f11	5	0ae2a363 623c5e72	a
9e8f3e	a	d12d8ee7 1f3c5e72	a
9e8f6c	5	547063a8 0dbc5e72	a
9e8f9b	5	063ff6e1 367c5e72	a
9e8fcb	a	c9bc5cfe f4fc5e72	a
9e8ffc	5	2cf00bec cffc5e72	a
9e902e	a	8ec5052f 5d025e72	a
9e9061	5	1074b15e 61825e72	a
9e9095	a	9d59ede6 2a425e72	a
9e90ca	a	f0be7b24 14c25e72	a
9e9100	5	10e10dd0 c0225e72	a
9e9137	a	f5ad5ac2 fb225e72	a
9e916f	a	f7fba8f8 7da25e72	a
9e91a8	5	2f490e5b c5625e72	a
9e91e2	a	94979982 91e25e72	a
9e921d	5	26cda478 2e125e72	a
9e9259	a	aacb81dd 26925e72	a
9e9296	a	bfac7f5b da525e72	a
9e92d4	a	c9a7b0a7 cad25e72	a
9e9313	a	c142bdde 32325e72	a
616cec	5	586a491f 0dcda18d	5
616ceb	5	37db2de7 b5cda18d	5
616ce9	5	7d056ab7 65cda18d	5
616ce6	a	df61566a 99cda18d	5
616ce2	5	6fb2fb63 51cda18d	5
616cdd	5	472bf454 2ecda18d	5
616cd7	a	c020eb21 bacda18d	5
616cd0	a	af918fd9 02cda18d	5
616cc8	a	9112f54f 44cda18d	5
616cbf	5	488b2af1 bf4da18d	5
616cb5	a	cf803584 2b4da18d	5
616caa	a	9eb22bea d54da18d	5
616c9e	a	a49cb509 9e4da18d	5
616c91	5	06f889d4 624da18d	5
616c83	a	bf70ec37 b04da18d	5
616c74	a	ed3f797e 8b8da18d	5
616c64	5	1e695bcd 898da18d	5
616c53	a	fb250cdf b28da18d	5
616c41	5	42ad693c 608da18d	5
616c2e	a	a5b7cc14 dd0da18d	5
616c1a	a	9f9952f7 960da18d	5
616c05	a	ceab4c99 680da18d	5
616bef	a	d403ddde fdf5a18d	5
616bd8	5	314f8acc c6f5a18d	5
616bc0	5	0fccf05a 80f5a18d	5
616ba7	5	25030d57 7975a18d	5
616b8d	a	dba3037b 6c75a18d	5
616b72	5	4439ce17 13b5a18d	5

Sample Data

616b56	a	8d417247 5ab5a18d	5
616b39	5	6a5bd76f e735a18d	5
616b1b	5	592e8166 b635a18d	5
616afc	5	28609d46 cfd5a18d	5
616adc	5	51cb8c1f 4ed5a18d	5
616abb	5	7b047112 b755a18d	5
616a99	5	4871271b e655a18d	5
616a76	5	24bdc8c4 9b95a18d	5
616a52	a	edc57494 d295a18d	5
616a2d	a	f989f30f 6d15a18d	5
616a07	5	0729fd23 7815a18d	5
6169e0	a	8bf0ba4f 81e5a18d	5
6169b8	a	89a64875 0765a18d	5
61698f	5	6cea1f67 3c65a18d	5
616965	5	2549d310 29a5a18d	5
61693a	5	48ae45d2 1725a18d	5
61690e	5	7280db31 5c25a18d	5
6168e1	a	ce1b9f34 61c5a18d	5
6168b3	5	4b46727b 7345a18d	5
616884	a	ae0a2569 4845a18d	5
616854	a	ea5fc581 4a85a18d	5
616823	5	33c61a3f b105a18d	5
6167f1	a	c49fb8c5 63f9a18d	5
6167be	5	5a2e0cb4 5f79a18d	5
61678a	5	60009257 1479a18d	5
616755	a	86314e62 eab9a18d	5
61671f	5	3defd9bb be39a18d	5
6166e8	a	bff7e728 c5d9a18d	5
6166b0	a	bda11512 4359a18d	5
616677	5	6513b3b1 fb99a18d	5
61663d	a	decd2468 af19a18d	5
616602	a	f6542b5f d019a18d	5
6165c6	a	dc44b49b d8e9a18d	5
616589	5	42f500ea e469a18d	5
61654b	a	bf2885e1 34a9a18d	5
61650c	a	ec4c69b5 4c29a18d	5

4 HEC AND PACKET HEADER SAMPLE DATA

This section contains examples of HECs computed for sample UAP and packet header contents (Data). The resulting 54 bit packet headers are shown in the rightmost column. Note that the UAP, Data and HEC values are in hexadecimal notation, while the header is in octal notation. The header is transmitted from left to right over the air.

UAP	Data	HEC	Header (octal)
00	123	e1	770007 007070 000777
47	123	06	770007 007007 700000
00	124	32	007007 007007 007700
47	124	d5	007007 007070 707077
00	125	5a	707007 007007 077070
47	125	bd	707007 007070 777707
00	126	e2	077007 007007 000777
47	126	05	077007 007070 700000
00	127	8a	777007 007007 070007
47	127	6d	777007 007070 770770
00	11b	9e	770770 007007 777007
47	11b	79	770770 007070 077770
00	11c	4d	007770 007070 770070
47	11c	aa	007770 007007 070707
00	11d	25	707770 007070 700700
47	11d	c2	707770 007007 000077
00	11e	9d	077770 007070 777007
47	11e	7a	077770 007007 077770
00	11f	f5	777770 007070 707777
47	11f	12	777770 007007 007000

5 CRC SAMPLE DATA

This section shows the CRC computed for a sample 10 byte payload and a UAP of 0x47.

Data:
-----

data[0] = 0x4e
data[1] = 0x01
data[2] = 0x02
data[3] = 0x03
data[4] = 0x04
data[5] = 0x05
data[6] = 0x06
data[7] = 0x07
data[8] = 0x08
data[9] = 0x09

UAP = 0x47

==> CRC = 6d d2

Codeword (hexadecimal notation):

4e 01 02 03 04 05 06 07 08 09 6d d2

NB: Over the air each byte in the codeword
    is sent with the LSB first.

6 COMPLETE SAMPLE PACKETS

6.1 EXAMPLE OF DH1 PACKET

```
Packet header: (MSB...LSB)
--------------------------
LT_ADDR = 011
TYPE = 0100 (DH1)
FLOW = 0
ARQN = 1
SEQN = 0

Payload: (MSB...LSB)
--------------------
payload length: 5 bytes
logical channel = 10 (UA/I, Start L2CAP message)
flow = 1
data byte 1 = 00000001
data byte 2 = 00000010
data byte 3 = 00000011
data byte 4 = 00000100
data byte 5 = 00000101

HEC and CRC initialization: (MSB...LSB)
---------------------------------------
uap = 01000111

NO WHITENING USED




AIR DATA (LSB...MSB)

Packet header (incl HEC):
-------------------------
111111000
000000111000
000111000
000111111000000000000000

Payload (incl payload header and CRC):
--------------------------------------------------------------
01110100
10000000
01000000
11000000
00100000
10100000
1110110000110110
```

6.2 EXAMPLE OF DM1 PACKET

```
Packet header: (MSB...LSB)
--------------------------
LT_ADDR = 011
TYPE = 0011 (DM1)
FLOW = 0
ARQN = 1
SEQN = 0

Payload: (MSB...LSB)
--------------------
payload length: 5 bytes
logical channel = 10 (UA/I, Start L2CAP message)
flow = 1
data byte 1 = 00000001
data byte 2 = 00000010
data byte 3 = 00000011
data byte 4 = 00000100
data byte 5 = 00000101

HEC and CRC initialization: (MSB...LSB)
---------------------------------------
uap = 01000111

NO WHITENING USED




AIR DATA (LSB...MSB)

Packet header (incl HEC):
-------------------------
111111000
111111000000
000111000
111000000111111111111000

Payload (incl payload header, FEC23, CRC and 6 padded zeros):
-------------------------------------------------------------
0111010010 11001
0000000100 01011
0000110000 11110
0000100000 00111
1010000011 01100
1011000011 00010
0110000000 10001
```

7 SIMPLE PAIRING SAMPLE DATA

This section provides sample data for the Simple Pairing cryptographic functions (f1, f2, f3, g and the ECDH calculations).

7.1 ELLIPTIC CURVE SAMPLE DATA

In each data set, the bytes are ordered from least significant on the right to most significant on the left.

7.1.1 P-192 Sample Data

7.1.1.1 P-192 Data Set 1

```
Private A:   07915f86918ddc27005df1d6cf0c142b625ed2eff4a518ff
Private B:   1e636ca790b50f68f15d8dbe86244e309211d635de00e16d
Public A(x): 15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
Public A(y): b09d42b81bc5bd009f79e4b59dbbaa857fca856fb9f7ea25
DHKey:       fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
```

7.1.1.2 P-192 Data Set 2

```
Private A:   52ec1ca6e0ec973c29065c3ca10be80057243002f09bb43e
Private B:   57231203533e9efe18cc622fd0e34c6a29c6e0fa3ab3bc53
Public A(x): 45571f027e0d690795d61560804da5de789a48f94ab4b07e
Public A(y): 0220016e8a6bce74b45ffec1e664aaa0273b7cbd907a8e2b
DHKey:       a20a34b5497332aa7a76ab135cc0c168333be309d463c0c0
```

7.1.1.3 P-192 Data Set 3

```
Private A:   00a0df08eaf51e6e7be519d67c6749ea3f4517cdd2e9e821
Private B:   2bf5e0d1699d50ca5025e8e2d9b13244b4d322a328be1821
Public A(x): 2ed35b430fa45f9d329186d754eeeb0495f0f653127f613d
Public A(y): 27e08db74e424395052ddae7e3d5a8fecb52a8039b735b73
DHKey:       3b3986ba70790762f282a12a6d3bcae7a2ca01e25b87724e
```

7.1.1.4 P-192 Data Set 4

```
Private A:   030a4af66e1a4d590a83e0284fca5cdf83292b84f4c71168
Private B:   12448b5c69ecd10c0471060f2bf86345c5e83c03d16bae2c
Public A(x): f24a6899218fa912e7e4a8ba9357cb8182958f9fa42c968c
Public A(y): 7c0b8a9ebe6ea92e968c3a65f9f1a9716fe826ad88c97032
DHKey:       4a78f83fba757c35f94abea43e92effdd2bc700723c61939
```

7.1.1.5 P-192 Data Set 5

```
Private A:   604df406c649cb460be16244589a40895c0db7367dc11a2f
```

Sample Data

```
Private B:   526c2327303cd505b9cf0c012471902bb9e842ce32b0addc
Public A(x): cbe3c629aceb41b73d475a79fbfe8c08cdc80ceec00ee7c9
Public A(y): f9f70f7ae42abda4f33af56f7f6aa383354e453fa1a2bd18
DHKey:       64d4fe35567e6ea0ca31f947e1533a635436d4870ce88c45
```

7.1.1.6 P-192 Data Set 6

```
Private A:   1a2c582a09852979eb2cee18fb0befb9a55a6d06f6a8fad3
Private B:   243778916920d68df535955bc1a3cccd5811133a8205ae41
Public A(x): eca2d8d30bbef3ba8b7d591fdb98064a6c7b870cdcebe67c
Public A(y): 2e4163a44f3ae26e70dae86f1bf786e1a5db5562a8ed9fee
DHKey:       6433b36a7e9341940e78a63e31b3cf023282f7f1e3bf83bd
```

7.1.1.7 P-192 Data Set 7

```
Private A:   0f494dd08b493edb07228058a9f30797ff147a5a2adef9b3
Private B:   2da4cd46d9e06e81b1542503f2da89372e927877bececc1be
Public A(x): 9f56a8aa27346d66652a546abacc7d69c17fd66e0853989f
Public A(y): d7234c1464882250df7bbe67e0fa22aae475dc58af0c4210
DHKey:       c67beda9baf3c96a30616bf87a7d0ae704bc969e5cad354b
```

7.1.1.8 P-192 Data Set 8

```
Private A:   7381d2bc6ddecb65126564cb1af6ca1985d19fb57f0fff16
Private B:   18e276beff75adc3d520badb3806822e1c820f1064447848
Public A(x): 61c7f3c6f9e09f41423dce889de1973d346f2505a5a3b19b
Public A(y): 919972ff4cd6aed8a4821e3adc358b41f7be07ede20137df
DHKey:       6931496eef2fcfb03e0b1eef515dd4e1b0115b8b241b0b84
```

7.1.1.9 P-192 Data Set 9

```
Private A:   41c7b484ddc37ef6b7952c379f87593789dac6e4f3d8d8e6
Private B:   33e4eaa77f78216e0e99a9b200f81d2ca20dc74ad62d9b78
Public A(x): 9f09c773adb8e7b66b5d986cd15b143341a66d824113c15f
Public A(y): d2000a91738217ab8070a76c5f96c03de317dfab774f4837
DHKey:       a518f3826bb5fa3d5bc37da4217296d5b6af51e5445c6625
```

7.1.1.10 P-192 Data Set 10

```
Private A:   703cf5ee9c075f7726d0bb36d131c664f5534a6e6305d631
Private B:   757291c620a0e7e9dd13ce09ceb729c0ce1980e64d569b5f
Public A(x): fa2b96d382cf894aeeb0bd985f3891e655a6315cd5060d03
Public A(y): f7e8206d05c7255300cc56c88448158c497f2df596add7a2
DHKey:       12a3343bb453bb5408da42d20c2d0fcc18ff078f56d9c68c
```

7.1.2 P-256 Sample Data

7.1.2.1 P-256 Data Set 1

```
Private A:   3f49f6d4 a3c55f38 74c9b3e3 d2103f50 4aff607b eb40b799 5899b8a6 cd3c1abd
Private B:   55188b3d 32f6bb9a 900afcfb eed4e72a 59cb9ac2 f19d7cfb 6b4fdd49 f47fc5fd
Public A(x): 20b003d2 f297be2c 5e2c83a7 e9f9a5b9 eff49111 acf4fddb cc030148 0e359de6
Public A(y): dc809c49 652aeb6d 63329abf 5a52155c 766345c2 8fed3024 741c8ed0 1589d28b
Public B(x): 1ea1f0f0 1faf1d96 09592284 f19e4c00 47b58afd 8615a69f 559077b2 2faaa190
Public B(y): 4c55f33e 429dad37 7356703a 9ab85160 472d1130 e28e3676 5f89aff9 15b1214a
DHKey:       ec0234a3 57c8ad05 341010a6 0a397d9b 99796b13 b4f866f1 868d34f3 73bfa698
```

7.1.2.2 P-256 Data Set 2

```
Private A:   06a51669 3c9aa31a 6084545d 0c5db641 b48572b9 7203ddff b7ac73f7 d0457663
Private B:   529aa067 0d72cd64 97502ed4 73502b03 7e8803b5 c60829a5 a3caa219 505530ba
Public A(x): 2c31a47b 5779809e f44cb5ea af5c3e43 d5f8faad 4a8794cb 987e9b03 745c78dd
Public A(y): 91951218 3898dfbe cd52e240 8e43871f d0211091 17bd3ed4 eaf84377 43715d4f
Public B(x): f465e43f f23d3f1b 9dc7dfc0 4da87581 84dbc966 204796ec cf0d6cf5 e16500cc
Public B(y): 0201d048 bcbbd899 eeefc424 164e33c2 01c2b010 ca6b4d43 a8a155ca d8ecb279
DHKey:       ab85843a 2f6d883f 62e5684b 38e30733 5fe6e194 5ecd1960 4105c6f2 3221eb69
```

7.2 HASH FUNCTIONS SAMPLE DATA

In each data set, the bytes are ordered from least significant on the right to most significant on the left.

7.2.1 f1()

7.2.1.1 f1() with P-192 Inputs

```
Set 1a
U:       15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
V:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:       d5cb8454d177733effffb2ec712baeab
Z:       00
output:  1bdc955a9d542ffc9f9e670cdf665010

Set 1b
U:      15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
V:      356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:      d5cb8454d177733effffb2ec712baeab
Z:      80
output: 611325ebcb6e5269b868113306095fa6

Set 1c
U:      15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
V:      356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:      d5cb8454d177733effffb2ec712baeab
Z:      81
output: b68df39fd8a406b06a6c517d3666cf91

Set 2a (swapped U and V inputs compared with set 1)
U:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
V:       15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
X:       d5cb8454d177733effffb2ec712baeab
Z:       00
output:  f4e1ec4b88f305e81477627b1643a927

Set 2b (swapped U and V inputs compared with set 1)
U:      356b31938421fbbf2fb331c89fd588a69367e9a833f56812
V:      15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
X:      d5cb8454d177733effffb2ec712baeab
Z:      80
output: ac6aa7cfa96ae99dd3a74225adb068ae
```

Sample Data

```
Set 2c (swapped U and V inputs compared with set 1)
U:      356b31938421fbbf2fb331c89fd588a69367e9a833f56812
V:      15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
X:      d5cb8454d177733effffb2ec712baeab
Z:      81
output: 5ad4721258aa1fa06082edad980d0cc5

Set 3a (U and V set to same value as U in set 1)
U:       15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
V:       15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
X:       d5cb8454d177733effffb2ec712baeab
Z:       00
output:  49125fc1e8cdc615826c15e5d23ede41

Set 3b (U and V set to same value as V in set 1)
U:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
V:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:       d5cb8454d177733effffb2ec712baeab
Z:       80
output:  159f204c520565175c2b9c523acad2eb

Set 3c (U and V set to same value as V in set 1)
U:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
V:       356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:       d5cb8454d177733effffb2ec712baeab
Z:       81
output:  9a162ff9a8235e5b12539ba0ff9179da
```

7.2.1.2 f1() with P-256 Inputs

```
Set 1a
U: 20b003d2f297be2c5e2c83a7e9f9a5b9eff49111acf4fddbcc0301480e359de6
V: 55188b3d32f6bb9a900afcfbeed4e72a59cb9ac2f19d7cfb6b4fdd49f47fc5fd
X: d5cb8454d177733effffb2ec712baeab
Z: 00
output: D301CE92CC7B9E3F51D2924B8B33FACA

Set 1b
U: 20b003d2f297be2c5e2c83a7e9f9a5b9eff49111acf4fddbcc0301480e359de6
V: 55188b3d32f6bb9a900afcfbeed4e72a59cb9ac2f19d7cfb6b4fdd49f47fc5fd
X: d5cb8454d177733effffb2ec712baeab
Z: 80
output: 7E431112C10DE8A3984C8AC8149FF6EC
```

7.2.2 g()

7.2.2.1 g() with P-192 Inputs

```
Set 1
U:        15207009984421a6586f9fc3fe7e4329d2809ea51125f8ed
V:        356b31938421fbbf2fb331c89fd588a69367e9a833f56812
X:        d5cb8454d177733effffb2ec712baeab
Y:        a6e8e7cc25a75f6e216583f7ff3dc4cf
output:             52146a1e
output (decimal):   1377069598
6 digits (decimal): 069598
```

7.2.2.2 g() with P-256 Inputs

```
Set 1
U: 20b003d2f297be2c5e2c83a7e9f9a5b9eff49111acf4fddbcc0301480e359de6
V: 55188b3d32f6bb9a900afcfbeed4e72a59cb9ac2f19d7cfb6b4fdd49f47fc5fd
X: d5cb8454d177733effffb2ec712baeab
Y: a6e8e7cc25a75f6e216583f7ff3dc4cf
output: 000240E0
output (decimal): 147680
6 digits (decimal): 147680
```

7.2.3 f2()

7.2.3.1 f2() with P-192 Inputs

```
Set 1
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
keyID:  62746c6b
A1:     56123737bfce
A2:     a713702dcfc1
output: c234c1198f3b520186ab92a2f874934e
```

7.2.3.2 f2() with P-256 Inputs

```
Set 1
W: ec0234a357c8ad05341010a60a397d9b99796b13b4f866f1868d34f373bfa698
N1: d5cb8454d177733effffb2ec712baeab
N2: a6e8e7cc25a75f6e216583f7ff3dc4cf
keyID: 62746c6b
A1: 56123737bfce
A2: a713702dcfc1
output: 47300bb95c7404129450674b1741104d
```

7.2.4 f3()

7.2.4.1 f3() with P-192 Inputs

```
Set 1
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000000
A1:     56123737bfce
A2:     a713702dcfc1
output: 5e6a346b8add7ee80e7ec0c2461b1509

Set 2
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000001
A1:     56123737bfce
A2:     a713702dcfc1
output: 7840e5445a13e3ce6e48a2decbe51482

Set 3
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000002
A1:     56123737bfce
A2:     a713702dcfc1
output: da9afb5c6c9dbe0af4722b532520c4b3

Set 4
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000003
A1:     56123737bfce
A2:     a713702dcfc1
output: 2c0f220c50075285852e01bcee4b5f90
```

Sample Data

```
Set 5
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000100
A1:     56123737bfce
A2:     a713702dcfc1
output: 0a096af0fa61dce0933987febe95fc7d

Set 6
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000101
A1:     56123737bfce
A2:     a713702dcfc1
output: 49b8d74007888e770e1a49d6810069b9

Set 7
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000102
A1:     56123737bfce
A2:     a713702dcfc1
output: 309cd0327dec2514894a0c88b101a436

Set 8
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000103
A1:     56123737bfce
A2:     a713702dcfc1
output: 4512274ba875b156c2187e2061b90434

Set 9 (same as set 1 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000000
A1:     a713702dcfc1
A2:     56123737bfce
output: 8d56dc59e70855f563b5e85e42d5964e
```

Sample Data

```
Set 10 (same as set 2 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000001
A1:     a713702dcfc1
A2:     56123737bfce
output: c92fdacbf0ce931e9c4087a9dfb7bc0b

Set 11 (same as set 3 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000002
A1:     a713702dcfc1
A2:     56123737bfce
output: 52ac910200dc34285bbbf2144883c498

Set 12 (same as set 4 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000003
A1:     a713702dcfc1
A2:     56123737bfce
output: c419d677e0d426e6bb36de5fa54c5041

Set 13 (same as set 5 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000100
A1:     a713702dcfc1
A2:     56123737bfce
output: fb0e1f9f7c623c1bf2675fcff1551137
```

Sample Data

```
Set 14 (same as set 6 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000101
A1:     a713702dcfc1
A2:     56123737bfce
output: 16c7be68184f1170fbbb2bef5a9c515d

Set 15 (same as set 7 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000102
A1:     a713702dcfc1
A2:     56123737bfce
output: 24849f33d3ac05fef9034c18d9adb310

Set 16 (same as set 8 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  000103
A1:     a713702dcfc1
A2:     56123737bfce
output: e0f484bb0b071483285903e85094046b

Set 17
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010000
A1:     56123737bfce
A2:     a713702dcfc1
output: 4bf22677415ed90aceb21873c71c1884

Set 18
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010001
A1:     56123737bfce
A2:     a713702dcfc1
output: 0d4b97992eb570efb369cfe45e1681b5
```

Sample Data

```
Set 19
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010002
A1:     56123737bfce
A2:     a713702dcfc1
output: 0f0906bbfa75e95c471e97c4211b2741

Set 20
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010003
A1:     56123737bfce
A2:     a713702dcfc1
output: 88f1f60ce1ff4bf8aa08a170dd061d4e

Set 21
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010100
A1:     56123737bfce
A2:     a713702dcfc1
output: 940f88f25317c358d9bd2f146778e36b

Set 22
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010101
A1:     56123737bfce
A2:     a713702dcfc1
output: 591396355ac4dc72be05a15e718ec945
```

Sample Data

```
Set 23
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010102
A1:     56123737bfce
A2:     a713702dcfc1
output: a3dc055f656abb1d6e11d3f37340189a

Set 24
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     d5cb8454d177733effffb2ec712baeab
N2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010103
A1:     56123737bfce
A2:     a713702dcfc1
output: fd5412a22ba5dd893852608f8ab0c934

Set 25 (same as set 1 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010000
A1:     a713702dcfc1
A2:     56123737bfce
output: 2a742039c5fd6c6faafce17b619ac56f

Set 26 (same as set 2 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010001
A1:     a713702dcfc1
A2:     56123737bfce
output: a60d89efb52db7905179a6c63b8f212a

Set 27 (same as set 3 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010002
A1:     a713702dcfc1
A2:     56123737bfce
output: cb02f803d755fd936f0a832f4ee9fd4a
```

Sample Data

```
Set 28 (same as set 4 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010003
A1:     a713702dcfc1
A2:     56123737bfce
output: 00786c04a24561485aaf22808871b874

Set 29 (same as set 5 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010100
A1:     a713702dcfc1
A2:     56123737bfce
output: 2a58ef2d99281d472a88027423f8215f

Set 30 (same as set 6 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010101
A1:     a713702dcfc1
A2:     56123737bfce
output: ff7ab3752a144232f2cbbcbf979f5517

Set 31 (same as set 7 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010102
A1:     a713702dcfc1
A2:     56123737bfce
output: 9d7fccef23625b1cc684fbf3f8b0e182

Set 32 (same as set 8 with N1 and N2 swapped and A1 and A2 swapped)
W:      fb3ba2012c7e62466e486e229290175b4afebc13fdccee46
N1:     a6e8e7cc25a75f6e216583f7ff3dc4cf
N2:     d5cb8454d177733effffb2ec712baeab
R:      12a3343bb453bb5408da42d20c2d0fc8
IOcap:  010103
A1:     a713702dcfc1
A2:     56123737bfce
output: 864f87e26dece4dfdde30ade1e463d4f
```

7.2.4.2 f3() with P-256 Inputs

```
Set 1
W: ec0234a357c8ad05341010a60a397d9b99796b13b4f866f1868d34f373bfa698
N1: d5cb8454d177733effffb2ec712baeab
N2: a6e8e7cc25a75f6e216583f7ff3dc4cf
R: 12a3343bb453bb5408da42d20c2d0fc8
IOcap: 000000
A1: 56123737bfce
A2: a713702dcfc1
output: 5634c83c9996a86b53473fe25979ec90
```

7.2.5 h2()

Each element in this section except for 'L' is a multi-octet integer arranged with the least significant octet on the right and the most significant octet on the left.

```
Set 1 (Generic AMP initial creation)
    W:      c234c1198f3b520186ab92a2f874934ec234c1198f3b520186ab92a2f874934e
    keyID:  67616d70 ('gamp')
    L:      32
    output: 7E010832407F59D51CB473FB0D3355899C077DD052D0F5F03F0FA4B964097A04

Set 2 (802.11)
    W:      7E010832407F59D51CB473FB0D3355899C077DD052D0F5F03F0FA4B964097A04
    keyID:  38303262 ('802b')
    L:      32
    output: D660DC08E542F1DCC32CDC2000B548F06BC1D7EB0F227DD809B50D9F1945C68E

Set 3 (Generic AMP refresh after 802.11)
    W:      7E010832407F59D51CB473FB0D3355899C077DD052D0F5F03F0FA4B964097A04
    keyID:  67616d70 ('gamp')
    L:      32
    output: AA8247E5DBAFC80F908C1C2ECA2F73E86D41DF754355994B220D5817040991B2

Set 4 (ECMA-368)
    W:      AA8247E5DBAFC80F908C1C2ECA2F73E86D41DF754355994B220D5817040991B2
    keyID:  65636d61 ('ecma')
    L:      16
    output: 89286411644B33DC378A93A1B1506AFF

Set 5 (Generic AMP refresh after ECMA-368)
    W:      AA8247E5DBAFC80F908C1C2ECA2F73E86D41DF754355994B220D5817040991B2
    keyID:  67616d70 ('gamp')
    L:      32
    output: 925CAE4683A2CCF105ED141F5370AB501448E83D2E43F38573120360B100F27D
```

Sample Data

7.2.6 h4()

```
Set 1a
keyID:  6274646b
A1:     56123737bfce
A2:     a713702dcfc1
input:  6274646b56123737bfcea713702dcfc1
W:      c234c1198f3b520186ab92a2f874934e
output: b089c4e39d7c192c3aba3c2109d24c0dc039e700adf3a263008e65a8b00fb1fa
Device Authentication Key: b089c4e39d7c192c3aba3c2109d24c0d
```

7.2.7 h5()

```
Set 1a
R1:     d5cb8454d177733effffb2ec712baeab
R2:     a6e8e7cc25a75f6e216583f7ff3dc4cf
input:  d5cb8454d177733effffb2ec712baeaba6e8e7cc25a75f6e216583f7ff3dc4cf
W:      b089c4e39d7c192c3aba3c2109d24c0d
output: 746af87e1eeb1137c683b97d9d421f911f3ddf100403871b362958c458976d65
SRESmaster: 746af87e
SRESslave:  1eeb1137
ACO:        c683b97d9d421f91
```

7.2.8 h3()

```
Set 1a
keyID:   6274616b
A1:      56123737bfce
A2:      a713702dcfc1
ACO:     c683b97d9d421f91
input:   6274616b56123737bfcea713702dcfc1c683b97d9d421f91
W:       c234c1198f3b520186ab92a2f874934e
output:  677b377f74a5d501121c46492d4cb489e27fe151026ab47f271a47399c8969ff
AES Encryption key: 677b377f74a5d501121c46492d4cb489
```

8 WHITENING SEQUENCE SAMPLE DATA

This section shows the output of the whitening sequence generator.

Whitening Sequence (=D7)	Whitening LFSR D7.....D0
1	1111111
1	1101111
1	1001111
0	0001111
0	0011110
0	0111100
1	1111000
1	1100001
1	1010011
0	0110111
1	1101110
1	1001101
0	0001011
0	0010110
0	0101100
1	1011000
0	0100001
1	1000010
0	0010101
0	0101010
1	1010100
0	0111001
1	1110010
1	1110101
1	1111011
1	1100111
1	1011111
0	0101111
1	1011110
0	0101101
1	1011010
0	0100101
1	1001010
0	0000101
0	0001010
0	0010100
0	0101000
1	1010000
0	0110001
1	1100010
1	1010101
0	0111011
1	1110110

Sample Data

1	1111101
1	1101011
1	1000111
0	0011111
0	0111110
1	1111100
1	1101001
1	1000011
0	0010111
0	0101110
1	1011100
0	0101001
1	1010010
0	0110101
1	1101010
1	1000101
0	0011011
0	0110110
1	1101100
1	1001001
0	0000011
0	0000110
0	0001100
0	0011000
0	0110000
1	1100000
1	1010001
0	0110011
1	1100110
1	1011101
0	0101011
1	1010110
0	0111101
1	1111010
1	1100101
1	1011011
0	0100111
1	1001110
0	0001101
0	0011010
0	0110100
1	1101000
1	1000001
0	0010011
0	0100110
1	1001100
0	0001001
0	0010010
0	0100100
1	1001000
0	0000001
0	0000010

Sample Data

0	0000100
0	0001000
0	0010000
0	0100000
1	1000000
0	0010001
0	0100010
1	1000100
0	0011001
0	0110010
1	1100100
1	1011001
0	0100011
1	1000110
0	0011101
0	0111010
1	1110100
1	1111001
1	1100011
1	1010111
0	0111111
1	1111110
1	1101101
1	1001011
0	0000111
0	0001110
0	0011100
0	0111000
1	1110000
1	1110001
1	1110011
1	1110111
1	1111111

9 FEC SAMPLE DATA

```
================================================
 Rate 2/3 FEC -- (15,10) Shortened Hamming Code
================================================

Data is in hexadecimal notation, the codewords are in binary notation. The codeword bits
are sent from left to right over the air interface. The space in the codeword indicates
the start of parity bits.

Data:           Codeword:

0x001       1000000000 11010
0x002       0100000000 01101
0x004       0010000000 11100
0x008       0001000000 01110
0x010       0000100000 00111
0x020       0000010000 11001
0x040       0000001000 10110
0x080       0000000100 01011
0x100       0000000010 11111
0x200       0000000001 10101
```

10 ENCRYPTION KEY SAMPLE DATA

Explanation:

For the Section 10.1 through Section 10.5, the hexadecimal sample data is written with the least significant byte at the leftmost position and the most significant byte at the rightmost position. Within each byte, the *least significant bit* (LSB) is at the rightmost position and the *most significant bit* (MSB) is at the leftmost position Thus, a line reading:

aco: 48afcdd4bd40fef76693b113

means aco[0]=0x48, ac[1]=0xaf, ..., aco[11]=0x13. The LSB of aco[11] is 1 and the MSB of aco[11] is 0.

Key [i]: denotes the ith sub-key in Ar or A'r;
round r: denotes the input to the rth round;
added ->: denotes the input to round 3 in
A'r after adding original input (of round 1).

10.1 FOUR TESTS OF E1

```
rand    :00000000000000000000000000000000
address :000000000000
key     :00000000000000000000000000000000
round  1:00000000000000000000000000000000
Key [ 1]:00000000000000000000000000000000
Key [ 2]:4697b1baa3b7100ac537b3c95a28ac64
round  2:78d19f9307d2476a523ec7a8a026042a
Key [ 3]:ecabaac66795580df89af66e66dc053d
Key [ 4]:8ac3d8896ae9364943bfebd4969b68a0
round  3:600265247668dda0e81c07bbb30ed503
Key [ 5]:5d57921fd5715cbb22c1be7bbc996394
Key [ 6]:2a61b8343219fdfb1740e6511d41448f
round  4:d7552ef7cc9dbde568d80c2215bc4277
Key [ 7]:dd0480dee731d67f01a2f739da6f23ca
Key [ 8]:3ad01cd1303e12a1cd0fe0a8af82592c
round  5:fb06bef32b52ab8f2a4f2b6ef7f6d0cd
Key [ 9]:7dadb2efc287ce75061302904f2e7233
Key [10]:c08dcfa981e2c4272f6c7a9f52e11538
round  6:b46b711ebb3cf69e847a75f0ab884bdd
Key [11]:fc2042c708e409555e8c147660ffdfd7
Key [12]:fa0b21001af9a6b9e89e624cd99150d2
round  7:c585f308ff19404294f06b292e978994
Key [13]:18b40784ea5ba4c80ecb48694b4e9c35
Key [14]:454d54e5253c0c4a8b3fcca7db6baef4
round  8:2665fadb13acf952bf74b4ab12264b9f
Key [15]:2df37c6d9db52674f29353b0f011ed83
Key [16]:b60316733b1e8e70bd861b477e2456f1
Key [17]:884697b1baa3b7100ac537b3c95a28ac
```

Sample Data

```
round  1:158ffe43352085e8a5ec7a88e1ff2ba8
Key [ 1]:e9e5dfc1b3a79583e9e5dfc1b3a79583
Key [ 2]:7595bf57e0632c59f435c16697d4c864
round  2:0b5cc75febcdf7827ca29ec0901b6b5b
Key [ 3]:e31b96afcc75d286ef0ae257cbbc05b7
Key [ 4]:0d2a27b471bc0108c6263aff9d9b3b6b
round  3:e4278526c8429211f7f2f0016220aef4
added ->:f1b68365fd6217f952de6a89831fd95c
Key [ 5]:98d1eb5773cf59d75d3b17b3bc37c191
Key [ 6]:fd2b79282408ddd4ea0aa7511133336f
round  4:d0304ad18337f86040145d27aa5c8153
Key [ 7]:331227756638a41d57b0f7e071ee2a98
Key [ 8]:aa0dd8cc68b406533d0f1d64aabacf20
round  5:84db909d213bb0172b8b6aaf71bf1472
Key [ 9]:669291b0752e63f806fce76f10e119c8
Key [10]:ef8bdd46be8ee0277e9b78adef1ec154
round  6:f835f52921e903dfa762f1df5abd7f95
Key [11]:f3902eb06dc409cfd78384624964bf51
Key [12]:7d72702b21f97984a721c99b0498239d
round  7:ae6c0b4bb09f25c6a5d9788a31b605d1
Key [13]:532e60bceaf902c52a06c2c283ecfa32
Key [14]:181715e5192efb2a64129668cf5d9dd4
round  8:744a6235b86cc0b853cc9f74f6b65311
Key [15]:83017c1434342d4290e961578790f451
Key [16]:2603532f365604646ff65803795ccce5
Key [17]:882f7c907b565ea58dae1c928a0dcf41
sres    :056c0fe6
aco     :48afcdd4bd40fef76693b113
----------------------------------------
rand    :bc3f30689647c8d7c5a03ca80a91eceb
address :7ca89b233c2d
key     :159dd9f43fc3d328efba0cd8a861fa57
round  1:bc3f30689647c8d7c5a03ca80a91eceb
Key [ 1]:159dd9f43fc3d328efba0cd8a861fa57
Key [ 2]:326558b3c15551899a97790e65ff669e
round  2:3e950edf197615638cc19c09f8fedc9b
Key [ 3]:62e879b65b9f53bbfbd020c624b1d682
Key [ 4]:73415f30bac8ab61f410adc9442992db
round  3:6a7640791cb536678936c5ecd4ae5a73
Key [ 5]:5093cfa1d31c1c48acd76df030ea3c31
Key [ 6]:0b4acc2b8f1f694fc7bd91f4a70f3009
round  4:fca2c022a577e2ffb2aa007589693ec7
Key [ 7]:2ca43fc817947804ecff148d50d6f6c6
Key [ 8]:3fcd73524b533e00b7f7825bea2040a4
round  5:e97f8ea4ed1a6f4a36ffc179dc6bb563
Key [ 9]:6c67bec76ae8c8cc4d289f69436d3506
Key [10]:95ed95ee8cb97e61d75848464bffb379
round  6:38b07261d7340d028749de1773a415c7
Key [11]:ff566c1fc6b9da9ac502514550f3e9d2
Key [12]:ab5ce3f5c887d0f49b87e0d380e12f47
round  7:58241f1aed7c1c3e047d724331a0b774
Key [13]:a2cab6f95eac7d655dbe84a6cd4c47f5
```

Sample Data

```
Key [14]:f5caff88af0af8c42a20b5bbd2c8b460
round  8:3d1aaeff53c0910de63b9788b13c490f
Key [15]:185099c1131cf97001e2f36fda415025
Key [16]:a0ebb82676bc75e8378b189eff3f6b1d
Key [17]:cf5b348aaee27ae332b4f1bfa10289a6
round  1:2e4b417b9a2a9cfd7d8417d9a6a556eb
Key [ 1]:fe78b835f26468ab069fd3991b086fda
Key [ 2]:095c5a51c6fa6d3ac1d57fa19aa382bd
round  2:b8bca81d6bb45af9d92beadd9300f5ed
Key [ 3]:1af866df817fd9f4ec00bc704192cffc
Key [ 4]:f4a8a059c1f575f076f5fbb24bf16590
round  3:351aa16dec2c3a4787080249ed323eae
added ->:1b65e2167656d6bafa8c19904bd79445
Key [ 5]:8c9d18d9356a9954d341b4286e88ea1f
Key [ 6]:5c958d370102c9881bf753e69c7da029
round  4:2ce8fef47dda6a5bee74372e33e478a2
Key [ 7]:7eb2985c3697429fbe0da334bb51f795
Key [ 8]:af900f4b63a1138e2874bfb7c628b7b8
round  5:572787f563e1643c1c862b7555637fb4
Key [ 9]:834c8588dd8f3d4f31117a488420d69b
Key [10]:bc2b9b81c15d9a80262f3f48e9045895
round  6:16b4968c5d02853c3a43aa4cdb5f26ac
Key [11]:f08608c9e39ad3147cba61327919c958
Key [12]:2d4131decf4fa3a959084714a9e85c11
round  7:10e4120c7cccef9dd4ba4e6da8571b01
Key [13]:c934fd319c4a2b5361fa8eef05ae9572
Key [14]:4904c17aa47868e40471007cde3a97c0
round  8:f9081772498fed41b6ffd72b71fcf6c6
Key [15]:ea5e28687e97fa3f833401c86e6053ef
Key [16]:1168f58252c4ecfccafbdb3af857b9f2
Key [17]:b3440f69ef951b78b5cbd6866275301b
sres    :8d5205c5
aco     :3ed75df4abd9af638d144e94
----------------------------------------
rand    :0891caee063f5da1809577ff94ccdcfb
address :c62f19f6ce98
key     :45298d06e46bac21421ddfbed94c032b
round  1:0891caee063f5da1809577ff94ccdcfb
Key [ 1]:45298d06e46bac21421ddfbed94c032b
Key [ 2]:8f03e1e1fe1c191cad35a897bc400597
round  2:1c6ca013480a685c1b28e0317f7167e1
Key [ 3]:4f2ce3a092dde854ef496c8126a69e8e
Key [ 4]:968caee2ac6d7008c07283daec67f2f2
round  3:06b4915f5fcc1fc551a52048f0af8a26
Key [ 5]:ab0d5c31f94259a6bf85ee2d22edf56c
Key [ 6]:dfb74855c0085ce73dc17b84bfd50a92
round  4:077a92b040acc86e6e0a877db197a167
Key [ 7]:8f888952662b3db00d4e904e7ea53b5d
Key [ 8]:5e18bfcc07799b0132db88cd6042f599
round  5:7204881fb300914825fdc863e8ceadf3
Key [ 9]:bfca91ad9bd3d1a06c582b1d5512dddf
Key [10]:a88bc477e3fa1d5a59b5e6cf793c7a41
```

Sample Data

```
round  6:27031131d86cea2d747deb4f756143aa
Key [11]:f3cfb8dac8aea2a6a8ef95af3a2a2767
Key [12]:77beb90670c5300b03aa2b2232d3d40c
round  7:fc8c13d49149b1ce8d86f96e44a00065
Key [13]:b578373650af36a06e19fe335d726d32
Key [14]:6bcee918c7d0d24dfdf42237fcf99d53
round  8:04ef5f5a7ddf846cda0a07782fc23866
Key [15]:399f158241eb3e079f45d7b96490e7ea
Key [16]:1bcfbe98ecde2add52aa63ea79fb917a
Key [17]:ee8bc03ec08722bc2b075492873374af
round  1:d989d7a40cde7032d17b52f8117b69d5
Key [ 1]:2ecc6cc797cc41a2ab02007f6af396ae
Key [ 2]:acfaef7609c12567d537ae1cf9dc2198
round  2:8e76eb9a29b2ad5eea790db97aee37c1
Key [ 3]:079c8ff9b73d428df879906a0b87a6c8
Key [ 4]:19f2710baf403a494193d201f3a8c439
round  3:346bb7c35b2539676375aafe3af69089
added ->:edf48e675703a955b2f0fc062b71f95c
Key [ 5]:d623a6498f915cb2c8002765247b2f5a
Key [ 6]:900109093319bc30108b3d9434a77a72
round  4:fafb6c1f3ebbd2477be2da49dd923f69
Key [ 7]:e28e2ee6e72e7f4e5b5c11f10d204228
Key [ 8]:8e455cd11f8b9073a2dfa5413c7a4bc5
round  5:7c72230df588060a3cf920f9b0a08f06
Key [ 9]:28afb26e2c7a64238c41cefc16c53e74
Key [10]:d08dcafc2096395ba0d2dddd0e471f4d
round  6:55991df991db26ff00073a12baa3031d
Key [11]:fcffdcc3ad8faae091a7055b934f87c1
Key [12]:f8df082d77060252c02d91e55bd6a7d6
round  7:70ec682ff864375f63701fa4f6be5377
Key [13]:bef3706e523d708e8a44147d7508bc35
Key [14]:3e98ab283ca2422d56a56cf8b06caeb3
round  8:172f12ec933da85504b4ea5c90f8f0ea
Key [15]:87ad9625d06645d22598dd5ef811ea2c
Key [16]:8bd3db0cc8168009e5da90877e13a36f
Key [17]:0e74631d813a8351ac7039b348c41b42
sres    :00507e5f
aco     :2a5f19fbf60907e69f39ca9f
----------------------------------------
rand    :0ecd61782b4128480c05dc45542b1b8c
address :f428f0e624b3
key     :35949a914225fabad91995d226de1d92
round  1:0ecd61782b4128480c05dc45542b1b8c
Key [ 1]:35949a914225fabad91995d226de1d92
Key [ 2]:ea6b3dcccc8ee5d88de349fa5010404f
round  2:8935e2e263fbc4b9302cabdfc06bce3e
Key [ 3]:920f3a0f2543ce535d4e7f25ad80648a
Key [ 4]:ad47227edf9c6874e80ba80ebb95d2c9
round  3:b4c8b878675f184a0c72f3dab51f8f05
Key [ 5]:81a941ca7202b5e884ae8fa493ecac3d
Key [ 6]:bcde1520bee3660e86ce2f0fb78b9157
round  4:77ced9f2fc42bdd5c6312b87fc2377c5
```

Sample Data

```
Key [ 7]:c8eee7423d7c6efa75ecec0d2cd969d3
Key [ 8]:910b3f838a02ed441fbe863a02b4a1d0
round  5:fe28e8056f3004d60bb207e628b39cf2
Key [ 9]:56c647c1e865eb078348962ae070972d
Key [10]:883965da77ca5812d8104e2b640aec0d
round  6:1f2ba92259d9e88101518f145a33840f
Key [11]:61d4cb7e4f8868a283327806a9bd8d4d
Key [12]:9f57de3a3ff310e21dc1e696ce060304
round  7:cc9b5d0218d29037e88475152ebebb2f
Key [13]:7aa1d8adc1aeed7127ef9a18f6eb2d8e
Key [14]:b4db9da3bf865912acd14904c7f7785d
round  8:b04d352bedc02682e4a7f59d7cda1dba
Key [15]:a13d7141ef1f6c7d867e3d175467381b
Key [16]:08b2bc058e50d6141cdd566a307e1acc
Key [17]:057b2b4b4be5dc0ac49e50489b8006c9
round  1:5cfacc773bae995cd7f1b81e7c9ec7df
Key [ 1]:1e717950f5828f3930fe4a9395858815
Key [ 2]:d1623369b733d98bbc894f75866c544c
round  2:d571ffa21d9daa797b1a0a3c962fc64c
Key [ 3]:4abf27664ae364cc8a7e5bcf88214cc4
Key [ 4]:2aaedda8dc4933dd6aeaf6e5c0d5a482
round  3:e17c8e498a00f125bf654c938c23f36d
added ->:bd765a3eb1ae8a796856048df0c1bab2
Key [ 5]:bc7f8ab2d86000f47b1946cc8d7a7a2b
Key [ 6]:6b28544cb13ec6c5d98470df2cf900b7
round  4:a9727c26f2f06bd9920e83c8605dcd76
Key [ 7]:1be840d9107f2c9523f66bb19f5464a1
Key [ 8]:61d6fb1aa2f0c2b26fb2a3d6de8c177c
round  5:aeff751f146eab7e4626b2e2c9e2fb39
Key [ 9]:adabfc82570c568a233173099f23f4c2
Key [10]:b7df6b55ad266c0f1ff7452101f59101
round  6:cf412b95f454d5185e67ca671892e5bd
Key [11]:8e04a7282a2950dcbaea28f300e22de3
Key [12]:21362c114433e29bda3e4d51f803b0cf
round  7:16165722fe4e07ef88f8056b17d89567
Key [13]:710c8fd5bb3cbb5f132a7061de518bd9
Key [14]:0791de7334f4c87285809343f3ead3bd
round  8:28854cd6ad4a3c572b15490d4b81bc3f
Key [15]:4f47f0e5629a674bfcd13770eb3a3bd9
Key [16]:58a6d9a16a284cc0aead2126c79608a1
Key [17]:a564082a0a98399f43f535fd5cefad34
sres    :80e5629c
aco     :a6fe4dcde3924611d3cc6ba1


========================================
```

Sample Data

10.2 FOUR TESTS OF E21

```
rand    :00000000000000000000000000000000
address :000000000000
round  1:00000000000000000000000000000000
Key [ 1]:00000000000000000000000000000006
Key [ 2]:4697b1baa3b7100ac537b3c95a28dc94
round  2:98611307ab76bbde9a86af1ce8cad412
Key [ 3]:ecabaac66795580df89af66e665d863d
Key [ 4]:8ac3d8896ae9364943bfebd4a2a768a0
round  3:820999ad2e6618f4b578974beeedf9e7
added ->:820999ad2e6618f4b578974beeedf9e7
Key [ 5]:5d57921fd5715cbb22c1bedb1c996394
Key [ 6]:2a61b8343219fdfb1740e9541d41448f
round  4:acd6edec87581ac22dbdc64ea4ced3a2
Key [ 7]:dd0480dee731d67f01ba0f39da6f23ca
Key [ 8]:3ad01cd1303e12a18dcfe0a8af82592c
round  5:1c7798732f09fbfe25795a4a2fbc93c2
Key [ 9]:7dadb2efc287ce7b0c1302904f2e7233
Key [10]:c08dcfa981e2f4572f6c7a9f52e11538
round  6:c05b88b56aa70e9c40c79bb81cd911bd
Key [11]:fc2042c708658a555e8c147660ffdfd7
Key [12]:fa0b21002605a6b9e89e624cd99150d2
round  7:abacc71b481c84c798d1bdf3d62f7e20
Key [13]:18b407e44a5ba4c80ecb48694b4e9c35
Key [14]:454d57e8253c0c4a8b3fcca7db6baef4
round  8:e8204e1183ae85cf19edb2c86215b700
Key [15]:2d0b946d9db52674f29353b0f011ed83
Key [16]:76c316733b1e8e70bd861b477e2456f1
Key [17]:8e4697b1baa3b7100ac537b3c95a28ac
Ka      :d14ca028545ec262cee700e39b5c39ee
----------------------------------------
rand    :2dd9a5503431913040l3b2d7e1189d09
address :cac4364303b6
round  1:cac4364303b6cac4364303b6cac43643
Key [ 1]:2dd9a5503431913040l3b2d7e1189d0f
Key [ 2]:14c4335b2c43910c5dcc71d81a14242b
round  2:e169f788aad45a9011f11db5270b1277
Key [ 3]:55bfb712cba168d1a48f6e74cd9f4388
Key [ 4]:2a2b3aacca695caef2821b0fb48cc253
round  3:540f9c76652e92c44987c617035037bf
added ->:9ed3d23566e45c007fcac9a1c9146dfc
Key [ 5]:a06aab22d9a287384042976b4b6b00ee
Key [ 6]:c229d054bb72e8eb230e6dcdb32d16b7
round  4:83659a41675f7171ea57909dc5a79ab4
Key [ 7]:23c4812ab1905ddf77dedaed4105649a
Key [ 8]:40d87e272a7a1554ae2e85e3638cdf52
round  5:0b9382d0ed4f2fccdbb69d0db7b130a4
Key [ 9]:bdc064c6a39f6b84fe40db359f62a3c4
Key [10]:58228db841ce3cee983aa721f36aa1b9
round  6:c6ebda0f8f489792f09c189568226c1f
Key [11]:a815bacd6fa747a0d4f52883ac63ebe7
```

Sample Data

```
Key [12]:a9ce513b38ea006c333ecaaefcf1d0f8
round  7:75a8aba07e69c9065bcd831c40115116
Key [13]:3635e074792d4122130e5b824e52cd60
Key [14]:511bdb61bb28de72a5d794bffbf407df
round  8:57a6e279dcb764cf7dd6a749dd60c735
Key [15]:a32f5f21044b6744b6d913b13cdb4c0a
Key [16]:9722bbaeef281496ef8c23a9d41e92f4
Key [17]:807370560ad7e8a13a054a65a03b4049
Ka      :e62f8bac609139b3999aedbc9d228042
----------------------------------------
rand    :dab3cffe9d5739d1b7bf4a667ae5ee24
address :02f8fd4cd661
round  1:02f8fd4cd66102f8fd4cd66102f8fd4c
Key [ 1]:dab3cffe9d5739d1b7bf4a667ae5ee22
Key [ 2]:e315a8a65d809ec7c289e69c899fbdcc
round  2:ef85ff081b8709405e19f3e275cec7dc
Key [ 3]:df6a119bb50945fc8a3394e7216448f3
Key [ 4]:87fe86fb0d58b5dd0fb3b6b1dab51d07
round  3:aa25c21bf577d92dd97381e3e9edcc54
added ->:a81dbf5723d8dbd524bf5782ebe5c918
Key [ 5]:36cc253c506c0021c91fac9d8c469e90
Key [ 6]:d5fda00f113e303809b7f7d78a1a2b0e
round  4:9e69ce9b53caec3990894d2baed41e0d
Key [ 7]:c14b5edc10cabf16bc2a2ba4a8ae1e40
Key [ 8]:74c6131afc8dce7e11b03b1ea8610c16
round  5:a5460fa8cedca48a14fd02209e01f02e
Key [ 9]:346cfc553c6cbc9713edb55f4dcbc96c
Key [10]:bddf027cb059d58f0509f8963e9bdec6
round  6:92b33f11eadcacc5a43dd05f13d334dd
Key [11]:8eb9e040c36c4c0b4a7fd3dd354d53c4
Key [12]:c6ffecdd5e135b20879b9dfa4b34bf51
round  7:fb0541aa5e5df1a61c51aef606eb5a41
Key [13]:bf12f5a6ba08dfc4fda4bdfc68c997d9
Key [14]:37c4656b9215f3c959ea688fb64ad327
round  8:f0bbd2b94ae374346730581fc77a9c98
Key [15]:e87bb0d86bf421ea4f779a8eee3a866c
Key [16]:faa471e934fd415ae4c0113ec7f0a5ad
Key [17]:95204a80b8400e49db7cf6fd2fd40d9a
Ka      :b0376d0a9b338c2e133c32b69cb816b3
----------------------------------------
rand    :13ecad08ad63c37f8a54dc56e82f4dc1
address :9846c5ead4d9
round  1:9846c5ead4d99846c5ead4d99846c5ea
Key [ 1]:13ecad08ad63c37f8a54dc56e82f4dc7
Key [ 2]:ad04f127bed50b5e671d6510d392eaed
round  2:97374e18cdd0a6f7a5aa49d1ac875c84
Key [ 3]:57ad159e5774fa222f2f3039b9cd5101
Key [ 4]:9a1e9e1068fede02ef90496e25fd8e79
round  3:9dd3260373edd9d5f4e774826b88fd2d
added ->:0519ebe9a7c6719331d1485bf3cec2c7
Key [ 5]:378dce167db62920b0b392f7cfca316e
Key [ 6]:db4277795c87286faee6c9e9a6b71a93
```

Sample Data

```
round  4:40ec6563450299ac4e120d88672504d6
Key [ 7]:ec01aa2f5a8a793b36c1bb858d254380
Key [ 8]:2921a66cfa5bf74ac535424564830e98
round  5:57287bbb041bd6a56c2bd931ed410cd4
Key [ 9]:07018e45aab61b3c3726ee3d57dbd5f6
Key [10]:627381f0fa4c02b0c7d3e7dfbffc3333
round  6:66affa66a8dcd36e36bf6c3f1c6a276e
Key [11]:33b57c925bd5551999f716e138efbe79
Key [12]:a6dc7f9aa95bcc9243aebd12608f657a
round  7:450e65184fd8c72c578d5cdecb286743
Key [13]:a6a6db00fd8c72a28ea57ea542f6e102
Key [14]:dcf3377daeb2e24e61f0ad6620951c1f
round  8:e5eb180b519a4e673f21b7c4f4573f3d
Key [15]:621240b9506b462a7fa250da41844626
Key [16]:ae297810f01f43dc35756cd119ee73d6
Key [17]:b959835ec2501ad3894f8b8f1f4257f9
Ka      :5b61e83ad04d23e9d1c698851fa30447
========================================
```

10.3 THREE TESTS OF E22

(for K_master and overlay generation)

```
rand    :001de169248850245a5f7cc7f0d6d633
PIN     :d5a51083a04a1971f18649ea8b79311a
round  1:001de169248850245a5f7cc7f0d6d623
Key [ 1]:d5a51083a04a1971f18649ea8b79311a
Key [ 2]:7317cdbff57f9b99f9810a2525b17cc7
round  2:5f05c143347b59acae3cb002db23830f
Key [ 3]:f08bd258adf1d4ae4a54d8ccb26220b2
Key [ 4]:91046cbb4ccc43db18d6dd36ca7313eb
round  3:c8f3e3300541a25b6ac5a80c3105f3c4
added ->:c810c45921c9f27f302424cbc1dbc9e7
Key [ 5]:67fb2336f4d9f069da58d11c82f6bd95
Key [ 6]:4fed702c75bd72c0d3d8f38707134c50
round  4:bd5e0c3a97fa55b91a3bbbf306ebb978
Key [ 7]:41c947f80cdc0464c50aa89070af314c
Key [ 8]:680eecfa8daf41c7109c9a5cb1f26d75
round  5:21c1a762c3cc33e75ce8976a73983087
Key [ 9]:6e33fbd94d00ff8f72e8a7a0d2cebc4c
Key [10]:f4d726054c6b948add99fabb5733ddc3
round  6:56d0df484345582f6b574a449ba155eb
Key [11]:4eda2425546a24cac790f49ef2453b53
Key [12]:cf2213624ed1510408a5a3e00b7333df
round  7:120cf9963fe9ff22993f7fdf9600d9b8
Key [13]:d04b1a25b0b8fec946d5ecfa626d04c9
Key [14]:01e5611b0f0e140bdb64585fd3ae5269
round  8:a6337400ad8cb47fefb91332f5cb2713
Key [15]:f15b2dc433f534f61bf718770a3698b1
Key [16]:f990d0273d8ea2b9e0b45917a781c720
Key [17]:f41b3cc13d4301297bb6bdfcb3e5a1dd
Ka      :539e4f2732e5ae2de1e0401f0813bd0d
```

Sample Data

```
---------------------------------------
rand    :67ed56bfcf99825f0c6b349369da30ab
PIN     :7885b515e84b1f082cc499976f1725ce
round  1:67ed56bfcf99825f0c6b349369da30bb
Key [ 1]:7885b515e84b1f082cc499976f1725ce
Key [ 2]:72445901fdaf506beb036f4412512248
round  2:6b160b66a1f6c26c1f3432f463ef5aa1
Key [ 3]:59f0e4982e97633e5e7fd133af8f2c5b
Key [ 4]:b4946ec77a41bf7c729d191e33d458ab
round  3:3f22046c964c3e5ca2a26ec9a76a9f67
added ->:580f5ad359e5c003ae0da25ace44cfdc
Key [ 5]:eb0b839f97bdf534183210678520bbef
Key [ 6]:cff0bc4a94e5c8b2a2d24d9f59031e19
round  4:87aa61fc0ff88e744c195249b9a33632
Key [ 7]:592430f14d8f93db95dd691af045776d
Key [ 8]:3b55b404222bf445a6a2ef5865247695
round  5:83dcf592a854226c4dcd94e1ecf1bc75
Key [ 9]:a9714b86319ef343a28b87456416bd52
Key [10]:e6598b24390b3a0bf2982747993b0d78
round  6:dee0d13a52e96bcf7c72045a21609fc6
Key [11]:62051d8c51973073bff959b032c6e1e2
Key [12]:29e94f4ab73296c453c833e217a1a85b
round  7:08488005761e6c7c4dbb203ae453fe3a
Key [13]:0e255970b3e2fc235f59fc5acb10e8ce
Key [14]:d0dfbb3361fee6d4ffe45babf1cd7abf
round  8:0d81e89bddde7a7065316c47574feb8f
Key [15]:c12eee4eb38b7a171f0f736003774b40
Key [16]:8f962523f1c0abd9a087a0dfb11643d3
Key [17]:24be1c66cf8b022f12f1fb4c60c93fd1
Ka      :04435771e03a9daceb8bb1a493ee9bd8
---------------------------------------
rand    :40a94509238664f244ff8e3d13b119d3
PIN     :1ce44839badde30396d03c4c36f23006
round  1:40a94509238664f244ff8e3d13b119c3
Key [ 1]:1ce44839badde30396d03c4c36f23006
Key [ 2]:6dd97a8f91d628be4b18157af1a9dcba
round  2:0eac5288057d9947a24eabc1744c4582
Key [ 3]:fef9583d5f55fd4107ad832a725db744
Key [ 4]:fc3893507016d7c1db2bd034a230a069
round  3:60b424f1082b0cc3bd61be7b4c0155f0
added ->:205d69f82bb17031f9604c465fb26e33
Key [ 5]:0834d04f3e7e1f7f85f0c1db685ab118
Key [ 6]:1852397f9a3723169058e9b62bb3682b
round  4:2c6b65a49d66af6566675afdd6fa7d7d
Key [ 7]:6c10da21d762ae4ac1ba22a96d9007b4
Key [ 8]:9aa23658b90470a78d686344b8a9b0e7
round  5:a2c537899665113a42f1ac24773bdc31
Key [ 9]:137dee3bf879fe7bd02fe6d888e84f16
Key [10]:466e315a1863f47d0f93bc6827cf3450
round  6:e26982980d79b21ed3e20f8c3e71ba96
Key [11]:0b33cf831465bb5c979e6224d7f79f7c
Key [12]:92770660268ede827810d707a0977d73
```

Sample Data

```
round  7:e7b063c4e2e3110b89b7e1631c762dd5
Key [13]:7be30ae4961cf24ca17625a77bb7a9f8
Key [14]:be65574a33ae30e6e82dbd2826d3cc1a
round  8:7a963e37b2c2e76b489cfe40a2cf00e5
Key [15]:ed0ba7dd30d60a5e69225f0a33011e5b
Key [16]:765c990f4445e52b39e6ed6105ad1c4f
Key [17]:52627bf9f35d94f30d5b07ef15901adc
Ka      :9cde4b60f9b5861ed9df80858bac6f7f


========================================
```

10.4 TESTS OF E22 WITH PIN AUGMENTING

for PIN lengths 1,...,16 bytes

```
rand    :24b101fd56117d42c0545a4247357048
PIN length =16 octets
PIN     :fd397c7f5c1f937cdf82d8816cc377e2
round  1:24b101fd56117d42c0545a4247357058
Key [ 1]:fd397c7f5c1f937cdf82d8816cc377e2
Key [ 2]:0f7aac9c9b53f308d9fdbf2c78e3c30e
round  2:838edfe1226266953ccba8379d873107
Key [ 3]:0b8ac18d4bb44fad2efa115e43945abc
Key [ 4]:887b16b062a83bfa469772c25b456312
round  3:8cd0c9283120aba89a7f9d635dd4fe3f
added ->:a881cad5673128ea5ad3f7211a096e67
Key [ 5]:2248cbe6d299e9d3e8fd35a91178f65b
Key [ 6]:b92af6237385bd31f8fb57fb1bdd824e
round  4:2648d9c618a622b10ef80c4dbaf68b99
Key [ 7]:2bf5ffe84a37878ede2d4c30be60203b
Key [ 8]:c9cb6cec60cb8a8f29b99fcf3e71e40f
round  5:b5a7d9e96f68b14ccebf361de3914d0f
Key [ 9]:5c2f8a702e4a45575b103b0cce8a91c6
Key [10]:d453db0c9f9ddbd11e355d9a34d9b11b
round  6:632a091e7eefe1336857ddafd1ff3265
Key [11]:32805db7e59c5ed4acabf38d27e3fece
Key [12]:fde3a8eedfa3a12be09c1a8a00890fd7
round  7:048531e9fd3efa95910540150f8b137b
Key [13]:def07eb23f3a378f059039a2124bc4c2
Key [14]:2608c58f23d84a09b9ce95e5caac1ab4
round  8:461814ec7439d412d0732f0a6f799a6a
Key [15]:0a7ed16481a623e56ee1442ffa74f334
Key [16]:12add59aca0d19532f1516979954e369
Key [17]:dd43d02d39ffd6a386a4b98b4ac6eb23
Ka      :a5f2adf328e4e6a2b42f19c8b74ba884
----------------------------------------
rand    :321964061ac49a436f9fb9824ac63f8b
PIN length =15 octets
PIN     :ad955d58b6b8857820ac1262d617a6
address :0314c0642543
round  1:321964061ac49a436f9fb9824ac63f9b
```

Sample Data

```
Key [ 1]:ad955d58b6b8857820ac1262d617a603
Key [ 2]:f281736f68e3d30b2ac7c67f125dc416
round  2:7c4a4ece1398681f4bafd309328b7770
Key [ 3]:43c157f4c8b360387c32ab330f9c9aa8
Key [ 4]:3a3049945a298f6d076c19219c47c3cb
round  3:9672b00738bdfaf9bd92a855bc6f3afb
added ->:a48b1401228194bad23161d7f6357960
Key [ 5]:c8e2eaa6d73b7de18f3228ab2173bc69
Key [ 6]:8623f44488222e66a293677cf30bf2bb
round  4:9b30247aad3bf133712d034b46d21c68
Key [ 7]:f3e500902fba31db9bae50ef30e484a4
Key [ 8]:49d4b1137c18f4752dd9955a5a8d2f43
round  5:4492c25fda08083a768b4b5588966b23
Key [ 9]:9d59c451989e74785cc097eda7e42ab8
Key [10]:251de25f3917dcd99c18646107a641fb
round  6:21ae346635714d2623041f269978c0ee
Key [11]:80b8f78cb1a49ec0c3e32a238e60fddf
Key [12]:beb84f4d20a501e4a24ecfbde481902b
round  7:9b56a3d0f8932f20c6a77a229514fb00
Key [13]:852571b44f35fd9d9336d3c1d2506656
Key [14]:d0a0d510fb06ba76e69b8ee3ebc1b725
round  8:6cd8492b2fd31a86978bcdf644eb08a8
Key [15]:c7ffd523f32a874ed4a93430a25976de
Key [16]:16cdcb25e62964876d951fdcc07030d3
Key [17]:def32c0e12596f9582e5e3c52b303f52
Ka      :c0ec1a5694e2b48d54297911e6c98b8f
----------------------------------------
rand    :d4ae20c80094547d7051931b5cc2a8d6
PIN length =14 octets
PIN     :e1232e2c5f3b833b3309088a87b6
address :fabecc58e609
round  1:d4ae20c80094547d7051931b5cc2a8c6
Key [ 1]:e1232e2c5f3b833b3309088a87b6fabe
Key [ 2]:5f0812b47cd3e9a30d7707050fffa1f2
round  2:1f45f16be89794bef33e4547c9c0916a
Key [ 3]:77b681944763244ffa3cd71b248b79b5
Key [ 4]:e2814e90e04f485958ce58c9133e2be6
round  3:b10d2f4ac941035263cee3552d774d2f
added ->:65bb4f82c9d5572f131f764e7139f5e9
Key [ 5]:520acad20801dc639a2c6d66d9b79576
Key [ 6]:c72255cdb61d42be72bd45390dd25ba5
round  4:ead4dc34207b6ea721c62166e155aaad
Key [ 7]:ebf04c02075bf459ec9c3ec06627d347
Key [ 8]:a1363dd2812ee800a4491c0c74074493
round  5:f507944f3018e20586d81d7f326aae9d
Key [ 9]:b0b6ba79493dc833d7f425be7b8dadb6
Key [10]:08cd23e536b9b9b53e85eb004cba3111
round  6:fff450f4302a2b3571e8405e148346da
Key [11]:fec22374c6937dcd26171f4d2edfada3
Key [12]:0f1a8ef5979c69ff44f620c2e007b6e4
round  7:de558779589897f3402a90ee78c3f921
Key [13]:901fb66f0779d6aad0c0fba1fe812cb5
```

Sample Data

```
Key [14]:a0cab3cd15cd23603adc8d4474efb239
round  8:b2df0aa0c9f07fbbaa02f510a29cf540
Key [15]:18edc3f4296dd6f1dea13f7c143117a1
Key [16]:8d3d52d700a379d72ded81687f7546c7
Key [17]:5927badfe602f29345f840bb53e1dea6
Ka      :d7b39be13e3692c65b4a9e17a9c55e17
----------------------------------------
rand    :272b73a2e40db52a6a61c6520549794a
PIN length =13 octets
PIN     :549f2694f353f5145772d8ae1e
address :20487681eb9f
round  1:272b73a2e40db52a6a61c6520549795a
Key [ 1]:549f2694f353f5145772d8ae1e204876
Key [ 2]:42c855593d66b0c458fd28b95b6a5fbf
round  2:d7276dc8073f7677c31f855bde9501e2
Key [ 3]:75d0a69ae49a2da92e457d767879df52
Key [ 4]:b3aa7e7492971afaa0fb2b64827110df
round  3:71aae503831133d19bc452da4d0e409b
added ->:56d558a1671ee8fbf12518884857b9c1
Key [ 5]:9c8cf1604a98e9a503c342e272de5cf6
Key [ 6]:d35bc2df6b85540a27642106471057d9
round  4:f41a709c89ea80481aa3d2b9b2a9f8ca
Key [ 7]:b454dda74aeb4eff227ba48a58077599
Key [ 8]:bcba6aec050116aa9b7c6a9b7314d796
round  5:20fdda20f4a26b1bd38eb7f355a7be87
Key [ 9]:d41f8a9de0a716eb7167a1b6e321c528
Key [10]:5353449982247782d168ab43f17bc4d8
round  6:a70e316997eeed49a5a9ef9ba5e913b5
Key [11]:32cbc9cf1a81e36a45153972347ce4ac
Key [12]:5747619006cf4ef834c749f2c4b9feb6
round  7:e66f2317a825f589f76b47b6aa6e73fb
Key [13]:f9b68beba0a09d2a570a7dc88cc3c3c2
Key [14]:55718f9a4f0b1f9484e8c6b186a41a4b
round  8:5f68f940440a9798e074776019804ada
Key [15]:4ecc29be1b4d78433f6aa30db974a7fb
Key [16]:8470a066ffb00cda7b08059599f919f5
Key [17]:f39a36d74e960a051e1ca98b777848f4
Ka      :9ac64309a37c25c3b4a584fc002a1618
----------------------------------------
rand    :7edb65f01a2f45a2bc9b24fb3390667e
PIN length =12 octets
PIN     :2e5a42797958557b23447ca8
address :04f0d2737f02
round  1:7edb65f01a2f45a2bc9b24fb3390666e
Key [ 1]:2e5a42797958557b23447ca804f0d273
Key [ 2]:18a97c856561eb23e71af8e9e1be4799
round  2:3436e12db8ffdc1265cb5a86da2fed0b
Key [ 3]:7c0908dcbc73201e17c4f7aa1ab8aec8
Key [ 4]:7cb58833602fbe4194c7cc797ce8c454
round  3:caed6af4226f67e4ad1914620803ef2a
added ->:b4c8cf04389eac4611b438993b935544
Key [ 5]:f4dce7d607b5234562d0ebb2267b08b8
```

Sample Data

```
Key [ 6]:560b75c5545751fd8fa99fa4346e654b
round  4:ee67c87d6f74bb75db98f68bff0192c1
Key [ 7]:32f10cefd8d3e6424c6f91f1437808af
Key [ 8]:a934a46045be30fb3be3a5f3f7b18837
round  5:792398dcbeb8d10bdb07ae3c819e943c
Key [ 9]:a0f12e97c677a0e8ac415cd2c8a7ca88
Key [10]:e27014c908785f5ca03e8c6a1da3bf13
round  6:e778b6e0c3e8e7edf90861c7916d97a8
Key [11]:1b4a4303bcc0b2e0f41c72d47654bd9f
Key [12]:4b1302a50046026d6c9054fc8387965a
round  7:1fafddc7efa5f04c1dec1869d3f2d9bb
Key [13]:58c334bb543d49eca562cdbe0280e0fc
Key [14]:bdb60d383c692d06476b76646c8dec48
round  8:3d7c326d074bd6aa222ea050f04a3c7f
Key [15]:78c0162506be0b5953e8403c01028f93
Key [16]:24d7dbbe834dbd7b67f57fcf0d39d60f
Key [17]:2e74f1f3331c0f6585e87b2f715e187e
Ka      :d3af4c81e3f482f062999dee7882a73b
----------------------------------------
rand    :26a92358294dce97b1d79ec32a67e81a
PIN length =11 octets
PIN     :05fbad03f52fa9324f7732
address :b9ac071f9d70
round  1:26a92358294dce97b1d79ec32a67e80a
Key [ 1]:05fbad03f52fa9324f7732b9ac071f9d
Key [ 2]:2504c9691c04a18480c8802e922098c0
round  2:0be20e3d76888e57b6bf77f97a8714fb
Key [ 3]:576b2791d1212bea8408212f2d43e77e
Key [ 4]:90ae36dcce8724adb618f912d1b27297
round  3:1969667060764453257d906b7e58bd5b
added ->:3f12892849c312c494542ea854bfa551
Key [ 5]:bc492c42c9e87f56ec31af5474e9226e
Key [ 6]:c135d1dbed32d9519acfb4169f3e1a10
round  4:ac404205118fe771e54aa6f392da1153
Key [ 7]:83ccbdbbaf17889b7d18254dc9252fa1
Key [ 8]:80b90a1767d3f2848080802764e21711
round  5:41795e89ae9a0cf776ffece76f47fd7a
Key [ 9]:cc24e4a86e8eed129118fd3d5223a1dc
Key [10]:7b1e9c0eb9dab083574be7b7015a62c9
round  6:29ca9e2f87ca00370ef1633505bfba4b
Key [11]:888e6d88cf4beb965cf7d4f32b696baa
Key [12]:6d642f3e5510b0b043a44daa2cf5eec0
round  7:81fc891c3c6fd99acc00028a387e2366
Key [13]:e224f85da2ab63a23e2a3a036e421358
Key [14]:c8dc22aaa739e2cb85d6a0c08226c7d0
round  8:e30b537e7a000e3d2424a9c0f04c4042
Key [15]:a969aa818c6b324bae391bedcdd9d335
Key [16]:6974b6f2f07e4c55f2cc0435c45bebd1
Key [17]:134b925ebd98e6b93c14aee582062fcb
Ka      :be87b44d079d45a08a71d15208c5cb50
----------------------------------------
rand    :0edef05327eab5262430f21fc91ce682
```

Sample Data

```
PIN length =10 octets
PIN     :8210e47390f3f48c32b3
address :7a3cdfe377d1
round  1:0edef05327eab5262430f21fc91ce692
Key [ 1]:8210e47390f3f48c32b37a3cdfe377d1
Key [ 2]:c6be4c3e425e749b620a94c779e33a7e
round  2:07ca3c7a7a6bcbc31d79a856d9cffc0e
Key [ 3]:2587cec2a4b8e4f996a9ed664350d5dd
Key [ 4]:70e4bf72834d9d3dbb7eb2c239216dc0
round  3:792ad2ac4e4559d1463714d2f161b6f4
added ->:7708c2ff692f0ef7626706cd387d9c66
Key [ 5]:6696e1e7f8ac037e1fff3598f0c164e2
Key [ 6]:23dbfe4d0b561bea08fbcef25e49b648
round  4:7d8c71a9d7fbdcbd851bdf074550b100
Key [ 7]:b03648acd021550edee904431a02f00c
Key [ 8]:cb169220b7398e8f077730aa4bf06baa
round  5:b6fcaa45064ffd557e4b7b30cfbb83e0
Key [ 9]:af602c2ba16a454649951274c2be6527
Key [10]:5d60b0a7a09d524143eca13ad680bc9c
round  6:b3416d391a0c26c558843debd0601e9e
Key [11]:9a2f39bfe558d9f562c5f09a5c3c0263
Key [12]:72cae8eebd7fabd9b1848333c2aab439
round  7:abe4b498d9c36ea97b8fd27d7f813913
Key [13]:15f27ea11e83a51645d487b81371d7dc
Key [14]:36083c8666447e03d33846edf444eb12
round  8:8032104338a945ba044d102eabda3b22
Key [15]:0a3a8977dd48f3b6c1668578befadd02
Key [16]:f06b6675d78ca0ee5b1761bdcdab516d
Key [17]:cbc8a7952d33aa0496f7ea2d05390b23
Ka      :bf0706d76ec3b11cce724b311bf71ff5
----------------------------------------
rand    :86290e2892f278ff6c3fb917b020576a
PIN length = 9 octets
PIN     :3dcdffcfd086802107
address :791a6a2c5cc3
round  1:86290e2892f278ff6c3fb917b0205765
Key [ 1]:3dcdffcfd0868021077791a6a2c5cc33d
Key [ 2]:b4962f40d7bb19429007062a3c469521
round  2:1ec59ffd3065f19991872a7863b0ef02
Key [ 3]:eb9ede6787dd196b7e340185562bf28c
Key [ 4]:2964e58aacf7287d1717a35b100ae23b
round  3:f817406f1423fc2fe33e25152679eaaf
added ->:7e404e47861574d08f7dde02969941ca
Key [ 5]:6abf9a314508fd61e486fa4e376c3f93
Key [ 6]:6da148b7ee2632114521842cbb274376
round  4:e9c2a8fac22b8c7cf0c619e2b3f890ed
Key [ 7]:df889cc34fda86f01096d52d116e620d
Key [ 8]:5eb04b147dc39d1974058761ae7b73fc
round  5:444a8aac0efee1c02f8d38f8274b7b28
Key [ 9]:8426cc59eee391b2bd50cf8f1efef8b3
Key [10]:8b5d220a6300ade418da791dd8151941
round  6:9185f983db150b1bccab1e5c12eb63a1
```

Sample Data

```
Key [11]:82ba4ddef833f6a4d18b07aa011f2798
Key [12]:ce63d98794682054e73d0359dad35ec4
round  7:5eded2668f5916dfd036c09e87902886
Key [13]:da794357652e80c70ad8b0715dbe33d6
Key [14]:732ef2c0c3220b31f3820c375e27bb29
round  8:88a5291b4acbba009a85b7dd6a834b3b
Key [15]:3ce75a61d4b465b70c95d7ccd5799633
Key [16]:5df9bd2c3a17a840cdaafb76c171db7c
Key [17]:3f8364b089733d902bccb0cd3386846f
Ka      :cdb0cc68f6f6fbd70b46652de3ef3ffb
----------------------------------------
rand    :3ab52a65bb3b24a08eb6cd284b4b9d4b
PIN length = 8 octets
PIN     :d0fb9b6838d464d8
address :25a868db91ab
round  1:3ab52a65bb3b24a08eb6cd284b4b9d45
Key [ 1]:d0fb9b6838d464d825a868db91abd0fb
Key [ 2]:2573f47b49dad6330a7a9155b7ae8ba1
round  2:ad2ffdff408fcfab44941016a9199251
Key [ 3]:d2c5b8fb80cba13712905a589adaee71
Key [ 4]:5a3381511b338719fae242758dea0997
round  3:2ddc17e570d7931a2b1d13f6ace928a5
added ->:17914180cb12b7baa5d3e0dee734c5e0
Key [ 5]:e0a4d8ac27fbe2783b7bcb3a36a6224d
Key [ 6]:949324c6864deac3eca8e324853e11c3
round  4:62c1db5cf31590d331ec40ad692e8df5
Key [ 7]:6e67148088a01c2d4491957cc9ddc4aa
Key [ 8]:557431deab7087bb4c03fa27228f60c6
round  5:9c8933bc361f4bde4d1bda2b5f8bb235
Key [ 9]:a2551aca53329e70ade3fd2bb7664697
Key [10]:05d0ad35de68a364b54b56e2138738fe
round  6:9156db34136aa06655bf28a05be0596a
Key [11]:1616a6b13ce2f2895c722e8495181520
Key [12]:b12e78a1114847b01f6ed2f5a1429a23
round  7:84dcc292ed836c1c2d523f2a899a2ad5
Key [13]:316e144364686381944e95afd8a026bb
Key [14]:1ab551b88d39d97ea7a9fe136dbfe2e1
round  8:87bdcac878d777877f4eccf042cfee5e
Key [15]:70e21ab08c23c7544524b64492b25cc9
Key [16]:35f730f2ae2b950a49a1bf5c8b9f8866
Key [17]:2f16924c22db8b74e2eadf1ba4ebd37c
Ka      :983218718ca9aa97892e312d86dd9516
----------------------------------------
rand    :a6dc447ff08d4b366ff96e6cf207e179
PIN length = 7 octets
PIN     :9c57e10b4766cc
address :54ebd9328cb6
round  1:a6dc447ff08d4b366ff96e6cf207e174
Key [ 1]:9c57e10b4766cc54ebd9328cb69c57e1
Key [ 2]:00a609f4d61db26993c8177e3ee2bba8
round  2:1ed26b96a306d7014f4e5c9ee523b73d
Key [ 3]:646d7b5f9aaa528384bda3953b542764
```

Sample Data

```
Key [ 4]:a051a42212c0e9ad5c2c248259aca14e
round  3:a53f526db18e3d7d53edbfc9711041ed
added ->:031b9612411b884b3ce62da583172299
Key [ 5]:d1bd5e64930e7f838d8a33994462d8b2
Key [ 6]:5dc7e2291e32435665ebd6956bec3414
round  4:9438be308ec83f35c560e2796f4e0559
Key [ 7]:10552f45af63b0f15e2919ab37f64fe7
Key [ 8]:c44d5717c114a58b09207392ebe341f8
round  5:b79a7b14386066d339f799c40479cb3d
Key [ 9]:6886e47b782325568eaf59715a75d8ff
Key [10]:8e1e335e659cd36b132689f78c147bda
round  6:ef232462228aa166438d10c34e17424b
Key [11]:8843efeedd5c2b7c3304d647f932f4d1
Key [12]:13785aaedd0adf67abb4f01872392785
round  7:02d133fe40d15f1073673b36bba35abd
Key [13]:837d7ca2722419e6be3fae35900c3958
Key [14]:93f8442973e7fccf2e7232d1d057c73a
round  8:275506a3d08c84e94cc58ed60054505e
Key [15]:8a7a9edffa3c52918bc6a45f57d91f5d
Key [16]:f214a95d777f763c56109882c4b52c84
Key [17]:10e2ee92c5ea1ddc5eb010e55510c403
Ka      :9cd6650ead86323e87cafb1ff516d1e0
----------------------------------------
rand    :3348470a7ea6cc6eb81b40472133262c
PIN length = 6 octets
PIN     :fcad169d7295
address :430d572f8842
round  1:3348470a7ea6cc6eb81b404721332620
Key [ 1]:fcad169d7295430d572f8842fcad169d
Key [ 2]:b3479d4d4fd178c43e7bc5b0c7d8983c
round  2:af976da9225066d563e10ab955e6fc32
Key [ 3]:7112462b37d82dd81a2a35d9eb43cb7c
Key [ 4]:c5a7030f8497945ac7b84600d1d161fb
round  3:d08f826ebd55a0bd7591c19a89ed9bde
added ->:e3d7c964c3fb6cd3cdac01dda820c1fe
Key [ 5]:84b0c6ef4a63e4dff19b1f546d683df5
Key [ 6]:f4023edfc95d1e79ed4bb4de9b174f5d
round  4:6cd952785630dfc7cf81eea625e42c5c
Key [ 7]:ea38dd9a093ac9355918632c90c79993
Key [ 8]:dbba01e278ddc76380727f5d7135a7de
round  5:93573b2971515495978264b88f330f7f
Key [ 9]:d4dc3a31be34e412210fafa6eca00776
Key [10]:39d1e190ee92b0ff16d92a8be58d2fa0
round  6:b3f01d5e7fe1ce6da7b46d8c389baf47
Key [11]:1eb081328d4bcf94c9117b12c5cf22ac
Key [12]:7e047c2c552f9f1414d946775fabfe30
round  7:0b833bff6106d5bae033b4ce5af5a924
Key [13]:e78e685d9b2a7e29e7f2a19d1bc38ebd
Key [14]:1b582272a3121718c4096d2d8602f215
round  8:23de0bbdc70850a7803f4f10c63b2c0f
Key [15]:8569e860530d9c3d48a0870dac33f676
Key [16]:6966b528fdd1dc222527052c8f6cf5a6
```

Sample Data

```
Key [17]:a34244c757154c53171c663b0b56d5c2
Ka      :98f1543ab4d87bd5ef5296fb5e3d3a21
----------------------------------------
rand    :0f5bb150b4371ae4e5785293d22b7b0c
PIN length = 5 octets
PIN     :b10d068bca
address :b44775199f29
round  1:0f5bb150b4371ae4e5785293d22b7b07
Key [ 1]:b10d068bcab44775199f29b10d068bca
Key [ 2]:aec70d1048f1bbd2c18040318a8402ad
round  2:342d2b79d7fb7cd110379742b9842c79
Key [ 3]:6d8d5cf338f29ef4420639ef488e4fa9
Key [ 4]:a1584117541b759ba6d9f7eb2bedcbba
round  3:9407e8e3e810603921bf81cfda62770a
added ->:9b6299b35c477addc437d35c088df20d
Key [ 5]:09a20676666aeed6f22176274eb433f4
Key [ 6]:840472c001add5811a054be5f5c74754
round  4:9a3ba953225a7862c0a842ed3d0b2679
Key [ 7]:fad9e45c8bf70a972fcd9bff0e8751f5
Key [ 8]:e8f30ff666dfd212263416496ff3b2c2
round  5:2c573b6480852e875df34b28a5c44509
Key [ 9]:964cdba0cf8d593f2fc40f96daf8267a
Key [10]:bcd65c11b13e1a70bcd4aafba8864fe3
round  6:21b0cc49e880c5811d24dee0194e6e9e
Key [11]:468c8548ea9653c1a10df6288dd03c1d
Key [12]:5d252d17af4b09d3f4b5f7b5677b8211
round  7:e6d6bdcd63e1d37d9883543ba86392fd
Key [13]:e814bf307c767428c67793dda2df95c7
Key [14]:4812b979fdc20f0ff0996f61673a42cc
round  8:e3dde7ce6bd7d8a34599aa04d6a760ab
Key [15]:5b1e2033d1cd549fc4b028146eb5b3b7
Key [16]:0f284c14fb8fe706a5343e3aa35af7b1
Key [17]:b1f7a4b7456d6b577fded6dc7a672e37
Ka      :c55070b72bc982adb972ed05d1a74ddb
----------------------------------------
rand    :148662a4baa73cfadb55489159e476e1
PIN length = 4 octets
PIN     :fb20f177
address :a683bd0b1896
round  1:148662a4baa73cfadb55489159e476eb
Key [ 1]:fb20f177a683bd0b1896fb20f177a683
Key [ 2]:47266cefbfa468ca7916b458155dc825
round  2:3a942eb6271c3f4e433838a5d3fcbd27
Key [ 3]:688853a6d6575eb2f6a2724b0fbc133b
Key [ 4]:7810df048019634083a2d9219d0b5fe0
round  3:9c835b98a063701c0887943596780769
added ->:8809bd3c1a0aace6d3dcdca4cf5c7d82
Key [ 5]:c78f6dcf56da1bbd413828b33f5865b3
Key [ 6]:eb3f3d407d160df3d293a76d1a513c4a
round  4:7e68c4bafa020a4a59b5a1968105bab5
Key [ 7]:d330e038d6b19d5c9bb0d7285a360064
Key [ 8]:9bd3ee50347c00753d165faced702d9c
```

Sample Data

```
round  5:227bad0cf0838bdb15b3b3872c24f592
Key [ 9]:9543ad0fb3fe74f83e0e2281c6d4f5f0
Key [10]:746cd0383c17e0e80e6d095a87fd0290
round  6:e026e98c71121a0cb739ef6f59e14d26
Key [11]:fa28bea4b1c417536608f11f406ea1dd
Key [12]:3aee0f4d21699df9cb8caf5354a780ff
round  7:cd6a6d8137d55140046f8991da1fa40a
Key [13]:372b71bc6d1aa6e785358044fbcf05f4
Key [14]:00a01501224c0405de00aa2ce7b6ab04
round  8:52cd7257fe8d0c782c259bcb6c9f5942
Key [15]:c7015c5c1d7c030e00897f104a006d4a
Key [16]:260a9577790c62e074e71e19fd2894df
Key [17]:c041b7a231493acd15ddcdaee94b9f52
Ka      :7ec864df2f1637c7e81f2319ae8f4671
----------------------------------------
rand    :193a1b84376c88882c8d3b4ee93ba8d5
PIN length = 3 octets
PIN     :a123b9
address :4459a44610f6
round  1:193a1b84376c88882c8d3b4ee93ba8dc
Key [ 1]:a123b94459a44610f6a123b94459a446
Key [ 2]:5f64d384c8e990c1d25080eb244dde9b
round  2:3badbd58f100831d781ddd3ccedefd3f
Key [ 3]:5abc00eff8991575c00807c48f6dbea5
Key [ 4]:127521158ad6798fb6479d1d2268abe6
round  3:0b53075a49c6bf2df2421c655fdedf68
added ->:128d22de7e3247a5decf572bb61987b4
Key [ 5]:f2a1f620448b8e56665608df2ab3952f
Key [ 6]:7c84c0af02aad91dc39209c4edd220b1
round  4:793f4484fb592e7a78756fd4662f990d
Key [ 7]:f6445b647317e7e493bb92bf6655342f
Key [ 8]:3cae503567c63d3595eb140ce60a84c0
round  5:9e46a8df925916a342f299a8306220a0
Key [ 9]:734ed5a806e072bbecb4254993871679
Key [10]:cda69ccb4b07f65e3c8547c11c0647b8
round  6:6bf9cd82c9e1be13fc58eae0b936c75a
Key [11]:c48e531d3175c2bd26fa25cc8990e394
Key [12]:6d93d349a6c6e9ff5b26149565b13d15
round  7:e96a9871471240f198811d4b8311e9a6
Key [13]:5c4951e85875d663526092cd4cbdb667
Key [14]:f19f7758f5cde86c3791efaf563b3fd0
round  8:e94ca67d3721d5fb08ec069191801a46
Key [15]:bf0c17f3299b37d984ac938b769dd394
Key [16]:7edf4ad772a6b9048588f97be25bde1c
Key [17]:6ee7ba6afefc5b561abbd8d6829e8150
Ka      :ac0daabf17732f632e34ef193658bf5d
----------------------------------------
rand    :1453db4d057654e8eb62d7d62ec3608c
PIN length = 2 octets
PIN     :3eaf
address :411fbbb51d1e
round  1:1453db4d057654e8eb62d7d62ec36084
```

Sample Data

```
Key [ 1]:3eaf411fbbb51d1e3eaf411fbbb51d1e
Key [ 2]:c3a1a997509f00fb4241aba607109c64
round  2:0b78276c1ebc65707d38c9c5fa1372bd
Key [ 3]:3c729833ae1ce7f84861e4dbad6305cc
Key [ 4]:c83a43c3a66595cb8136560ed29be4ff
round  3:23f3f0f6441563d4c202cee0e5cb2335
added ->:3746cbbb418bb73c2964a536cb8e83b1
Key [ 5]:18b26300b86b70acdd1c8f5cbc7c5da8
Key [ 6]:04efc75309b98cd8f1cef5513c18e41e
round  4:c61afa90d3c14bdf588320e857afdc00
Key [ 7]:517c789cecadc455751af73198749fb8
Key [ 8]:fd9711f913b5c844900fa79dd765d0e2
round  5:a8a0e02ceb556af8bfa321789801183a
Key [ 9]:bb5cf30e7d3ceb930651b1d16ee92750
Key [10]:3d97c7862ecab42720e984972f8efd28
round  6:0b58e922438d224db34b68fca9a5ea12
Key [11]:4ce730344f6b09e449dcdb64cd466666
Key [12]:38828c3a56f922186adcd9b713cdcc31
round  7:b90664c4ac29a8b4bb26debec9ffc5f2
Key [13]:d30fd865ea3e9edcff86a33a2c319649
Key [14]:1fdb63e54413acd968195ab6fa424e83
round  8:6934de3067817cefd811abc5736c163b
Key [15]:a16b7c655bbaa262c807cba8ae166971
Key [16]:7903dd68630105266049e23ca607cda7
Key [17]:888446f2d95e6c2d2803e6f4e815ddc9
Ka      :1674f9dc2063cc2b83d3ef8ba692ebef
----------------------------------------
rand    :1313f7115a9db842fcedc4b10088b48d
PIN length = 1 octets
PIN     :6d
address :008aa9be62d5
round  1:1313f7115a9db842fcedc4b10088b48a
Key [ 1]:6d008aa9be62d56d008aa9be62d56d00
Key [ 2]:46ebfeafb6657b0a1984a8dc0893accf
round  2:839b23b83b5701ab095bafd162ec0ac7
Key [ 3]:8e15595edcf058af62498ee3c1dc6098
Key [ 4]:dd409c3444e94b9cc08396ae967542a0
round  3:c0a2010cc44f2139427f093f4f97ae68
added ->:d3b5f81d9eecd97bbe6ccd8e4f1f62e2
Key [ 5]:487deff5d519f6a6481e947b926f633c
Key [ 6]:5b4b6e3477ed5c2c01f6e607d3418963
round  4:1a5517a0efad3575931d8ea3bee8bd07
Key [ 7]:34b980088d2b5fd6b6a2aceeda99c9c4
Key [ 8]:e7d06d06078acc4ecdbc8da800b73078
round  5:d3ce1fdfe716d72c1075ff37a8a2093f
Key [ 9]:7d375bad245c3b757380021af8ecd408
Key [10]:14dac4bc2f4dc4929a6cceec47f4c3a3
round  6:47e90cb55be6e8dd0f583623c2f2257b
Key [11]:66cfda3c63e464b05e2e7e25f8743ad7
Key [12]:77cfccda1ad380b9fdf1df10846b50e7
round  7:f866ae6624f7abd4a4f5bd24b04b6d43
Key [13]:3e11dd84c031a470a8b66ec6214e44cf
```

Sample Data

```
Key [14]:2f03549bdb3c511eea70b65ddbb08253
round  8:02e8e17cf8be4837c9c40706b613dfa8
Key [15]:e2f331229ddfcc6e7bea08b01ab7e70c
Key [16]:b6b0c3738c5365bc77331b98b3fba2ab
Key [17]:f5b3973b636119e577c5c15c87bcfd19
Ka      :38ec0258134ec3f08461ae5c328968a1

========================================
```

10.5 FOUR TESTS OF E3

```
rand    :00000000000000000000000000000000
aco     :48afcdd4bd40fef76693b113
key     :00000000000000000000000000000000
round  1:00000000000000000000000000000000
Key [ 1]:00000000000000000000000000000000
Key [ 2]:4697b1baa3b7100ac537b3c95a28ac64
round  2:78d19f9307d2476a523ec7a8a026042a
Key [ 3]:ecabaac66795580df89af66e66dc053d
Key [ 4]:8ac3d8896ae9364943bfebd4969b68a0
round  3:600265247668dda0e81c07bbb30ed503
Key [ 5]:5d57921fd5715cbb22c1be7bbc996394
Key [ 6]:2a61b8343219fdfb1740e6511d41448f
round  4:d7552ef7cc9dbde568d80c2215bc4277
Key [ 7]:dd0480dee731d67f01a2f739da6f23ca
Key [ 8]:3ad01cd1303e12a1cd0fe0a8af82592c
round  5:fb06bef32b52ab8f2a4f2b6ef7f6d0cd
Key [ 9]:7dadb2efc287ce75061302904f2e7233
Key [10]:c08dcfa981e2c4272f6c7a9f52e11538
round  6:b46b711ebb3cf69e847a75f0ab884bdd
Key [11]:fc2042c708e409555e8c147660ffdfd7
Key [12]:fa0b21001af9a6b9e89e624cd99150d2
round  7:c585f308ff19404294f06b292e978994
Key [13]:18b40784ea5ba4c80ecb48694b4e9c35
Key [14]:454d54e5253c0c4a8b3fcca7db6baef4
round  8:2665fadb13acf952bf74b4ab12264b9f
Key [15]:2df37c6d9db52674f29353b0f011ed83
Key [16]:b60316733b1e8e70bd861b477e2456f1
Key [17]:884697b1baa3b7100ac537b3c95a28ac
round  1:5d3ecb17f26083df0b7f2b9b29aef87c
Key [ 1]:e9e5dfc1b3a79583e9e5dfc1b3a79583
Key [ 2]:7595bf57e0632c59f435c16697d4c864
round  2:de6fe85c5827233fe22514a16f321bd8
Key [ 3]:e31b96afcc75d286ef0ae257cbbc05b7
Key [ 4]:0d2a27b471bc0108c6263aff9d9b3b6b
round  3:7cd335b50d09d139ea6702623af85edb
added ->:211100a2ff6954e6e1e62df913a656a7
Key [ 5]:98d1eb5773cf59d75d3b17b3bc37c191
Key [ 6]:fd2b79282408ddd4ea0aa7511133336f
round  4:991dccb3201b5b1c4ceff65a3711e1e9
Key [ 7]:331227756638a41d57b0f7e071ee2a98
```

Sample Data

```
Key [ 8]:aa0dd8cc68b406533d0f1d64aabacf20
round  5:18768c7964818805fe4c6ecae8a38599
Key [ 9]:669291b0752e63f806fce76f10e119c8
Key [10]:ef8bdd46be8ee0277e9b78adef1ec154
round  6:82f9aa127a72632af43d1a17e7bd3a09
Key [11]:f3902eb06dc409cfd78384624964bf51
Key [12]:7d72702b21f97984a721c99b0498239d
round  7:1543d7870bf2d6d6efab3cbf62dca97d
Key [13]:532e60bceaf902c52a06c2c283ecfa32
Key [14]:181715e5192efb2a64129668cf5d9dd4
round  8:eee3e8744a5f8896de95831ed837ffd5
Key [15]:83017c1434342d4290e961578790f451
Key [16]:2603532f365604646ff65803795ccce5
Key [17]:882f7c907b565ea58dae1c928a0dcf41
kc      :cc802aecc7312285912e90af6a1e1154
----------------------------------------
rand    :950e604e655ea3800fe3eb4a28918087
aco     :68f4f472b5586ac5850f5f74
key     :34e86915d20c485090a6977931f96df5
round  1:950e604e655ea3800fe3eb4a28918087
Key [ 1]:34e86915d20c485090a6977931f96df5
Key [ 2]:8de2595003f9928efaf37e5229935bdb
round  2:d46f5a04c967f55840f83d1cdb5f9afc
Key [ 3]:46f05ec979a97cb6ddf842ecc159c04a
Key [ 4]:b468f0190a0a83783521deae8178d071
round  3:e16ededе9cb6297f32e1203e442ac73a
Key [ 5]:8a171624dedbd552356094daaadcf12a
Key [ 6]:3085e07c85e4b99313f6e0c837b5f819
round  4:805144e55e1ece96683d23366fc7d24b
Key [ 7]:fe45c27845169a66b679b2097d147715
Key [ 8]:44e2f0c35f64514e8bec66c5dc24b3ad
round  5:edbaf77af070bd22e9304398471042f1
Key [ 9]:0d534968f3803b6af447eaf964007e7b
Key [10]:f5499a32504d739ed0b3c547e84157ba
round  6:0dab1a4c846aef0b65b1498812a73b50
Key [11]:e17e8e456361c46298e6592a6311f3fb
Key [12]:ec6d14da05d60e8abac807646931711f
round  7:1e7793cac7f55a8ab48bd33bc9c649e0
Key [13]:2b53dde3d89e325e5ff808ed505706ae
Key [14]:41034e5c3fb0c0d4f445f0cf23be79b0
round  8:3723768baa78b6a23ade095d995404da
Key [15]:e2ca373d405a7abf22b494f28a6fd247
Key [16]:74e09c9068c0e8f1c6902d1b70537c30
Key [17]:767a7f1acf75c3585a55dd4a428b2119
round  1:39809afb773efd1b7510cd4cb7c49f34
Key [ 1]:1d0d48d485abddd3798b483a82a0f878
Key [ 2]:aed957e600a5aed5217984dd5fef6fd8
round  2:6436ddbabe92655c87a7d0c12ae5e5f6
Key [ 3]:fee00bb0de89b6ef0a289696a4faa884
Key [ 4]:33ce2f4411db4dd9b7c42cc586b8a2ba
round  3:cec690f7e0aa5f063062301e049a5cc5
added ->:f7462a0c97e85c1d4572fd52b35efbf1
```

Sample Data

```
Key [ 5]:b5116f5c6c29e05e4acb4d02a46a3318
Key [ 6]:ff4fa1f0f73d1a3c67bc2298abc768f9
round  4:dcdfe942e9f0163fc24a4718844b417d
Key [ 7]:5453650c0819e001e48331ad0e9076e0
Key [ 8]:b4ff8dda778e26c0dce08349b81c09a1
round  5:265a16b2f766afae396e7a98c189fda9
Key [ 9]:f638fa294427c6ed94300fd823b31d10
Key [10]:1ccfa0bd86a9879b17d4bc457e3e03d6
round  6:628576b5291d53d1eb8611c8624e863e
Key [11]:0eaee2ef4602ac9ca19e49d74a76d335
Key [12]:6e1062f10a16e0d378476da3943842e9
round  7:d7b9c2e9b2d5ea5c27019324cae882b3
Key [13]:40be960bd22c744c5b23024688e554b9
Key [14]:95c9902cb3c230b44d14ba909730d211
round  8:97fb6065498385e47eb3df6e2ca439dd
Key [15]:10d4b6e1d1d6798aa00aa2951e32d58d
Key [16]:c5d4b91444b83ee578004ab8876ba605
Key [17]:1663a4f98e2862eddd3ec2fb03dcc8a4
kc      :c1beafea6e747e304cf0bd7734b0a9e2
----------------------------------------
rand    :6a8ebcf5e6e471505be68d5eb8a3200c
aco     :658d791a9554b77c0b2f7b9f
key     :35cf77b333c294671d426fa79993a133
round  1:6a8ebcf5e6e471505be68d5eb8a3200c
Key [ 1]:35cf77b333c294671d426fa79993a133
Key [ 2]:c4524e53b95b4bf2d7b2f095f63545fd
round  2:ade94ec585db0d27e17474b58192c87a
Key [ 3]:c99776768c6e9f9dd3835c52cea8d18a
Key [ 4]:f1295db23823ba2792f21217fc01d23f
round  3:da8dc1a10241ef9e6e069267cd2c6825
Key [ 5]:9083db95a6955235bbfad8aeefec5f0b
Key [ 6]:8bab6bc253d0d0c7e0107feab728ff68
round  4:e6665ca0772ceecbc21222ff7be074f8
Key [ 7]:2fa1f4e7a4cf3ccd876ec30d194cf196
Key [ 8]:267364be247184d5337586a19df8bf84
round  5:a857a9326c9ae908f53fee511c5f4242
Key [ 9]:9aef21965b1a6fa83948d107026134c7
Key [10]:d2080c751def5dc0d8ea353cebf7b973
round  6:6678748a1b5f21ac05cf1b117a7c342f
Key [11]:d709a8ab70b0d5a2516900421024b81e
Key [12]:493e4843805f1058d605c8d1025f8a56
round  7:766c66fe9c460bb2ae39ec01e435f725
Key [13]:b1ed21b71daea03f49fe74b2c11fc02b
Key [14]:0e1ded7ebf23c72324a0165a698c65c7
round  8:396e0ff7b2b9b7a3b35c9810882c7596
Key [15]:b3bf4841dc92f440fde5f024f9ce8be9
Key [16]:1c69bc6c2994f4c84f72be8f6b188963
Key [17]:bb7b66286dd679a471e2792270f3bb4d
round  1:45654f2f26549675287200f07cb10ec9
Key [ 1]:1e2a5672e66529e4f427b0682a3a34b6
Key [ 2]:974944f1ce0037b1febcf61a2bc961a2
round  2:990cd869c534e76ed4f4af7b3bfbc6c8
```

Sample Data

```
Key [ 3]:8147631fb1ce95d624b480fc7389f6c4
Key [ 4]:6e90a2db33d284aa13135f3c032aa4f4
round  3:ceb662f875aa6b94e8192b5989abf975
added ->:8b1bb1d753fe01e1c08b2ba9f55c07bc
Key [ 5]:cbad246d24e36741c46401e6387a05f9
Key [ 6]:dcf52aaec5713110345a41342c566fc8
round  4:d4e000be5de78c0f56ff218f3c1df61b
Key [ 7]:8197537aa9d27e67d17c16b182c8ec65
Key [ 8]:d66e00e73d835927a307a3ed79d035d8
round  5:9a4603bdef954cfaade2052604bed4e4
Key [ 9]:71d46257ecc1022bcd312ce6c114d75c
Key [10]:f91212fa528379651fbd2c32890c5e5f
round  6:09a0fd197ab81eb933eece2fe0132dbb
Key [11]:283acc551591fadce821b02fb9491814
Key [12]:ca5f95688788e20d94822f162b5a3920
round  7:494f455a2e7a5db861ece816d4e363e4
Key [13]:ba574aef663c462d35399efb999d0e40
Key [14]:6267afc834513783fef1601955fe0628
round  8:37a819f91c8380fb7880e640e99ca947
Key [15]:fdcd9be5450eef0f8737e6838cd38e2b
Key [16]:8cfbd9b8056c6a1ce222b92b94319b38
Key [17]:4f64c1072c891c39eeb95e63318462e0
kc      :a3032b4df1cceba8adc1a04427224299
----------------------------------------
rand    :5ecd6d75db322c75b6afbd799cb18668
aco     :63f701c7013238bbf88714ee
key     :b9f90c53206792b1826838b435b87d4d
round  1:5ecd6d75db322c75b6afbd799cb18668
Key [ 1]:b9f90c53206792b1826838b435b87d4d
Key [ 2]:15f74bbbde4b9d1e08f858721f131669
round  2:72abb85fc80c15ec2b00d72873ef9ad4
Key [ 3]:ef7fb29f0b01f82706c7439cc52f2dab
Key [ 4]:3003a6aecdee06b9ac295cce30dcdb93
round  3:2f10bab93a0f73742183c68f712dfa24
Key [ 5]:5fcdbb3afdf7df06754c954fc6340254
Key [ 6]:ddaa90756635579573fe8ca1f93d4a38
round  4:183b145312fd99d5ad08e7ca4a52f04e
Key [ 7]:27ca8a7fc703aa61f6d7791fc19f704a
Key [ 8]:702029d8c6e42950762317e730ec5d18
round  5:cbad52d3a026b2e38b9ae6fefffecc32
Key [ 9]:ff15eaa3f73f4bc2a6ccfb9ca24ed9c5
Key [10]:034e745246cd2e2cfc3bda39531ca9c5
round  6:ce5f159d0a1acaacd9fb4643272033a7
Key [11]:0a4d8ff5673731c3dc8fe87e39a34b77
Key [12]:637592fab43a19ac0044a21afef455a2
round  7:8a49424a10c0bea5aba52dbbffcbcce8
Key [13]:6b3fde58f4f6438843cdbe92667622b8
Key [14]:a10bfa35013812f39bf2157f1c9fca4e
round  8:f5e12da0e93e26a5850251697ec0b917
Key [15]:2228fe5384e573f48fdd19ba91f1bf57
Key [16]:5f174db2bc88925c0fbc6b5485bafc08
Key [17]:28ff90bd0dc31ea2bb479feb7d8fe029
```

Sample Data

```
round  1:0c75eed2b54c1cfb9ff522daef94ed4d
Key [ 1]:a21ceb92d3c027326b4de775865fe8d0
Key [ 2]:26f64558a9f0a1652f765efd546f3208
round  2:48d537ac209a6aa07b70000016c602e8
Key [ 3]:e64f9ef630213260f1f79745a0102ae5
Key [ 4]:af6a59d7cebfd0182dcca9a537c4add8
round  3:8b6d517ac893743a401b3fb7911b64e1
added ->:87e23fa87ddf90c1df10616d7eaf51ac
Key [ 5]:9a6304428b45da128ab64c8805c32452
Key [ 6]:8af4d1e9d80cb73ec6b44e9b6e4f39d8
round  4:9f0512260a2f7a5067efc35bf1706831
Key [ 7]:79cc2d138606f0fca4e549c34a1e6d19
Key [ 8]:803dc5cdde0efdbee7a1342b2cd4d344
round  5:0cfd7856edfafac51f29e86365de6f57
Key [ 9]:e8fa996448e6b6459ab51e7be101325a
Key [10]:2acc7add7b294acb444cd933f0e74ec9
round  6:2f1fa34bf352dc77c0983a01e8b7d622
Key [11]:f57de39e42182efd6586b86a90c86bb1
Key [12]:e418dfd1bb22ebf1bfc309cd27f5266c
round  7:ee4f7a53849bf73a747065d35f3752b1
Key [13]:80a9959133856586370854db6e0470b3
Key [14]:f4c1bc2f764a0193749f5fc09011a1ae
round  8:8fec6f7249760ebf69e370e9a4b80a92
Key [15]:d036cef70d6470c3f52f1b5d25b0c29d
Key [16]:d0956af6b8700888a1cc88f07ad226dc
Key [17]:1ce8b39c4c7677373c30849a3ee08794
kc      :ea520cfc546b00eb7c3a6cea3ecb39ed

========================================
```

11 CONNECTIONLESS SLAVE BROADCAST SAMPLE DATA

This section contains an example of the DM3 packet used for the synchronization train (see [Vol 2] Part B, Section 8.11.2).

```
Packet header: (MSB...LSB)
--------------------------
LT_ADDR = 0
TYPE = 1010 (DM3)
FLOW = 0
ARQN = 0
SEQN = 0

Payload:
--------
logical channel = 10 (binary) (L2CAP start or no fragmentation)
payload length = 28 bytes
flow = 0
current CLK = 0x2345678
next connectionless slave broadcast instant = 0x23457a0
AFH channel map = all channels used except 16 and 42 to 47
master BD_ADDR = NAP 0xACDE, UAP 0x48, LAP 0x610316
connectionless slave broadcast interval = 564 slots
connectionless slave broadcast LT_ADDR = 1
service data = 0x69


AIR DATA

Packet header (including HEC, in transmitted bit order):
--------------------------------------------------------
000000000
000111000111
000
000
000
111111111000000000000111

Payload
-------
The data forming the payload consists of the following 32 octets
(given in hexadecimal) in the order transmitted:

e2 00
78 56 34 02
d0 2b 1a 01
ff ff fe ff ff 03 ff ff ff 7f
16 03 61 48 de ac
34 02
01
69
f2 85
```

Sample Data

```
The bit sequence transmitted (including FEC) will therefore begin:

0100011100 01001
0000000001 10101
1110011010 11011

and end:

0100111110 10001
1000010000 00011
```

SECURITY SPECIFICATION

This document describes the specification of the security system which may be used at the link layer. The Encryption, Authentication and Key Generation schemes are specified. The requirements for the supporting process of random number generation are also specified.

CONTENTS

1 SECURITY OVERVIEW

Bluetooth wireless technology provides peer-to-peer communications over short distances. In order to provide usage protection and information confidentiality, the system provides security measures both at the application layer and the link layer. These measures are designed to be appropriate for a peer environment.

This means that in each device, the authentication and encryption routines are implemented in the same way.

The security mechanisms used in BR/EDR have evolved over the course of multiple Core Specifications in three phases: legacy, Secure Simple Pairing, and Secure Connections. The encryption, authentication and key generation algorithms associated with each is shown in Table 1.1.

Security Mechanism	Legacy	Secure Simple Pairing	Secure Connections
Encryption	E0	E0	AES-CCM
Authentication	SAFER+	SAFER+	HMAC-SHA256
Key Generation	SAFER+	P-192 ECDH HMAC-SHA-256	P-256 ECDH HMAC-SHA-256

Table 1.1: Security algorithms

The legacy encryption, authentication and key generation algorithms are described in Section 3 to 6. The algorithms used for Secure Simple Pairing and Secure Connections are described in Section 7 to 9.

Four different entities are used for maintaining security at the link layer: a Bluetooth device address, two secret keys, and a pseudo-random number that shall be regenerated for each new transaction. The four entities and their sizes are summarized in Table 1.2.

Entity	Size
BD_ADDR	48 bits
Private user key, authentication	128 bits
Private user key, encryption configurable length (byte-wise)	8-128 bits
RAND	128 bits

Table 1.2: Entities used in authentication and encryption procedures.

The Bluetooth device address (BD_ADDR) is the 48-bit address. The BD_ADDR can be obtained via user interactions, or, automatically, via an inquiry routine by a device.

The secret keys are derived during initialization and are never disclosed. The encryption key is derived from the authentication key during the authentication process. For the authentication algorithm, the size of the key used is always 128 bits. For the encryption algorithm, the key size may vary between 1 and 16 octets (8 - 128 bits). The size of the encryption key is configurable for two reasons. The first has to do with the many different requirements imposed on cryptographic algorithms in different countries – both with respect to export regulations and official attitudes towards privacy in general. The second reason is to facilitate a future upgrade path for the security without the need of a costly redesign of the algorithms and encryption hardware; increasing the effective key size is the simplest way to combat increased computing power at the opponent side.

The encryption key is entirely different from the authentication key. Each time encryption is activated, a new encryption key shall be generated. Thus, the lifetime of the encryption key does not necessarily correspond to the lifetime of the authentication key.

It is anticipated that the authentication key will be more static in its nature than the encryption key – once established, the particular application running on the device decides when, or if, to change it. To underline the fundamental importance of the authentication key to a specific link, it is often referred to as the link key.

The RAND is a pseudo-random number which can be derived from a random or pseudo-random process in the device. This is not a static parameter and will change frequently.

In the remainder of this chapter, the terms user and application are used interchangeably to designate the entity that is at either side.

1.1 PAUSING ENCRYPTION AND ROLE SWITCH

To perform a role switch on a connection encryption must be disabled or paused as the encryption is based off the master's clock and Bluetooth address information. Unfortunately, if the role switch is required, and encryption is turned off, the device on the other end of the link will not be aware of the reason for disabling encryption, and can therefore take two possible actions: send clear text data, or disconnect. Neither of these possible actions is desirable. When performing a role switch on an encrypted link, the role switch shall be performed as a single operation where possible. If this is not possible because the other device does not support the encryption pause feature, then when a device wishes to have an encrypted link, and encryption is disabled, then the device should not send any user data, and should not disconnect. If both devices support the encryption pause feature, then this procedure shall be used.

1.2 CHANGE CONNECTION LINK KEYS

It is possible to perform a change of connection link keys while a link is encrypted, but it is not possible to use the new link keys until encryption has been stopped and then restarted. As with role switches, disabling encryption and then re-enabling it again can cause user data to be sent in the clear or a disconnection to occur. The use of encryption pausing prevents this problem from occurring. On devices that do not support the encryption pause feature, when a device wishes to have an encrypted link, and encryption is disabled, then the device should not send any data, and should not disconnect. If both devices support the encryption pause feature, then this procedure shall be used.

1.3 PERIODICALLY REFRESHING ENCRYPTION KEYS

If both devices support the encryption pause feature, then the encryption keys shall be refreshed by the Link Manager at least once every 2^{28} Bluetooth Clocks (about 23.3 hours) when E0 encryption is used and before the PayloadCounter or dayCounter roll over (at least 2^{38} Bluetooth Clocks or at least 2.72 years) when AES-CCM encryption is used if it is not refreshed by the Host or the remote Link Manager. To refresh an encryption key, the Host may use the Change Connection Link Key procedure or request an encryption key refresh. If the encryption key has not been refreshed before going stale, a device may disconnect the link.

2 RANDOM NUMBER GENERATION

Each device has a pseudo-random number generator. Pseudo-random numbers are used for many purposes within the security functions – for instance, for the challenge-response scheme, for generating authentication and encryption keys, nonces used in Simple Pairing, for Passkeys used in authentication. A device shall use a pseudo random number generator compliant with [FIPS PUB 140-2] (http://csrc.nist.gov/publications/fips/fips140-2/fips1402annexc.pdf).

An example of a possible random generator is provided in [FIPS PUB 186-2] Appendix 3.1 (http://dx.doi.org/10.6028/NIST.FIPS.186-4), which can be used by replacing SHA-1 function with the SHA-256 function.

The device shall use a seed with at least the minimum entropy required by the pseudo random number generator.

The random number generator shall be tested against the [FIPS SP800-22] (http://csrc.nist.gov/publications/nistpubs/800-22-rev1a/SP800-22rev1a.pdf). This encompasses the verification of the following statistical tests performed on the output of the PRNG as specified by the [FIPS SP800-22]:

1. The Frequency (Monobit) Test
2. Frequency Test within a Block
3. The Runs Test
4. Test for the Longest-Run-of-Ones in a Block
5. The Binary Matrix Rank Test
6. The Discrete Fourier Transform (Spectral) Test
7. The Non-overlapping Template Matching Test
8. The Overlapping Template Matching Test
9. Maurer's "Universal Statistical" Test
10. The Linear Complexity Test
11. The Serial Test
12. The Approximate Entropy Test
13. The Cumulative Sums (Cusums) Test
14. The Random Excursions Test
15. The Random Excursions Variant Test

These tests are part of standard statistical mathematical packages. Some test suites, like the Diehard test suite can be used to verify the compliance. Alternatively, other tools, such as the DieHarder (http://www.phy.duke.edu/~rgb/General/rand_rate.php) or the available NIST tools (http://csrc.nist.gov/groups/ST/toolkit/random_number.html) and the corresponding recommendations (http://csrc.nist.gov/publications/nistpubs/800-22-rev1/SP800-22rev1.pdf) may also be used.

3 KEY MANAGEMENT

It is important that the encryption key size within a specific device cannot be set by the user – this should be a factory preset entity. In order to prevent the user from over-riding the permitted key size, the Bluetooth baseband processing shall not accept an encryption key given from higher software layers. Whenever a new encryption key is required, it shall be created as defined in Section 6.4.

Changing a link key shall also be done through the defined baseband procedures. Depending on what kind of link key it is, different approaches are required. The details are found in Section 3.2.7.

3.1 KEY TYPES

The link key is a 128-bit random number which is shared between two or more parties and is the base for all security transactions between these parties. The link key itself is used in the authentication routine. Moreover, the link key is used as one of the parameters when the encryption key is derived.

In the following, a session is defined as the time interval for which the device is a member of a particular piconet. Thus, the session terminates when the device disconnects from the piconet.

The link keys are either semi-permanent or temporary. A semi-permanent link key may be stored in non-volatile memory and may be used after the current session is terminated. Consequently, once a semi-permanent link key is defined, it may be used in the authentication of several subsequent connections between the devices sharing it. The designation semi-permanent is justified by the possibility of changing it. How to do this is described in Section 3.2.7.

The lifetime of a temporary link key is limited by the lifetime of the current session – it shall not be reused in a later session. Typically, in a point-to-multipoint configuration where the same information is to be distributed securely to several recipients, a common encryption key is useful. To achieve this, a special link key (denoted master key) may temporarily replace the current link keys. The details of this procedure are found in Section 3.2.6.

In the following, the current link key is the link key in use at the current moment. It can be semi-permanent or temporary. Thus, the current link key is used for all authentications and all generation of encryption keys in the on-going connection (session).

In order to accommodate different types of applications, four types of link keys have been defined:

- the combination key K_{AB}
- the unit key K_A
- the temporary key K_{master}
- the initialization key K_{init}

Note: The use of unit keys is deprecated since it is implicitly insecure.

In addition to these keys there is an encryption key, denoted K_c. This key is derived from the current link key. Whenever encryption is activated by an LM command, the encryption key shall be changed automatically. The purpose of separating the authentication key and encryption key is to facilitate the use of a shorter encryption key without weakening the strength of the authentication procedure. There are no governmental restrictions on the strength of authentication algorithms. However, in some countries, such restrictions exist on the strength of encryption algorithms.

The combination key K_{AB} and the unit key K_A are functionally indistinguishable; the difference is in the way they are generated. The unit key K_A is generated in, and therefore dependent on, a single device A. The unit key shall be generated once at installation of the device; thereafter, it is very rarely changed. The combination key is derived from information in both devices A and B, and is therefore always dependent on two devices. The combination key is derived for each new combination of two devices.

It depends on the application or the device whether a unit key or a combination key is used. Devices which have little memory to store keys, or are installed in equipment that will be accessible to a large group of users, should use their own unit key. In that case, they only have to store a single key. Applications that require a higher security level should use the combination keys. These applications will require more memory since a combination key for each link to a different device has to be stored.

The master key, K_{master}, shall only be used during the current session. It shall only replace the original link key temporarily. For example, this may be utilized when a master wants to reach more than two devices simultaneously using the same encryption key, see Section 3.2.6.

The initialization key, K_{init}, shall be used as the link key during the initialization process when no combination or unit keys have been defined and exchanged yet or when a link key has been lost. The initialization key protects the transfer of initialization parameters. The key is derived from a random number, an L-octet PIN code, and a BD_ADDR. This key shall only be used during initialization.

The PIN may be a fixed number provided with the device (for example when there is no user interface as in a PSTN plug). Alternatively, the PIN can be

selected by the user, and then entered in both devices that are to be matched. The latter procedure should be used when both devices have a user interface, for example a phone and a laptop. Entering a PIN in both devices is more secure than using a fixed PIN in one of the devices, and should be used whenever possible. Even if a fixed PIN is used, it shall be possible to change the PIN; this is in order to prevent re-initialization by users who once obtained the PIN. If no PIN is available, a default value of zero may be used. The length of this default PIN is one byte, PIN (default) = 0x00. This default PIN may be provided by the Host.

For many applications the PIN code will be a relatively short string of numbers. Typically, it may consist of only four decimal digits. Even though this gives sufficient security in many cases, there exist countless other, more sensitive, situations where this is not reliable enough. Therefore, the PIN code may be chosen to be any length from 1 to 16 octets. For the longer lengths, the devices exchanging PIN codes may use software at the application layer rather than mechanical (i.e. human) interaction. For example, this can be a Diffie-Hellman key agreement, where the exchanged key is passed on to the K_{init} generation process in both devices, just as in the case of a shorter PIN code.

3.2 KEY GENERATION AND INITIALIZATION

The link keys must be generated and distributed among the devices in order to be used in the authentication procedure. Since the link keys shall be secret, they shall not be obtainable through an inquiry routine in the same way as the Bluetooth device addresses. The exchange of the keys takes place during an initialization phase which shall be carried out separately for each two devices that are using authentication and encryption. The initialization procedures consist of the following five parts:

- generation of an initialization key
- generation of link key
- link key exchange
- authentication
- generation of encryption key in each device (optional)

After the initialization procedure, the devices can proceed to communicate, or the link can be disconnected. If encryption is implemented, the E_0 algorithm shall be used with the proper encryption key derived from the current link key. For any new connection established between devices A and B, they should use the common link key for authentication, instead of once more deriving K_{init} from the PIN. A new encryption key derived from that particular link key shall be created next time encryption is activated.

If no link key is available, the LM shall automatically start an initialization procedure.

3.2.1 Generation of Initialization Key, K_{init}

A link key is used temporarily during initialization, the initialization key K_{init}. This key shall be derived by the E_{22} algorithm from a BD_ADDR, a PIN code, the length of the PIN (in octets), and a random number IN_RAND. The principle is depicted in Figure 6.4. The 128-bit output from E_{22} shall be used for key exchange during the generation of a link key. When the devices have performed the link key exchange, the initialization key shall be discarded.

When the initialization key is generated, the PIN is augmented with the BD_ADDR. If one device has a fixed PIN the BD_ADDR of the other device shall be used. If both devices have a variable PIN the BD_ADDR of the device that received IN_RAND shall be used. If both devices have a fixed PIN they cannot be paired. Since the maximum length of the PIN used in the algorithm cannot exceed 16 octets, it is possible that not all octets of BD_ADDR will be used. This procedure ensures that K_{init} depends on the identity of the device with a variable PIN. A fraudulent device may try to test a large number of PINs by claiming another BD_ADDR each time. It is the application's responsibility to take countermeasures against this threat. If the device address is kept fixed, the waiting interval before the next try may be increased exponentially (see Section 5.1).

The details of the E_{22} algorithm can be found in Section 6.3.

3.2.2 Authentication

The legacy authentication procedure shall be carried out as described in Section 5. During each legacy authentication, a new AU_RAND_A shall be issued.

For legacy authentication, mutual authentication is achieved by first performing the authentication procedure in one direction and then immediately performing the authentication procedure in the opposite direction.

The secure authentication procedure is always a mutual authentication. Secure authentication shall be carried out as described in Section 7.7.8. During each secure authentication, new AU_RAND_M and AU_RAND_S shall be used.

As a side effect of a successful authentication procedure an auxiliary parameter, the Authenticated Ciphering Offset (ACO), will be computed. The ACO shall be used for ciphering key generation as described in Section 3.2.5.

The claimant/verifier status is determined by the LM.

3.2.3 Generation of a Unit Key

A unit key K_A shall be generated when the device is in operation for the first time; i.e. not during each initialization. The unit key shall be generated by the E_{21} algorithm as described in Section 6.3. Once created, the unit key should be stored in non-volatile memory and very rarely changed. If after initialization the

unit key is changed, any previously initialized devices will possess a wrong link key. At initialization, the application must determine which of the two parties will provide the unit key as the link key. Typically, this will be the device with restricted memory capabilities, since this device only has to remember its own unit key. The unit key shall be transferred to the other party and then stored as the link key for that particular party. So, for example in Figure 3.1, the unit key of device A, K_A, is being used as the link key for the connection A-B; device A sends the unit key K_A to device B; device B will store K_A as the link key K_{BA}. For another initialization, for example with device C, device A will reuse its unit key K_A, whereas device C stores it as K_{CA}.

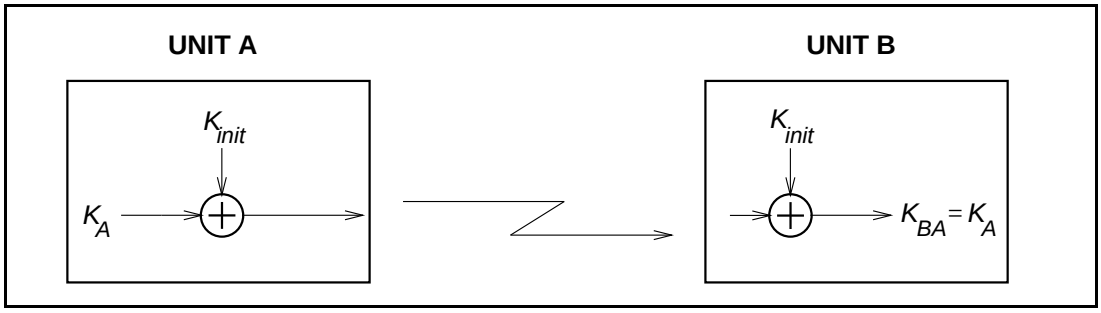

Figure 3.1: Generation of unit key. When the unit key has been exchanged, the initialization key is discarded in both devices.

3.2.4 Generation of a Combination Key

To use a combination key, it is first generated during the initialization procedure. The combination key is the combination of two numbers generated in device A and B, respectively. First, each device shall generate a random number, LK_RAND_A and LK_RAND_B. Then, utilizing E_{21} with the random number and their own BD_ADDRs, the two random numbers

$$LK\_K_A = E_{21}(LK\_RAND_A, BD\_ADDR_A), \quad \text{(EQ 1)}$$

and

$$LK\_K_B = E_{21}(LK\_RAND_B, BD\_ADDR_B), \quad \text{(EQ 2)}$$

shall be created in device A and device B, respectively. These numbers constitute the devices' contribution to the combination key that is to be created. Then, the two random numbers LK_RAND_A and LK_RAND_B shall be exchanged securely by XORing with the current link key, K. Thus, device A shall send $K \oplus LK\_RAND_A$ to device B, while device B shall send $K \oplus LK\_RAND_B$ to device A. If this is done during the initialization phase the link key $K = K_{init}$.

When the random numbers LK_RAND_A and LK_RAND_B have been mutually exchanged, each device shall recalculate the other device's contribution to the combination key. This is possible since each device knows the Bluetooth device address of the other device. Thus, device A shall calculate (EQ 2) and device B shall calculate (EQ 1). After this, both devices shall combine the two

numbers to generate the 128-bit link key. The combining operation is a simple bitwise modulo-2 addition (i.e. XOR). The result shall be stored in device A as the link key K_{AB} and in device B as the link key K_{BA}. When both devices have derived the new combination key, a mutual authentication procedure shall be initiated to confirm the success of the transaction. The old link key shall be discarded after a successful exchange of a new combination key. The message flow between master and slave and the principle for creating the combination key is depicted in Figure 3.2.

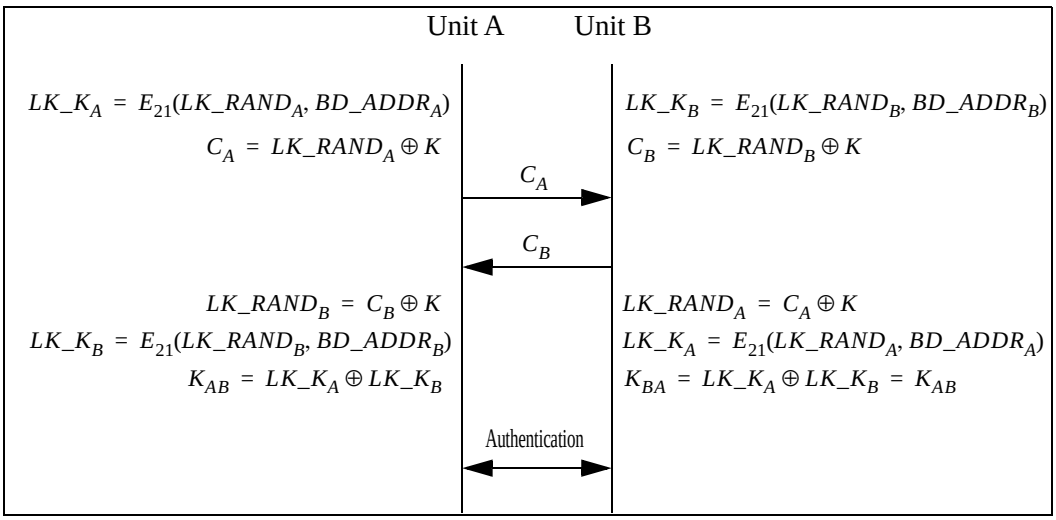

Figure 3.2: Generating a combination key. The old link key (K) is discarded after the exchange of a new combination key has succeeded

3.2.5 Generating the Encryption Key

The encryption key, K_C, is derived by algorithm E_3 from the current link key, a 96-bit Ciphering OFfset number (COF), and a 128-bit random number. The COF is determined in one of two ways. If the current link key is a master key, then COF shall be derived from the master BD_ADDR. Otherwise the value of COF shall be set to the value of ACO as computed during the authentication procedure. Therefore:[1]

$$\text{COF} = \begin{cases} \text{BD\_ADDR} \cup \text{BD\_ADDR}, & \text{if link key is a master key} \\ \text{ACO}, & \text{otherwise.} \end{cases} \quad \text{(EQ 3)}$$

There is an explicit call of E_3 when the LM activates encryption. Consequently, the encryption key is automatically changed each time the device enters encryption mode. The details of the key generating function E_3 can be found in Section 6.4.

1. $x \cup y$ denotes the concatenation of x and y.

3.2.6 Point-to-Multipoint Configuration

It is possible for the master to use separate encryption keys for each slave in a point-to-multipoint configuration with ciphering activated. Then, if the application requires more than one slave to listen to the same payload, each slave must be addressed individually. This can cause unwanted capacity loss for the piconet. Moreover, a slave might not be capable of switching between two or more encryption keys in real time (e.g., after looking at the LT_ADDR in the header). Thus, the master cannot use different encryption keys for broadcast messages and individually addressed traffic. Therefore, the master may tell several slave devices to use a common link key (and, hence, indirectly also to use a common encryption key) and may then broadcast the information encrypted. For many applications, this key is only of temporary interest. In the following discussion, this key is denoted by K_{master}.

The transfer of necessary parameters shall be protected by the routine described in Section 3.2.8. After the confirmation of successful reception in each slave, the master shall issue a command to the slaves to replace their respective current link key by the new (temporary) master key. Before encryption can be activated, the master shall also generate and distribute a common EN_RAND to all participating slaves. Using this random number and the newly derived master key, each slave shall generate a new encryption key.

Note that the master must negotiate the encryption key length to use individually with each slave that will use the master key. If the master has already negotiated with some of these slaves, it has knowledge of the sizes that can be accepted. There may be situations where the permitted key lengths of some devices are incompatible. In that case, the master must exclude the limiting device from the group.

When all slaves have received the necessary data, the master can communicate information on the piconet securely using the encryption key derived from the new temporary link key. Each slave in possession of the master key can eavesdrop on all encrypted traffic, not only the traffic intended for itself. The master may tell all participants to fall back to their old link keys simultaneously.

3.2.7 Modifying the Link Keys

A link key based on a unit key can be changed. The unit key is created once during first use. Typically, the link key should be changed rather than the unit key, as several devices may share the same unit key as link key (e.g. a printer whose unit key is distributed to all users using the printer's unit key as link key). Changing the unit key will require re-initialization of all devices connecting. Changing the unit key can be justified in some circumstances, e.g. to deny access to all previously allowed devices.

If the key change concerns combination keys, then the procedure is straightforward. The change procedure is identical to the procedure described

in Figure 3.2, using the current value of the combination key as link key. This procedure can be carried out at any time after the authentication and encryption start. Since the combination key corresponds to a single link, it can be modified each time this link is established. This will improve the security of the system since then old keys lose their validity after each session.

Starting up an entirely new initialization procedure is also possible. In that case, user interaction is necessary since a PIN will be required in the authentication and encryption procedures.

3.2.8 Generating a Master Key

The key-change routines described so far are semi-permanent. To create the master link key, which can replace the current link key during a session (see Section 3.2.6), other means are needed. First, the master shall create a new link key from two 128-bit random numbers, RAND1 and RAND2. This shall be done by

$$K_{master} = E_{22}(\text{RAND1}, \text{RAND2}, 16). \quad \text{(EQ 4)}$$

This key is a 128-bit random number. The reason for using the output of E_{22} and not directly choosing a random number as the key, is to avoid possible problems with degraded randomness due to a poor implementation of the random number generator within the device.

Then, a third random number, RAND, shall be transmitted to the slave. Using E_{22} with the current link key and RAND as inputs, both the master and the slave shall compute a 128-bit overlay. The master shall send the bitwise XOR of the overlay and the new link key to the slave. The slave, who knows the overlay, shall recalculate K_{master}. To confirm the success of this transaction, the devices shall perform a mutual authentication procedure using the new link key. This procedure shall then be repeated for each slave that receives the new link key. The ACO values from the authentications shall not replace the current ACO, as this ACO is needed to (re)compute a ciphering key when the master falls back to the previous (non-temporary) link key.

The master activates encryption by an LM command. Before activating encryption, the master shall ensure that all slaves receive the same random number, EN_RAND, since the encryption key is derived through the means of E_3 individually in all participating devices. Each slave shall compute a new encryption key as follows:

$$K_C = E_3(K_{master}, \text{EN\_RAND}, \text{COF}) \quad \text{(EQ 5)}$$

where the value of COF shall be derived from the master's BD_ADDR as specified by equation (EQ 3). The details of the encryption key generating function are described in Section 6.4. The message flow between the master and the slave when generating the master key is depicted in Figure 3.3. Note

that in this case the ACO produced during the authentication is not used when computing the ciphering key.

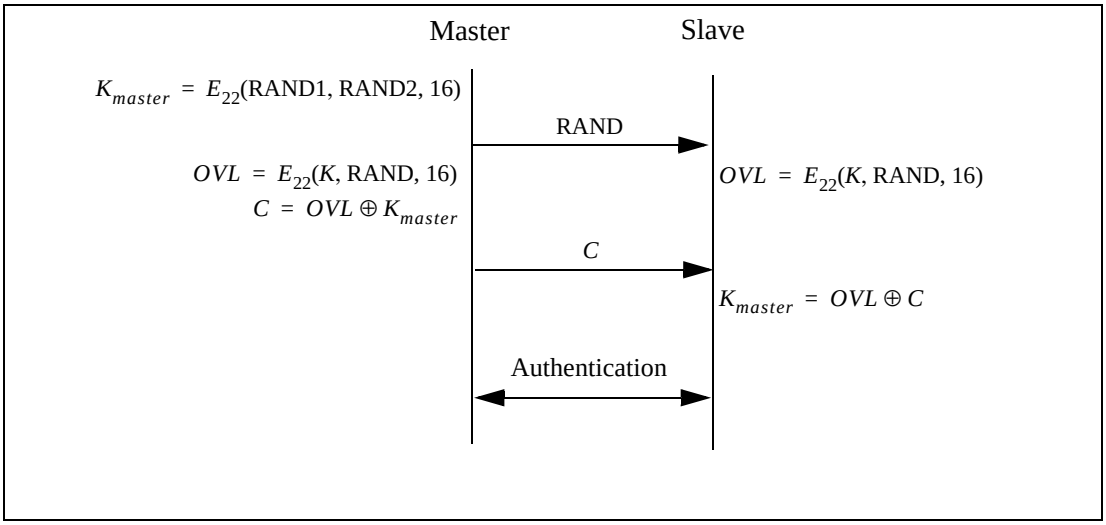

Figure 3.3: Master link key distribution and computation of the corresponding encryption key.

4 ENCRYPTION (E0)

User information can be protected by encryption of the packet payload; the access code and the packet header shall never be encrypted. The encryption of the payload shall be carried out with a stream cipher called E_0 that shall be re-synchronized for every payload. The overall principle is shown in Figure 4.1.

The stream cipher system E_0 shall consist of three parts:

- the first part performs initialization (generation of the payload key). The payload key generator shall combine the input bits in an appropriate order and shall shift them into the four LFSRs used in the key stream generator.
- the second part generates the key stream bits and shall use a method derived from the summation stream cipher generator attributable to Massey and Rueppel. The second part is the main part of the cipher system, as it will also be used for initialization.
- the third part performs encryption and decryption.

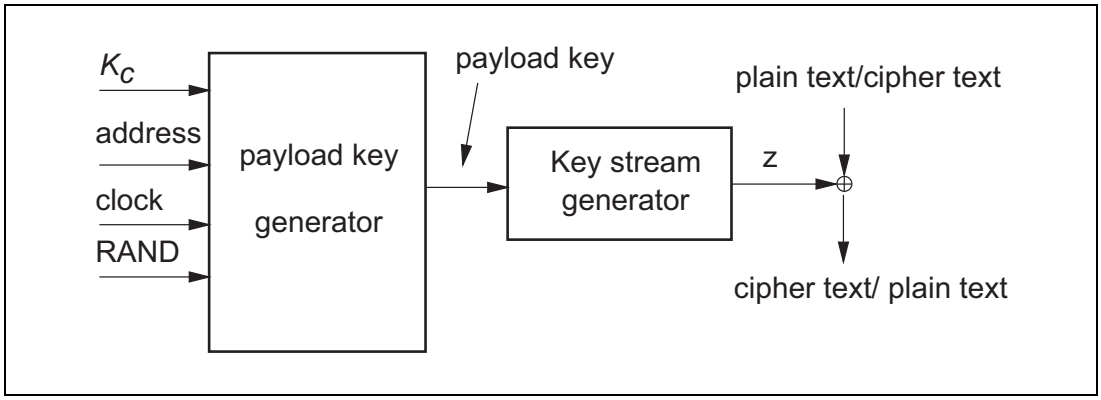

Figure 4.1: Stream ciphering for Bluetooth with E_0.

4.1 ENCRYPTION KEY SIZE NEGOTIATION

Each device implementing the baseband specification shall have a parameter defining the maximal allowed key length, L_{max}, $1 \leq L_{max} \leq 16$ (number of octets in the key). For each application using encryption, a number L_{min} shall be defined indicating the smallest acceptable key size for that particular application. Before generating the encryption key, the devices involved shall negotiate to decide the key size to use.

The master shall send a suggested value, $L_{sug}^{(M)}$, to the slave. Initially, the suggested value shall be set to $L_{max}^{(M)}$. If $L_{min}^{(S)} \leq L_{sug}^{(M)}$, and, the slave supports the suggested length, the slave shall acknowledge and this value shall be the length of the encryption key for this link. However, if both conditions are not fulfilled, the slave shall send a new proposal, $L_{sug}^{(S)} < L_{sug}^{(M)}$, to the master. This value shall be the largest among all supported lengths less than the previous master suggestion. Then, the master shall perform the corresponding test on

the slave suggestion. This procedure shall be repeated until a key length agreement is reached, or, one device aborts the negotiation. An abort may be caused by lack of support for L_{sug} and all smaller key lengths, or if $L_{sug} < L_{min}$ in one of the devices. In case of an abort link encryption cannot be employed.

The possibility of a failure in setting up a secure link is an unavoidable consequence of letting the application decide whether to accept or reject a suggested key size. However, this is a necessary precaution. Otherwise a fraudulent device could enforce a weak protection on a link by claiming a small maximum key size.

4.2 ENCRYPTION OF BROADCAST MESSAGES

There may be three settings for the baseband regarding encryption:

1. No encryption.
   This is the default setting. No messages are encrypted
2. Point-to-point only encryption.
   Broadcast messages are not encrypted. This may be enabled either during the connection establishment procedure or after the connection has been established.
3. Point-to-point and broadcast encryption.
   All messages are encrypted. This may be enabled after the connection has been established only. This setting should not be enabled unless all affected links share the same master link key as well as the same EN_RAND value, both used in generating the encryption key.

4.3 ENCRYPTION CONCEPT

Broadcast traffic	Individually addressed traffic
No encryption	No encryption
No encryption	Encryption, K_{master}
Encryption, K_{master}	Encryption, K_{master}

Table 4.1: Possible encryption modes for a slave in possession of a master key.

For the encryption routine, a stream cipher algorithm is used in which ciphering bits are bit-wise modulo-2 added to the data stream to be sent over the air interface. The payload is ciphered after the CRC bits are appended, but, prior to the FEC encoding.

Each packet payload shall be ciphered separately. The cipher algorithm E_0 uses the master Bluetooth device address (BD_ADDR), 26 bits of the master real-time clock (CLK $_{26\text{-}1}$) and the encryption key K_C as input, see Figure 4.2 (where it is assumed that device A is the master).

The encryption key K_C is derived from the current link key, COF, and a random number, EN_RAND_A (see Section 6.4). The random number shall be issued by the master before entering encryption mode. Note that EN_RAND_A is publicly known since it is transmitted as plain text over the air.

Within the E_0 algorithm, the encryption key K_C is modified into another key denoted K'_C. The maximum effective size of this key shall be factory preset and may be set to any multiple of eight between one and sixteen (8-128 bits). The procedure for deriving the key is described in Section 4.5.

The real-time clock is incremented for each slot. The E_0 algorithm shall be re-initialized at the start of each new packet (i.e. for Master-to-Slave as well as for Slave-to-Master transmission). By using $CLK_{26\text{-}1}$ at least one bit is changed between two transmissions. Thus, a new keystream is generated after each re-initialization. For packets covering more than a single slot, the Bluetooth clock as found in the first slot shall be used for the entire packet.

The encryption algorithm E_0 generates a binary keystream, K_{cipher}, which shall be modulo-2 added to the data to be encrypted. The cipher is symmetric; decryption shall be performed in exactly the same way using the same key as used for encryption.

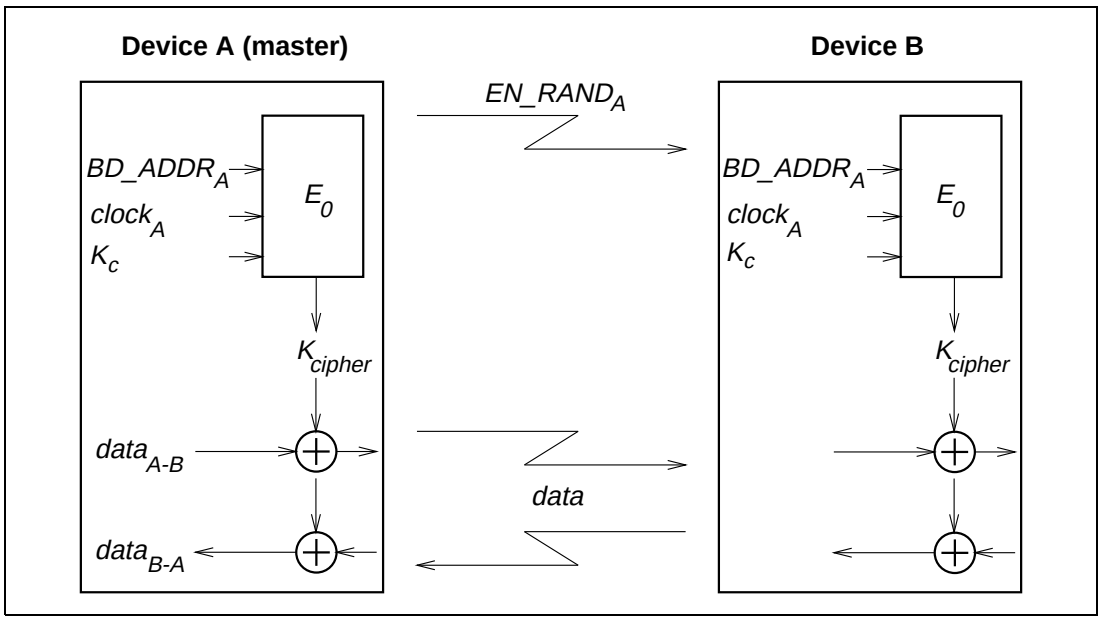

Figure 4.2: Functional description of the encryption procedure

4.4 ENCRYPTION ALGORITHM

The system uses linear feedback shift registers (LFSRs) whose output is combined by a simple finite state machine (called the summation combiner) with 16 states. The output of this state machine is the key stream sequence, or, during initialization phase, the randomized initial start value. The algorithm

uses an encryption key K_C, a 48-bit Bluetooth address, the master clock bits $CLK_{26\text{-}1}$, and a 128-bit RAND value. Figure 4.3 shows the setup.

There are four LFSRs ($LFSR_1$,...,$LFSR_4$) of lengths $L_1 = 25$, $L_2 = 31$, $L_3 = 33$, and, $L_4 = 39$, with feedback polynomials as specified in Table 4.2. The total length of the registers is 128. These polynomials are all primitive. The Hamming weight of all the feedback polynomials is chosen to be five – a reasonable trade-off between reducing the number of required XOR gates in the hardware implementation and obtaining good statistical properties of the generated sequences.

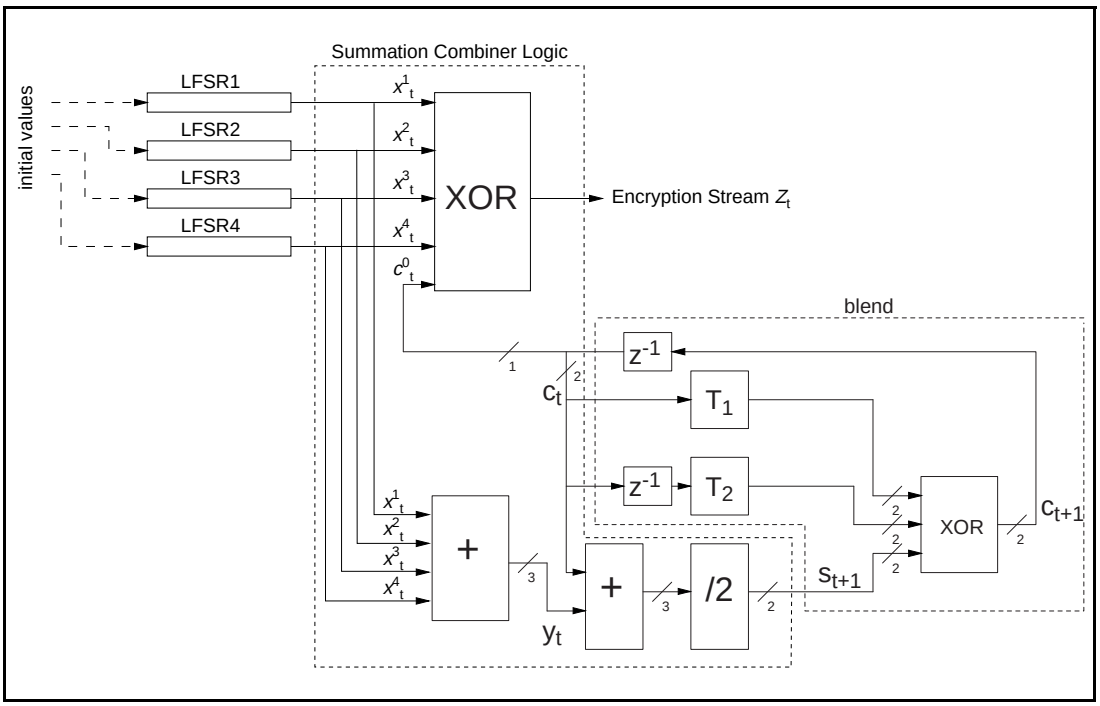

Figure 4.3: Concept of the encryption engine.

i	L_i	**feedback** $f_i(t)$	**weight**
1	25	$t^{25} + t^{20} + t^{12} + t^8 + 1$	5
2	31	$t^{31} + t^{24} + t^{16} + t^{12} + 1$	5
3	33	$t^{33} + t^{28} + t^{24} + t^4 + 1$	5
4	39	$t^{39} + t^{36} + t^{28} + t^4 + 1$	5

Table 4.2: The four primitive feedback polynomials.

Let x_t^i denote the t^{th} symbol of $LFSR_i$. The value y_t is derived from the four-tuple $x_t^1, \ldots, x_t^4$ using the following equation:

$$y_t = \sum_{i=1}^{4} x_t^i, \quad \text{(EQ 6)}$$

where the sum is over the integers. Thus y_t can take the values 0,1,2,3, or 4. The output of the summation generator is obtained by the following equations:

$$z_t = x_t^1 \oplus x_t^2 \oplus x_t^3 \oplus x_t^4 \oplus c_t^0 \in \{0, 1\}, \quad \text{(EQ 7)}$$

$$s_{t+1} = (s_{t+1}^1, s_{t+1}^0) = \left\lfloor \frac{y_t + c_t}{2} \right\rfloor \in \{0, 1, 2, 3\}, \quad \text{(EQ 8)}$$

$$c_{t+1} = (c_{t+1}^1, c_{t+1}^0) = s_{t+1} \oplus T_1[c_t] \oplus T_2[c_{t-1}], \quad \text{(EQ 9)}$$

where $T_1[.]$ and $T_2[.]$ are two different linear bijections over GF(4). Suppose GF(4) is generated by the irreducible polynomial $x^2 + x + 1$, and let α be a zero of this polynomial in GF(4). The mappings T_1 and T_2 are now defined as:

$$T_1: \text{GF}(4) \rightarrow \text{GF}(4)$$

$$x \mapsto x$$

$$T_2: \text{GF}(4) \rightarrow \text{GF}(4)$$

$$x \mapsto (\alpha + 1)x.$$

The elements of GF(4) can be written as binary vectors. This is summarized in Table 4.3.

x	$T_1[x]$	$T_2[x]$
00	00	00
01	01	11
10	10	01
11	11	10

Table 4.3: The mappings T_1 and T_2.

Since the mappings are linear, they can be implemented using XOR gates; i.e.

$$T_1: \quad (x_1, x_0) \mapsto (x_1, x_0),$$

$$T_2: \quad (x_1, x_0) \mapsto (x_0, x_1 \oplus x_0).$$

4.4.1 The Operation of the Cipher

Figure 4.4 gives an overview of the operation in time. The encryption algorithm shall run through the initialization phase before the start of transmission or reception of a new packet. Thus, for multislot packets the cipher is initialized using the clock value of the first slot in the multislot sequence.

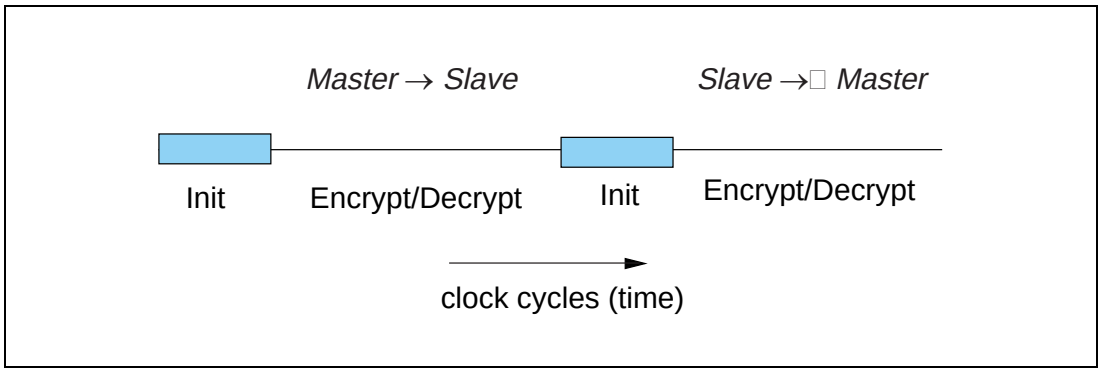

Figure 4.4: Overview of the operation of the encryption engine. Between each start of a packet (TX or RX), the LFSRs are re-initialized.

4.5 LFSR INITIALIZATION

The key stream generator is loaded with an initial value for the four LFSRs (in total 128 bits) and the 4 bits that specify the values of c_0 and c_{-1}. The 132 bit initial value is derived from four inputs by using the key stream generator. The input parameters are the key K_C, a 128-bit random number RAND, a 48-bit Bluetooth device address, and the 26 master clock bits $CLK_{26\text{-}1}$.

The effective length of the encryption key may vary between 8 and 128 bits. Note that the actual key length as obtained from E_3 is 128 bits. Then, within E_0, the key length may be reduced by a modulo operation between K_C and a polynomial of desired degree. After reduction, the result is encoded with a block code in order to distribute the starting states more uniformly. The operation shall be as defined in (EQ 10).

When the encryption key has been created the LFSRs are loaded with their initial values. Then, 200 stream cipher bits are created by operating the generator. Of these bits, the last 128 are fed back into the key stream generator as an initial value of the four LFSRs. The values of c_t and c_{t-1} are kept. From this point on, when clocked the generator produces the encryption (decryption) sequence which is bitwise XORed to the transmitted (received) payload data.

In the following, octet i of a binary sequence X is $X[i]$. Bit 0 of X is the LSB. Then, the LSB of $X[i]$ corresponds to bit $8i$ of the sequence X, the MSB of $X[i]$ is bit $8i+7$ of X. For instance, bit 24 of the Bluetooth device address is the LSB of BD_ADDR[3].

The details of the initialization shall be as follows:

1. Create the encryption key to use from the 128-bit secret key K_C and the 128-bit publicly known EN_RAND. Let $L, 1 \le L \le 16$, be the

effective key length in number of octets. The resulting encryption key is K'_C:

$$K'_C(x) = g_2^{(L)}(x)(K_C(x) \bmod g_1^{(L)}(x)), \quad \text{(EQ 10)}$$

where $\deg(g_1^{(L)}(x)) = 8L$ and $\deg(g_2^{(L)}(x)) \leq 128 - 8L$. The polynomials are defined in Table 4.4.

2. Shift the 3 inputs K'_C, the Bluetooth device address, the clock, and the six-bit constant 111001 into the LFSRs. In total, 208 bits are shifted in:

   a) Open all switches shown in Figure 4.5;

   b) Arrange inputs bits as shown in Figure 4.5; Set the content of all shift register elements to zero. Set $t = 0$.

   c) Start shifting bits into the LFSRs. The rightmost bit at each level of Figure 4.5 is the first bit to enter the corresponding LFSR.

   d) When the first input bit at level i reaches the rightmost position of $LFSR_i$, close the switch of this LFSR.

   e) At $t = 39$ (when the switch of $LFSR_4$ is closed), reset both blend registers $c_{39} = c_{39-1} = 0$; Up to this point, the content of c_t and c_{t-1} has been of no concern. However, their content will now be used in computing the output sequence.

   f) From now on output symbols are generated. The remaining input bits are continuously shifted into their corresponding shift registers. When the last bit has been shifted in, the shift register is clocked with input = 0;

   Note: When finished, $LFSR_1$ has effectively clocked 30 times with feedback closed, $LFSR_2$ has clocked 24 times, $LFSR_3$ has clocked 22 times, and $LFSR_4$ has effectively clocked 16 times with feedback closed.

3. To mix initial data, continue to clock until 200 symbols have been produced with all switches closed ($t = 239$);

4. Keep blend registers c_t and c_{t-1}, make a parallel load of the last 128 generated bits into the LFSRs according to Figure 4.6 at $t = 240$;

After the parallel load in item 4, the blend register contents shall be updated for each subsequent clock.

L	deg	$g_1^{(L)}$	deg	$g_2^{(L)}$
1	[8]	00000000 00000000 00000000 0000011d	[119]	00e275a0 abd218d4 cf928b9b bf6cb08f
2	[16]	00000000 00000000 00000000 0001003f	[112]	0001e3f6 3d7659b3 7f18c258 cff6efef
3	[24]	00000000 00000000 00000000 010000db	[104]	000001be f66c6c3a b1030a5a 1919808b
4	[32]	00000000 00000000 00000001 000000af	[96]	00000001 6ab89969 de17467f d3736ad9

Table 4.4: Polynomials used when creating K'_c. . [1]

L	deg	$g_1^{(L)}$	deg	$g_2^{(L)}$
5	[40]	00000000 00000000 00000100 00000039	[88]	00000000 01630632 91da50ec 55715247
6	[48]	00000000 00000000 00010000 00000291	[77]	00000000 00002c93 52aa6cc0 54468311
7	[56]	00000000 00000000 01000000 00000095	[71]	00000000 000000b3 f7fffce2 79f3a073
8	[64]	00000000 00000001 00000000 0000001b	[63]	00000000 00000000 a1ab815b c7ec8025
9	[72]	00000000 00000100 00000000 00000609	[49]	00000000 00000000 0002c980 11d8b04d
10	[80]	00000000 00010000 00000000 00000215	[42]	00000000 00000000 0000058e 24f9a4bb
11	[88]	00000000 01000000 00000000 0000013b	[35]	00000000 00000000 0000000c a76024d7
12	[96]	00000001 00000000 00000000 000000dd	[28]	00000000 00000000 00000000 1c9c26b9
13	[104]	00000100 00000000 00000000 0000049d	[21]	00000000 00000000 00000000 0026d9e3
14	[112]	00010000 00000000 00000000 0000014f	[14]	00000000 00000000 00000000 00004377
15	[120]	01000000 00000000 00000000 000000e7	[7]	00000000 00000000 00000000 00000089
16	[128]	1 00000000 00000000 00000000 00000000	[0]	00000000 00000000 00000000 00000001

Table 4.4: Polynomials used when creating K'_c. . [1]

1. All polynomials are in hexadecimal notation. The LSB is in the rightmost position.

In Figure 4.5, all bits are shifted into the LFSRs, starting with the least significant bit (LSB). For instance, from the third octet of the address, BD_ADDR[2], first BD_ADDR_{16} is entered, followed by BD_ADDR_{17}, etc. Furthermore, CL_0 corresponds to CLK_1,..., CL_{25} corresponds to CLK_{26}.

Note that the output symbols $x_t^i, i = 1, \ldots, 4$ are taken from the positions 24, 24, 32, and 32 for $LFSR_1$, $LFSR_2$,$LFSR_3$, and $LFSR_4$, respectively (counting the leftmost position as number 1).

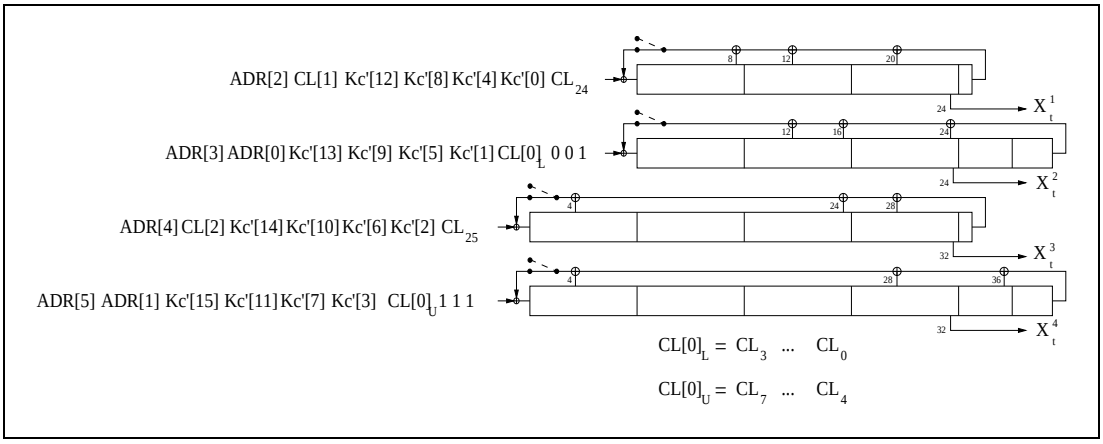

Figure 4.5: Arranging the input to the LFSRs.

In Figure 4.6, the 128 binary output symbols Z_0,..., Z_{127} are arranged in octets denoted Z[0],..., Z[15]. The LSB of Z[0] corresponds to the first of these symbols, the MSB of Z[15] is the last output from the generator. These bits shall be loaded into the LFSRs according to the figure. It is a parallel load and no update of the blend registers is done. The first output symbol is generated at the same time. The octets shall be written into the registers with the LSB in the leftmost position (i.e. the opposite of before). For example, Z_{24} is loaded into position 1 of $LFSR_4$.

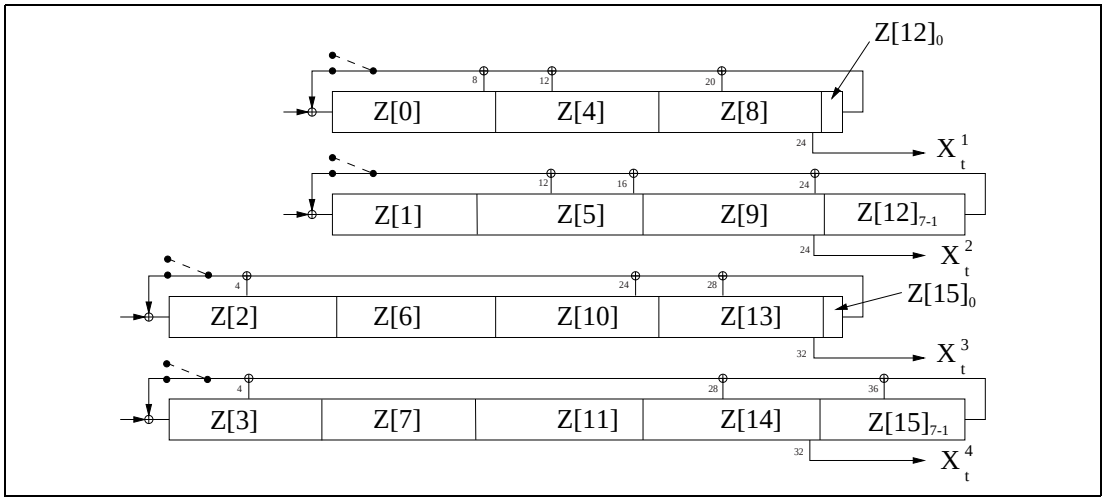

Figure 4.6: Distribution of the 128 last generated output symbols within the LFSRs.

4.6 KEY STREAM SEQUENCE

When the initialization is finished, the output from the summation combiner is used for encryption/decryption. The first bit to use shall be the one produced at the parallel load, i.e. at $t = 240$. The circuit shall be run for the entire length of the current payload. Then, before the reverse direction is started, the entire initialization process shall be repeated with updated values on the input parameters.

Sample data of the encryption output sequence can be found in [Vol 2] Part G, Section 1.1. A necessary, but not sufficient, condition for all Bluetooth compliant implementations of encryption is to produce these encryption streams for identical initialization values.

5 AUTHENTICATION

Legacy authentication uses a challenge-response scheme in which a claimant's knowledge of a secret key is checked through a 2-move protocol using symmetric secret keys. The latter implies that a correct claimant/verifier pair share the same secret key, for example K. In the challenge-response scheme the verifier challenges the claimant to authenticate a random input (the challenge), denoted by AU_RAND_A, with an authentication code, denoted by E_1, and return the result SRES to the verifier, see Figure 5.1. This figure also shows that the input to E_1 consists of the tuple AU_RAND_A and the Bluetooth device address (BD_ADDR) of the claimant. The use of this address prevents a simple reflection attack[1]. The secret K shared by devices A and B is the current *link key*.

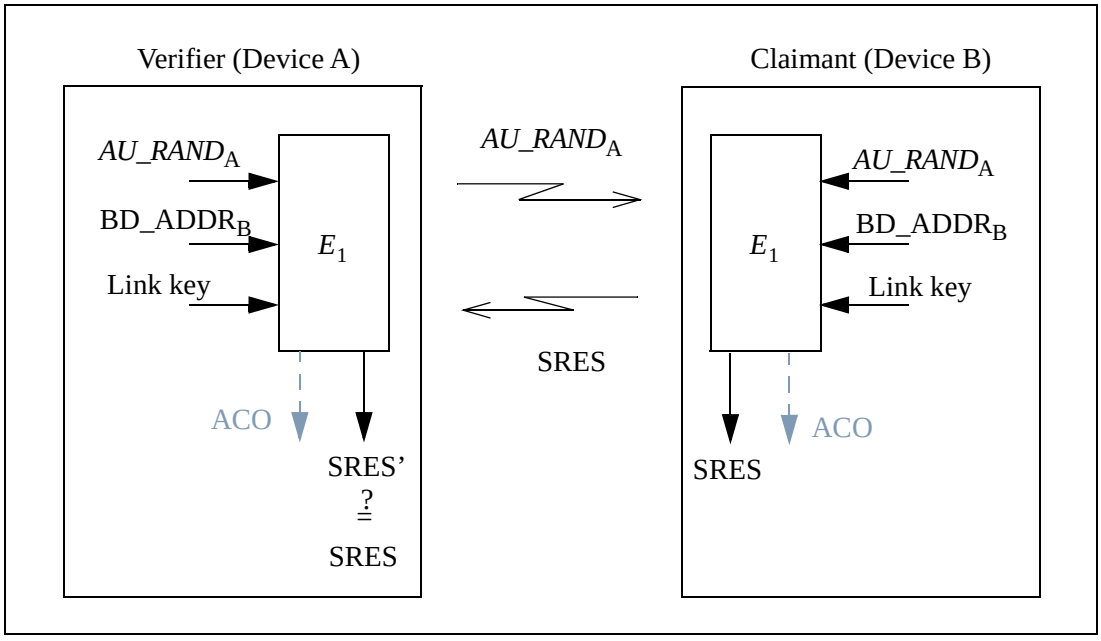

Figure 5.1: Challenge-response for the Bluetooth.

The challenge-response scheme for symmetric keys in legacy authentication is depicted in Figure 5.2.

1. The reflection attack actually forms no threat because all service requests are dealt with on a FIFO basis. When preemption is introduced, this attack is potentially dangerous.

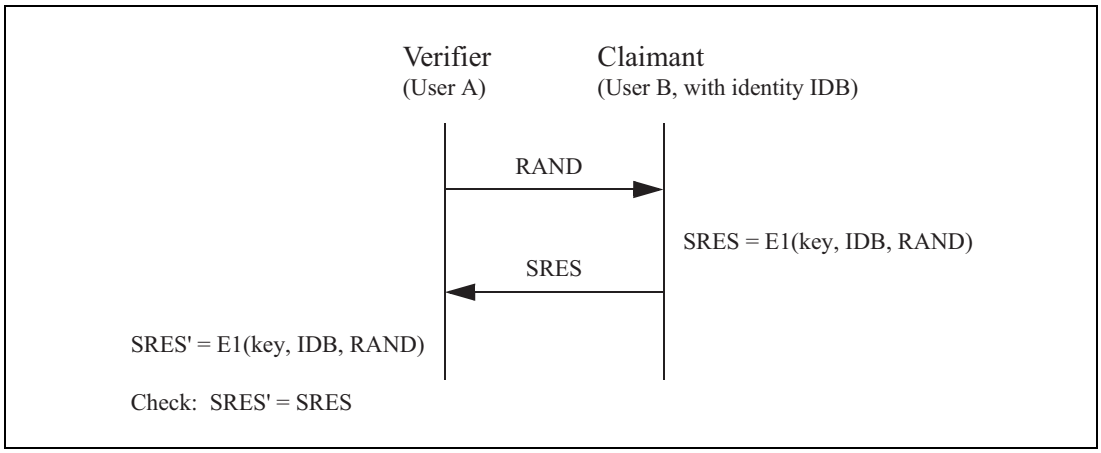

Figure 5.2: Challenge-response for symmetric key systems.

In legacy authentication, the verifier is not required to be the master. The application indicates which device has to be authenticated. Some applications only require a one-way authentication. However, some peer-to-peer communications, should use a mutual authentication in which each device is subsequently the challenger (verifier) in two authentication procedures. The LM shall process authentication preferences from the application to determine in which direction(s) the authentication(s) takes place. For mutual authentication with the devices of Figure 5.1, after device A has successfully authenticated device B, device B could authenticate device A by sending an AU_RAND_B (different from the AU_RAND_A that device A issued) to device A, and deriving the SRES and SRES' from the new AU_RAND_B, the address of device A, and the link key K_{AB}.

If a legacy authentication is successful the value of ACO as produced by E_1 shall be retained.

Secure Authentication uses a challenge-response scheme in which both devices act as a verifier and claimant in the same sequence where the knowledge of a secret key is checked through a 4-move protocol using symmetric secret keys. The latter implies that a correct claimant/verifier pair share the same secret key, for example K. In the challenge-response scheme the master challenges the slave to authenticate a random input (the challenge), denoted by AU_RANDm, with an authentication code, denoted by h4 and h5, and return the resulting SRESs to the verifier, see Figure 5.3. Similarly, the slave challenges the master to authenticate a random input (the challenge), denoted AU_RANDs, with an authentication code, denoted by h4 and h5, and return the resulting SRESm to the verifier. This figure also shows that the inputs to h4 and h5 consist of a secret, a string “btdk”, the Bluetooth device address of the master (BD_ADDRm), and the Bluetooth device address of the slave (BD_ADDRs). The use of these addresses prevents a simple reflection attack. The secret K shared by the master and slave is the current link key.

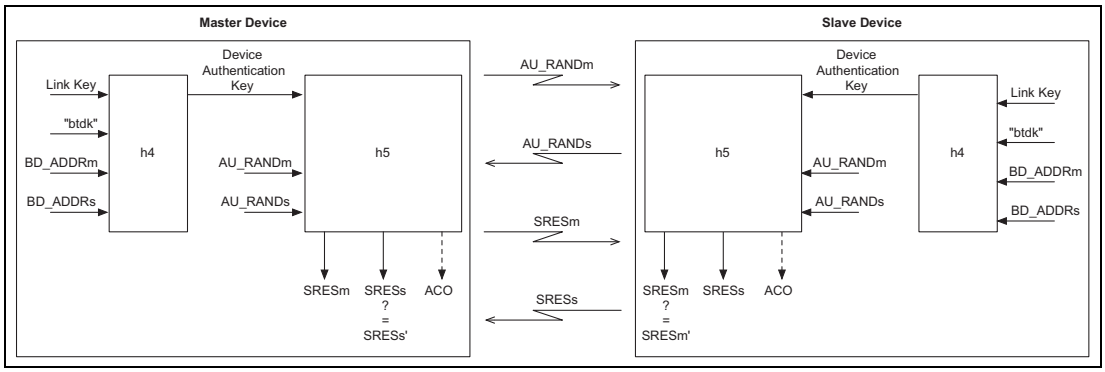

Figure 5.3: Challenge and response for secure authententication.

The challenge-response scheme for symmetric keys in secure authentication is depicted in Figure 5.4.

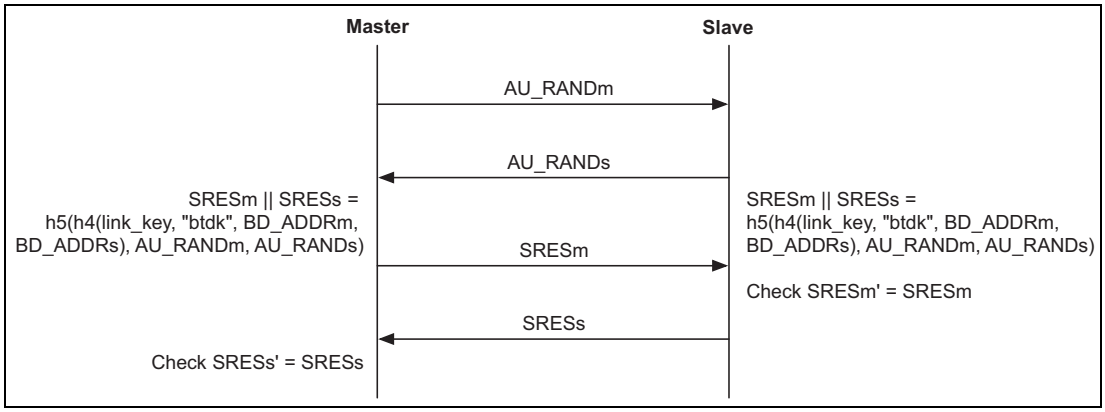

Figure 5.4: Challenge-response for secure authentication.

In secure authentication, both the master and slave are the verifier and claimant. The application indicates which device has to be authenticated, but secure authentication is always a mutual authentication.

If a secure authentication is successful the value of ACO as produced by h5 shall be retained.

5.1 REPEATED ATTEMPTS

When the authentication attempt fails, a waiting interval shall pass before the verifier will initiate a new authentication attempt to the same claimant, or before it will respond to an authentication attempt initiated by a device claiming the same identity as the failed device. For each subsequent authentication failure, the waiting interval shall be increased exponentially. For example, after each failure, the waiting interval before a new attempt can be made could be twice

as long as the waiting interval prior to the previous attempt[1]. The waiting interval shall be limited to a maximum.

The maximum waiting interval depends on the implementation. The waiting time shall exponentially decrease to a minimum when no new failed attempts are made during a certain time period. This procedure prevents an intruder from repeating the authentication procedure with a large number of different keys.

To protect a device's private key, a device should implement a method to prevent an attacker from retrieving useful information about the device's private key using invalid public keys. For this purpose, a device can use one of the following methods:

- Change its private key after three failed attempts from any BD_ADDR and after 10 successful pairings from any BD_ADDR; or after a combination of these such that 3 successful pairings count as one failed pairing; or
- Verify that the received public keys from any BD_ADDR are on the correct curve; or
- Implement elliptic curve point addition and doubling using formulas that are valid only on the correct curve.

1. Another appropriate value larger than 1 may be used.

6 THE AUTHENTICATION AND KEY-GENERATING FUNCTIONS

This section describes the algorithms used for authentication and key generation.

6.1 THE AUTHENTICATION FUNCTION E_1

The authentication function E_1 is a computationally secure authentication code. E_1 uses the encryption function SAFER+. The algorithm is an enhanced version of an existing 64-bit block cipher SAFER-SK128, and it is freely available. In the following discussion, the block cipher will be denoted as the function A_r which maps using a 128-bit key, a 128-bit input to a 128-bit output, i.e.

$$A_r\colon \{0,1\}^{128}\times\{0,1\}^{128}\rightarrow\{0,1\}^{128}$$
$$(k\times x)\mapsto t. \qquad \text{(EQ 11)}$$

The details of A_r are given in the next section. The function E_1 is constructed using A_r as follows

$$E_1\colon \{0,1\}^{128}\times\{0,1\}^{128}\times\{0,1\}^{48}\rightarrow\{0,1\}^{32}\times\{0,1\}^{96}$$
$$(K,\text{RAND},\text{address})\mapsto(\text{SRES},\text{ACO}), \qquad \text{(EQ 12)}$$

where $\text{SRES} = Hash(K,\text{RAND},\text{address},6)[0,\ldots,3]$, where $Hash$ is a keyed hash function defined as[1],

$$Hash\colon\{0,1\}^{128}\times\{0,1\}^{128}\times\{0,1\}^{8\times L}\times\{6,12\}\rightarrow\{0,1\}^{128}$$
$$(K,I_1,I_2,L)\mapsto A'_r([\tilde{K}],[E(I_2,L)+_{16}(A_r(K,I_1)\hat{\Uparrow}_{16}I_1)]), \qquad \text{(EQ 13)}$$

and where

$$E\colon\{0,1\}^{8\times L}\times\{6,12\}\rightarrow\{0,1\}^{8\times 16}$$
$$(X[0,\ldots,L-1],L)\mapsto(X[i(\text{mod L})]\ \text{ for } i=0...15), \qquad \text{(EQ 14)}$$

is an expansion of the L octet word X into a 128-bit word. The function A_r is evaluated twice for each evaluation of E_1. The key $\tilde{K}$ for the second use of A_r (actually A'_r) is offset from K as follows[2]

1. The operator $+_{16}$ denotes bytewise addition mod 256 of the 16 octets, and the operator $\oplus_{16}$ denotes bytewise XORing of the 16 octets.
2. The constants are the largest primes below 257 for which 10 is a primitive root.

$$
\begin{aligned}
\tilde{K}[0] &= (K[0] + 233) \mod 256, & \tilde{K}[1] &= K[1] \oplus 229, \\
\tilde{K}[2] &= (K[2] + 223) \mod 256, & \tilde{K}[3] &= K[3] \oplus 193, \\
\tilde{K}[4] &= (K[4] + 179) \mod 256, & \tilde{K}[5] &= K[5] \oplus 167, \\
\tilde{K}[6] &= (K[6] + 149) \mod 256, & \tilde{K}[7] &= K[7] \oplus 131, \\
\tilde{K}\{8\} &= K[8] \oplus 233, & \tilde{K}[9] &= (K[9] + 229) \mod 256, \\
\tilde{K}[10] &= K[10] \oplus 223, & \tilde{K}[11] &= (K[11] + 193) \mod 256, \\
\tilde{K}[12] &= K[12] \oplus 179, & \tilde{K}[13] &= (K[13] + 167) \mod 256, \\
\tilde{K}[14] &= K[14] \oplus 149, & \tilde{K}[15] &= (K[15] + 131) \mod 256.
\end{aligned}
\qquad \text{(EQ 15)}
$$

A data flowchart of the computation of E_1 is shown in Figure 6.1. E_1 is also used to deliver the parameter ACO (Authenticated Ciphering Offset) that is used in the generation of the ciphering key by E_3, see equations (EQ 3) and (EQ 23). The value of ACO is formed by the octets 4 through 15 of the output of the hash function defined in (EQ 13):

$$\text{ACO} = Hash(K, \text{RAND}, \text{address}, 6)[4, \ldots, 15]. \qquad \text{(EQ 16)}$$

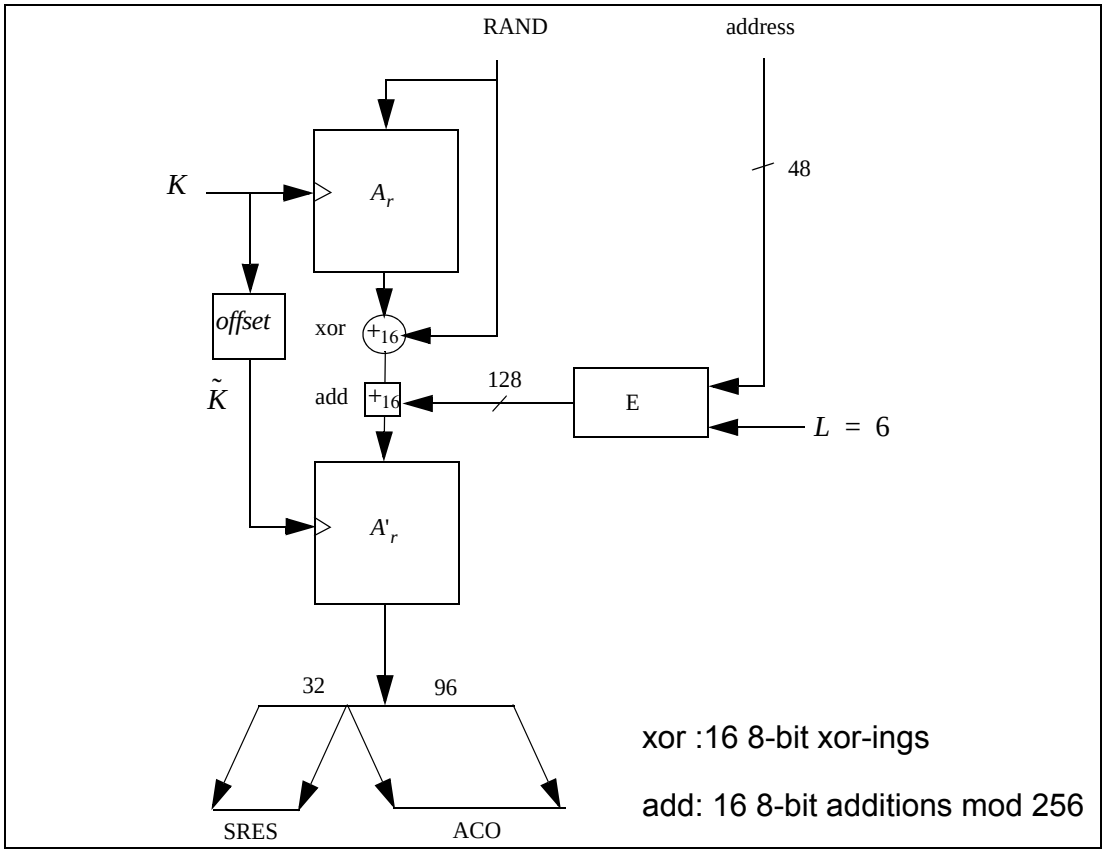

Figure 6.1: Flow of data for the computation of E_1.

6.2 THE FUNCTIONS A_r AND A'_r

The function A_r is identical to SAFER+. It consists of a set of 8 layers, (each layer is called a round) and a parallel mechanism for generating the sub keys $K_p[j]$, $p = 1, 2, \ldots, 17$, which are the round keys to be used in each round. The function will produce a 128-bit result from a 128-bit random input string and a 128-bit key. Besides the function A_r, a slightly modified version referred to as A'_r is used in which the input of round 1 is added to the input of round 3. This is done to make the modified version non-invertible and prevents the use of A'_r (especially in E_{2x}) as an encryption function. See Figure 6.2 for details.

6.2.1 The Round Computations

The computations in each round are a composition of encryption with a round key, substitution, encryption with the next round key, and, finally, a Pseudo Hadamard Transform (PHT). The computations in a round shall be as shown in Figure 6.2. The sub keys for round $r, r = 1, 2, \ldots, 8$ are denoted $K_{2r-1}[j]$, $K_{2r}[j]$, $j = 0, 1, \ldots, 15$. After the last round $K_{17}[j]$ is applied identically to all previous odd numbered keys.

6.2.2 The Substitution Boxes “e” and “l”

In Figure 6.2 two boxes are shown, marked “e” and “l”. These boxes implement the same substitutions as are used in SAFER+; i.e. they implement

$$
\begin{aligned}
e, l \quad &: \quad \{0, \ldots, 255\} \rightarrow \{0, \ldots, 255\}, \\
e \quad &: \quad i \mapsto (45^i \pmod{257}) \pmod{256}, \\
l \quad &: \quad i \mapsto j \text{ s.t. } i = e(j).
\end{aligned}
$$

Their role, as in the SAFER+ algorithm, is to introduce non-linearity.

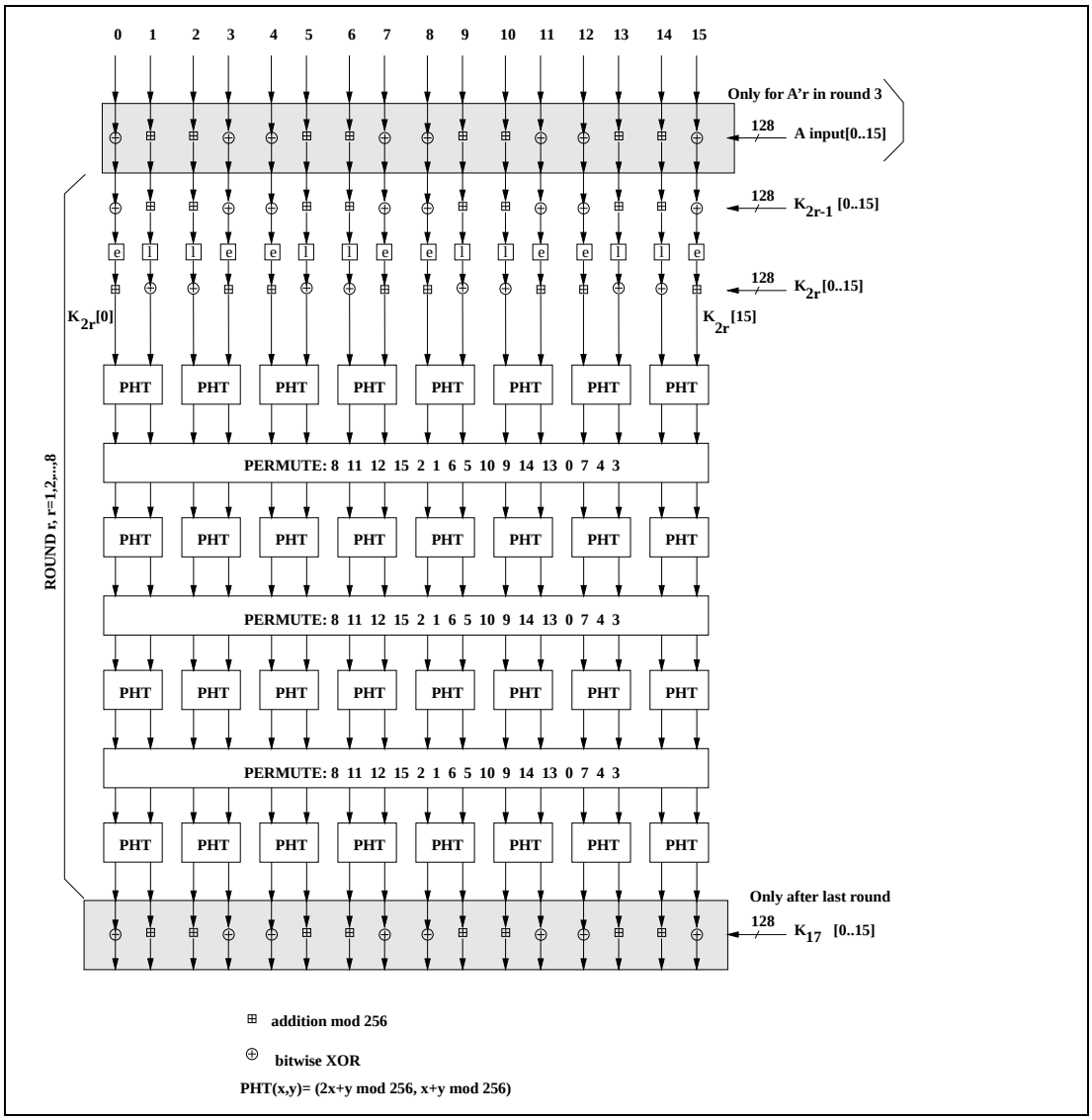

Figure 6.2: One round in A_r and A'_r.

In Section 6.2, the permutation boxes show how input byte indices are mapped onto output byte indices. Thus, position 8 is mapped on position 0 (leftmost), position 11 is mapped on position 1, etc.

6.2.3 Key Scheduling

In each round, 2 batches of 16 octet-wide keys are needed. These round keys are derived as specified by the key scheduling in SAFER+. Figure 6.3 gives an overview of how the round keys $K_p[j]$ are determined. The bias vectors B_2, B_3, ..., B_{17} shall be computed according to following equation:

$$B_p[i] = ((45^{(45^{17p+i+1} \bmod 257)} \bmod 257) \bmod 256), \text{ for } i = 0, \ldots, 15. \qquad \text{(EQ 17)}$$

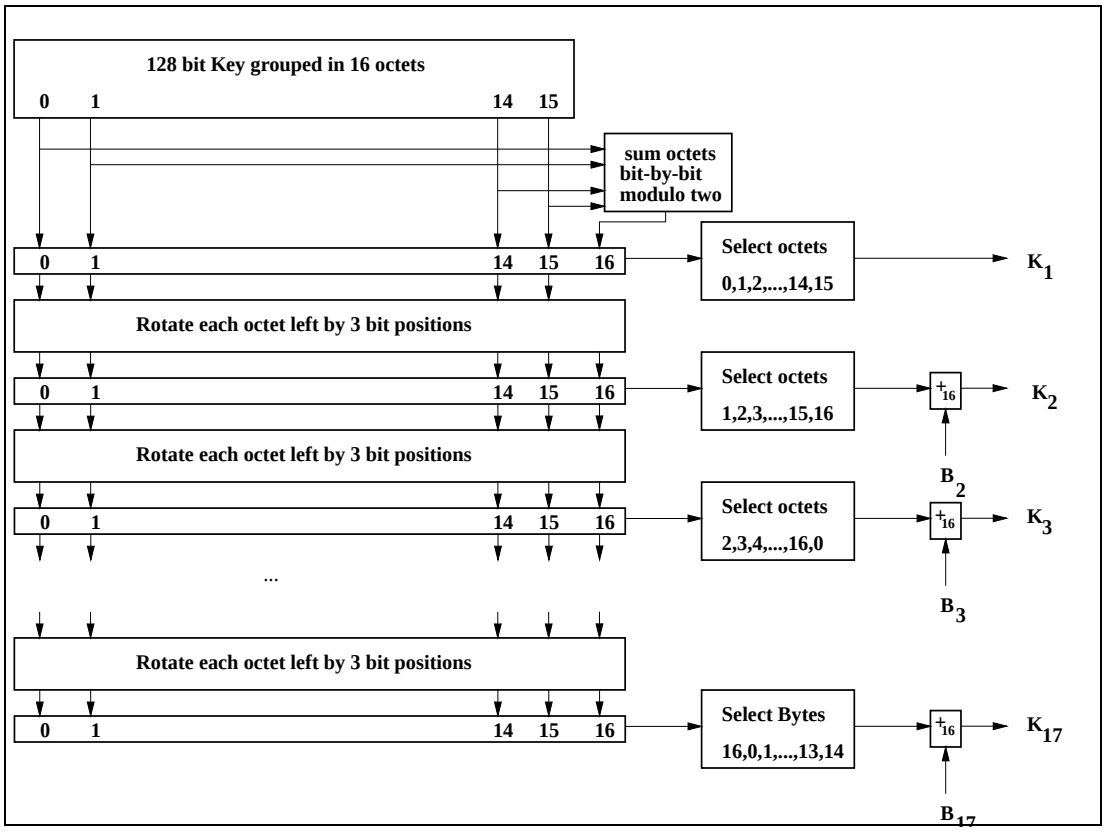

Figure 6.3: Key scheduling in A_f.

6.3 E_2-KEY GENERATION FUNCTION FOR AUTHENTICATION

The key used for authentication shall be derived through the procedure that is shown in Figure 6.4. The figure shows two modes of operation for the algorithm. In the first mode, E_{21} produces a 128-bit kink key, K, using a 128-bit RAND value and a 48-bit address. This mode shall be utilized when creating unit keys and combination keys. In the second mode, E_{22} produces a 128-bit link key, K, using a 128-bit RAND value and an L octet user PIN. The second mode shall be used to create the initialization key, and also when a master key is to be generated.

When the initialization key is generated, the PIN is augmented with the BD_ADDR, see Section 3.2.1 for which address to use. The augmentation shall always start with the least significant octet of the address immediately following the most significant octet of the PIN. Since the maximum length of the PIN used in the algorithm cannot exceed 16 octets, it is possible that not all octets of BD_ADDR will be used.

This key generating algorithm again exploits the cryptographic function E_2. for mode 1 (denoted E_{21}) is computed according to following equations:

$$E_{21}: \{0,1\}^{128} \times \{0,1\}^{48} \rightarrow \{0,1\}^{128}$$
$$(\text{RAND}, \text{address}) \mapsto A'_r(X, Y) \qquad \text{(EQ 18)}$$

where (for mode 1)

$$\begin{cases} X = \text{RAND}[0 \ldots 14] \cup (\text{RAND}[15] \oplus 6) \\ Y = \bigcup_{i=0}^{15} \text{address}[i \pmod 6] \end{cases} \qquad \text{(EQ 19)}$$

Let L be the number of octets in the user PIN. The augmenting is defined by

$$\text{PIN}' = \begin{cases} \text{PIN}[0 \ldots L-1] \cup \text{BD\_ADDR}[0 \ldots \min\{5, 15-L\}], & L < 16, \\ \text{PIN}[0 \ldots L-1], & L = 16, \end{cases} \qquad \text{(EQ 20)}$$

Then, in mode 2, E_2 (denoted E_{22}) is

$$E_{22}: \{0,1\}^{8L'} \times \{0,1\}^{128} \times \{1, 2, \ldots, 16\} \rightarrow \{0,1\}^{128}$$
$$(\text{PIN}', \text{RAND}, \text{L}') \mapsto A'_r(X, Y) \qquad \text{(EQ 21)}$$

where

$$\begin{cases} X = \bigcup_{i=0}^{15} \text{PIN}'[i \pmod{L'}], \\ Y = \text{RAND}[0 \ldots 14] \cup (\text{RAND}[15] \oplus L'), \end{cases} \qquad \text{(EQ 22)}$$

and $L' = \min\{16, L+6\}$ is the number of octets in PIN'.

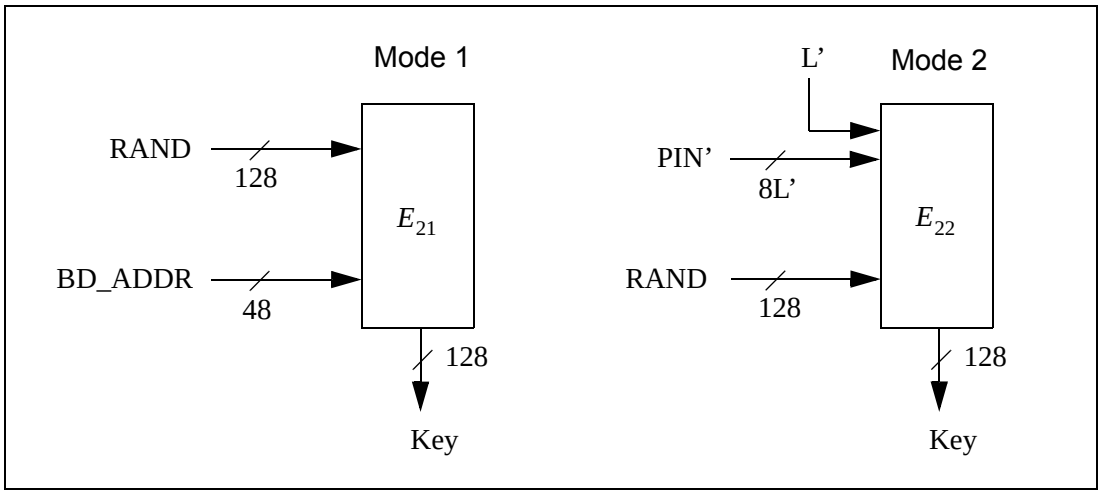

Figure 6.4: Key generating algorithm E_2 and its two modes. Mode 1 is used for unit and combination keys, while mode 2 is used for K_{init} and K_{master}.

6.4 E_3-KEY GENERATION FUNCTION FOR ENCRYPTION

The ciphering key K_C used by E_0 shall be generated by E_3. The function E_3 is constructed using A'_r as follows

$$E_3\colon \{0,1\}^{128} \times \{0,1\}^{128} \times \{0,1\}^{96} \rightarrow \{0,1\}^{128}$$
$$(K, \text{RAND}, \text{COF}) \mapsto Hash(K, \text{RAND}, \text{COF}, 12) \qquad \text{(EQ 23)}$$

where $Hash$ is the hash function as defined by (EQ 13). The key length produced is 128 bits. However, before use within E_0, the encryption key K_C is shortened to the correct encryption key length, as described in Section 4.5. A block scheme of E_3 is depicted in Figure 6.5.

The value of COF is determined as specified by equation (EQ 3).

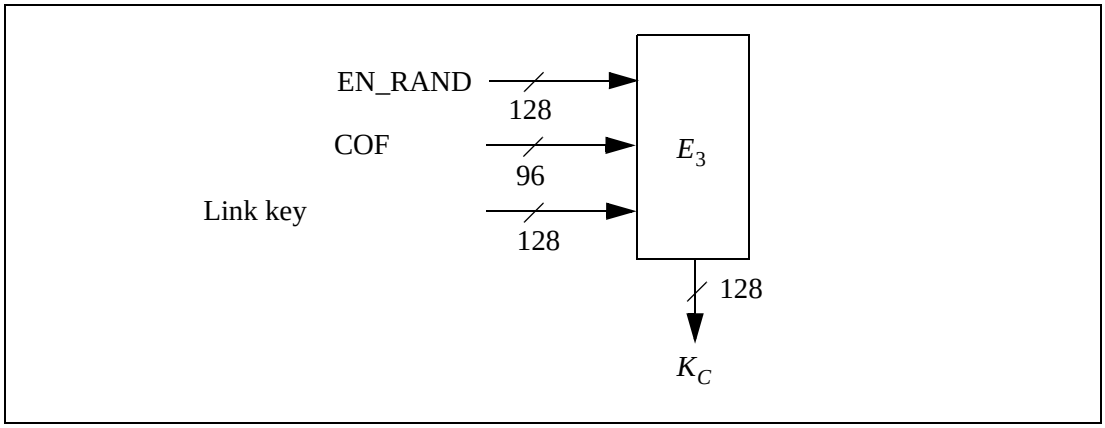

Figure 6.5: Generation of the encryption key

7 SECURE SIMPLE PAIRING

The Secure Simple Pairing security functions and procedures are described in this section. In addition, a cryptographic analysis of each procedure is provided.

There are five phases of Secure Simple Pairing:

- Phase 1: Public key exchange
- Phase 2: Authentication Stage 1
- Phase 3: Authentication Stage 2
- Phase 4: Link key calculation
- Phase 5: LMP Authentication and Encryption

Phases 1, 3, 4 and 5 are the same for all protocols whereas phase 2 (Authentication Stage 1) is different depending on the protocol used. Distributed through these five phases are 13 steps.

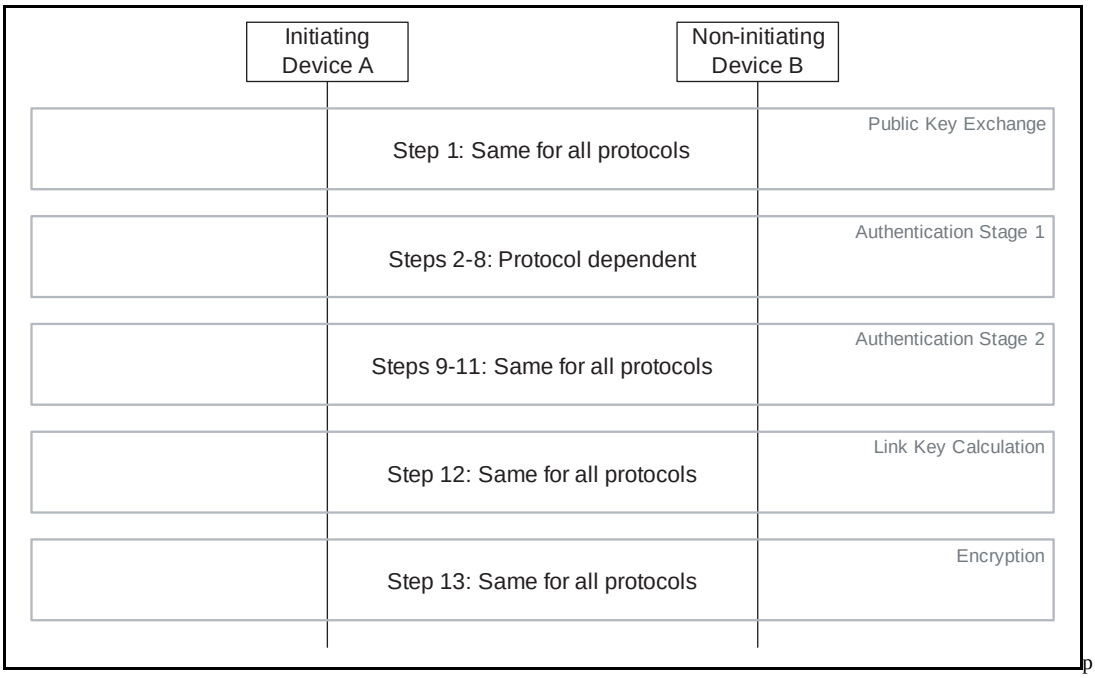

Figure 7.1: Simple Pairing Security Phases

The terminology used in the security sections is defined in Table 7.1:

Term	Definition
Cx	Commitment value from device X
Cxi	i^{th} commitment value from device X. Only used in the passkey entry protocol

Table 7.1: Terminology

Term	Definition
DHKey	Diffie Hellman key
Ex	Check value from device X
f1( )	Used to generate the 128-bit commitment values Ca and Cb
f2( )	Used to compute the link key and possible other keys from the DHKey and random nonces
f3( )	Used to compute check values Ea and Eb in Authentication Stage 2
g( )	Used to compute numeric check values
h2( )	Used to compute Generic AMP and Dedicated AMP keys
IOcapA	IO capabilities of device A
IOcapB	IO capabilities of device B
LK	Link Key
Nx	Nonce (unique random value) from device X
Nxi	i^{th} nonce (unique random value) from device X. Only used in the passkey entry protocol
PKx	Public Key of device X
rx	Random value generated by device X
rxi	Bit i of the random value rx. Only used in the passkey entry protocol
SKx	Secret (Private) Key of device X
Vx	Confirmation value on device X. Only used in the numeric compare protocol.
X	BD_ADDR of device X

Table 7.1: Terminology

7.1 PHASE 1: PUBLIC KEY EXCHANGE

Initially, each device generates its own Elliptic Curve Diffie-Hellman (ECDH) public-private key pair (step 1). This key pair needs to be generated only once per device and may be computed in advance of pairing. A device may, at any time, choose to discard its public-private key pair and generate a new one, although there is not a requirement to do so.

Pairing is initiated by the initiating device sending its public key to the receiving device (step 1a). The responding device replies with its own public key (step 1b) These public keys are not regarded as secret although they may identify the devices. Note that steps 1a and 1b are the same in all three protocols.

When both device's Controllers and Hosts support Secure Connections, the P-256 elliptic curve is used. When at least one device's Controller or Host doesn't support Secure Connections, the P-192 elliptic curve is used.

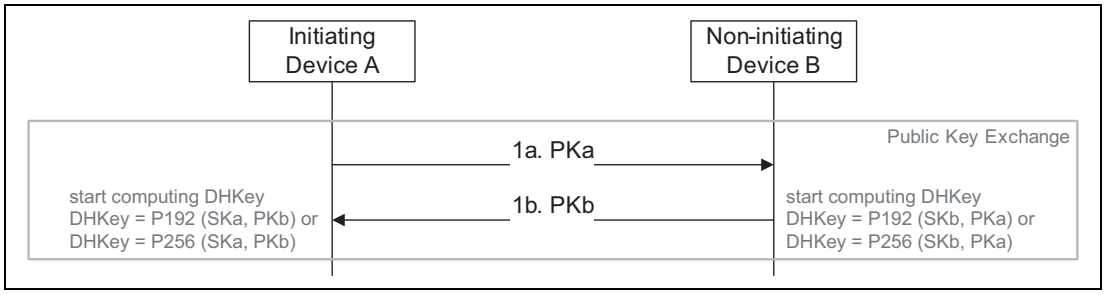

Figure 7.2: Public Key Exchange Details

7.2 PHASE 2: AUTHENTICATION STAGE 1

Authentication Stage 1 has three different protocols: Numeric Comparison, Out-of-Band, and Passkey Entry. Note that there is not a separate protocol for the Just Works association model. This association model shares the Numeric Comparison protocol.

The protocol is chosen based on the IO capabilities of the two devices.

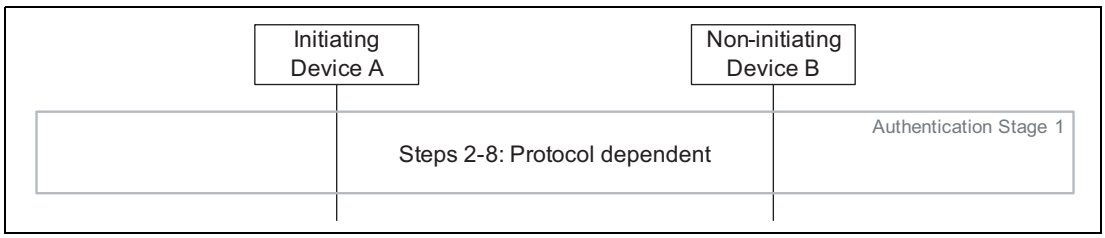

Figure 7.3: Authentication Stage 1 (High Level)

The three protocols are described in the following sections.

7.2.1 Authentication Stage 1: Numeric Comparison Protocol

The Numeric Comparison protocol provides limited protection against active "man-in-the-middle" (MITM) attacks as an active man-in-the-middle will succeed with a probability of 0.000001 on each iteration of the protocol. Provided that there is no MITM at the time the pairing is performed, the shared Link Key that is generated is computationally secure from even a passive eavesdropper that may have been present during the pairing.

The sequence diagram of Authentication Stage 1 for the Numeric Comparison protocol from the cryptographic point of view is shown below:

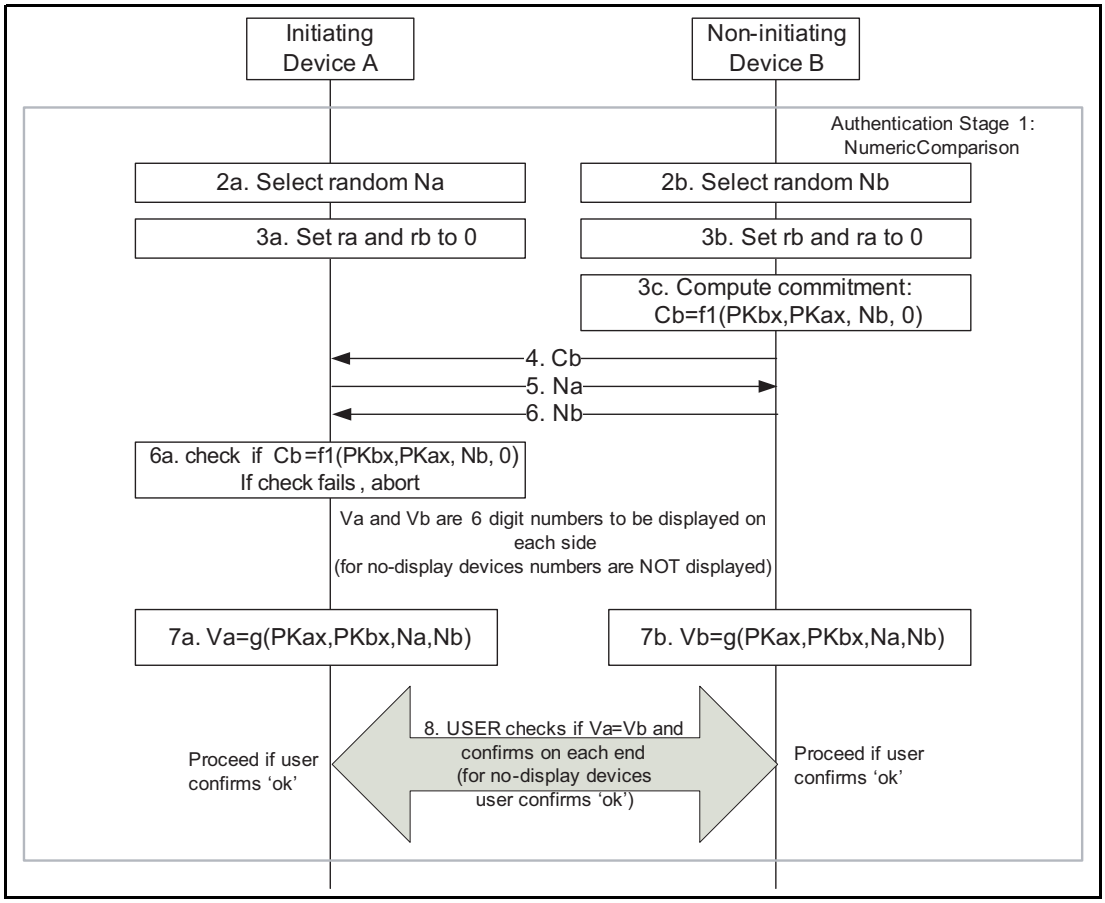

Figure 7.4: Authentication Stage 1: Numeric Comparison Protocol Details

After the public keys have been exchanged, each device selects a pseudo-random 128-bit nonce (step 2). This value is used to prevent replay attacks and must be freshly generated with each instantiation of the pairing protocol. This value should be generated directly from a physical source of randomness or with a good pseudo-random generator seeded with a random value from a physical source.

Following this the responding device then computes a commitment to the two public keys that have been exchanged and its own nonce value (step 3c). This commitment is computed as a one-way function of these values and is transmitted to the initiating device (step 4). The commitment prevents an attacker from changing these values at a later time.

The initiating and responding devices then exchange their respective nonce values (steps 5 and 6) and the initiating device confirms the commitment (step 6a). A failure at this point indicates the presence of an attacker or other transmission error and causes the protocol to abort. The protocol may be repeated with or without the generation of new public-private key pairs, but new nonces must be generated if the protocol is repeated.

Assuming that the commitment check succeeds, the two devices each compute 6-digit confirmation values that are displayed to the user on their

respective devices (steps 7a, 7b, and 8). The user is expected to check that these 6-digit values match and to confirm if there is a match. If there is no match, the protocol aborts and, as before, new nonces must be generated if the protocol is to be repeated.

An active MITM must inject its own key material into this process to have any effect other than denial-of-service. A simple MITM attack will result in the two 6-digit display values being different with probability 0.999999. A more sophisticated attack may attempt to engineer the display values to match, but this is thwarted by the commitment sequence. If the attacker first exchanges nonces with the responding device, it must commit to the nonce that it will use with the initiating device before it sees the nonce from the initiating device. If the attacker first exchanges nonces with the initiating device, it must send a nonce to the responding device before seeing the nonce from the responding device. In each case, the attacker must commit to at least the second of its nonces before knowing the second nonce from the legitimate devices. It therefore cannot choose its own nonces in such a way as to cause the display values to match.

7.2.2 Authentication Stage 1: Out of Band Protocol

The Out-of-Band protocol is used when authentication information has been received by at least one of the devices and indicated in the OOB Authentication Data Present parameter in the LMP IO capability exchange sequence. The mode in which the discovery of the peer device is first done in-band and then followed by the transmission of authentication parameters through OOB interface is not supported. The sequence diagram for Authentication Stage 1 for Out of Band from the cryptographic point of view is shown below:

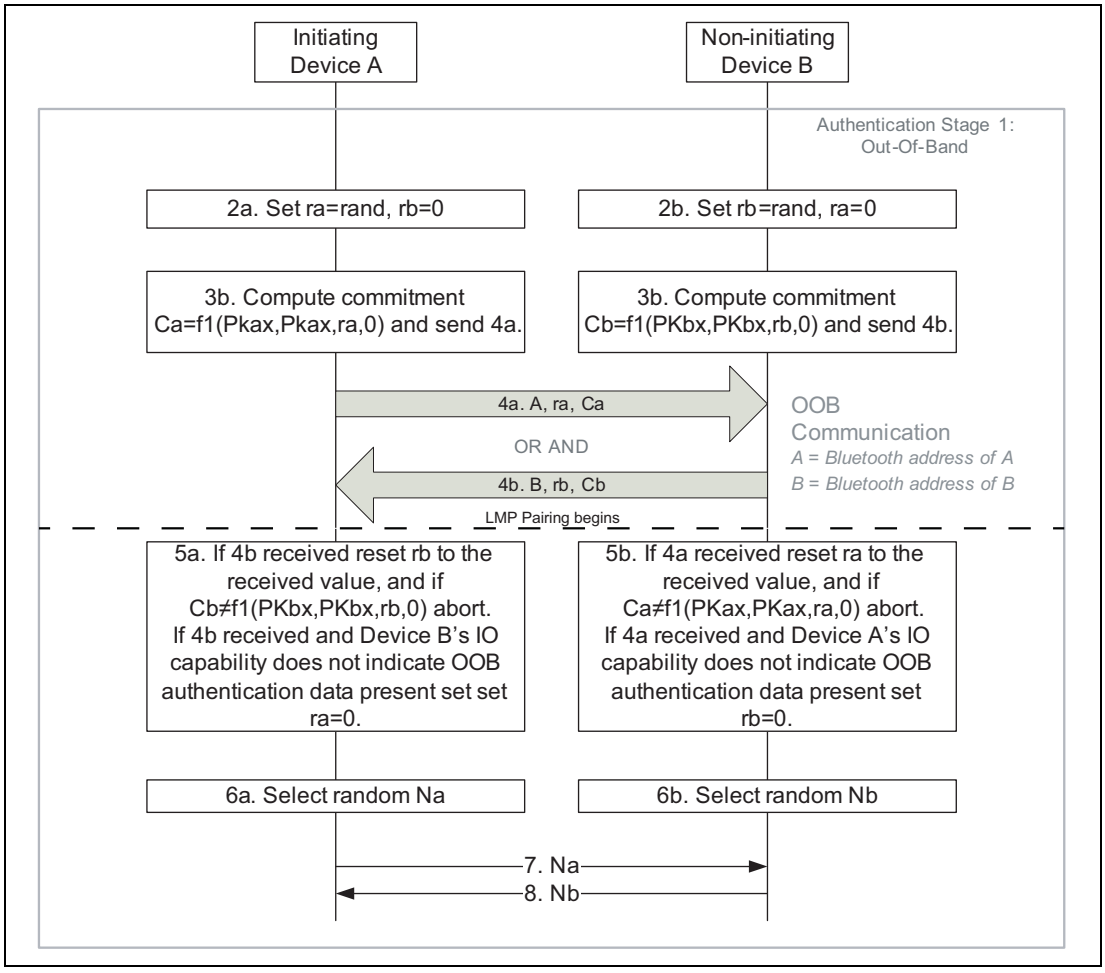

Figure 7.5: Authentication Stage 1: Out of Band Details

Principle of operation: If both devices can transmit and/or receive data over an out-of-band channel, then mutual authentication will be based on the commitments of the public keys (Ca and Cb) exchanged OOB in Authentication stage 1. If OOB communication is possible only in one direction, then authentication of the device receiving the OOB communication will be based on that device knowing a random number r sent via OOB. In this case, r must be secret: r can be created afresh every time, or access to the device sending r must be restricted. If r is not sent by a device, it is assumed to be 0 by the device receiving the OOB information in step 4a or 4b.

Roles of A and B: The OOB Authentication Stage 1 protocol is symmetric with respect to the roles of A and B. It does not require that device A always will initiate pairing and it automatically resolves asymmetry in the OOB communication, e.g. in the case when one of the devices has an NFC tag and can only transmit OOB.

Order of steps: The public key exchange must happen before the verification step 5. In the diagram the in-band public key exchange between the devices (step 1) is done before the OOB communication (step 4). But when the pairing

is initiated by an OOB interface, public key exchange will happen after the OOB communication (step 1 will be between steps 4 and 5).

Values of ra and rb: Since the direction of the peer's OOB interface cannot be verified before the OOB communication takes place, a device should always generate and if possible transmit through its OOB interface a random number r to the peer. Each device applies the following rules locally to set the values of its own r and the value of the peer's r:

1. Initially, r of the device is set to a random number and r of the peer is set to 0 (step 2).
2. If a device has received OOB, it sets the peer's r value to what was sent by the peer (Step 5).
3. If the remote device's OOB Authentication Data parameter sent in the LMP IO capabilities exchange sequence is set to No OOB Data Received, it sets its own r value to 0 (Step 5)

These rules ensure that when entering Authentication Stage 2, both A and B have the same values for ra and rb if OOB communication took place.

7.2.3 Authentication Stage 1: Passkey Entry Protocol

The Passkey Entry protocol is used when LMP IO capability exchange sequence indicates that Passkey Entry shall be used.

The sequence diagram for Authentication Stage 1 for Passkey Entry from the cryptographic point of view is shown in Figure 7.6.

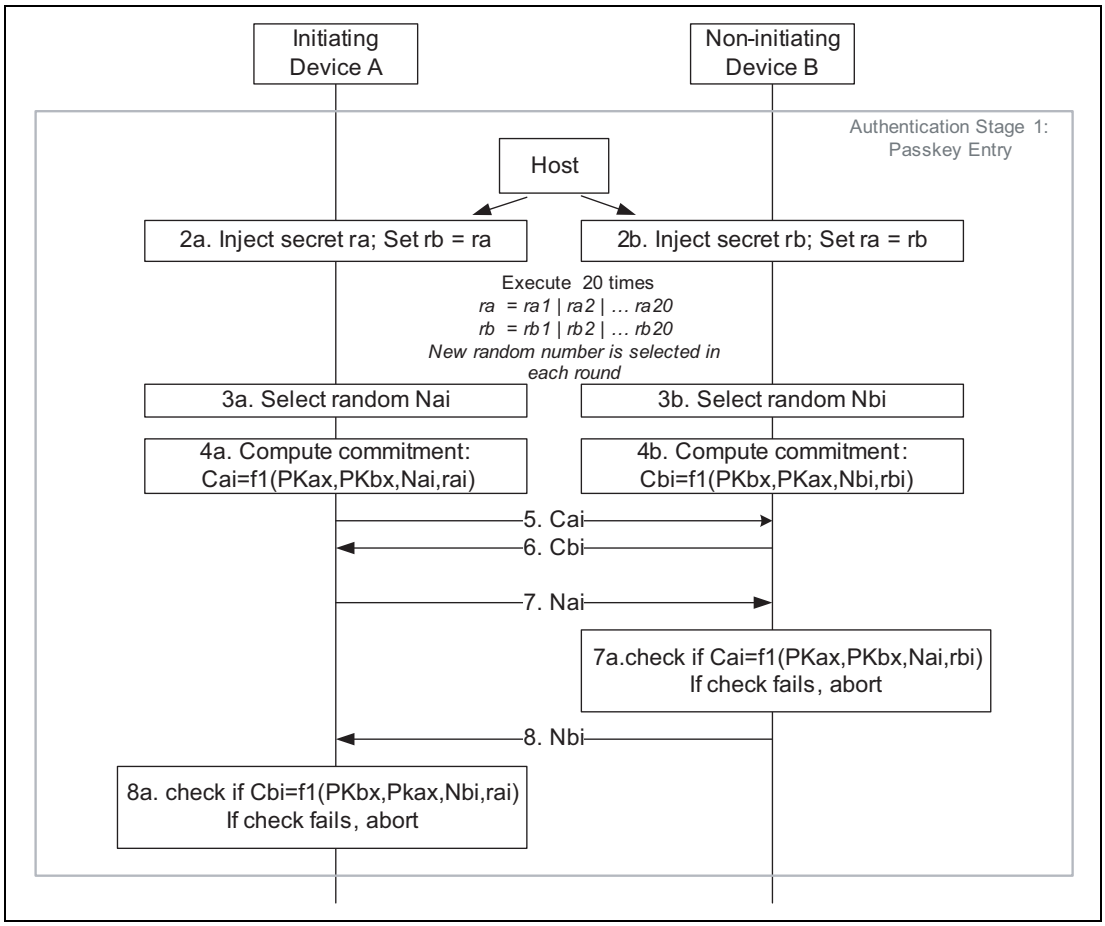

Figure 7.6: Authentication Stage 1: Passkey Entry Details

The user inputs an identical Passkey into both devices. Alternately, the Passkey may be generated and displayed on one device, and the user then inputs it into the other (step 2). This short shared key will be the basis of the mutual authentication of the devices. Steps 3 through 8 are repeated k times for a k-bit Passkey --e.g., k=20 for a 6-digit Passkey (999999=0xF423F).

In Steps 3-8, each side commits to each bit of the Passkey, using a long nonce (128 bits), and sending the hash of the nonce, the bit of the Passkey, and both public keys to the other party. The parties then take turns revealing their commitments until the entire Passkey has been mutually disclosed. The first party to reveal a commitment for a given bit of the Passkey effectively reveals that bit of the Passkey in the process, but the other party then has to reveal the corresponding commitment to show the same bit value for that bit of the Passkey, or else the first party will then abort the protocol, after which no more bits of the Passkey are revealed.

This "gradual disclosure" prevents leakage of more than 1 bit of un-guessed Passkey information in the case of a MITM attack. A MITM attacker with only partial knowledge of the Passkey will only receive one incorrectly-guessed bit of the Passkey before the protocol fails. Hence, a MITM attacker who engages

first one side, then the other will only gain an advantage of at most two bits over a simple brute-force guesser which succeeds with probability 0.000001.

The long nonce is included in the commitment hash to make it difficult to brute-force even after the protocol has failed. The public Diffie-Hellman values are included to tie the Passkey protocol to the original ECDH key exchange, to prevent a MITM from substituting the attacker's public key on both sides of the ECDH exchange in standard MITM fashion.

At the end of this stage, Na is set to Na_{20} and Nb is set to Nb_{20} for use in Authentication Stage 2.

7.3 PHASE 3: AUTHENTICATION STAGE 2

The second stage of authentication then confirms that both devices have successfully completed the exchange. This stage is identical in all three protocols.

Each device computes a new confirmation value that includes the previously exchanged values and the newly derived shared key (step 9). The initiating device then transmits its confirmation value which is checked by the responding device (step 10). If this check fails, it indicates that the initiating device has not confirmed the pairing, and the protocol must be aborted. The responding device then transmits its confirmation value which is checked by the initiating device (step 11). A failure indicates that the responding device has not confirmed the pairing and the protocol should abort.

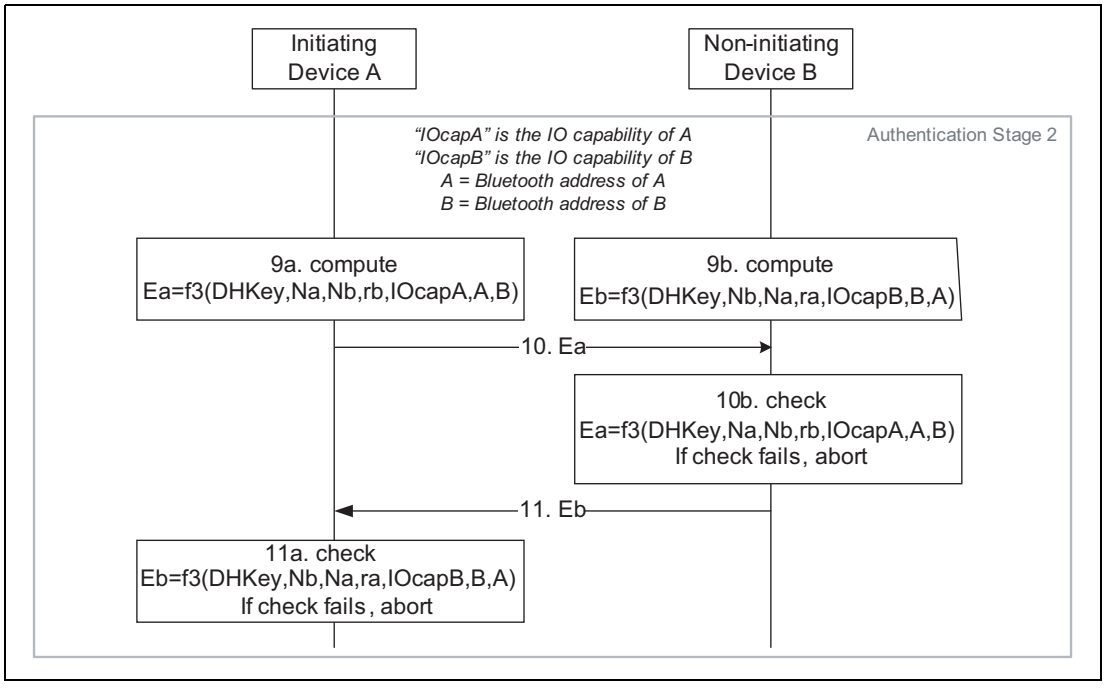

Figure 7.7: Authentication Stage 2

7.4 PHASE 4: LINK KEY CALCULATION

Once both sides have confirmed the pairing, a link key is computed from the derived shared key and the publicly exchanged data (step 12). The nonces ensure the freshness of the key even if long-term ECDH values are used by both sides. This link key is used to maintain the pairing.

When computing the link key both parties shall input the parameters in the same order to ensure that both devices compute the same key: device A's parameters are those of the piconet master and device B's parameters are those of the piconet slave.

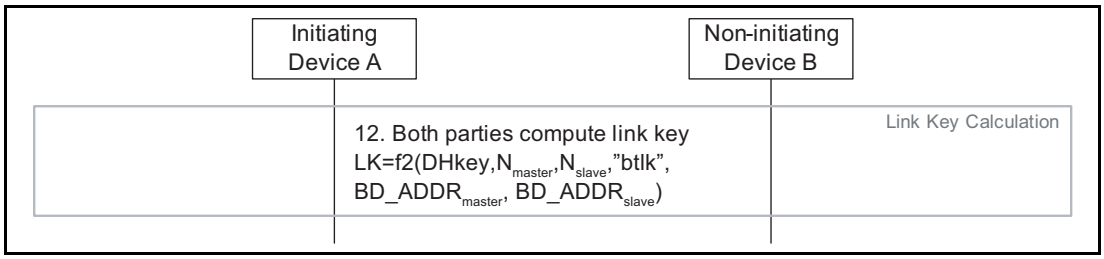

Figure 7.8: Link Key Calculation

7.5 PHASE 5: LMP AUTHENTICATION AND ENCRYPTION

The final phase in Simple Pairing consists of authentication and generation of the encryption key. This is the same as the final steps in legacy pairing.

7.6 ELLIPTIC CURVE DEFINITION

Simple Pairing supports two elliptic curves: P-192 and P-256.

Simple Pairing uses the FIPS P-192 and P-256 curves defined in FIPS 186-3[1]. Elliptic curves are specified by p, a, b and are of the form:

$$E: y^2 = x^3 + ax + b \pmod{p}$$

For each value of b a unique curve can be developed. In NIST P-192 and P-256:

$a = \text{mod}(-3, p)$

b is defined and its method of generation can be verified by using SHA-1 (with a given seed s and using $b^2c = -27 \pmod{p}$)

1. http://dx.doi.org/10.6028/NIST.FIPS.186-4

The following parameters are given:

- The prime modulus p, order r, base point x-coordinate Gx, base point y-coordinate Gy.
- The integers p and r are given in decimal form; bit strings and field elements are given in hex.

For P-192:

```
p  = 6277101735386680763835789423207666416083908700390324961279
r  = 6277101735386680763835789423176059013767194773182842284081
b  = 64210519 e59c80e7 0fa7e9ab 72243049 feb8deec c146b9b1
Gx = 188da80e b03090f6 7cbf20eb 43a18800 f4ff0afd 82ff1012
Gy = 07192b95 ffc8da78 631011ed 6b24cdd5 73f977a1 1e794811
```

The function P192 is defined as follows. Given an integer u, 0 < u < r, and a point V on the curve E, the value P192(u,V) is computed as the x-coordinate of the u^{th} multiple uV of the point V.

The private keys shall be between 1 and r/2, where r is the Order of the Abelian Group on the elliptic curve (e.g. between 1 and $2^{192}/2$).

For P-256:

```
p  = 1157920892103562487626974469494075735300861434152903141955336313088670978539 51
r  = 1157920892103562487626974469494075735299969552241357603424222590610685120443 69
b  = 5ac635d8 aa3a93e7 b3ebbd55 769886bc 651d06b0 cc53b0f6 3bce3c3e 27d2604b
Gx = 6b17d1f2 e12c4247 f8bce6e5 63a440f2 77037d81 2deb33a0 f4a13945 d898c296
Gy = 4fe342e2 fe1a7f9b 8ee7eb4a 7c0f9e16 2bce3357 6b315ece cbb64068 37bf51f5
```

The function P-256 is defined as follows. Given an integer u, 0 < u < r, and a point V on the curve E, the value P-256(u,V) is computed as the x-coordinate of the u^{th} multiple uV of the point V.

The private keys shall be between 1 and r/2, where r is the Order of the Abelian Group on the elliptic curve (e.g. between 1 and $2^{256}/2$).

7.7 CRYPTOGRAPHIC FUNCTION DEFINITIONS

In addition to computing the Elliptic Curve Diffie Hellman key, the Numeric Comparison, Out-of-Band and Passkey Entry protocols require four cryptographic functions. These functions are known as *f1*, *g*, *f2* and *f3*.

f1 is used to generate the 128-bit commitment values Ca and Cb

g is used to compute the 6-digit numeric check values

f2 is used to compute the link key and possible other keys from the DHKey and random nonces

f3 is used to compute check values Ea and Eb in Authentication Stage 2.

The basic building block for these functions is based on as it already exists in the key derivation function E3 (which is the same as E1 but with a larger input).

Inside the f1, g, f2, and f3 cryptographic functions, when a multi-octet integer input parameter is used as input to the SHA-256 and HMAC-SHA-256 functions, the most significant octet of the integer parameter shall be the first octet of the stream and the least significant octet of the integer parameter shall be the last octet of the stream. The output of the f1, g, f2 and f3 cryptographic functions is a multi-octet integer where the first octet out of SHA-256 and HMAC-SHA-256 shall be the MSB and the last octet shall be the LSB of that parameter.

Inside the h2 cryptographic function, when a multi-octet integer input parameter is used as input to the SHA-256 and HMAC-SHA-256 functions, the most significant octet of the integer parameter shall be the last octet of the stream and the least significant octet of the integer parameter shall be the first octet of the stream. The output of the h2 cryptographic function is a multi-octet integer where the first octet out of SHA-256 and HMAC-SHA-256 shall be the LSB and the last octet shall be the MSB of that parameter.

7.7.1 The Simple Pairing Commitment Function f1

The commitments are computed with function f1. The definition of the Simple Pairing commitment function makes use of the MAC function HMAC based on $SHA\text{-}256_x$, which is denoted as $HMAC\text{-}SHA\text{-}256_X$ with 128-bit key X.

The inputs to the Simple Pairing function f1 are:

Input	Bits with P-192	Bits with P-256
U	192	256
V	192	256
X	128	128
Z	8	8

Z is zero (i.e., 8 bits of zeros) for Numeric Comparison and OOB protocol. In the Passkey protocol the most significant bit of Z is set equal to one and the least significant bit is made up from one bit of the passkey e.g. if the passkey bit is 1 then Z = 0x81 and if the passkey bit is 0 then Z = 0x80.

The output of the Simple Pairing f1 function is:

$$f1(U, V, X, Z) = \text{HMAC-SHA-256}_X (U \,||\, V \,||\, Z) / 2^{128}$$

The inputs to *f1* are different depending on the different protocols.

Numeric Comparison	Out-Of-Band	Passkey Entry
Ca = f1(PKax, PKbx, Na, 0)	Ca = f1(PKax, PKax, ra, 0)	Cai = f1(PKax, PKbx, Nai, rai)
Cb = f1(PKbx, PKax, Nb, 0)	Cb = f1(PKbx, PKbx, rb, 0)	Cbi = f1(PKbx, PKax, Nbi, rbi)

Table 7.2: Inputs to f1 for the different protocols

where PKax denotes the x-coordinate of the public key PKa of A. Similarly, PKbx denotes the x-coordinate of the public key PKb of B. Nai is the nonce value of i^{th} round. For each round Nai value is a new 128 bit number. Similarly, rai is one bit value of the passkey expanded to 8 bits (either 0x80 or 0x81).

Na and Nb are nonces from Devices A and B. ra and rb are random values generated by devices A and B.

7.7.2 The Simple Pairing Numeric Verification Function *g*

The Simple Pairing *g* function is defined as follows:

The inputs to the Simple Pairing function *g* are:

Input	Bits with P-192	Bits with P-256
U	192	256
V	192	256
X	128	128
Y	128	128

The output of the Simple Pairing g function is:

$$g(U, V, X, Y) = \text{SHA-256}(U \,||\, V \,||\, X \,||\, Y) \bmod 2^{32}$$

The numeric verification value is taken as six least significant digits of the 32-bit integer *g*(PKax, PKbx, Na, Nb) where PKax denotes the x-coordinate of the public key PKa of A and PKbx denotes the x-coordinate of the public key PKb of B.

Output of SHA-256 is truncated to 32 bits by taking the least significant 32 bits of the output of SHA-256. This value is converted to decimal numeric value. The checksum used for numeric comparison is the least significant six digits.

$$Compare\ Value = g(U, V, X, Y) \bmod 10^6$$

For example, if output = 0x 01 2e b7 2a then decimal value = 19838762 and the checksum used for numeric comparison is 838762.

7.7.3 The Simple Pairing Key Derivation Function f2

The definition of the Simple Pairing key derivation function makes use of the MAC function HMAC based on SHA-256, which is denoted as HMAC-SHA-256_W with 192-bit or 256-bit key W.

The inputs to the Simple Pairing function *f2* are:

Input	Bits with P-192	Bits with P-256
W	192	256
N_1	128	128
N_2	128	128
keyID	32	32
A_1	48	48
A_2	48	48

The string "btlk" is mapped into keyID using extended ASCII[1] as follows:

keyID[0] = `0110 1011 (lsb)`
keyID[1] = `0110 1100`
keyID[2] = `0111 0100`
keyID[3] = `0110 0010`

KeyID = `0x62746c6b`

The output of the Simple Pairing f2 function is:

$$f2(W, N_1, N_2, KeyID, A_1, A_2) = HMAC\text{-}SHA\text{-}256_W\ (N1 \,||\, N2 \,||\, KeyID \,||\, A_1 \,||\, A_2) / 2^{128}$$

The output of *f2* is taken as the 128 most significant (leftmost) bits of the output of HMAC-SHA-256.

The link key is then calculated as:

LK = f2(DHKey, N_master, N_slave, "btlk", BD_ADDR_master, BD_ADDR_slave)

1. ISO/IEC 8859-1(see www.iso.org)

7.7.4 The Simple Pairing Check Function f3

The definition of the Simple Pairing f3 check function makes use of the MAC function HMAC based on SHA-256, which is denoted as HMAC-SHA-256$_W$ with 192-bit or 256-bit key W.

The inputs to the Simple Pairing function f3 are:

Input	Bits with P-192	Bits with P-256
W	192	256
N_1	128	128
N_2	128	128
IOcap	24	24
A_1	48	48
A_2	48	48

IOcap is three octets with the most significant octet as the Authentication Requirements parameter, the middle octet as the LMP Out-of-Band Authentication Data parameter, and the least significant octet as the LMP IO capability parameter.

The output of the Simple Pairing *f3* function is:

$$f3(W, N_1, N_2, R, IOcap, A_1, A_2) = HMAC\text{-}SHA\text{-}256W\ (N_1 \,||\, N_2 \,||\, R \,||\, IOcap \,||\, A_1 \,||\, A_2) / 2^{128}$$

The output of *f3* is taken as the 128 most significant (leftmost) bits of the output of HMAC-SHA-256. The check values are computed with function f3. The inputs to f3 are different depending on the different protocols:

Numeric Comparison	Out-Of-Band	Passkey Entry
Ea = *f3*(DHKey, Na, Nb, 0, IOcapA, A, B)	Ea = *f3*(DHKey, Na, Nb, rb, IOcapA, A, B)	Ea = *f3*(DHKey, Na20, Nb20, rb, IOcapA, A, B)
Eb = *f3*(DHKey, Nb, Na, 0, IOcapB, B, A)	Eb = *f3*(DHKey, Nb, Na, ra, IOcapB, B, A)	Eb = *f3*(DHKey, Nb20, Na20, ra, IOcapB, B, A)

Table 7.3: Inputs to f3 for the different protocols

DHKey denotes the shared secret Diffie-Hellman Key computed as P192(SKa, PKb) or P256(SKa, PKb) by A and as P192(SKb, PKa) or P256(SKb, PKb) by B. IOcapA denotes the IO capability data of A and IOcapB denotes the IO capability data of B. In Passkey Entry, the data ra and rb are 6-digit passkey values which are expressed as a 128-bit integer. For instance, if the 6-digit value of ra is 131313

then R = 0x 00 00 00 00 00 00 00 00 00 00 00 00 00 02 00 f1.

The input A is the BD_ADDR of device A and the input B is the BD_ADDR of device B.

7.7.5 The Simple Pairing AMP Key Derivation Function h2

The definition of the Simple Pairing dedicated AMP key derivation function makes use of the MAC function HMAC based on SHA-256, which is denoted as HMAC-SHA-256$_W$ with 256-bit key W.

The inputs to the Simple Pairing function h2 are as follows:

W is 256 bits

keyID is 32 bits

L is 8 bits

The output of the Simple Pairing *h2* function is as follows:

$$h2(W, keyID, L) = HMAC\text{-}SHA\text{-}256_W (keyID) / 2^{256-(L*8)}$$

For each Dedicated AMP, a fixed value of the key identifier KeyID is specified. A master key MK_{AMP} of length L_{AMP}, $0 \leq L_{AMP} \leq 32$, is computed as

$$MK_{AMP} = h2 (GAMP\_LK, keyID_{AMP}, L_{AMP}).$$

7.7.5.1 Initial GAMP_LK Creation

The Generic AMP Link Key (GAMP_LK) shall be created every time the link key (LK) is changed or created using the f2 function (see Section 7.7.3). Whenever the GAMP_LK is created, all dedicated AMP link keys associated with the remote BD_ADDR shall be discarded.

A fixed value of the key identifier KeyID is specified ('gamp'). The string 'gamp' is mapped into keyID using extended ASCII[1] as follows:

keyID[0] = *0111 0000 (lsb)*
keyID[1] = *0110 1101*
keyID[2] = *0110 0001*
keyID[3] = *0110 0111*
keyID = *0x67616d70*

The initial GAMP_LK shall be created in the Host using the h2 function.

GAMP_LK = *h2* (W, 'gamp', 32)

Where W = LK || LK

7.7.5.2 Dedicated AMP Link Key Generation

Each AMP uses a defined keyID and keyLength. Both values are defined in the Assigned numbers page.

A dedicated AMP link key is computed as

1. ISO_8859-1

Dedicated_AMP_Link_Key = *h2* (GAMP_LK, keyID, keyLength)

7.7.5.3 GAMP_LK Regeneration

Each time the GAMP_LK is used to generate a valid dedicated AMP link key it shall be regenerated by computing

New_ GAMP_LK = *h2* (GAMP_LK, 'gamp', 32)

and then setting

GAMP_LK = New_GAMP_LK

7.7.5.4 Debug AMP Link Key Generation

When the BR/EDR link key is a debug link key, the dedicated AMP link keys are set equal to the keyLength least significant octets of the Generic AMP link key. When debug link keys are used, the Generic AMP link key shall not be regenerated.

7.7.6 The AES Encryption Key Generation Function h3

AES encryption keys are created using the AES encryption key generation function *h3*. The definition of the AES encryption key generation function makes use of the MAC function HMAC based on SHA-256, which is denoted as HMAC-SHA-256$_T$ with 128-bit key T.

The inputs to function *h3* are:

Input	Bits with P-256
T	128
keyID	32
A_1	48
A_2	48
ACO	64

A_1 is the BD_ADDR of the master. A_2 is the BD_ADDR of the slave. ACO is the 64 bit ACO output from h5. T is the 128 bit Bluetooth Link Key derived from f2.

The string “btak” (Bluetooth AES Key) is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0110 1011 (lsb)
keyID[1] = 0110 0001
keyID[2] = 0111 0100
keyID[3] = 0110 0010
KeyID = 0x6274616b
```

The output of function *h3* is:

$h3(W, keyID, A_1, A_2, ACO) =$

$HMAC\text{-}SHA\text{-}256_T(KeyID \,||\, A_1 \,||\, A_2 \,||\, ACO) / 2^{128}$

The output of *h3* is taken as the 128 most significant (leftmost) bits of the output of HMAC-SHA-256.

7.7.7 The Device Authentication Key Generation Function h4

With Secure Connections, a device authentication key is created using function *h4*. The definition of the device authentication key generation function makes use of the MAC function HMAC based on SHA-256, which is denoted as $HMAC\text{-}SHA\text{-}256_T$ with 128-bit key T.

The inputs to function *h4* are:

Input	Bits with P-256
T	128
keyID	32
A_1	48
A_2	48

A_1 is the BD_ADDR of the master. A_2 is the BD_ADDR of the slave. T is the 128 bit Bluetooth Link Key derived from f2.

The string “btdk” (Bluetooth Device Key) is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0110 1011 (lsb)
keyID[1] = 0110 0100
keyID[2] = 0111 0100
keyID[3] = 0110 0010
KeyID = 0x6274646b
```

The output of function *h4* is:

$h4(W, KeyID, A_1, A_2) = HMAC\text{-}SHA\text{-}256_T(KeyID \,||\, A_1 \,||\, A_2) / 2^{128}$

The output of h4 is taken as the 128 most significant (leftmost) bits of the output of HMAC-SHA-256.

7.7.8 The Device Authentication Confirmation Function h5

With Secure Connections, device authentication confirmation values are created using function *h5*. The definition of the device authentication confirmation function makes use of the MAC function HMAC based on SHA-256, which is denoted as HMAC-SHA-256$_S$ with 128-bit key S.

The inputs to function *h5* are:

Input	Bits with P-256
S	128
R_1	128
R_2	128

R_1 is the 128 bit random number (AU_RAND_M) from the master during the Link Manager device authentication sequence. R_2 is the 128 bit random number from the slave (AU_RAND_S) during the Link Manager device authentication sequence. S is the 128-bit Bluetooth Device Authentication Key derived from h4.

The output of function *h5* is:

$$h5(W, R_1, R_2) = \text{HMAC-SHA-256}_S(R_1 \,||\, R_2) / 2^{128}$$

The output of *h5* is taken as the 128 most significant (leftmost) bits of the output of HMAC-SHA-256. The first 32 bits (leftmost) become the SRESmaster. The next 32 bits become the SRESslave. The final 64 bits become the Authentication Ciphering Offset (ACO), which is used in h3 and as the IV for Encryption Start for the encryption nonce.

8 AMP SECURITY

8.1 CREATION OF THE INITIAL GENERIC AMP LINK KEY

AMP security starts any time the BR/EDR link key is created or changed. This may be as the result of the f2 function during Phase 4 of the Secure Simple Pairing process (see Section 7.7.3) or due to a change connection link key procedure. The initial Generic AMP link key, GAMP_LK, is created with the h2 function using the BR/EDR Link Key concatenated together with itself to form a 256-bit value and with the KeyID 'gamp' (see Section 7.7.5.1). The Generic AMP Link Key (GAMP_LK) is stored in the security database alongside the BR/EDR Link Key once pairing has completed.

Whenever the Generic AMP Link Key is created, all Dedicated AMP Link Keys associated with the remote device shall be discarded and any active AMP Physical Links to the remote device shall be disconnected. Note that when a Host initiates a Change Connection Link Key procedure, all active AMP physical links between the two devices will be disconnected.

Since AMP security does not affect the BR/EDR Link Key, backwards compatibility is maintained for devices that support the Generic AMP feature with devices that do not. The Generic AMP Link Key is generated as part of Secure Simple Pairing regardless of whether the devices both support the Generic AMP feature or any AMP in common.

8.2 CREATION OF DEDICATED AMP LINK KEYS

When an AMP is used for the first time, a dedicated AMP key is created by the AMP Manager for that AMP type using the new Secure Simple Pairing function h2 and a KeyID for the AMP type. The length of the Dedicated AMP Link Key depends on the AMP Type. If the Dedicated AMP Link Key already exists due to a previous connection the AMP link key is not created and the stored key is reused.

The Dedicated AMP Link Key is sent down to the PAL in the *HCI Create Physical Link* and *HCI Accept Physical Link* commands (see [Vol 2] Part E, Section 7.1.37 and [Vol 2] Part E, Section 7.1.38). Each PAL is responsible for establishing security from the Dedicated AMP Link Key. Note that a Dedicated AMP Link Key may be used for multiple sessions over the same AMP.

Each time a dedicated AMP key is created and the AMP Create Physical Link sequence completes successfully (see [Vol 3] Part E, Section 2.3.3), the Generic AMP Link Key is updated. This is performed using the h2 function with KeyID 'gamp.' If the AMP Create Physical Link sequence does not complete successfully, the dedicated AMP link key shall be discarded and the Generic AMP Link Key shall not be updated.

Figure 8.1 shows an overview of the AMP key generation in the Host.

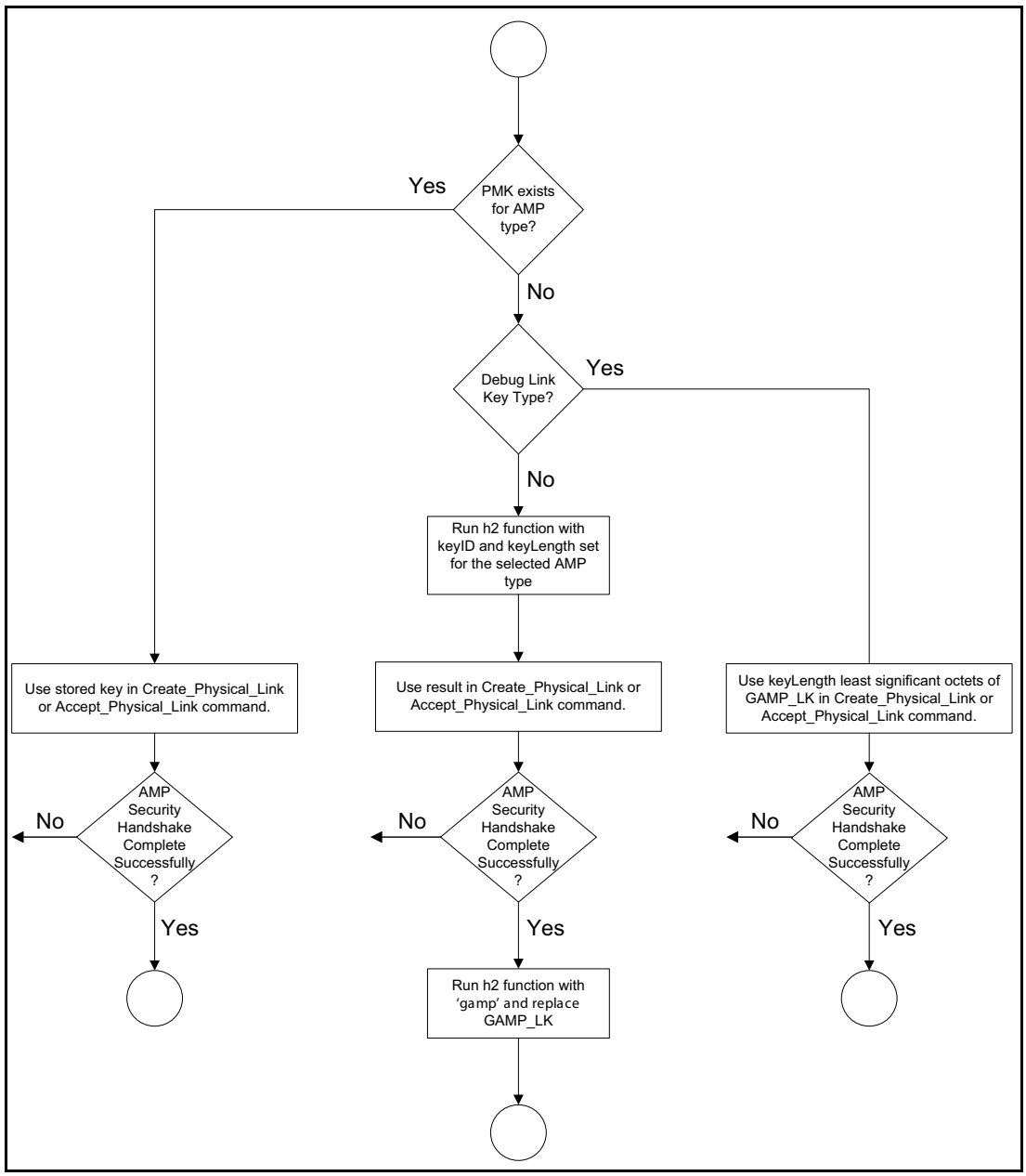

Figure 8.1: AMP key generation in Host

Creation of the dedicated AMP keys and updates to the Generic AMP Link Key are the responsibility of the AMP Manager (see [Vol 3] Part E, Section 2.3.3).

8.3 DEBUG CONSIDERATIONS

Since the AMP architecture requires encryption to be enabled on each AMP, in order to support sniffers for debug as well as to enable testing over the air, provisions need to be made in the AMP architecture to support debug combination keys. In this document, this is supported in two ways:

- Passing the link key type along with the link key (and length) in the HCI_Create_Physical_Link and HCI_Accept_Physical_Link commands and
- Requiring that the GAMP_LK is used as the dedicated AMP key when the key type is set to "debug combination key.”

9 AES-CCM ENCRYPTION FOR BR/EDR

The Baseband provides security using Counter with Cipher Block Chaining-Message Authentication Code (CCM) as defined in IETF RFC 3610 (http://www.ietf.org/rfc/rfc3610.txt) with a modification to the B_1 counter mode block format that omits the length of the additional authenticated data. The description of the algorithm can also be found in the NIST Special Publication 800-38C (http://csrc.nist.gov/publications/PubsSPs.html).

Using the notation in [4], CCM has two size parameters, M and L.
The Baseband defines these to be:

M = 4; indicating that the MIC length is 4 octets (32 bits)

Size of M represents a trade-off between message expansion and the probability that an attacker can undetectably modify a message.

L = 2; indicating that the Length field is 2 octets (16 bits)

Size of L requires a trade-off between the maximum message size and the size of the Nonce.

9.1 NONCE FORMATS

All of the parameters in the nonce are unique per logical transport. The nonce will be 13 octets and will have two formats. The first format is called the payload counter format and is used for ACL packets on the primary LT_ADDR. The second format is called the clock format and is used for eSCO packets.

The reason for two formats has to do with two factors: potential security attacks and synchronization. Since ACL packets on the primary LT_ADDR carry protocol, they are susceptible to attacks that eSCO packets (only data) are not.

The descriptions of the two nonce formats are provided in Table 9.1.

Octet	Field	Octets	Payload Counter Format Description	Clock Format Description
0	Nonce0	1	PayloadCounter[7:0]	CLK[8:1]
1	Nonce1	1	PayloadCounter[15:8]	CLK[16:9]
2	Nonce2	1	PayloadCounter[23:16]	CLK[24:17]

Table 9.1: Nonce Formats.

Octet	Field	Octets	Payload Counter Format Description	Clock Format Description
3	Nonce3	1	PayloadCounter[31:24]	Bit 2 – Bit 0: CLK[27:25] Bit 7 – Bit 3: dayCounter[4:0]
4	Nonce4	1	Bits 3 - 0: PayloadCounter[35:32] Bit 4: zero-length ACL-U continuation packet (1=zero-length ACL-U continuation packet, 0=otherwise) Bit 5: direction (0=master to slave, 1=slave to master) Bits 7-6: nonceType = 00b (ACL)	Bit 5 – Bit 0: dayCounter[10:5] Bits 7-6: nonceType = 01b (eSCO)
5	Nonce5	1	Octet0 (LSO) of IV	
6	Nonce6	1	Octet1 of IV	
7	Nonce7	1	Octet2 of IV	
8	Nonce8	1	Octet3 of IV	
9	Nonce9	1	Octet4 of IV	
10	Nonce10	1	Octet5 of IV	
11	Nonce11	1	Octet6 of IV	
12	Nonce12	1	Octet7 (MSO) of IV	

Table 9.1: Nonce Formats.

In the payload counter format, the PayloadCounter starts at zero for the first encrypted packet in each direction after encryption is started or resumed and increments every time an encrypted payload including zero-length payloads is accepted by the remote device. Note: It is possible that when encryption is being enabled or resumed, a packet may first get transmitted unencrypted and then get retransmitted encrypted. In such a case, the PayloadCounter gets incremented when the encrypted retransmission of the packet gets accepted by the remote device.

Bit 4 of Octet 4 shall be set to 1 for a zero length ACL-U continuation packet (see [Vol 2] Part B, Section 7.6.2.2), otherwise it shall be set to 0.

In the clock format, the master clock (CLK) used for the nonce shall be the value in the first slot of the packet. After a new ACL connection has been established or a role switch has been successfully performed and when eSCO

is successfully established for the first time then the dayCounter value shall be initialized to:

1 if CLK27 in the first clock format nonce is 0, and initialization procedure 2 (see [Vol 2] Part B, Section 8.6.3) is used

0 otherwise.

After the dayCounter has been initialized, it shall increment every time the master clock (CLK) rolls over to 0x0000000 (approximately every 23.3 hours).
Note: When Security Mode 4 is in use, eSCO will not be established before encryption is started.

The IV is an 8 octet field. For encryption start, all octets of the IV are from the ACO output of the last execution of h5 prior to the start of encryption.
Note: Multiple device authentications may occur prior to starting encryption but only the ACO of the last device authentication is used. After an encryption resume, all 8 octets of the IV are from the EN_RAND sent by the device initiating the encryption pause (see [Vol 2] Part C, Section 4.2.5.5). An encryption pause and resume will be required prior to the PayloadCounter or dayCounter rolling over in order to keep the nonce fresh for an encryption key.

Octet	IV for Encryption Start	IV After Resume Encryption
0	ACO[0]	EN_RAND[0]
1	ACO[1]	EN_RAND[1]
2	ACO[2]	EN_RAND[2]
3	ACO[3]	EN_RAND[3]
4	ACO[4]	EN_RAND[4]
5	ACO[5]	EN_RAND[5]
6	ACO[6]	EN_RAND[6]
7	ACO[7]	EN_RAND[7]

Table 9.2: IV Construction.

9.2 COUNTER MODE BLOCKS

For calculating the MIC, the payload is broken into two or more counter mode blocks. The CCM specification refers to these blocks as blocks B_0 – B_n. B_0 applies to the nonce, B_1 applies to the associated data {that is packet header and payload header} and additional B blocks are generated as needed for

authentication of the payload body.

Offset (octets)	Field	Size (octets)	Value	Description
0	Flags	1	0x49	As per the CCM specification
1	Nonce	13	variable	The nonce as described in Section 9.1. Nonce0 shall have offset 1. Nonce12 shall have offset 13.
14	Length[MSO]	1	variable	The most significant octet of the length of the payload body
15	Length[LSO]	1	variable	The least significant octet of the length of the payload body

Table 9.3: B_0 Counter Mode Block Format.

Offset	Field	Size (octets)	Value	Description
0	Packet_Header [MSO]	1	Variable	The most significant octet of the packet header: Bit 0: 0b (ARQN masked) Bit 1: 0b (SEQN masked) Bit 7 – Bit 2: 000000b
1	Packet_Header [LSO]	1	Variable	The least significant octet of the packet header: Bit 2 – Bit 0: LT_ADDR Bit 6 – Bit 3: TYPE Bit 7: 0b (FLOW masked)
2	Payload_Header	1	Variable	The payload header: Bit 1 – Bit 0: LLID Bit 2: 0b (FLOW masked) Bit 7 – Bit 3: 00000b
3	Padding	13	0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00	These octets are only used to pad the block. They are not part of the packet and never transmitted.

Table 9.4: B_1 Counter Mode Block Format.

9.3 ENCRYPTION BLOCKS

The CCM algorithm uses the A_i blocks to generate a keystream that is used to encrypt the MIC and payload body. Block A_0 is always used to encrypt and decrypt the MIC, when present. Block A_1 is always used to encrypt and decrypt the first 16 octets of the payload body. Subsequent blocks are always used to encrypt and decrypt the rest of the payload body as needed.

Offset (octets)	Field	Size (octets)	Value	Description
0	Flags	1	0x01	As per the CCM specification
1	Nonce	13	variable	The nonce as described in Section 9.1. Nonce0 shall have offset 1. Nonce12 shall have offset 13.
14	i[MSO]	1	variable	The most significant octet of the counter i
15	i[LSO]	1	variable	The least significant octet of the counter i

Table 9.5: Encryption Mode Block Format.

9.4 ENCRYPTION KEY SIZE REDUCTION

When the devices have negotiated a key size shorter than the maximum length, the key will be shortened by replacing LSOs of the key with 0x00.

9.5 REPEATED MIC FAILURES

Anytime the MIC check fails and the CRC passes on a given packet, it is considered an authentication failure. No more than three authentication failures shall be permitted during the lifetime of an encryption key with a given IV. The third authentication failure shall initiate an encryption key refresh (see [Vol 2] Part C, Section 4.2.5.8). If a fourth authentication failure occurs prior to the encryption key refresh procedure completing, the link shall be disconnected with reason code *Connection Rejected Due to Security Reasons* (0x0E).
Note: The MIC is not checked when the CRC is invalid.

Core System Package

[Host volume]

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Contributors

The persons who contributed to this specification are listed in the [Vol 0] Part C, Appendix.

Web Site

This specification can also be found on the official Bluetooth web site:
https://www.bluetooth.org/en-us/specification/adopted-specifications

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LOGICAL LINK CONTROL AND ADAPTATION PROTOCOL SPECIFICATION

The Bluetooth logical link control and adaptation protocol (L2CAP) supports higher level protocol multiplexing, packet segmentation and reassembly, and the conveying of quality of service information. The protocol state machine, packet format, and composition are described in this document.

CONTENTS

1 INTRODUCTION

This section of the Bluetooth Specification defines the Logical Link Control and Adaptation Layer Protocol, referred to as L2CAP. L2CAP provides connection-oriented and connectionless data services to upper layer protocols with protocol multiplexing capability and segmentation and reassembly operation. L2CAP permits higher level protocols and applications to transmit and receive upper layer data packets (L2CAP Service Data Units, SDU) up to 64 kilobytes in length. L2CAP also permits per-channel flow control and retransmission.

The L2CAP layer provides logical channels, named L2CAP channels, which are multiplexed over one or more logical links.

1.1 L2CAP FEATURES

The functional requirements for L2CAP include protocol/channel multiplexing, segmentation and reassembly (SAR), per-channel flow control, and error control. L2CAP sits above a lower layer composed of one of the following:

1. BR/EDR Controller and zero or more AMP Controllers or
2. BR/EDR/LE Controller (supporting BR/EDR and LE) and zero or more AMP Controllers, or
3. LE Controller (supporting LE only)

L2CAP interfaces with upper layer protocols.

Figure 1.1 breaks down L2CAP into its architectural components. The Channel Manager provides the control plane functionality and is responsible for all internal signaling, L2CAP peer-to-peer signaling and signaling with higher and lower layers. It performs the state machine functionality described in Section 6 and uses message formats described in Section 4, and Section 5. The Retransmission and Flow Control block provides per-channel flow control and error recovery using packet retransmission. The Resource Manager is responsible for providing a frame relay service to the Channel Manager, the Retransmission and Flow Control block and those application data streams that do not require Retransmission and Flow Control services. It is responsible for coordinating the transmission and reception of packets related to multiple L2CAP channels over the facilities offered at the lower layer interface.

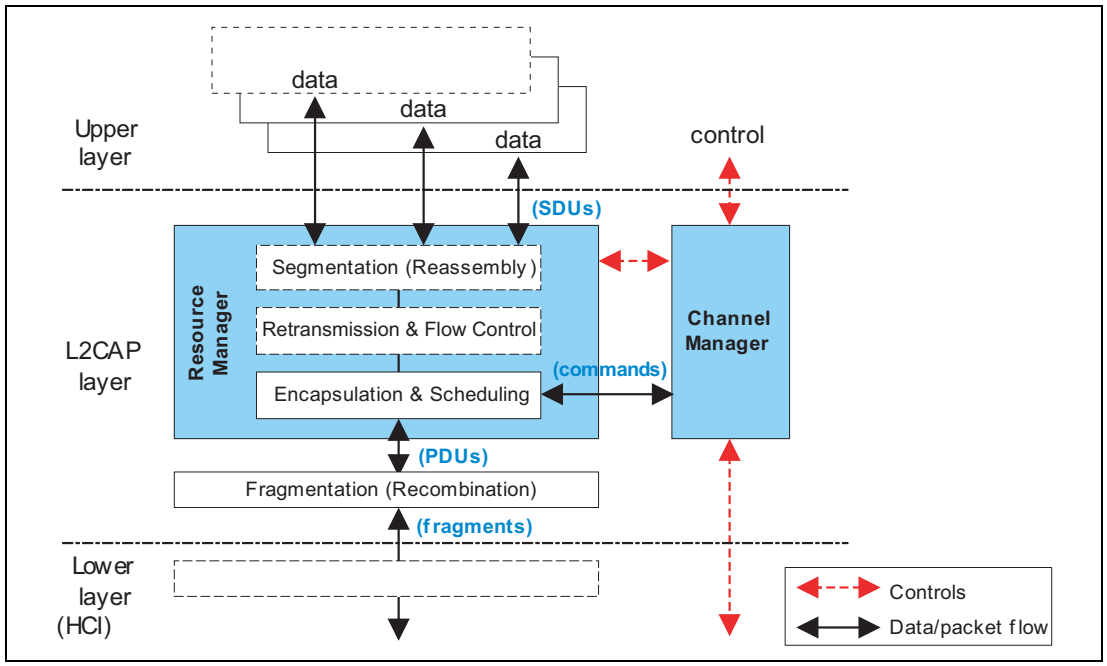


Figure 1.1: L2CAP architectural blocks

- *Protocol/channel multiplexing*

  L2CAP supports multiplexing over individual Controllers and across multiple Controllers. An L2CAP channel shall operate over one Controller at a time.

  During channel setup, protocol multiplexing capability is used to route the connection to the correct upper layer protocol.

  For data transfer, logical channel multiplexing is needed to distinguish between multiple upper layer entities. There may be more than one upper layer entity using the same protocol.

- *Segmentation and reassembly*

  With the frame relay service offered by the Resource Manager, the length of transport frames is controlled by the individual applications running over L2CAP. Many multiplexed applications are better served if L2CAP has control over the PDU length. This provides the following benefits:

  a) Segmentation will allow the interleaving of application data units in order to satisfy latency requirements.

  b) Memory and buffer management is easier when L2CAP controls the packet size.

  c) Error correction by retransmission can be made more efficient.

  d) The amount of data that is destroyed when an L2CAP PDU is corrupted or lost can be made smaller than the application's data unit.

  e) The application is decoupled from the segmentation required to map the application packets into the lower layer packets.

- *Flow control per L2CAP channel*

  Controllers provide error and flow control for data going over the air and HCI flow control exists for data going over an HCI transport. When several data streams run over the same Controller using separate L2CAP channels, each channel requires individual flow control. A window based flow control scheme is provided.

- *Error control and retransmissions*

  When L2CAP channels are moved from one Controller to another data can be lost. Also, some applications require a residual error rate much smaller than some Controllers can deliver. L2CAP provides error checks and retransmissions of L2CAP PDUs. The error checking in L2CAP protects against errors due to Controllers falsely accepting packets that contain errors but pass Controller-based integrity checks. L2CAP error checking and retransmission also protect against loss of packets due to flushing by the Controller. The error control works in conjunction with flow control in the sense that the flow control mechanism will throttle retransmissions as well as first transmissions.

- *Support for Streaming*

  Streaming applications such as audio set up an L2CAP channel with an agreed-upon data rate and do not want flow control mechanisms, including those in the Controller, to alter the flow of data. A flush timeout is used to keep data flowing on the transmit side. Streaming mode is used to stop HCI and Controller based flow control from being applied on the receiving side.

- *Fragmentation and Recombination*

  Some Controllers may have limited transmission capabilities and may require fragment sizes different from those created by L2CAP segmentation. Therefore layers below L2CAP may further fragment and recombine L2CAP PDUs to create fragments which fit each layer's capabilities. During transmission of an L2CAP PDU, many different levels of fragmentation and recombination may occur in both peer devices.

  The HCI driver or Controller may fragment L2CAP PDUs to honor packet size constraints of a Host Controller interface transport scheme. This results in HCI data packet payloads carrying start and continuation fragments of the L2CAP PDU. Similarly the Controller may fragment L2CAP PDUs to map them into Controller packets. This may result in Controller packet payloads carrying start and continuation fragments of the L2CAP PDU.

  Each layer of the protocol stack may pass on different sized fragments of L2CAP PDUs, and the size of fragments created by a layer may be different in each peer device. However the PDU is fragmented within the stack, the receiving L2CAP entity still recombines the fragments to obtain the original L2CAP PDU.

- *Quality of Service*

  The L2CAP connection establishment process allows the exchange of information regarding the quality of service (QoS) expected between two Bluetooth devices. Each L2CAP implementation monitors the resources used by the protocol and ensures that QoS contracts are honored.

  For a BR/EDR or BR/EDR/LE Controller, L2CAP may support both isochronous (Guaranteed) and asynchronous (Best Effort) data flows over the same ACL logical link by marking packets as automatically-flushable or non-automatically-flushable by setting the appropriate value for the Packet_Boundary_Flag in the HCI ACL Data Packet (see [Vol 2] Part E, Section 5.4.2). Automatically-flushable L2CAP packets are flushed according to the automatic flush timeout set for the ACL logical link on which the L2CAP channels are mapped (see [Vol 2] Part E, Section 6.19). Non-automatically-flushable L2CAP packets are not affected by the automatic flush timeout and will not be flushed. All L2CAP packets can be flushed by using the HCI Flush command (see [Vol 2] Part E, Section 7.3.4).

  For AMP Controllers, L2CAP places all asynchronous data flows going to the same remote device over a single logical link (aggregation). L2CAP places each isochronous data flow over its own logical link.

1.2 ASSUMPTIONS

The protocol is designed based on the following assumptions:

1. Controllers provide orderly delivery of data packets, although there might be individual packet corruption and duplicates. For devices with a BR/EDR or BR/EDR/LE Controller, no more than one ACL-U logical link exists between any two devices. For devices with a given AMP Controller, more than one AMP-U logical link may exist between any two devices. For devices with a BR/EDR/LE or LE Controller, no more than one LE-U logical link exists between any two devices.
2. Controllers always provide the impression of full-duplex communication channels. This does not imply that all L2CAP communications are bi-directional. Unidirectional traffic does not require duplex channels.
3. The L2CAP layer provides a channel with a degree of reliability based on the mechanisms available in Controllers and with additional packet segmentation, error detection, and retransmission that can be enabled in the enhanced L2CAP layer. Some Controllers perform data integrity checks and resend data until it has been successfully acknowledged or a timeout occurs. Other Controllers will resend data up to a certain number of times whereupon the data is flushed. Because acknowledgments may be lost, timeouts may occur even after the data has been successfully sent. Note that the use of baseband broadcast packets in a BR/EDR or BR/EDR/LE Controller is unreliable and that all broadcasts start the first segment of an L2CAP packet with the same sequence bit.
4. Controllers provide error and flow control for data going over the air and HCI flow control exists for data going over an HCI transport but some

applications will want better error control than some Controllers provide. Also, moving channels between Controllers requires L2CAP flow and error control. The Flow and Error Control block provides four modes. Enhanced Retransmission mode and Retransmission Mode offer segmentation, flow control and L2CAP PDU retransmissions. Flow control mode offers just the segmentation and flow control functions. Streaming mode offers segmentation and receiver side packet flushing.

1.3 SCOPE

The following features are outside the scope of L2CAP's responsibilities:

- L2CAP does not transport synchronous data designated for SCO or eSCO logical transports.
- L2CAP does not support a reliable broadcast channel. See Section 3.2.

1.4 TERMINOLOGY

The following formal definitions apply:

Term	Description
Upper layer	The system layer above the L2CAP layer, which exchanges data with L2CAP in the form of SDUs. The upper layer may be represented by an application or higher protocol entity known as the Service Level Protocol. The interface of the L2CAP layer with the upper layer is not specified.
Lower layer	The system layer below the L2CAP layer, which exchanges data with the L2CAP layer in the form of PDUs, or fragments of PDUs. The lower layer is mainly represented within the Controller, however a Host Controller Interface (HCI) may be involved, such that an HCI Host driver could also be seen as the lower layer. Except for the HCI functional specification (in case HCI is involved) the interface between L2CAP and the lower layer is not specified.
L2CAP channel	The logical connection between two endpoints in peer devices, characterized by their Channel Identifiers (CID), which is multiplexed over one Controller based logical link.
SDU, or L2CAP SDU	Service Data Unit: a packet of data that L2CAP exchanges with the upper layer and transports transparently over an L2CAP channel using the procedures specified here. The term SDU is associated with data originating from upper layer entities only, i.e. does not include any protocol information generated by L2CAP procedures.
Segment, or SDU segment	A part of an SDU, as resulting from the Segmentation procedure. An SDU may be split into one or more segments. Note: This term is relevant only to Enhanced Retransmission mode, Streaming mode, Retransmission Mode and Flow Control Mode, not to the Basic L2CAP Mode.

Table 1.1: Terminology

Term	Description
Segmentation	A procedure used in the L2CAP Retransmission and Flow Control Modes, resulting in an SDU being split into one or more smaller units, called Segments, as appropriate for the transport over an L2CAP channel. Note: This term is relevant only to the Enhanced Retransmission mode, Streaming mode, Retransmission Mode and Flow Control Mode, not to the Basic L2CAP Mode.
Reassembly	The reverse procedure corresponding to Segmentation, resulting in an SDU being re-established from the segments received over an L2CAP channel, for use by the upper layer. Note that the interface between the L2CAP and the upper layer is not specified; therefore, reassembly may actually occur within an upper layer entity although it is conceptually part of the L2CAP layer. Note: This term is relevant only to Enhanced Retransmission mode, Streaming mode, Retransmission Mode and Flow Control Mode, not to the Basic L2CAP Mode.
PDU, or L2CAP PDU	Protocol Data Unit: a packet of data containing L2CAP protocol information fields, control information, and/or upper layer information data. A PDU is always started by a Basic L2CAP header. Types of PDUs are: B-frames, I-frames, S-frames, C-frames, G-frames, and LE-Frames.
Basic L2CAP header	Minimum L2CAP protocol information that is present in the beginning of each PDU: a length field and a field containing the Channel Identifier (CID).
Basic information frame (B-frame)	A B-frame is a PDU used in the Basic L2CAP mode for L2CAP data packets. It contains a complete SDU as its payload, encapsulated by a Basic L2CAP header.
Information frame (I-frame)	An I-frame is a PDU used in Enhanced Retransmission Mode, Streaming mode, Retransmission mode, and Flow Control Mode. It contains an SDU segment and additional protocol information, encapsulated by a Basic L2CAP header
Supervisory frame (S-frame)	An S-frame is a PDU used in Enhanced Retransmission Mode, Retransmission Mode, and Flow Control Mode. It contains protocol information only, encapsulated by a Basic L2CAP header, and no SDU data.
Control frame (C-frame)	A C-frame is a PDU that contains L2CAP signaling messages exchanged between the peer L2CAP entities. C-frames are exclusively used on the L2CAP signaling channel.
Group frame (G-frame)	A G-frame is a PDU exclusively used on the Connectionless L2CAP channel. It is encapsulated by a Basic L2CAP header and contains the PSM followed by the completed SDU. G-frames may be used to broadcast data to active slaves via Active Broadcast or to send unicast data to a single remote device.
LE Information frame (LE-frame)	An LE-frame is a PDU used in LE Credit Based Flow Control Mode. It contains an SDU segment and additional protocol information, encapsulated by a Basic L2CAP header.

Table 1.1: Terminology

Term	Description
Fragment	A part of a PDU, as resulting from a fragmentation operation. Fragments are used only in the delivery of data to and from the lower layer. They are not used for peer-to-peer transportation. A fragment may be a Start or Continuation Fragment with respect to the L2CAP PDU. A fragment does not contain any protocol information beyond the PDU; the distinction of start and continuation fragments is transported by lower layer protocol provisions. Note: Start Fragments always begin with the Basic L2CAP header of a PDU.
Fragmentation	A procedure used to split L2CAP PDUs to smaller parts, named fragments, appropriate for delivery to the lower layer transport. Although described within the L2CAP layer, fragmentation may actually occur in an HCI Host driver, and/or in a Controller, to accommodate the L2CAP PDU transport to HCI data packet or Controller packet sizes. Fragmentation of PDUs may be applied in all L2CAP modes. Note: In version 1.1, Fragmentation and Recombination was referred to as “Segmentation and Reassembly“.
Recombination	The reverse procedure corresponding to fragmentation, resulting in an L2CAP PDU re-established from fragments. In the receive path, full or partial recombination operations may occur in the Controller and/or the Host, and the location of recombination does not necessarily correspond to where fragmentations occurs on the transmit side.
Maximum Transmission Unit (MTU)	The maximum size of payload data, in octets, that the upper layer entity is capable of accepting, i.e. the MTU corresponds to the maximum SDU size.
Maximum PDU payload Size (MPS)	The maximum size of payload data in octets that the L2CAP layer entity is capable of accepting, i.e. the MPS corresponds to the maximum PDU payload size. Note: In the absence of segmentation, or in the Basic L2CAP Mode, the Maximum Transmission Unit is the equivalent to the Maximum PDU payload Size and shall be made equal in the configuration parameters.
Signaling MTU (MTU_{sig})	The maximum size of command information that the L2CAP layer entity is capable of accepting. The MTU_{sig}, refers to the signaling channel only and corresponds to the maximum size of a C-frame, excluding the Basic L2CAP header. The MTU_{sig} value of a peer is discovered when a C-frame that is too large is rejected by the peer.
Connectionless MTU (MTU_{cnl})	The maximum size of the connection packet information that the L2CAP layer entity is capable of accepting. The MTU_{cnl} refers to the connectionless channel only and corresponds to the maximum G-frame, excluding the Basic L2CAP header and the PSM which immediately follows it. The MTU_{cnl} of a peer can be discovered by sending an Information Request.

Table 1.1: Terminology

Term	Description
MaxTransmit	In Enhanced Retransmission mode and Retransmission mode, MaxTransmit controls the number of transmissions of a PDU that L2CAP is allowed to try before assuming that the PDU (and the link) is lost. The minimum value is 1 (only 1 transmission permitted). In Enhanced Retransmission mode a value 0 means infinite transmissions. Note: Setting MaxTransmit to 1 prohibits PDU retransmissions. Failure of a single PDU will cause the link to drop. By comparison, in Flow Control mode, failure of a single PDU will not necessarily cause the link to drop.

Table 1.1: Terminology

2 GENERAL OPERATION

L2CAP is based around the concept of *'channels'*. Each one of the endpoints of an L2CAP channel is referred to by a *channel identifier (CID).*

2.1 CHANNEL IDENTIFIERS

A channel identifier (CID) is the local name representing a logical channel endpoint on the device. The scope of CIDs is related to the logical link as shown in Figure 2.1. The null identifier (0x0000) shall never be used as a destination endpoint. Identifiers from 0x0001 to 0x003F are reserved for specific L2CAP functions. These channels are referred to as Fixed Channels. At a minimum, the L2CAP Signaling channel (Fixed Channel 0x0001) or the L2CAP LE Signaling channel (Fixed Channel 0x0005) shall be supported. If Fixed Channel 0x0005 is supported, then Fixed Channels 0x0004 and 0x0006 shall be supported (see Table 2.2). Other fixed channels may be supported. The Information Request / Response mechanism (described in Section 4.10 and Section 4.11) shall be used to determine which fixed channels a remote device supports over the ACL-U logical link.

The characteristics of each fixed channel are defined on a per channel basis. Fixed channel characteristics include configuration parameters (e.g., reliability, MTU size, QoS), security, and the ability to change parameters using the L2CAP configuration mechanism. Table 2.1 lists the defined fixed channels, provides a reference to where the associated channel characteristics are defined and specifies the logical link over which the channel may operate. Fixed channels are available as soon as the ACL-U or LE-U logical link is set up. All initialization that is normally performed when a channel is created shall be performed for each of the supported fixed channels when the ACL-U or LE-U logical link is set up. Fixed channels shall only run over ACL-U, ASB-U, or LE-U logical links and shall not be moved.

Implementations are free to manage the remaining CIDs in a manner best suited for that particular implementation, with the provision that two simultaneously active L2CAP channels shall not share the same CID. A different CID name space exists for each ACL-U, ASB-U, and LE-U logical link. The AMP-U logical link shares the CID name space with its associated ACL-U logical link. Table 2.1 and Table 2.2 summarizes the definition and partitioning of the CID name space for each logical link.

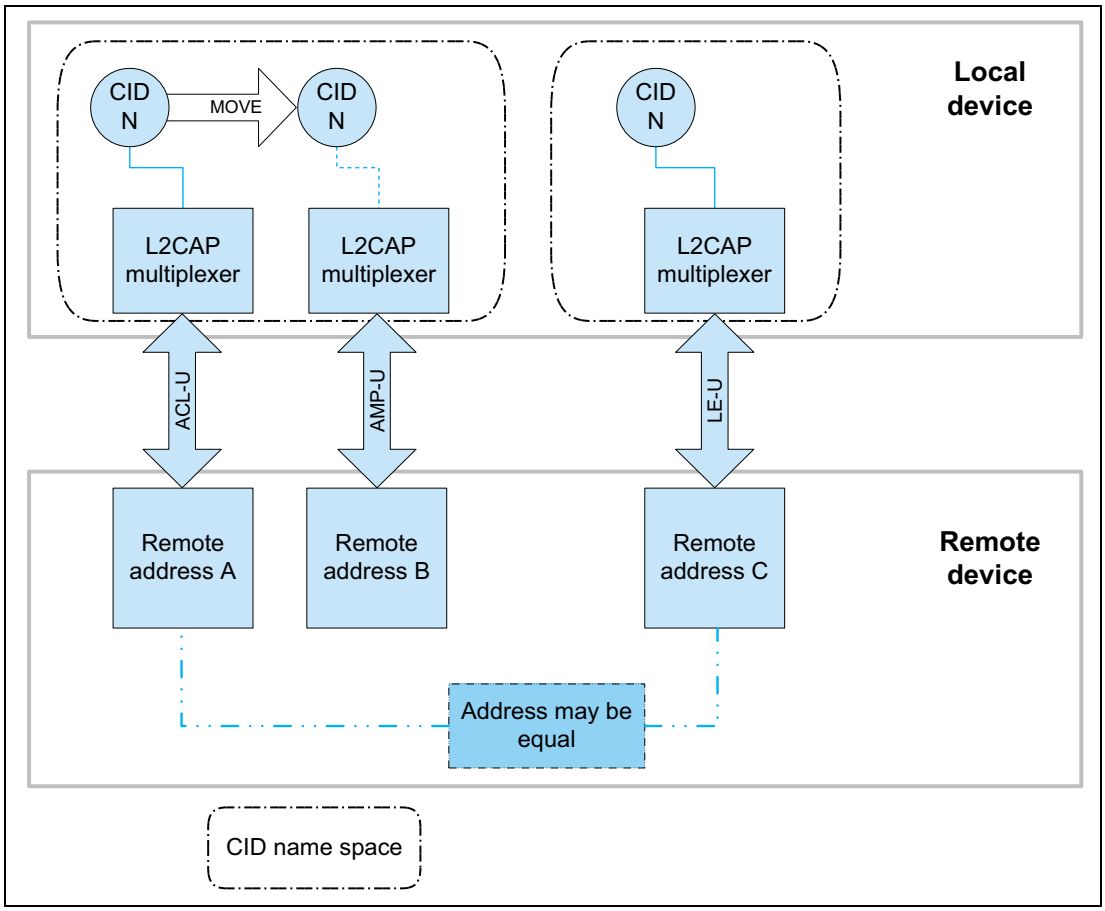


Figure 2.1: Dynamically allocated CID assignments

Assignment of dynamically allocated CIDs is relative to a particular logical link and a device can assign CIDs independently from other devices. Thus, even if the same CID value has been assigned to (remote) channel endpoints by several remote devices connected to a single local device, the local device can still uniquely associate each remote CID with a different device. Further, even if the same CID value has been assigned to (remote) channel endpoints by the same remote device, these can be distinguished because they will be bound to a different logical link.

The CID name space for the ACL-U, ASB-C, and AMP-U logical links is as follows:

CID	Description	Channel Characteristics	Logical Link Supported
0x0000	Null identifier	Not allowed	
0x0001	L2CAP Signaling channel	See Section 4	ACL-U
0x0002	Connectionless channel	See Section 7.6	ACL-U, ASB-U

Table 2.1: CID name space on ACL-U, ASB-U, and AMP-U logical links

CID	Description	Channel Characteristics	Logical Link Supported
0x0003	AMP Manager Protocol	See [Vol 3] Part E, Section 2.2.	ACL-U
0x0004-0x0006	Reserved for Future Use	Not applicable	
0x0007	BR/EDR Security Manager	See [Vol 3] Part H	ACL-U
0x0008-0x003E	Reserved for Future Use	Not applicable	
0x003F	AMP Test Manager	See [Vol 3] Part D, Section 1.2.3	ACL-U
0x0040-0xFFFF	Dynamically allocated	Communicated using L2CAP configuration mechanism (see Section 7.1)	ACL-U, AMP-U

Table 2.1: CID name space on ACL-U, ASB-U, and AMP-U logical links

The CID name space for the LE-U logical link is as follows:

CID	Description	Channel Characteristics	Logical Link Supported
0x0000	Null identifier	Not Allowed	
0x0001-0x0003	Reserved for Future Use	Not applicable	
0x0004	Attribute Protocol	See [Vol 3] Part F	LE-U
0x0005	Low Energy L2CAP Signaling channel	See Section 4	LE-U
0x0006	Security Manager Protocol	See [Vol 3] Part H	LE-U
0x0007-0x001F	Reserved for Future Use	Not applicable	
0x0020-0x003E	Assigned Numbers		LE-U
0x003F	Reserved for Future Use	Not applicable	
0x0040-0x007F	Dynamically allocated	Communicated using the L2CAP LE credit based create connection mecha-nism (see Section 4.22)	LE-U
Other	Reserved for Future Use	Not applicable	

Table 2.2: CID name space on LE-U logical link

2.2 OPERATION BETWEEN DEVICES

Figure 2.2 illustrates the use of CIDs in a communication between corresponding peer L2CAP entities in separate devices. The connection-oriented data channels represent a connection between two devices, where a CID, combined with the logical link, identifies each endpoint of the channel. When used for broadcast transmissions, the connectionless channel restricts data flow to a single direction. The connectionless channel may be used to transmit data to all active slaves, using Active Broadcast. When used for unicast transmissions the connectionless channel may be used in either direction between a master and a slave.

There are also a number of CIDs reserved for special purposes. The L2CAP signaling channels are examples of reserved channels. Fixed channel 0x0001 is used to create and establish connection-oriented data channels and to negotiate changes in the characteristics of connection-oriented channels and to discover characteristics of the connectionless channel operating over the ACL-U logical link.

The L2CAP signaling channel (0x0001) and all supported fixed channels are available immediately when the ACL-U logical link is established between two devices. Another CID (0x0002) is reserved for all incoming and outgoing connectionless data traffic, whether broadcast or unicast. Connectionless data traffic may flow immediately once the ACL-U logical link is established between two devices and once the transmitting device has determined that the remote device supports connectionless traffic.

The L2CAP LE signaling channel (0x0005) and all supported fixed channels are available immediately when the LE-U logical link is established between two devices.

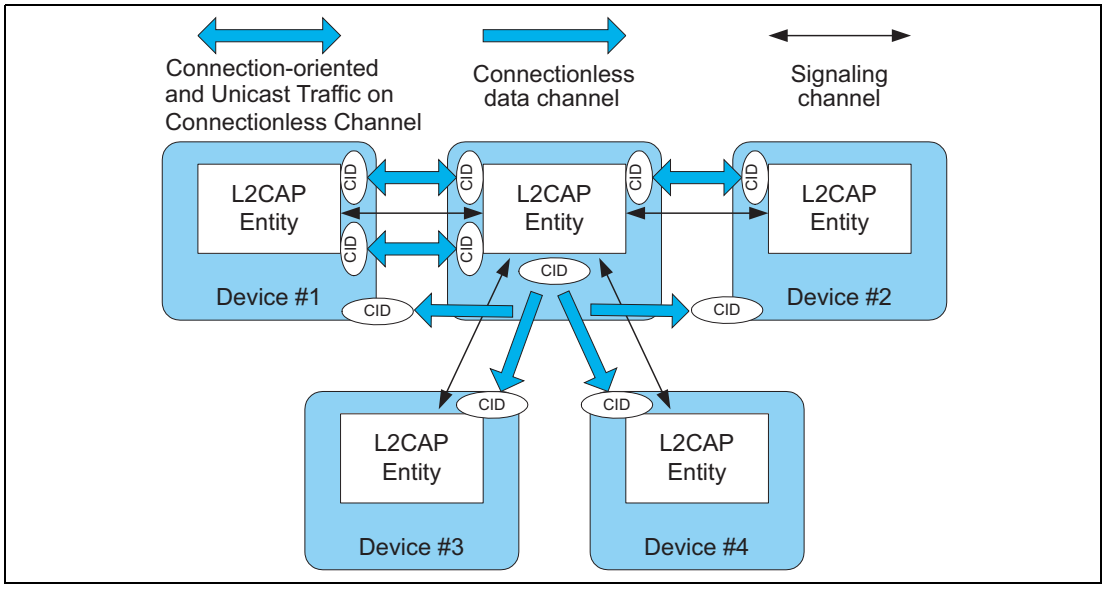


Figure 2.2: Channels between devices

Table 2.3 describes the various channel types and their source and destination identifiers. A dynamically allocated CID is allocated to identify, along with the logical link, the local endpoint and shall be in the range 0x0040 to 0xFFFF for ACL-U, 0x0040 to 0x007F for LE-U. Section 6 describes the state machine associated with each connection-oriented channel with a dynamically allocated CID. Section 3.1 and Section 3.3 describe the packet format associated with connection-oriented channels. Section 3.2 describes the packet format associated with the connectionless channel.

Channel Type	Local CID (sending)	Remote CID (receiving)
Connection-oriented	Dynamically allocated and fixed	Dynamically allocated and fixed
Connectionless data	0x0002 (fixed)	0x0002 (fixed)
L2CAP Signaling	0x0001 and 0x0005 (fixed)	0x0001 and 0x0005 (fixed)

Table 2.3: Types of Channel Identifiers

2.3 OPERATION BETWEEN LAYERS

L2CAP implementations should follow the general architecture described below. L2CAP implementations transfer data between upper layer protocols and the lower layer protocol. This document lists a number of services that should be exported by any L2CAP implementation. Each implementation shall also support a set of signaling commands for use between L2CAP implementations. L2CAP implementations should also be prepared to accept certain types of events from lower layers and generate events to upper layers. How these events are passed between layers is implementation specific.

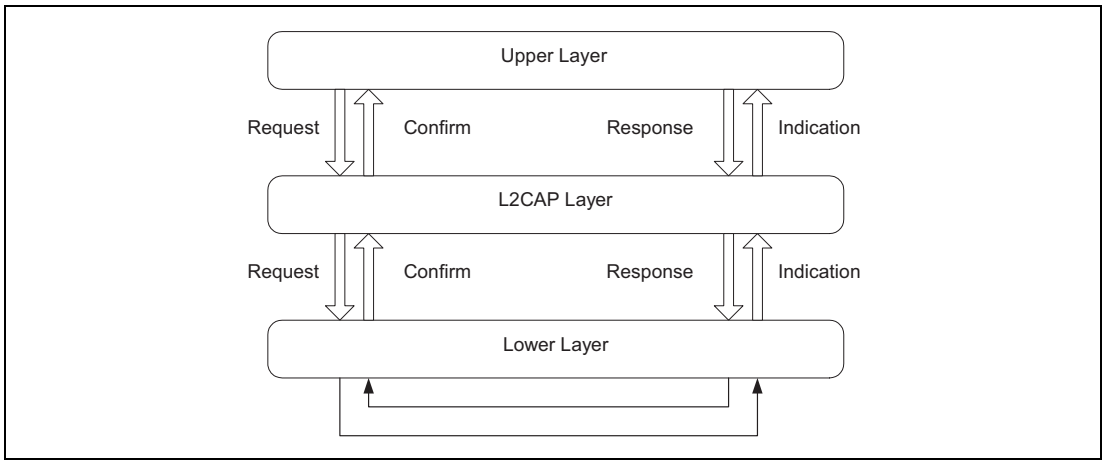


Figure 2.3: L2CAP transaction model

2.4 MODES OF OPERATION

L2CAP channels may operate in one of five different modes as selected for each L2CAP channel.

The modes are:

- Basic L2CAP Mode (equivalent to L2CAP specification in Bluetooth v1.1) [1]
- Flow Control Mode
- Retransmission Mode
- Enhanced Retransmission Mode
- Streaming Mode
- LE Credit Based Flow Control Mode

The modes are enabled using the configuration procedure described in Section 7.1. The Basic L2CAP Mode shall be the default mode, which is used when no other mode is agreed. Enhanced Retransmission mode shall be used for all reliable channels created over AMP-U logical links and for ACL-U logical links operating as described in Section 7.10. Enhanced Retransmission mode should be enabled for reliable channels created over ACL-U logical links not operating as described in Section 7.10. Streaming mode shall be used for streaming applications created over AMP-U logical links and ACL-U logical links operating as described in Section 7.10. Streaming mode should be enabled for streaming applications created over ACL-U logical links not operating as described in Section 7.10. Either Enhanced Retransmission mode or Streaming mode should be enabled when supported by both L2CAP entities. Flow Control Mode and Retransmission mode shall only be enabled when communicating with L2CAP entities that do not support either Enhanced Retransmission mode or Streaming mode.

In Flow Control mode, Retransmission mode, and Enhanced Retransmission mode, PDUs exchanged with a peer entity are numbered and acknowledged. The sequence numbers in the PDUs are used to control buffering, and a TxWindow size is used to limit the required buffer space and/or provide a method for flow control.

In Flow Control Mode no retransmissions take place, but missing PDUs are detected and can be reported as lost.

In Retransmission Mode a timer is used to ensure that all PDUs are delivered to the peer, by retransmitting PDUs as needed. A go-back-n repeat mechanism is used to simplify the protocol and limit the buffering requirements.

Enhanced Retransmission mode is similar to Retransmission mode. It adds the ability to set a POLL bit to solicit a response from a remote L2CAP entity, adds

1. Specification of the Bluetooth System v1.1 (Feb 22nd 2001): volume 1, part D.

the SREJ S-frame to improve the efficiency of error recovery and adds an RNR S-frame to replace the R-bit for reporting a local busy condition.

Streaming mode is for real-time isochronous traffic. PDUs are numbered but are not acknowledged. A finite flush timeout is set on the sending side to flush packets that are not sent in a timely manner. On the receiving side if the receive buffers are full when a new PDU is received then a previously received PDU is overwritten by the newly received PDU. Missing PDUs can be detected and reported as lost. TxWindow size is not used in Streaming mode.

Note: Although L2CAP Basic mode may be used for L2CAP channels operating over ACL-U logical links, only L2CAP channels which have been configured to use Enhanced Retransmission mode or Streaming mode may be moved to operate over an AMP-U logical link. (see Section 4.16).

LE Credit Based Flow Control Mode is used for LE L2CAP connection oriented channels for flow control using a credit based scheme for L2CAP data (i.e. not signaling packets). This is the only mode that shall be used for LE L2CAP connection oriented channels.

L2CAP channels used for multiplexing layers such as RFCOMM can serve a variety of higher layer protocols. In cases where the local device and remote device have mutual support for an AMP and complementary support for profiles on a multiplexing layer which requires reliability (e.g. RFCOMM), the multiplexing layer should be configured to use Enhanced Retransmission mode to ensure that profiles utilizing the multiplexer are not prevented from being moved to the AMP-U logical link. Similarly, in cases where the local device and remote device have mutual support for an AMP and complementary support for profiles on a multiplexing layer which does not require reliability, the multiplexing layer should be configured to use Streaming mode to ensure that profiles utilizing the multiplexer are not prevented from being moved to the AMP-U logical link.

Care should be taken in selecting the parameters used for Enhanced Retransmission mode and Streaming mode when they are used beneath legacy profile implementations to ensure that performance is not negatively impacted relative to the performance achieved when using the same profile with Basic mode on an ACL-U logical link. When there can never be a mutually supported AMP, nor complementary support for a profile which would benefit from AMP, it may be preferable to configure Basic mode to minimize the risk of negative performance impacts.

2.5 MAPPING CHANNELS TO LOGICAL LINKS

L2CAP maps channels to Controller logical links, which in turn run over Controller physical links. All logical links going between a local Controller and remote Controller run over a single physical link. There is one ACL-U logical link per BR/EDR physical link and one LE-U logical link per LE physical link, while there may be multiple AMP-U logical links per AMP physical link.

All Best Effort and Guaranteed channels going over a BR/EDR physical link between two devices shall be mapped to a single ACL-U logical link. All Best Effort channels going over an AMP physical link between two Controllers shall be mapped to a single AMP-U logical link while each Guaranteed channel going between two Controllers shall be mapped to its own AMP-U logical link with one AMP-U logical link per Guaranteed channel. All channels going over an LE physical link between two devices shall be treated as best effort and mapped to a single LE-U logical link.

When a Guaranteed channel is created or moved to a Controller, a corresponding Guaranteed logical link shall be created to carry the channel traffic. Creation of a Guaranteed logical link involves admission control. Admission control is verifying that the guarantee can be achieved without compromising existing guarantees. For an AMP Controller, L2CAP shall tell the Controller to create a Guaranteed logical link and admission control shall be performed by the Controller. For a BR/EDR Controller, admission control (creation of a Guaranteed logical link) shall be performed by the L2CAP layer.

3 DATA PACKET FORMAT

L2CAP is packet-based but follows a communication model based on *channels*. A channel represents a data flow between L2CAP entities in remote devices. Channels may be connection-oriented or connectionless. Fixed channels other than the L2CAP connectionless channel (CID 0x0002) and the two L2CAP signaling channels (CIDs 0x0001 and 0x0005) are considered connection-oriented. All channels with dynamically assigned CIDs are connection-oriented. All L2CAP layer packet fields shall use Little Endian byte order with the exception of the information payload field. The endian-ness of higher layer protocols encapsulated within L2CAP information payload is protocol-specific.

3.1 CONNECTION-ORIENTED CHANNELS IN BASIC L2CAP MODE

Figure 3.1 illustrates the format of the L2CAP PDU used on connection-oriented channels. In basic L2CAP mode, the L2CAP PDU on a connection-oriented channel is also referred to as a "B-frame".

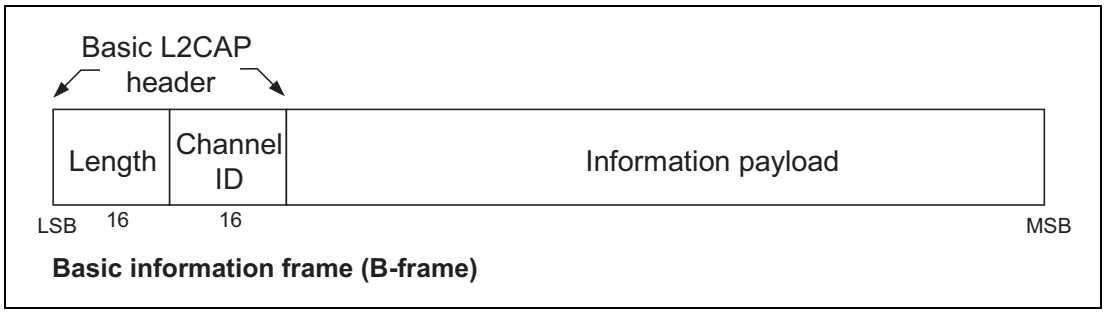


Figure 3.1: L2CAP PDU format in Basic L2CAP mode on connection-oriented channels (field sizes in bits)

The fields shown are:

- *Length: 2 octets (16 bits)*

  Length indicates the size of the information payload in octets, excluding the length of the L2CAP header. The length of an information payload can be up to 65535 octets. The Length field is used for recombination and serves as a simple integrity check of the recombined L2CAP packet on the receiving end.

- *Channel ID: 2 octets*

  The channel ID (CID) identifies the destination channel endpoint of the packet.

- *Information payload: 0 to 65535 octets*

  This contains the payload received from the upper layer protocol (outgoing packet), or delivered to the upper layer protocol (incoming packet). The MTU for channels with dynamically allocated CIDs is determined during channel

configuration (see Section 5.1). The minimum supported MTU values for the signaling PDUs are shown in Table 4.1).

3.2 CONNECTIONLESS DATA CHANNEL IN BASIC L2CAP MODE

Figure 3.2 illustrates the L2CAP PDU format within a connectionless data channel. Here, the L2CAP PDU is also referred to as a "G-frame".

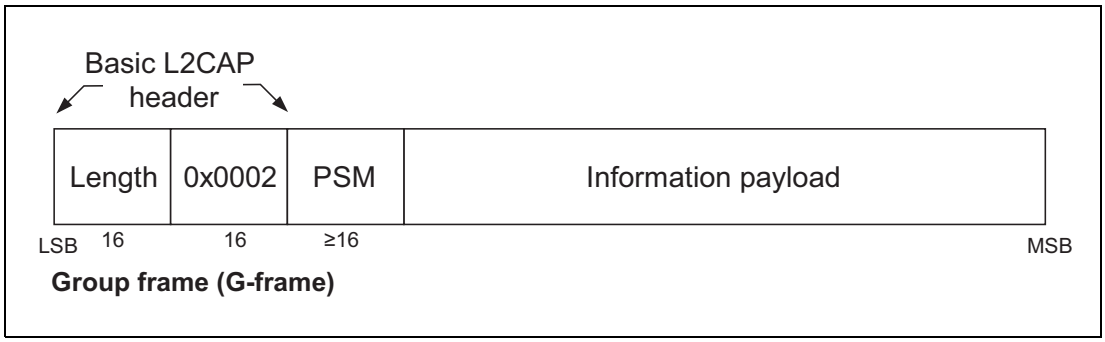


Figure 3.2: L2CAP PDU format on the Connectionless channel

The fields shown are:

- *Length: 2 octets*

  Length indicates the size of information payload plus the PSM field in octets.

- *Channel ID: 2 octets*

  Channel ID (0x0002) reserved for connectionless traffic.

- *Protocol/Service Multiplexer (PSM): 2 octets (minimum)*

  For information on the PSM field see Section 4.2.

- *Information payload: 0 to 65533 octets*

  This parameter contains the payload information to be distributed to all slaves in the piconet for broadcast connectionless traffic, or to a specific remote device for data sent via the L2CAP connectionless channel. Implementations shall support a connectionless MTU (MTU_{cnl}) of 48 octets on the connectionless channel. Devices may also explicitly change to a larger or smaller connectionless MTU (MTU_{cnl}).

  Note: The maximum size of the Information payload field decreases accordingly if the PSM field is extended beyond the two octet minimum.

3.3 CONNECTION-ORIENTED CHANNEL IN RETRANSMISSION/FLOW CONTROL/STREAMING MODES

To support flow control, retransmissions, and streaming, L2CAP PDU types with protocol elements in addition to the Basic L2CAP header are defined. The information frames (I-frames) are used for information transfer between L2CAP entities. The supervisory frames (S-frames) are used to acknowledge I-frames and request retransmission of I-frames.

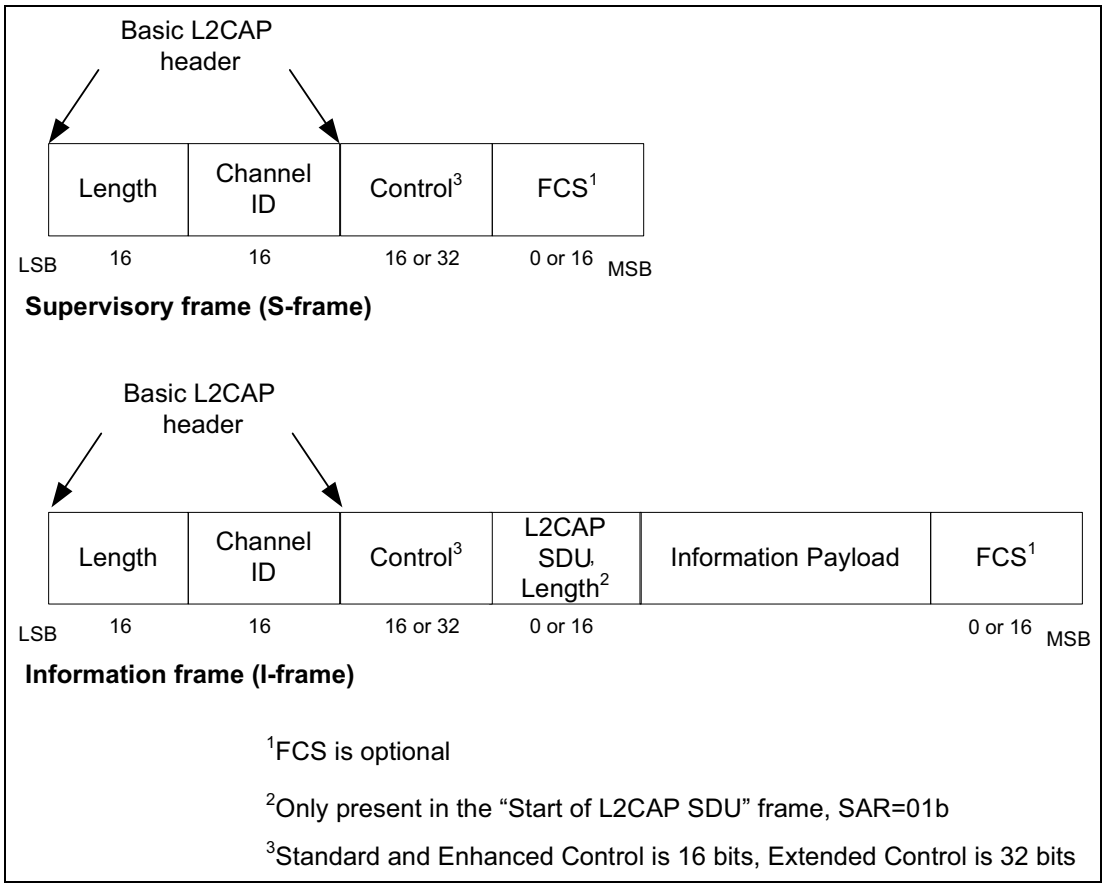


Figure 3.3: L2CAP PDU formats in Flow Control and Retransmission Modes

3.3.1 L2CAP header fields

- *Length: 2 octets*

  The first two octets in the L2CAP PDU contain the length of the entire L2CAP PDU in octets, excluding the Length and CID field.

  For I-frames and S-frames, the Length field therefore includes the octet lengths of the Control, L2CAP SDU Length (when present), Information octets and frame check sequence (FCS) (when present) fields.

  The maximum number of Information octets in one I-frame is based on which fields are present and the type of the Control Field. The maximum number of Information octets in an I-frame with a Standard Control field is as follows:

L2CAP SDU Length present and FCS present	65529 octets
L2CAP SDU Length present and FCS not present	65531 octets
L2CAP SDU Length not present and FCS present	65531 octets
L2CAP SDU Length not present and FCS not present	65533 octets

  The maximum number of Information octets in an I-frame with an Extended Control field is as follows:

L2CAP SDU Length present and FCS present	65527 octets
L2CAP SDU Length present and FCS not present	65529 octets
L2CAP SDU Length not present and FCS present	65529 octets
L2CAP SDU Length not present and FCS not present	65531 octets

- *Channel ID: 2 octets*

  This field contains the Channel Identification (CID).

3.3.2 Control field (2 or 4 octets)

The Control Field identifies the type of frame. There are three different Control Field formats: the Standard Control Field, the Enhanced Control Field, and the Extended Control Field. The Standard Control Field shall be used for Retransmission mode and Flow Control mode. The Enhanced Control Field shall be used for Enhanced Retransmission mode and Streaming mode. The Extended Control Field may be used for Enhanced Retransmission mode and Streaming mode. The Control Field will contain sequence numbers where applicable. Its coding is shown in Table 3.1, Table 3.2, and Table 3.3. There are two different frame types, Information frame types and Supervisory frame types. Information and Supervisory frames types are distinguished by the least significant bit in the Control Field, as shown in Table 3.1, Table 3.2, and Table 3.3.

- *Information frame format (I-frame)*

  The I-frames are used to transfer information between L2CAP entities. Each I-frame has a TxSeq(Send sequence number), ReqSeq(Receive sequence number) which may or may not acknowledge additional I-frames received by the data link layer entity. Each I-frame with a Standard Control field has a retransmission bit (R bit) that affects whether I-frames are retransmitted. Each I-frame with an Enhanced Control Field or an Extended Control Field has an F-bit that is used in Poll/Final bit functions.

  The SAR field in the I-frame is used for segmentation and reassembly control. The L2CAP SDU Length field specifies the length of an SDU, including the aggregate length across all segments if segmented.

- *Supervisory frame format (S-frame)*

  S-frames are used to acknowledge I-frames and request retransmission of I-frames. Each S-frame has an ReqSeq sequence number which may acknowledge additional I-frames received by the data link layer entity. Each S-frame with a Standard Control Field has a retransmission bit (R bit) that affects whether I-frames are retransmitted. Each S-frame with an Enhanced Control field or an Extended Control Field has a Poll bit (P-bit) and a Final bit (F-bit) and does not have an R-bit.

  Defined types of S-frames are RR (Receiver Ready), REJ (Reject), RNR (Receiver Not Ready) and SREJ (Selective Reject).

Frame type	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
I	SAR		ReqSeq						R	TxSeq						0
S	X	X	ReqSeq						R	X	X	X	S		0	1

X denotes bits reserved for future use.

Table 3.1: Standard Control Field formats

Frame type	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
I	SAR		ReqSeq						F	TxSeq						0
S	X	X	ReqSeq						F	X	X	P	S		0	1

X denotes bits reserved for future use.

Table 3.2: Enhanced Control Field formats

Frame type	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
I	ReqSeq														F	0
	TxSeq														SAR	
S	ReqSeq														F	1
									X	X	X	X	X	P	S	

X denotes bits reserved for future use.

Table 3.3: Extended Control Field formats

- *Send Sequence Number - TxSeq (6 bits or 14 bits)*

  The send sequence number is used to number each I-frame, to enable sequencing and retransmission.

- *Receive Sequence Number - ReqSeq (6 bits or 14 bits)*

  The receive sequence number is used by the receiver side to acknowledge I-frames, and in the REJ and SREJ frames to request the retransmission of an I-frame with a specific send sequence number.

- *Retransmission Disable Bit - R (1 bit)*

  The Retransmission Disable bit is used to implement Flow Control. The receiver sets the bit when its internal receive buffer is full, this happens when one or more I-frames have been received but the SDU reassembly function has not yet pulled all the frames received. When the sender receives a frame with the Retransmission Disable bit set it shall disable the RetransmissionTimer, this causes the sender to stop retransmitting I-frames.

  R=0: Normal operation. Sender uses the RetransmissionTimer to control retransmission of I-frames. Sender does not use the MonitorTimer.

  R=1: Receiver side requests sender to postpone retransmission of I-frames. Sender monitors signaling with the MonitorTimer. Sender does not use the RetransmissionTimer.

  The functions of ReqSeq and R are independent.

- *Segmentation and Reassembly - SAR (2 bits)*

  The SAR bits define whether an L2CAP SDU is segmented. For segmented SDUs, the SAR bits also define which part of an SDU is in this I-frame, thus allowing one L2CAP SDU to span several I-frames.

  An I-frame with SAR=”Start of L2CAP SDU” also contains a length indicator, specifying the number of information octets in the total L2CAP SDU. The encoding of the SAR bits is shown in Table 3.4.

00b	Unsegmented L2CAP SDU
01b	Start of L2CAP SDU
10b	End of L2CAP SDU
11b	Continuation of L2CAP SDU

Table 3.4: SAR control element format

- *Supervisory function - S (2 bits)*

  The S-bits mark the type of S-frame. There are four types defined: RR (Receiver Ready), REJ (Reject), RNR (Receiver Not Ready) and SREJ (Selective Reject). The encoding is shown in Table 3.5.

00b	RR - Receiver Ready
01b	REJ - Reject
10b	RNR - Receiver Not Ready
11b	SREJ - Select Reject

Table 3.5: S control element format: type of S-frame

- *Poll - P (1 bit)*

  The P-bit is set to 1 to solicit a response from the receiver. The receiver shall respond immediately with a frame with the F-bit set to 1.

- *Final - F (1 bit)*

  The F-bit is set to 1 in response to an S-frame with the P bit set to 1.

3.3.3 L2CAP SDU Length Field (2 octets)

When an SDU spans more than one I-frame, the first I-frame in the sequence shall be identified by SAR=01b=”Start of L2CAP SDU”. The L2CAP SDU Length field shall specify the total number of octets in the SDU. The L2CAP SDU Length field shall be present in I-frames with SAR=01b (Start of L2CAP SDU) and shall not be used in any other I-frames. When the SDU is unsegmented (SAR=00b), the L2CAP SDU Length field is not needed and shall not be present.

3.3.4 Information Payload Field

The information payload field consists of an integral number of octets. The maximum number of octets in this field is the same as the negotiated value of the MPS configuration parameter. The maximum number of octets in this field is also limited by the range of the Basic L2CAP header length field. This ranges from 65533 octets for I-frames with a Standard or Enhanced Control Field, no SDU length field, and no FCS field to 65527 octets for I-frames with an Enhanced Control Field, an SDU length field, and FCS field. Thus, even if an MPS of 65533 has been negotiated, the range of the Basic L2CAP header length field will restrict the number of octets in this field. For example, when an Enhanced Control Field, an SDU length field, and FCS field are present the number of octets in this field is restricted to 65529.

3.3.5 Frame Check Sequence (2 octets)

The Frame Check Sequence (FCS) is 2 octets. The FCS is constructed using the generator polynomial $g(D) = D^{16} + D^{15} + D^2 + 1$ (see Figure 3.4). The 16 bit LFSR is initially loaded with the value 0x0000, as depicted in Figure 3.5. The switch S is set in position 1 while data is shifted in, LSB first for each octet. After the last bit has entered the LFSR, the switch is set in position 2, and the register contents are transmitted from right to left (i.e. starting with position 15, then position 14, etc.). The FCS covers the Basic L2CAP header, Control, L2CAP-SDU length and Information payload fields, if present, as shown in Figure 3.3.

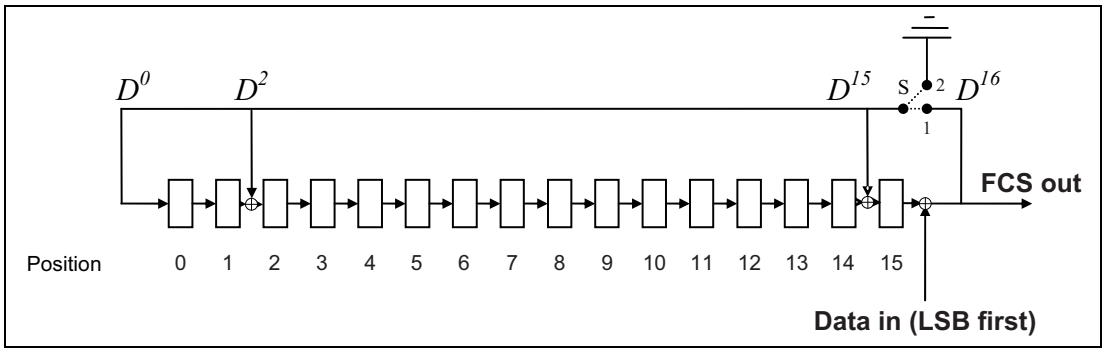


Figure 3.4: The LFSR circuit generating the FCS

Position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LFSR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3.5: Initial state of the FCS generating circuit

Examples of FCS calculation, $g(D) = D^{16} + D^{15} + D^2 + 1$:

1. ***I Frame***
   Length = 14
   Control = 0x0002 (SAR=00b, ReqSeq=000000b, R=0b, TxSeq=000001b)
   Information Payload = 00 01 02 03 04 05 06 07 08 09 (10 octets, hexadecimal notation)
   ==> FCS = 0x6138
   ==> Data to Send = 0E 00 40 00 02 00 00 01 02 03 04 05 06 07 08 09 38 61 (hexadecimal notation)
2. ***RR Frame***
   Length = 4
   Control = 0x0101 (ReqSeq=000001b, R=0b, S=00b)
   ==> FCS = 0x14D4
   ==> Data to Send = 04 00 40 00 01 01 D4 14 (hexadecimal notation)

3.3.6 Invalid Frame Detection

For Retransmission mode and Flow Control mode, a received PDU shall be regarded as invalid, if one of the following conditions occurs:

1. Contains an unknown CID.
2. Contains an FCS error.
3. Contains a length greater than the maximum PDU payload size (MPS).
4. I-frame that has fewer than 8 octets.
5. I-frame with SAR=01b (Start of L2CAP SDU) that has fewer than 10 octets.
6. I-frame with SAR bits that do not correspond to a normal sequence of either unsegmented or start, continuation, end for the given CID.
7. S-frame where the length field is not equal to 4.

These error conditions may be used for error reporting.

3.3.7 Invalid Frame Detection Algorithm

For Enhanced Retransmission mode and Streaming mode the following algorithm shall be used for received PDUs. It may be used for Retransmission mode and Flow Control mode:

1. Check the CID. If the PDU contains an unknown CID then it shall be ignored.
2. Check the FCS. If the PDU contains an FCS error then it shall be ignored. If the channel is configured to use "No FCS" then the PDU is considered to have a good FCS (no FCS error).

3. Check the following conditions. If one of the conditions occurs the channel shall be closed or in the case of fixed channels the ACL shall be disconnected.
   a) PDU contains a length greater than the maximum PDU payload size (MPS)
   b) I-frame that has fewer than the required number of octets.If the channel is configured to use a Standard or Enhanced Control Field then the required number of octets is 6 if "No FCS" is configured; otherwise, it is 8. If the channel is configured to use the Extended Control Field then the required number of octets is 8 if "No FCS" is configured; otherwise, it is 10.
   c) S-frame where the length field is invalid. If the channel is configured to use a Standard or Enhanced Control Field then the length field shall be 2 if "No FCS" is configured; otherwise, the length field shall be 4. If the channel is configured to use the Extended Control Field then the length field shall be 4 if "No FCS" is configured; otherwise, the length field shall be 6.
4. Check the SAR bits. The SAR check is performed after the frame has been successfully received in the correct sequence. The PDU is invalid if one of the following conditions occurs:
   a) I-frame with SAR=01b (Start of L2CAP SDU) that has fewer than the required number of octets. If the channel is configured to use a Standard or Enhanced Control field then the required number of octets is 8 if "No FCS" is configured; otherwise, the required number of octets is 10. If the channel is configured to use an Extended Control field then the required number of octets is 10 if "No FCS" is configured; otherwise, the required number of octets is 12.
   b) I-frame with SAR bits that do not correspond to a normal sequence of either unsegmented or start, continuation, end for the given CID.
   c) I-frame with SAR= 01b (Start of L2CAP SDU) where the value in the L2CAP SDU length field exceeds the configured MTU.
5. If the I-frame has been received in the correct sequence and is invalid as described in 4 then the channel shall be closed or in the case of fixed channels the ACL shall be disconnected. For Streaming mode and Flow Control mode if one or more I-frames are missing from a sequence of I-frames using SAR bits of start, continuation and end then received I-frames in the sequence may be ignored. For Flow Control mode and Streaming mode I-frames received out of sequence with SAR bits of unsegmented may be accepted.

If the algorithm is used for Retransmission mode or Flow control mode then it shall be used instead of Invalid Frame detection described in Section 3.3.6.

These error conditions may be used for error reporting.

3.4 CONNECTION-ORIENTED CHANNELS IN LE CREDIT BASED FLOW CONTROL MODE

To support LE Credit Based Flow Control Mode, L2CAP PDU type with protocol elements in addition to the Basic L2CAP header are defined. In LE Credit Based Flow Control Mode, the L2CAP PDU on a connection-oriented channel is an LE information frame (LE-frame).

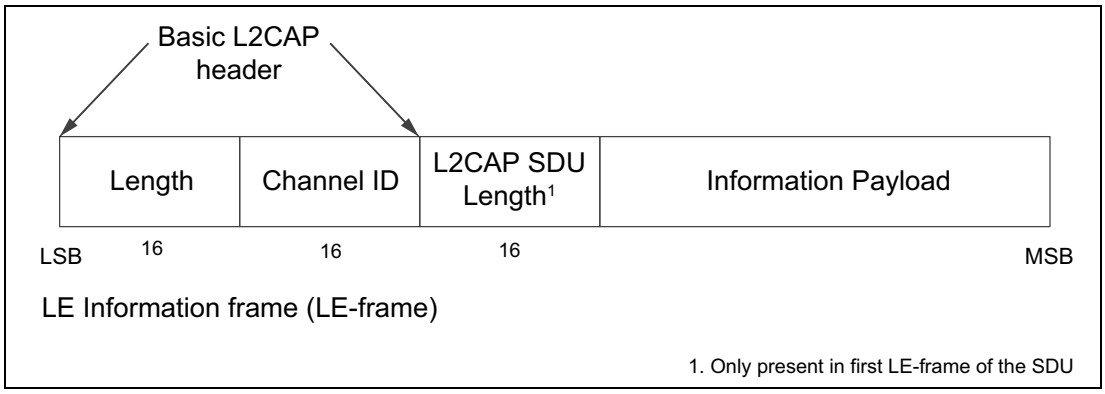


Figure 3.6: L2CAP PDU format in LE Credit Based Flow Control Mode

3.4.1 L2CAP Header Fields

- *Length: 2 octets*

  The first two octets in the L2CAP PDU contain the length of the entire L2CAP PDU in octets, excluding the Length and CID fields.

  For LE-frames, the Length field includes the octet lengths of the L2CAP SDU Length when present and Information Payload fields.

- *Channel ID: 2 octets*

  The channel ID (CID) identifies the destination channel endpoint of the packet.

3.4.2 L2CAP SDU Length Field (2 octets)

The first LE-frame of the SDU shall contain the L2CAP SDU Length field that shall specify the total number of octets in the SDU. All subsequent LE-frames that are part of the same SDU shall not contain the L2CAP SDU Length field.

3.4.3 Information Payload Field

The information payload field consists of an integral number of octets. The maximum number of octets in this field is the same as the peer's MPS. The maximum number of octets in this field is also limited by the range of the Basic L2CAP header length field, of 65533 octets.

The number of octets contained in the first LE-frame information payload of the SDU is equal to the L2CAP header length field minus 2 octets. All subsequent

LE-frames of the same SDU contain the number of octets in the information payload equal to the L2CAP header length field.

If the SDU length field value exceeds the receiver's MTU, the receiver shall disconnect the channel. If the payload length of any LE-frame exceeds the receiver's MPS, the receiver shall disconnect the channel. If the sum of the payload lengths for the LE-frames exceeds the specified SDU length, the receiver shall disconnect the channel.

4 SIGNALING PACKET FORMATS

This section describes the signaling commands passed between two L2CAP entities on peer devices. All signaling commands are sent over a signaling channel. The signaling channel for managing channels over ACL-U logical links shall use CID 0x0001 and the signaling channel for managing channels over LE-U logical links shall use CID 0x0005. Signaling channels are available as soon as the lower layer logical transport is set up and L2CAP traffic is enabled. Figure 4.1 illustrates the general format of L2CAP PDUs containing signaling commands (C-frames). Multiple commands may be sent in a single C-frame over Fixed Channel CID 0x0001 while only one command per C-frame shall be sent over Fixed Channel CID 0x0005. Commands take the form of Requests and Responses. All L2CAP implementations shall support the reception of C-frames with a payload length that does not exceed the signaling MTU. The minimum supported payload length for the C-frame (MTU_{sig}) is defined in Table 4.1. L2CAP implementations should not use C-frames that exceed the MTU_{sig} of the peer device. If a device receives a C-frame that exceeds its MTU_{sig} then it shall send a Command Reject containing the supported MTU_{sig}. Implementations shall be able to handle the reception of multiple commands in an L2CAP packet sent over Fixed Channel CID 0x0001.

Logical Link	Minimum Supported Payload Length for the C-frame (MTU_{sig})
ACL-U not supporting Extended Flow Specification	48 octets
ACL-U supporting the Extended Flow Specification feature	672 octets
LE-U	23 octets

Table 4.1: Minimum Signaling MTU

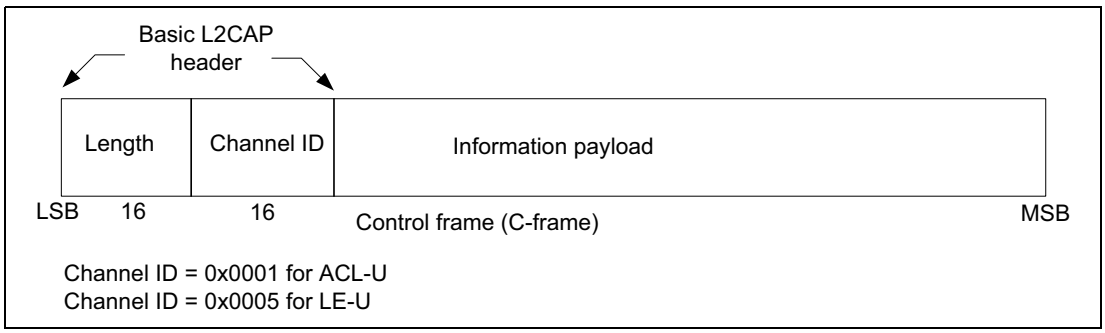


Figure 4.1: L2CAP PDU format on a signaling channel

Figure 4.2 displays the general format of all signaling commands.

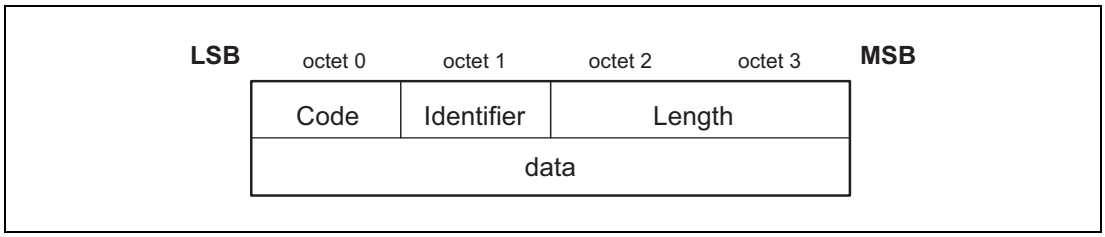


Figure 4.2: Command format

The fields shown are:

- *Code (1 octet)*

  The Code field is one octet long and identifies the type of command. When a packet is received with a Code field that is unknown or disallowed on the signaling channel it is received on, a Command Reject packet (defined in Section 4.1) is sent in response.

  Table 4.2 lists the codes defined by this document. All codes are specified with the most significant bit in the left-most position.

Code	Description	CIDs on which Code is Allowed
0x00	Reserved for Future Use	Any
0x01	Command reject	0x0001 and 0x0005
0x02	Connection request	0x0001
0x03	Connection response	0x0001
0x04	Configure request	0x0001
0x05	Configure response	0x0001
0x06	Disconnection request	0x0001 and 0x0005
0x07	Disconnection response	0x0001 and 0x0005
0x08	Echo request	0x0001
0x09	Echo response	0x0001
0x0A	Information request	0x0001
0x0B	Information response	0x0001
0x0C	Create Channel request	0x0001
0x0D	Create Channel response	0x0001
0x0E	Move Channel request	0x0001
0x0F	Move Channel response	0x0001
0x10	Move Channel Confirmation	0x0001
0x11	Move Channel Confirmation response	0x0001

Table 4.2: Signaling Command Codes

Code	Description	CIDs on which Code is Allowed
0x12	Connection Parameter Update request	0x0005
0x13	Connection Parameter Update response	0x0005
0x14	LE Credit Based Connection request	0x0005
0x15	LE Credit Based Connection response	0x0005
0x16	LE Flow Control Credit	0x0005
Other	Reserved for Future Use	Any

Table 4.2: Signaling Command Codes (Continued)

- *Identifier (1 octet)*

  The Identifier field is one octet long and matches responses with requests. The requesting device sets this field and the responding device uses the same value in its response. Within each signaling channel a different Identifier shall be used for each successive command. Following the original transmission of an Identifier in a command, the Identifier may be recycled if all other Identifiers have subsequently been used.

  RTX and ERTX timers are used to determine when the remote end point is not responding to signaling requests. On the expiration of a RTX or ERTX timer, the same identifier shall be used if a duplicate Request is re-sent as stated in Section 6.2.

  A device receiving a duplicate request on a particular signaling channel should reply with a duplicate response on the same signaling channel. A command response with an invalid identifier is silently discarded. Signaling identifier 0x00 is an illegal identifier and shall never be used in any command.

- *Length (2 octets)*

  The Length field is two octets long and indicates the size in octets of the data field of the command only, i.e., it does not cover the Code, Identifier, and Length fields.

- *Data (0 or more octets)*

  The Data field is variable in length. The Code field determines the format of the Data field. The length field determines the length of the data field.

4.1 COMMAND REJECT (CODE 0x01)

A Command Reject packet shall be sent in response to a command packet with an unknown command code or when sending the corresponding response is inappropriate. Figure 4.3 displays the format of the packet. The identifier shall match the identifier of the command packet being rejected. Implementations shall always send these packets in response to unidentified signaling packets. Command Reject packets should not be sent in response to an identified Response packet.

When multiple commands are included in an L2CAP packet and the packet exceeds the signaling MTU (MTU_{sig}) of the receiver, a single Command Reject packet shall be sent in response. The identifier shall match the first Request command in the L2CAP packet. If only Responses are recognized, the packet shall be silently discarded.

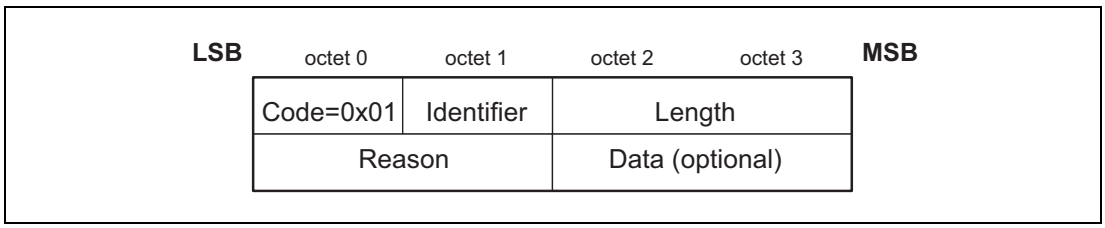


Figure 4.3: Command Reject Packet

Figure 4.3 shows the format of the Command Reject packet. The data fields are:

- *Reason (2 octets)*

  The Reason field describes why the Request packet was rejected, and is set to one of the Reason codes in Table 4.3.

Reason value	Description
0x0000	Command not understood
0x0001	Signaling MTU exceeded
0x0002	Invalid CID in request
Other	Reserved for Future Use

Table 4.3: Reason Code Descriptions

- *Data (0 or more octets)*

  The length and content of the Data field depends on the Reason code. If the Reason code is 0x0000, “Command not understood”, no Data field is used. If the Reason code is 0x0001, “Signaling MTU Exceeded”, the 2-octet Data field represents the maximum signaling MTU the sender of this packet can accept.

  If a command refers to an invalid channel then the Reason code 0x0002 will be returned. Typically a channel is invalid because it does not exist. The data

field shall be 4 octets containing the local (first) and remote (second) channel endpoints (relative to the sender of the Command Reject) of the disputed channel. The remote endpoint is the source CID from the rejected command. The local endpoint is the destination CID from the rejected command. If the rejected command contains only one of the channel endpoints, the other one shall be replaced by the null CID 0x0000.

Reason value	Data Length	Data value
0x0000	0 octets	N/A
0x0001	2 octets	Actual MTU_{sig}
0x0002	4 octets	Requested CID

Table 4.4: Reason Data values

4.2 CONNECTION REQUEST (CODE 0x02)

Connection request packets are sent to create an L2CAP channel between two devices. The L2CAP channel shall be established before configuration begins. Figure 4.4 illustrates a Connection Request packet.

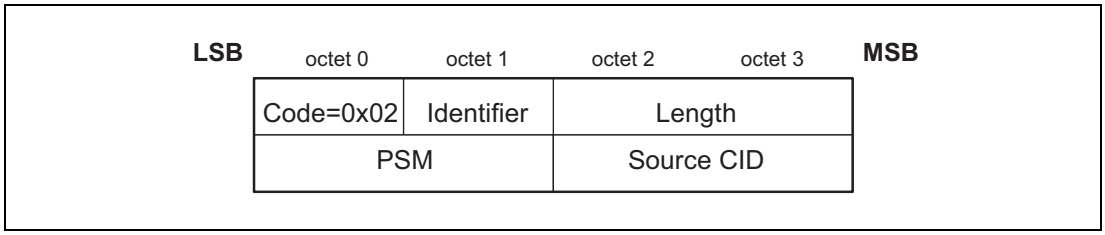


Figure 4.4: Connection Request Packet

The data fields are:

- *Protocol/Service Multiplexer - PSM (2 octets (minimum))*

  The PSM field is at least two octets in length. The structure of the PSM field is based on the ISO 3309 extension mechanism for address fields. All PSM values shall be ODD, that is, the least significant bit of the least significant octet must be 1. Also, all PSM values shall have the least significant bit of the most significant octet equal to 0. This allows the PSM field to be extended beyond 16 bits. PSM values are separated into two ranges. Valid values in the first range are assigned by the Bluetooth SIG and indicate protocols. The second range of values are dynamically allocated and used in conjunction with the Service Discovery Protocol (SDP). The dynamically assigned values may be used to support multiple implementations of a particular protocol.

PSM values are defined in the Assigned Numbers document.

Range	Type	Server Usage	Client Usage
0x0001-0x0EFF (Note [1])	Fixed, SIG assigned	PSM is fixed for all implementations.	PSM may be obtained via SDP or may be assumed for a fixed service. Protocol used is indicated by the PSM as defined in the Assigned Numbers page.
>0x1000	Dynamic	PSM may be fixed for a given implementation or may be assigned at the time the service is registered in SDP.	PSM shall be obtained via SDP upon every reconnection. PSM for one direction will typically be different from the other direction.

Table 4.5: PSM ranges and usage

1. PSMs shall be odd and the least significant bit of the most significant byte shall be zero, hence the following ranges do not contain valid PSMs: 0x0100-0x01FF, 0x0300-0x03FF, 0x0500-0x05FF, 0x0700-0x07FF, 0x0900-0x09FF, 0x0B00-0x0BFF, 0x0D00-0x0DFF, 0x0F00-0x0FFF. All even values are also not valid as PSMs.

- *Source CID - SCID (2 octets)*

  The source CID is two octets in length and represents a channel endpoint on the device sending the request. Once the channel has been configured, data packets flowing to the sender of the request shall be sent to this CID. Thus, the Source CID represents the channel endpoint on the device sending the request and receiving the response. The value of the Source CID shall be from the dynamically allocated range as defined in Table 2.1 and shall not be already allocated to a different channel on the device sending the request.

4.3 CONNECTION RESPONSE (CODE 0x03)

When a device receives a Connection Request packet, it shall send a Connection Response packet. Note: Implementations conforming to previous versions of this specification may respond with a Command Reject (Reason 0x0002 – Invalid CID In Request) packet under conditions now covered by result codes of 0x0006 and 0x0007.
The format of the connection response packet is shown in Figure 4.5.

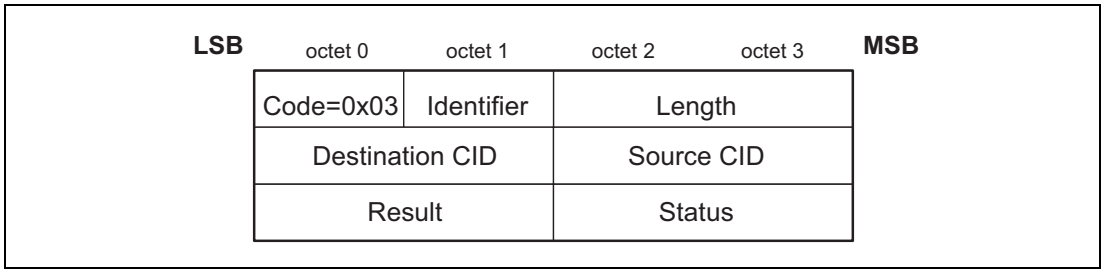


Figure 4.5: Connection Response Packet

The data fields are:

- *Destination Channel Identifier - DCID (2 octets)*

  This field contains the channel endpoint on the device sending this Response packet. Thus, the Destination CID represents the channel endpoint on the device receiving the request and sending the response. The value of the Destination CID shall be from the dynamically allocated range as defined in Table 2.1 and shall not be already allocated to a different channel on the device sending the response.

- *Source Channel Identifier - SCID (2 octets)*

  This field contains the channel endpoint on the device receiving this Response packet. This is copied from the SCID field of the connection request packet.

- *Result (2 octets)*

  The result field indicates the outcome of the connection request. The result value of 0x0000 indicates success while a non-zero value indicates the connection request failed or is pending. A logical channel is established on the receipt of a successful result unless the DCID field is outside of the dynamically allocated range (see Table 2.1) or is already allocated on the device sending the response. Table 4.6 defines values for this field. If the result field does not indicate the connection was successful, the DCID and SCID fields may be invalid and shall be ignored.

Value	Description
0x0000	Connection successful.
0x0001	Connection pending

Table 4.6: Result values

Value	Description
0x0002	Connection refused – PSM not supported.
0x0003	Connection refused – security block.
0x0004	Connection refused – no resources available.
0x0005	Reserved for Future Use
0x0006	Connection refused – invalid Source CID
0x0007	Connection refused – Source CID already allocated
Other	Reserved for Future Use.

Table 4.6: Result values (Continued)

- *Status (2 octets)*

  Only defined for Result = Pending. Indicates the status of the connection. The status is set to one of the values shown in Table 4.7.

Value	Description
0x0000	No further information available
0x0001	Authentication pending
0x0002	Authorization pending
Other	Reserved for Future Use

Table 4.7: Status values

4.4 CONFIGURATION REQUEST (CODE 0x04)

Configuration Request packets are sent to establish an initial logical link transmission contract between two L2CAP entities and also to re-negotiate this contract whenever appropriate. The contract consists of a set of configuration parameter options defined in Section 5. All parameter options have default values and can have previously agreed values which are values that were accepted in a previous configuration process or in a previous step in the current configuration process. The only parameters that should be included in the Configuration Request packet are those that require different values than the default or previously agreed values.

If no parameters need to be negotiated or specified then no options shall be inserted and the continuation flag (C) shall be set to zero. Any missing configuration parameters are assumed to have their most recently explicitly or implicitly accepted values. Even if all default values are acceptable, a Configuration Request packet with no options shall be sent. Implicitly accepted values are default values for the configuration parameters that have not been explicitly negotiated for the specific channel under configuration.

See Section 7.1 for details of the configuration procedure.

Figure 4.6 defines the format of the Configuration Request packet.

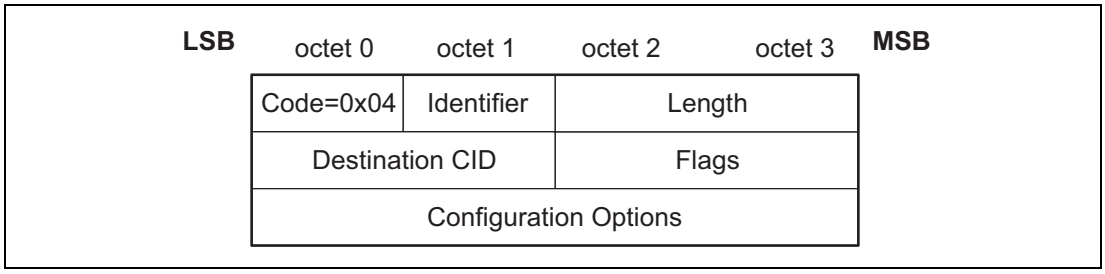


Figure 4.6: Configuration Request Packet

The data fields are:

- *Destination CID - DCID (2 octets)*

  This field contains the channel endpoint on the device receiving this Request packet.

- *Flags (2 octets)*

  Figure 4.7 shows the two-octet Flags field. Note the most significant bit is shown on the left.

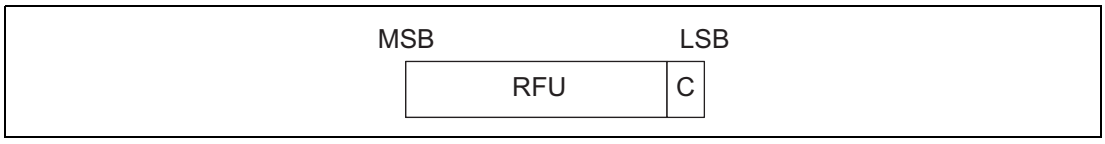


Figure 4.7: Configuration Request Flags field format

Only one flag is defined, the Continuation flag (C).

When both L2CAP entities support the Extended Flow Specification option, the Continuation flag shall not be used and shall be set to zero in all Configuration Request and Response packets.

When all configuration options cannot fit into a Configuration Request with length that does not exceed the receiver's MTU_{sig}, the options shall be passed in multiple configuration command packets. If all options fit into the receiver's MTU_{sig}, then they shall be sent in a single configuration request with the continuation flag set to zero. Each Configuration Request shall contain an integral number of options - partially formed options shall not be sent in a packet. Each Request shall be tagged with a different Identifier and shall be matched with a Response with the same Identifier.

When used in the Configuration Request, the continuation flag indicates the responder should expect to receive multiple request packets. The responder shall reply to each Configuration Request packet. The responder may reply to each Configuration Request with a Configuration Response containing the same option(s) present in the Request (except for those error conditions more appropriate for a Command Reject), or the responder may reply with a "Success" Configuration Response packet containing no options, delaying those options until the full Request has been received. The Configuration Request packet with the continuation flag cleared shall be treated as the Configuration Request event in the channel state machine.

When used in the Configuration Response, the continuation flag shall be set to one if the flag is set to one in the Request. If the continuation flag is set to one in the Response when the matching Request has the flag set to zero, it indicates the responder has additional options to send to the requestor. In this situation, the requestor shall send null-option Configuration Requests (with continuation flag set to zero) to the responder until the responder replies with a Configuration Response where the continuation flag is set to zero. The Configuration Response packet with the continuation flag set to zero shall be treated as the Configuration Response event in the channel state machine.

The result of the configuration transaction is the union of all the result values. All the result values must succeed for the configuration transaction to succeed.

Other flags are reserved for future use.

- *Configuration Options*

  A list of the parameters and their values to be negotiated shall be provided in the Configuration Options field. These are defined in Section 5. A Configuration Request may contain no options (referred to as an empty or null configuration request) and can be used to request a response. For an empty configuration request the length field is set to 0x0004.

4.5 CONFIGURATION RESPONSE (CODE 0x05)

Configuration Response packets shall be sent in reply to Configuration Request packets except when the error condition is covered by a Command Reject response. Each configuration parameter value (if any is present) in a Configuration Response reflects an 'adjustment' to a configuration parameter value that has been sent (or, in case of default values, implied) in the corresponding Configuration Request. For example, if a configuration request relates to traffic flowing from device A to device B, the sender of the configuration response may adjust this value for the same traffic flowing from device A to device B, but the response cannot adjust the value in the reverse direction.

The options sent in the Response depend on the value in the Result field. Figure 4.8 defines the format of the Configuration Response packet. See also Section 7.1 for details of the configuration process.

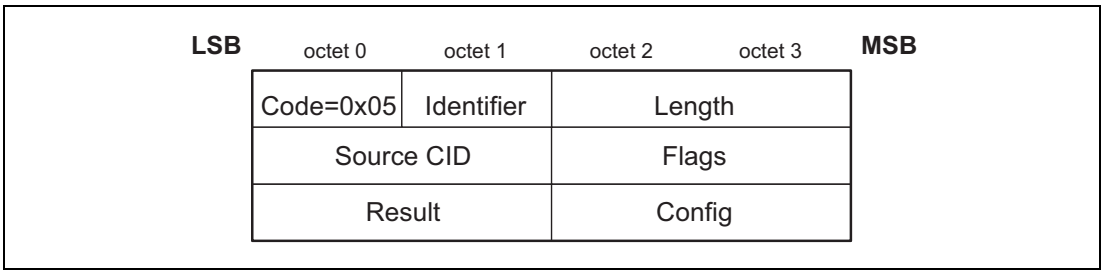


Figure 4.8: Configuration Response Packet

The data fields are:

- *Source CID - SCID (2 octets)*

  This field contains the channel endpoint on the device receiving this Response packet. The device receiving the Response shall check that the Identifier field matches the same field in the corresponding configuration request command and the SCID matches its local CID paired with the original DCID.

- *Flags (2 octets)*

  Figure 4.9 displays the two-octet Flags field. Note the most significant bit is shown on the left.

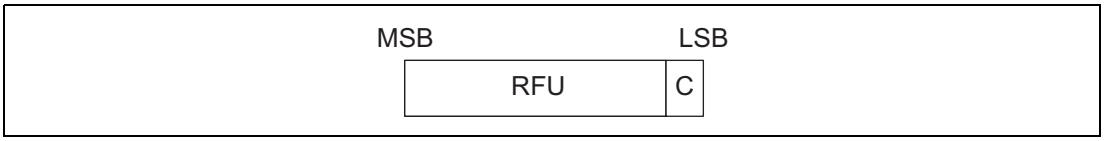


Figure 4.9: Configuration Response Flags field format

Only one flag is defined, the Continuation flag (C).

When both L2CAP entities support the Extended Flow Specification option, the Continuation flag shall not be used and shall be set to zero in all Configuration Request and Response packets.

More configuration responses will follow when C is set to one. This flag indicates that the parameters included in the response are a partial subset of parameters being sent by the device sending the Response packet.

The other flag bits are reserved for future use.

- *Result (2 octets)*

  The Result field indicates whether or not the Request was acceptable. See Table 4.8 for possible result codes.

Result	Description
0x0000	Success
0x0001	Failure – unacceptable parameters
0x0002	Failure – rejected (no reason provided)
0x0003	Failure – unknown options
0x0004	Pending
0x0005	Failure - flow spec rejected
Other	Reserved for Future Use

Table 4.8: Configuration Response Result codes

- *Configuration Options*

  This field contains the list of parameters being configured. These are defined in Section 5. On a successful result (Result=0x0000) and pending result (Result=0x0004), these parameters contain the return values for any wild card parameter values (see Section 5.3) and “adjustments” to non-negotiated configuration parameter values contained in the request. A response with the result code of 0x0000 (Success) is also referred to as a positive response.

  On an unacceptable parameters failure (Result=0x0001) the rejected parameters shall be sent in the response with the values that would have been accepted if sent in the original request. Any missing configuration parameters in the Configuration Request are assumed to have their default value or previously agreed value and they too shall be included in the Configuration Response if they need to be changed. A response with the result code of 0x0001 is also referred to as a negative response.

  On an unknown option failure (Result=0x0003), the option(s) that contain an option type field that is not understood by the recipient of the Request shall be included in the Response unless they are hints. Hints are those options in the Request that are skipped if not understood (see Section 5). Hints shall not be included in the Response and shall not be the sole cause for rejecting the Request.

On a flow spec rejected failure (Result=0x0005), an Extended Flow Spec option may be included to reflect the QoS level that would be acceptable (see Section 7.1.3).

The decision on the amount of time (or messages) spent arbitrating the channel parameters before terminating the negotiation is implementation specific.

4.6 DISCONNECTION REQUEST (CODE 0x06)

Terminating an L2CAP channel requires that a disconnection request be sent and acknowledged by a disconnection response. Figure 4.10 shows a disconnection request. The receiver shall ensure that both source and destination CIDs match before initiating a channel disconnection.

Once a Disconnection Request is issued, all incoming data in transit on this L2CAP channel shall be discarded and any new additional outgoing data shall be discarded. Once a disconnection request for a channel has been received, all data queued to be sent out on that channel shall be discarded.

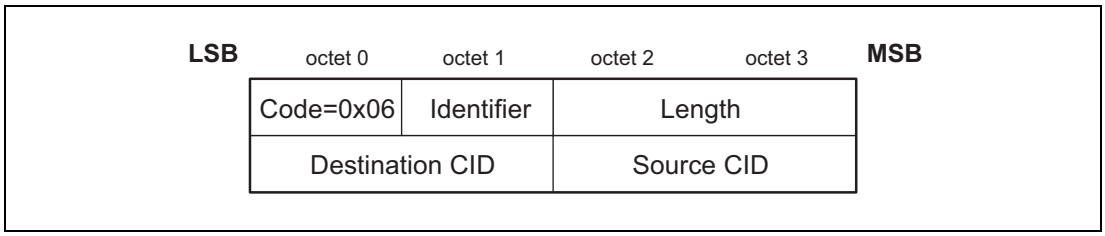


Figure 4.10: Disconnection Request Packet

The data fields are:

- *Destination CID - DCID (2 octets)*

  This field specifies the endpoint of the channel to be disconnected on the device receiving this request.

- *Source CID - SCID (2 octets)*

  This field specifies the endpoint of the channel to be disconnected on the device sending this request.

The SCID and DCID are relative to the sender of this request and shall match those of the channel to be disconnected. If the DCID is not recognized by the receiver of this message, a CommandReject message with ’invalid CID’ result code shall be sent in response. If the receiver finds a DCID match but the SCID fails to find the same match, the request should be silently discarded.

4.7 DISCONNECTION RESPONSE (CODE 0x07)

Disconnection responses shall be sent in response to each valid disconnection request.

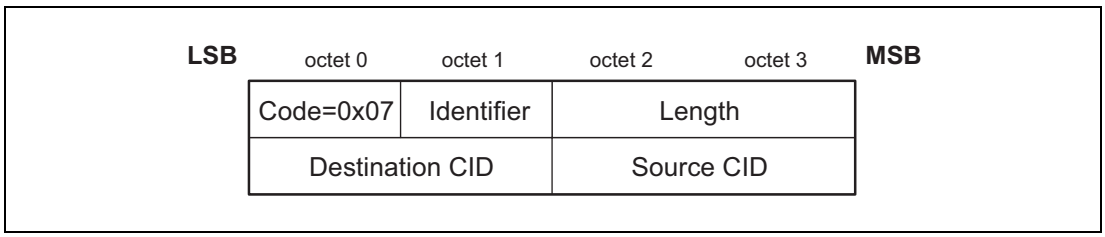


Figure 4.11: Disconnection Response Packet

The data fields are:

- *Destination CID - DCID (2 octets)*

  This field identifies the channel endpoint on the device sending the response.

- *Source CID - SCID (2 octets)*

  This field identifies the channel endpoint on the device receiving the response.

  The DCID and the SCID (which are relative to the sender of the request), and the Identifier fields shall match those of the corresponding disconnection request command. If the CIDs do not match, the response should be silently discarded at the receiver.

4.8 ECHO REQUEST (CODE 0x08)

Echo requests are used to request a response from a remote L2CAP entity. These requests may be used for testing the link or for passing vendor specific information using the optional data field. L2CAP entities shall respond to a valid Echo Request packet with an Echo Response packet. The Data field is optional and implementation specific. L2CAP entities should ignore the contents of this field if present.

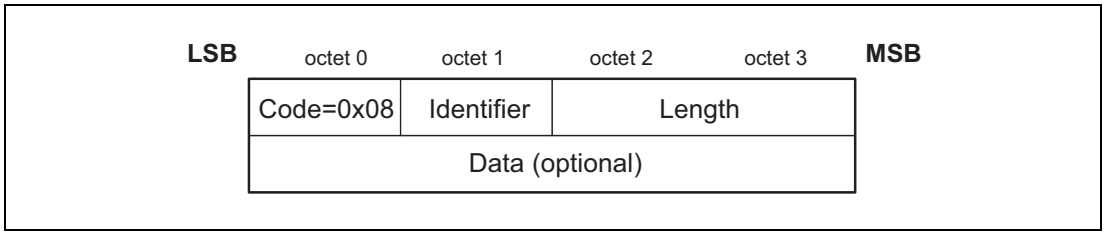


Figure 4.12: Echo Request Packet

4.9 ECHO RESPONSE (CODE 0x09)

An Echo response shall be sent upon receiving a valid Echo Request. The identifier in the response shall match the identifier sent in the Request. The optional and implementation specific data field may contain the contents of the data field in the Request, different data, or no data at all.

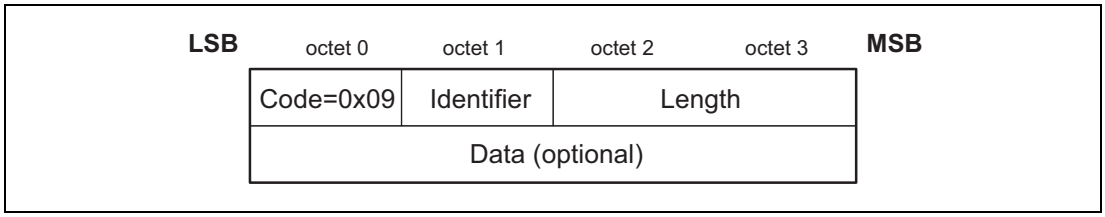


Figure 4.13: Echo Response Packet

4.10 INFORMATION REQUEST (CODE 0x0A)

Information requests are used to request implementation specific information from a remote L2CAP entity. L2CAP implementations shall respond to a valid Information Request with an Information Response. It is optional to send Information Requests.

An L2CAP implementation shall only use optional features or attribute ranges for which the remote L2CAP entity has indicated support through an Information Response. Until an Information Response which indicates support for optional features or ranges has been received only mandatory features and ranges shall be used.

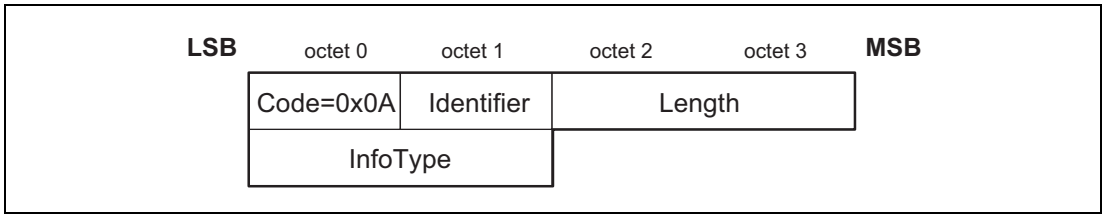


Figure 4.14: Information Request Packet

The data field is:

- *InfoType (2 octets)*

  The InfoType defines the type of implementation specific information being requested. See Section 4.11 for details on the type of information requested.

Value	Description
0x0001	Connectionless MTU
0x0002	Extended features supported

Table 4.9: InfoType definitions

Value	Description
0x0003	Fixed Channels supported
Other	Reserved for Future Use

Table 4.9: InfoType definitions (Continued)

L2CAP entities shall not send an Information Request packet with InfoType 0x0003 over Fixed Channel CID 0x0001 until first verifying that the Fixed Channels bit is set in the Extended feature mask of the remote device. Support for fixed channels is mandatory for devices with BR/EDR/LE or LE Controllers. Information Request and Information Response shall not be used over Fixed Channel CID 0x0005.

4.11 INFORMATION RESPONSE (CODE 0x0B)

An information response shall be sent upon receiving a valid Information Request. The identifier in the response shall match the identifier sent in the Request. The data field shall contain the value associated with the InfoType field sent in the Request, or shall be empty if the InfoType is not supported.

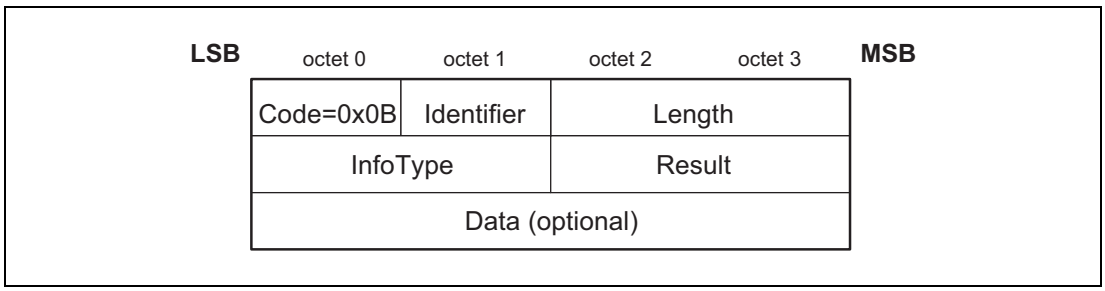


Figure 4.15: Information Response Packet

The data fields are:

- *InfoType (2 octets)*

  The InfoType defines the type of implementation specific information that was requested. This value shall be copied from the InfoType field in the Information Request.

- *Result (2 octets)*

  The Result contains information about the success of the request. If result is "Success," the data field contains the information as specified in Table 4.11. If result is "Not supported," no data shall be returned.

Value	Description
0x0000	Success
0x0001	Not supported

Table 4.10: Information Response Result values

Value	Description
Other	Reserved for Future Use

Table 4.10: Information Response Result values (Continued)

- *Data (0 or more octets)*

  The contents of the Data field depends on the InfoType.
  For InfoType = 0x0001 the data field contains the remote entity's 2-octet acceptable connectionless MTU. The default value is defined in Section 3.2.

  For InfoType = 0x0002, the data field contains the 4 octet L2CAP extended feature mask. The feature mask refers to the extended features that the L2CAP entity sending the Information Response supports. The feature bits contained in the L2CAP feature mask are specified in Section 4.12.

  For InfoType = 0x0003, the data field contains an 8 octet bit map that indicates which Fixed L2CAP Channels (i.e., the L2CAP channels that use a CID from 0x0000 to 0x003F) are supported. A list of available fixed channels is provided in Table 2.1 in Section 2.1. A detailed description of this InfoType data field is given in Section 4.13.

  Note: L2CAP entities of versions prior to version 1.2, receiving an Information Request with InfoType = 0x0002 for an L2CAP feature discovery, return an Information Response with result code "Not supported." L2CAP entities at version 1.2 to 2.1 + EDR that have an all zero extended features mask may return an Information Response with result code "Not supported."

InfoType	Data	Data Length (octets)
0x0001	Connectionless MTU	2
0x0002	Extended feature mask	4
0x0003	Fixed Channels Supported	8

Table 4.11: Information Response Data fields

4.12 EXTENDED FEATURE MASK

The features are represented as a bit mask in the Information Response data field (see Section 4.11). For each feature a single bit is specified which shall be set to 1 if the feature is supported and set to 0 otherwise. All unknown or unassigned feature bits are reserved for future use.

The feature mask shown in Table 4.12 consists of 4 octets (numbered octet 0 ... 3), with bit numbers 0 ... 7 each. Within the Information Response packet data field, bit 0 of octet 0 is aligned leftmost, bit 7 of octet 3 is aligned rightmost.

Note: The L2CAP feature mask was introduced in Bluetooth v1.2 and contains features introduced after Bluetooth v1.1.

No.	Supported feature	Octet	Bit
0	Flow control mode	0	0
1	Retransmission mode	0	1
2	Bi-directional QoS[1]	0	2
3	Enhanced Retransmission Mode	0	3
4	Streaming Mode	0	4
5	FCS Option	0	5
6	Extended Flow Specification for BR/EDR	0	6
7	Fixed Channels	0	7
8	Extended Window Size	1	0
9	Unicast Connectionless Data Reception	1	1
31	Reserved for feature mask extension	3	7

Table 4.12: Extended feature mask

1. Peer side supports upper layer control of the Link Manager's Bi-directional QoS, see Section 5.3 for more details.

4.13 FIXED CHANNELS SUPPORTED

Each Fixed Channel is represented by a single bit in an 8 octet bit mask. The bit associated with a channel shall be set to 1 if the L2CAP entity supports signaling on that channel. The L2CAP signaling channel is mandatory and therefore the bit associated with that channel shall be set to 1.Table 4.13 shows the format of the bit mask.

CID	Fixed Channel	Value	Octet	Bit
0x0000	Null identifier	Shall be set to 0	0	0
0x0001	L2CAP Signaling channel	Shall be set to 1	0	1
0x0002	Connectionless reception	0 – if not supported 1 – if supported	0	2
0x0003	AMP Manager Protocol Channel	0 – if not supported 1 – if supported	0	3
0x0004-0x0006	Reserved for Future Use		0	4-6
0x0007	BR/EDR Security Manager	0 – if not supported 1 – if supported	0	7
0x0008-0x003E	Reserved for Future Use		1-6 7	0-7 0-6
0x003F	AMP Test Manager	0 – if not supported 1 – if supported	7	7
Other	Reserved for Future Use		Other	

Table 4.13: Fixed Channels Supported bit mask

An L2CAP entity shall not transmit on any fixed channel (with the exception of the L2CAP signaling channel) until it has received a Fixed Channels Supported InfoType from the peer L2CAP entity indicating support for the channel, or has received a valid signaling packet from the remote device on the Fixed channel. All packets received on a non-supported fixed channel shall be ignored.

4.14 CREATE CHANNEL REQUEST (CODE 0x0C)

The Create Channel request packet, shown in Figure 4.16, is sent to create an L2CAP channel between two devices over the Controller identified by the Controller ID.

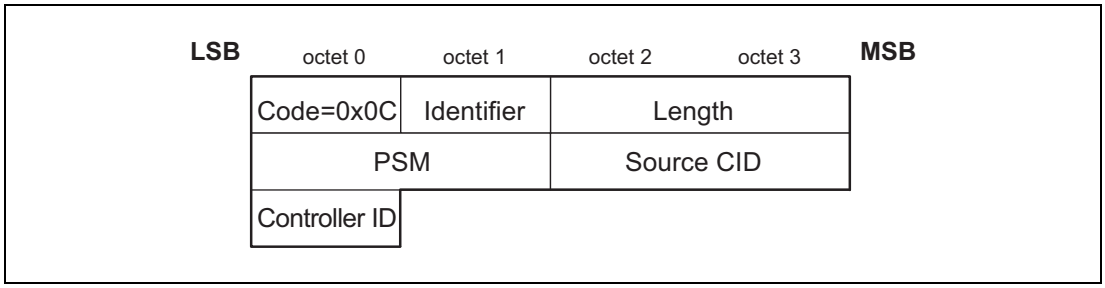


Figure 4.16: Create Channel Request Packet

The data fields are:

- *Protocol/Service Multiplexer –PSM (2 octets (minimum))*

  The PSM field is at least two octets in length. The structure of the PSM field is based on the ISO 3309 extension mechanism for address fields. All PSM values shall be *odd*, that is, the least significant bit of the least significant octet must be 1. Also, all PSM values shall have the least significant bit of the most significant octet equal to 0. This allows the PSM field to be extended beyond 16 bits. PSM values are separated into two ranges. Values in the first range are assigned by the Bluetooth SIG and indicate protocols. The second range of values are dynamically allocated and used in conjunction with the Service Discovery Protocol (SDP). The dynamically assigned values may be used to support multiple implementations of a particular protocol. PSM values are defined in the Assigned Numbers document.

- *Source CID –SCID (2 octets)*

  The source CID is two octets in length and represents a channel endpoint on the device sending the request. Once the channel has been configured, data packets flowing to the sender of the request shall be sent to this CID. Thus, the Source CID represents the channel endpoint on the device sending the request and receiving the response. The value of the Source CID shall be from the dynamically allocated range as defined in Table 2.1 and shall not be already allocated to a different channel on the device sending the request.

- *Controller Identifier –Controller ID (1 octet)*

  The Controller ID is one octet in length and represents the Controller physical link over which the channel shall be created. The Controller ID is the identifier of the Controller on the remote device obtained via an AMP Manager Discover Available AMPs request. See [Vol 3] Part E, AMP Manager Protocol Specification The Controller physical link shall already exist.

4.15 CREATE CHANNEL RESPONSE (CODE 0x0D)

When a device receives a Create Channel Request Packet, it shall send a Create Channel Response packet. Note: Implementations conforming to versions prior to 4.2 may respond with a Command Reject (Reason 0x0002 – Invalid CID In Request) packet under conditions now covered by result codes of 0x0006 and 0x0007 of this packet.
The format of the Create Channel Response packet is shown in Figure 4.17.

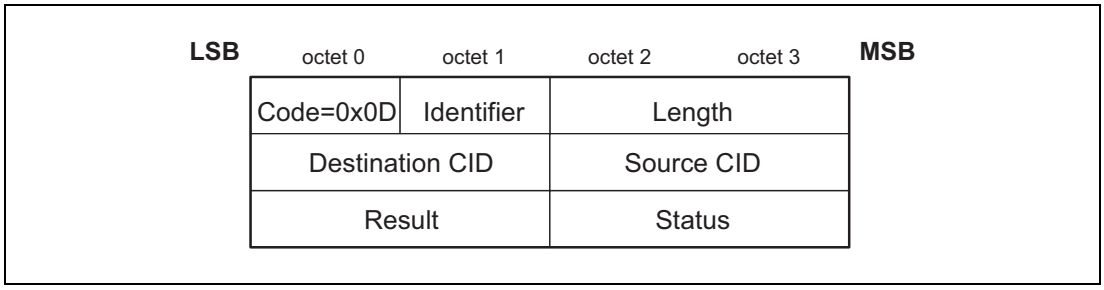


Figure 4.17: Create Channel Response Packet

The data fields are:

- *Destination Channel Identifier–DCID (2 octets)*

  This field contains the channel endpoint on the device sending this Response packet. Thus, the Destination CID represents the channel endpoint on the device receiving the request and sending the response. The value of the Destination CID shall be from the dynamically allocated range as defined in Table 2.1 and shall not be already allocated to a different channel on the device sending the response.

- *Source Channel Identifier–SCID (2 octets)*

  This field contains the channel endpoint on the device receiving this Response packet. This is copied from the SCID field of the Create Channel Request packet.

- *Result (2 octets)*

  The result field indicates the outcome of the Create Channel Request. The result value of 0x0000 indicates success while a non-zero value indicates the Create Channel Request failed or is pending. A logical channel is established on the receipt of a successful result unless the DCID field is outside of the dynamically allocated range (see Table 2.1) or is already allocated on the device sending the response. Table 4.14 defines values for this field. The DCID and SCID fields shall be ignored when the result field indicates the connection was refused.

Result	Description
0x0000	Connection successful

Table 4.14: Result values

Result	Description
0x0001	Connection pending
0x0002	Connection refused - PSM not supported
0x0003	Connection refused - security block
0x0004	Connection refused - no resources available
0x0005	Connection refused - Controller ID not supported
0x0006	Connection refused – invalid Source CID
0x0007	Connection refused – Source CID already allocated
Other	Reserved for Future Use

Table 4.14: Result values (Continued)

- *Status (2 octets)*

  Only defined for Result = Pending. Indicates the status of the connection. The status is set to one of the values shown in Table 4.15.

Value	Description
0x0000	No further information available
0x0001	Authentication pending
0x0002	Authorization pending
Other	Reserved for Future Use

Table 4.15: Status values

4.16 MOVE CHANNEL REQUEST (CODE 0x0E)

Move Channel request packets are sent to move an existing L2CAP channel from a physical link on one Controller to a physical link on another Controller. The CIDs for the L2CAP channel are not changed by a Move operation. Figure 4.18 illustrates a Move Channel request packet. Channels shall only be moved if configured to use Enhanced Retransmission mode or Streaming mode. Fixed channels (see Section 2.1) shall not be moved.

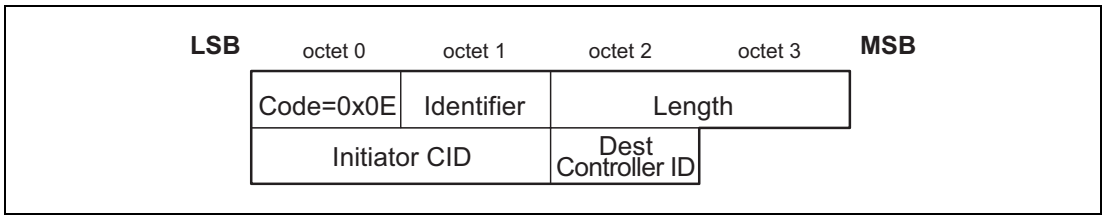


Figure 4.18: Move Channel Request Packet

The data fields are:

- *Initiator Channel Identifier - ICID (2 octets)*

  This field contains the channel endpoint on the device sending this Request packet.

- *Destination Controller Identifier - Dest Controller ID (1 octet)*

  The Dest Controller ID is one octet in length and represents the Controller physical link to which the channel shall be moved. The Controller ID is the identifier of the Controller on the remote device obtained via an AMP Manager Discover Available AMPs request. See [Vol 3] Part E, AMP Manager Protocol Specification.The Controller physical link shall already exist.

4.17 MOVE CHANNEL RESPONSE (CODE 0x0F)

When a device receives a Move Channel request packet it shall send a Move Channel response packet. If the device has sent its own Move Channel request then a collision has occurred. One of the requests shall be rejected while the other shall proceed. The Move Channel request that shall be rejected is based on the algorithm in Section 7.7

The format of Move Channel response packet is shown in Figure 4.19.

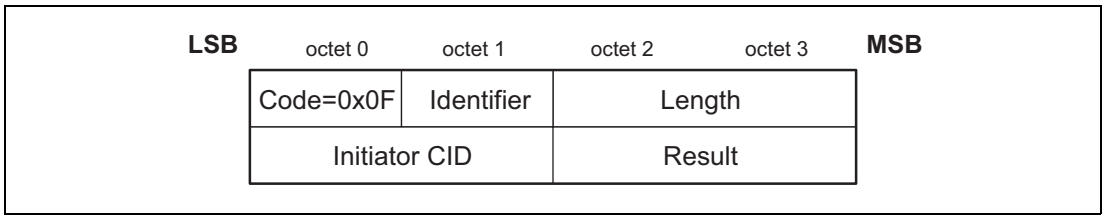


Figure 4.19: Move Channel Response Packet

The data fields are:

- *Initiator Channel Identifier – ICID (2 octets)*

  This field contains the channel endpoint on the device that sent the Move Channel Request (device receiving this Response packet). This is the same value as was sent in the Move Channel Request packet.

- *Result (2 octets)*

  The result field indicates the outcome of the move request. The result value of 0x0000 indicates success while a non-zero value indicates the move request failed. A logical channel is moved on the receipt of a successful result. Table 4.16 defines values for this field. The ICID field shall be ignored when the result field indicates the move was refused.

Result	Description
0x0000	Move Success
0x0001	Move Pending
0x0002	Move refused - Controller ID not supported
0x0003	Move refused - new Controller ID is same as old Controller ID
0x0004	Move refused - Configuration not supported
0x0005	Move refused - Move Channel collision
0x0006	Move refused - Channel not allowed to be moved
Other	Reserved for Future Use

Table 4.16: Result values

4.18 MOVE CHANNEL CONFIRMATION (CODE 0x10)

When the initiator of a Move Channel request receives a Move Channel response with a result code other than "pending" from the responder, it shall send a Move Channel confirmation packet, that will conclude the Move Channel procedure, informing the responder that all the QoS parameters were successfully (or not) negotiated. The format of Move Channel confirmation packet is shown in Figure 4.20.

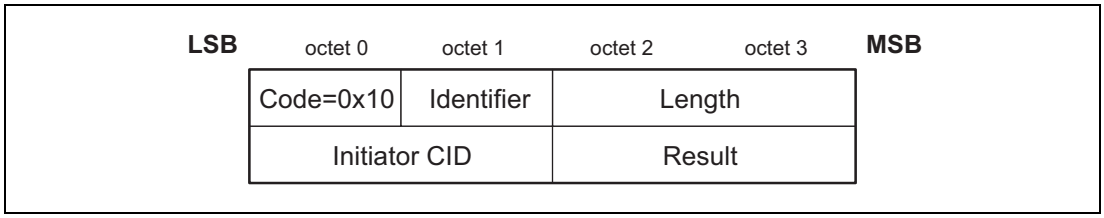


Figure 4.20: Move Channel Confirmation Packet

The data fields are:

- *Initiator Channel Identifier – ICID (2 octets)*

  This field contains the channel endpoint on the device sending the Move Channel Confirmation packet. This is the same value as was sent in the original Move Channel Request packet.

- *Result (2 octets)*

  The result field indicates the outcome of the move confirmation. The result value of 0x0000 indicates success while a non-zero value indicates the move failed.

Result	Description
0x0000	Move success - both sides succeed
0x0001	Move failure - one or both sides refuse
Other	Reserved for Future Use

Table 4.17: Result values

4.19 MOVE CHANNEL CONFIRMATION RESPONSE (CODE 0x11)

When a device receives a Move Channel Confirmation packet it shall send a Move Channel Confirmation response packet. The purpose of the Move Channel Confirmation Response is so that Move Channel Confirmation is consistent with the command/response style. The format of Move Channel Confirmation response packet is shown in Figure 4.21.

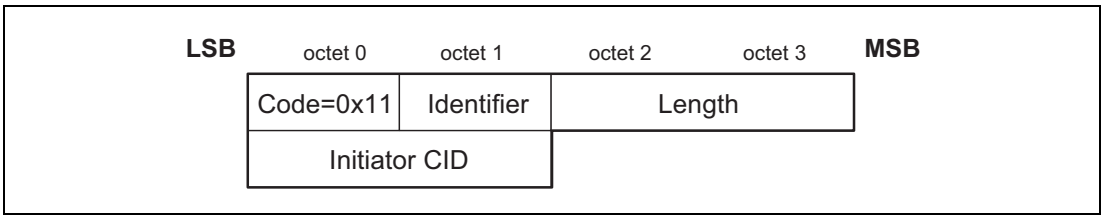


Figure 4.21: Move Channel Confirmation Response Packet

The data field is:

- *Initiator Channel Identifier – ICID (2 octets)*

  This field contains the channel endpoint on the device that sent the Move Channel Confirmation packet.

4.20 CONNECTION PARAMETER UPDATE REQUEST (CODE 0x12)

This command shall only be sent from the LE slave device to the LE master device and only if one or more of the LE slave Controller, the LE master Controller, the LE slave Host and the LE master Host do not support the Connection Parameters Request Link Layer Control Procedure ([Vol 6] Part B, Section 5.1.7). If an LE slave Host receives a Connection Parameter Update Request packet it shall respond with a Command Reject packet with reason 0x0000 (Command not understood).

The Connection Parameter Update Request allows the LE slave Host to request a set of new connection parameters. When the LE master Host receives a Connection Parameter Update Request packet, depending on the parameters of other connections, the LE master Host may accept the requested parameters and deliver the requested parameters to its Controller or reject the request. In devices supporting HCI, the LE master Host delivers the requested parameters to its Controller using the HCI_LE_Connection_Update command (see [Vol 2] Part E, Section 7.8.18). If the LE master Host accepts the requested parameters it shall send the Connection Parameter Update Response packet with result 0x0000 (Parameters accepted) otherwise it shall set the result to 0x0001 (request rejected).

The LE slave Host will receive an indication from the LE slave Controller when the connection parameters have been updated. In devices supporting HCI, this

notification will be in the form of an LE Connection Update Complete event (see [Vol 2] Part E, Section 7.7.65.3). If the LE master Controller rejects the updated connection parameters no indication from the LE slave Controller will be sent to the LE slave Host.

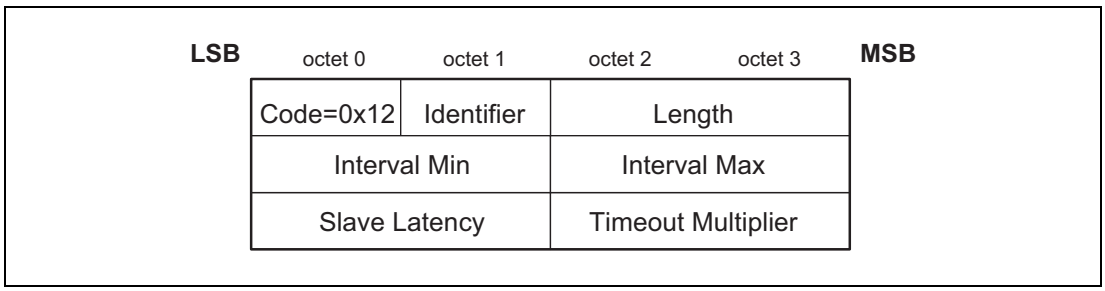


Figure 4.22: Connection Parameters Update Request Packet

The data fields are:

- *Interval Min (2 octets)*

  Defines minimum value for the connection interval in the following manner:
  connIntervalMin = Interval Min * 1.25 ms. Interval Min range: 6 to 3200 frames where 1 frame is 1.25 ms and equivalent to 2 BR/EDR slots. Values outside the range are reserved for future use. Interval Min shall be less than or equal to Interval Max.

- *Interval Max (2 octets)*

  Defines maximum value for the connection interval in the following manner:
  connIntervalMax = Interval Max * 1.25 ms. Interval Max range: 6 to 3200 frames. Values outside the range are reserved for future use. Interval Max shall be equal to or greater than the Interval Min.

- *Slave Latency (2 octets)*

  Defines the slave latency parameter (as number of LL connection events) in the following manner:
  connSlaveLatency = Slave Latency. The Slave Latency field shall have a value in the range of 0 to ((connSupervisionTimeout / (connIntervalMax*2)) -1).
  The Slave Latency field shall be less than 500.

- *Timeout Multiplier (2 octets)*

  Defines connection timeout parameter in the following manner:
  connSupervisionTimeout = Timeout Multiplier * 10 ms

  The Timeout Multiplier field shall have a value in the range of 10 to 3200.

4.21 CONNECTION PARAMETER UPDATE RESPONSE (CODE 0x13)

This response shall only be sent from the LE master device to the LE slave device.

The Connection Parameter Update Response packet shall be sent by the master Host when it receives a Connection Parameter Update Request packet. If the LE master Host accepts the request it shall send the connection parameter update to its Controller.

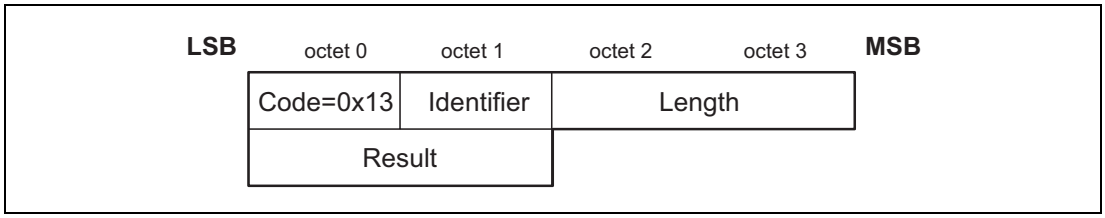


Figure 4.23: Connection Parameters Update Response Packet

The data field is:

- *Result (2 octets)*

  The result field indicates the response to the Connection Parameter Update Request. The result value of 0x0000 indicates that the LE master Host has accepted the connection parameters while 0x0001 indicates that the LE master Host has rejected the connection parameters.

Result	Description
0x0000	Connection Parameters accepted
0x0001	Connection Parameters rejected
Other	Reserved for Future Use

Table 4.18: Result values

4.22 LE CREDIT BASED CONNECTION REQUEST (CODE 0x14)

LE Credit Based Connection Request packets are sent to create and configure an L2CAP channel between two devices. Figure 4.24 illustrates a Connection Request packet.

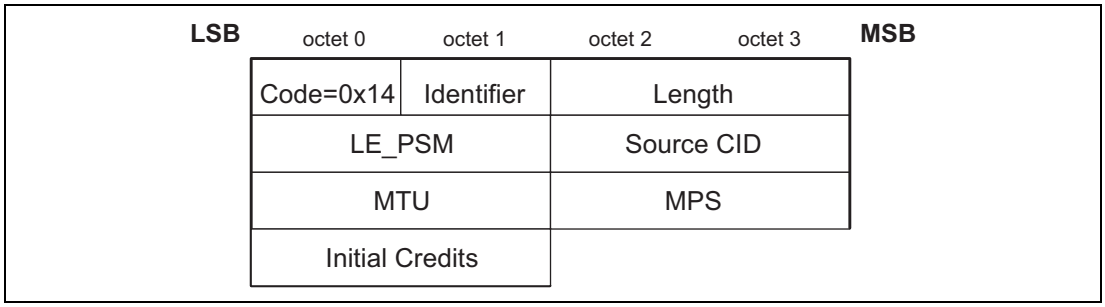


Figure 4.24: LE Credit Based Connection Request Packet

The data fields are:

- *LE Protocol/Service Multiplexer – LE_PSM (2 octets)*

  The LE_PSM field is two octets in length. LE_PSM values are separated into two ranges. Values in the first range are assigned by the Bluetooth SIG and indicate protocols. Values in the second range are dynamically allocated and used in conjunction with services defined in the GATT server. The dynamically assigned values may be used to support multiple implementations of a particular protocol.

  LE_PSM values are defined in the table below.

Range	Type	Server Usage	Client Usage
0x0001-0x007F	Fixed, SIG assigned	LE_PSM is fixed for all implementations	LE_PSM may be assumed for fixed service. Protocol used is indicated by the LE_PSM as defined in the Assigned Numbers page.
0x0080-0x00FF	Dynamic	LE_PSM may be fixed for a given implementation or may be assigned at the time the service is registered in GATT	LE_PSM shall be obtained from the service in GATT upon every reconnection. LE_PSM for one direction will typically be different from the other direction.
Other	RFU	Not applicable	Not applicable

Table 4.19: LE Credit Based Connection Request LE_PSM ranges

- *Source CID – SCID (2 octets)*

  The source CID is two octets in length and represents a channel endpoint on the device sending the request. Once the channel has been created, data packets flowing to the sender of the request shall be sent to this CID. Thus,

the Source CID represents the channel endpoint on the device sending the request and receiving the response.

- *Maximum Transmission Unit – MTU (2 octets)*

  The MTU field specifies the maximum SDU size (in octets) that the L2CAP layer entity sending the LE Credit Based Connection Request can receive on this channel. L2CAP implementations shall support a minimum MTU size of 23 octets.

- *Maximum PDU Size – MPS (2 octets)*

  The MPS field specifies the maximum payload size (in octets) that the L2CAP layer entity sending the LE Credit Based Connection Request is capable of receiving on this channel. L2CAP implementations shall support a minimum MPS of 23 octets and may support an MPS up to 65533 octets.

- *Initial Credits – (2 octets)*

  The initial credit value indicates the number of LE-frames that the peer device can send to the L2CAP layer entity sending the LE Credit Based Connection Request. The initial credit value shall be in the range of 0 to 65535.

4.23 LE CREDIT BASED CONNECTION RESPONSE (CODE 0x15)

When a device receives a LE Credit Based Connection Request packet, it shall send a LE Credit Based Connection Response packet. The format of the connection response packet is shown in Figure 4.25.

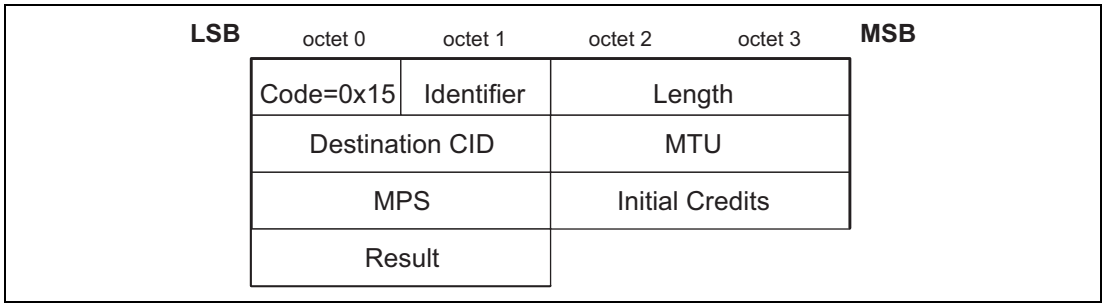


Figure 4.25: LE Credit Based Connection Response Packet

The data fields are:

- *Destination CID – DCID (2 octets)*

  The destination CID is two octets in length and represents a channel endpoint on the device sending the response. Once the channel has been created, data packets flowing to the sender of the response shall be sent to this CID. Thus, the destination CID represents the channel endpoint on the device receiving the request and sending the response.

- *Maximum Transmission Unit – MTU (2 octets)*

  The MTU field specifies the maximum SDU size (in octets) that the L2CAP layer entity sending the LE Credit Based Connection Response can receive on this channel. L2CAP implementations shall support a minimum MTU size of 23 octets.

- *Maximum PDU Size – MPS (2 octets)*

  The MPS field specifies the maximum payload size (in octets) that the L2CAP layer entity sending the LE Credit Based Connection Response is capable of receiving on this channel. L2CAP implementations shall support a minimum MPS of 23 octets and may support an MPS up to 65533 octets.

- *Initial Credits – (2 octets)*

  The initial credit value indicates the number of LE-frames that the peer device can send to the L2CAP layer entity sending the LE Credit Based Connection Response. The initial credit value shall be in the range of 0 to 65535.

- *Result – (2 octets)*

  The result field indicates the outcome of the connection request. A result value of 0x0000 indicates success while a non-zero value indicates the connection request was refused. A logical channel is established on the receipt of a successful result. Table 4.20 defines values for this field. The DCID, MTU, MPS and Initial Credits fields shall be ignored when the result field indicates the connection was refused.

Value	Description
0x0000	Connection successful
0x0001	Reserved for Future Use
0x0002	Connection refused – LE_PSM not supported
0x0003	Reserved for Future Use
0x0004	Connection refused – no resources available
0x0005	Connection refused – insufficient authentication
0x0006	Connection refused – insufficient authorization
0x0007	Connection refused – insufficient encryption key size
0x0008	Connection refused – insufficient encryption
0x0009	Connection refused – invalid Source CID
0x000A	Connection refused – Source CID already allocated
0x000B	Connection refused – unacceptable parameters
Other	Reserved for Future Use

Table 4.20: Result values for LE Credit Based Connection Response

4.24 LE FLOW CONTROL CREDIT (CODE 0x16)

A device shall send a LE Flow Control Credit packet when it is capable of receiving additional LE-frames (for example after it has processed one or more LE-frames).

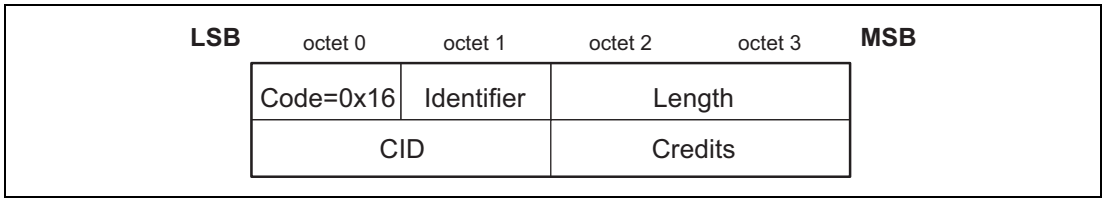


Figure 4.26: LE Flow Control Credit Packet

The data fields are:

- *CID – (2 octets)*

  The CID is two octets in length and represents the source channel endpoint of the device sending the LE Flow Control Credit packet. For example, a received LE Flow Control Credit packet with a given CID (0x0042) would provide credits for the receiving device's destination CID (0x0042).

- *Credits – (2 octets)*

  The credit value field represents number of credits the receiving device can increment, corresponding to the number of LE-frames that can be sent to the peer device sending the LE Flow Control Credit packet. The credit value field shall be a number between 1 and 65535.

5 CONFIGURATION PARAMETER OPTIONS

Options are a mechanism to extend the configuration parameters. Options shall be transmitted as information elements containing an option type, an option length, and one or more option data fields. Figure 5.1 illustrates the format of an option.

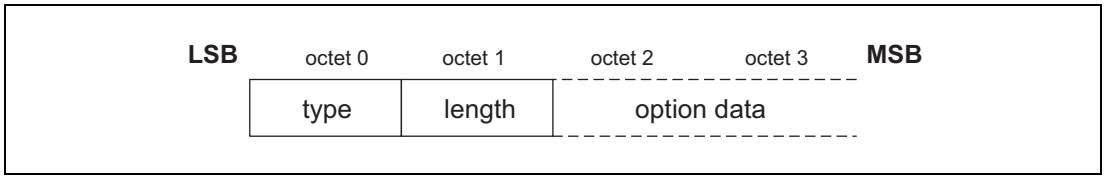


Figure 5.1: Configuration option format

The configuration option fields are:

- *Type (1 octet)*

  The option type field defines the parameters being configured. The most significant bit of the type determines the action taken if the option is not recognized.

  0 - option must be recognized; if the option is not recognized then refuse the configuration request

  1 - option is a hint; if the option is not recognized then skip the option and continue processing

- *Length (1 octet)*

  The length field defines the number of octets in the option data. Thus an option type without option data has a length of 0.

- *Option data*

  The contents of this field are dependent on the option type.

5.1 MAXIMUM TRANSMISSION UNIT (MTU)

This option specifies the maximum SDU size the sender of this option is capable of accepting for a channel. The type is 0x01, and the payload length is 2 octets, carrying the two-octet MTU size value as the only information element (see Figure 5.2). Unlike the B-Frame length field, the I-frame length field may be greater than the configured MTU because it includes the octet lengths of the Control, L2CAP SDU Length (when present), and frame check sequence fields as well as the Information octets.

MTU is not a negotiated value, it is an informational parameter that each device can specify independently. It indicates to the remote device that the local device can receive, in this channel, an MTU larger than the minimum required. All L2CAP implementations shall support a minimum MTU of 48 octets over the ACL-U logical link and 23 octets over the LE-U logical link; however, some protocols

and profiles explicitly require support for a larger MTU. The minimum MTU for a channel is the larger of the L2CAP minimum 48 octet MTU and any MTU explicitly required by the protocols and profiles using that channel. (Note: The MTU is only affected by the profile directly using the channel. For example, if a service discovery transaction is initiated by a non service discovery profile, that profile does not affect the MTU of the L2CAP channel used for service discovery).

The following rules shall be used when responding to a configuration request specifying the MTU for a channel:

- A request specifying any MTU greater than or equal to the minimum MTU for the channel shall be accepted.
- A request specifying an MTU smaller than the minimum MTU for the channel may be rejected.

The signaling described in Section 4.5 may be used to reject an MTU smaller than the minimum MTU for a channel. The "failure-unacceptable parameters" result sent to reject the MTU shall include the proposed value of MTU that the remote device intends to transmit. It is implementation specific whether the local device continues the configuration process or disconnects the channel.

If the remote device sends a positive configuration response it should include the actual MTU to be used on this channel for traffic flowing into the local device. Following the above rules, the actual MTU cannot be less than 48 bytes.This is the minimum of the MTU in the configuration request and the outgoing MTU capability of the device sending the configuration response. The new agreed value (the default value in a future re-configuration) is the value specified in the response.

Note: For backwards compatibility reception of the MTU option in a negative Configuration Response where the MTU option is not in error should be interpreted in the same way as it is in a positive Configuration Response (e.g. the case where another configuration option value is unacceptable but the negative Configuration Response contains the MTU option in addition to the unacceptable option).

The MTU to be used on this channel for the traffic flowing in the opposite direction will be established when the remote device sends its own Configuration Request as explained in Section 4.4.

If the configured mode is Enhanced Retransmission mode or Streaming mode then MTU shall not be reconfigured to a smaller size.

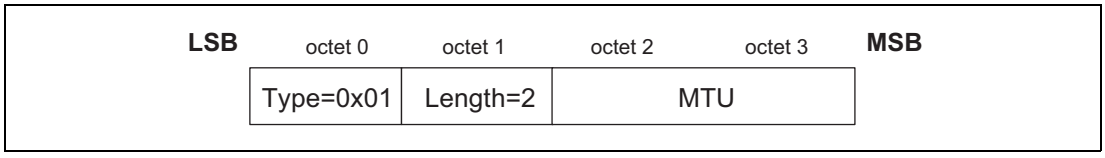


Figure 5.2: MTU Option Format

The option data field is:

- *Maximum Transmission Unit - MTU (2 octets)*

  The MTU field is the maximum SDU size, in octets, that the originator of the Request can accept for this channel. The MTU is asymmetric and the sender of the Request shall specify the MTU it can receive on this channel if it differs from the default value. L2CAP implementations shall support a minimum MTU size of 48 octets. The default value is 672 octets[1].

5.2 FLUSH TIMEOUT OPTION

This option is used to inform the recipient of the Flush Timeout the sender is going to use. This option shall not be used if the Extended Flow Specification is used. The Flush Timeout is defined in the BR/EDR Baseband specification [Vol 2] Part B, Section 7.6.3. The type is 0x02 and the payload size is 2 octets. The Flush Timeout option is negotiable.

If the remote device returns a negative response to this option and the local device cannot honor the proposed value, then it shall either continue the configuration process by sending a new request with the original value, or disconnect the channel. The flush timeout applies to all channels on the same ACL logical transport but may be overridden on a packet by packet basis by marking individual L2CAP packets as non-automatically-flushable via the Packet_Boundary_Flag in the HCI ACL Data Packet (see Section 1.1).

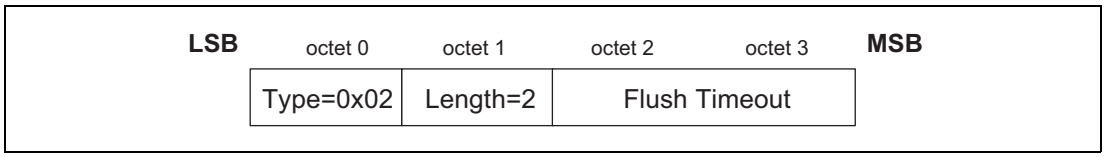


Figure 5.3: Flush Timeout option format

The option data field is:

- *Flush Timeout*

  This value is the Flush Timeout in milliseconds. This is an asymmetric value and the sender of the Request shall specify its flush timeout value if it differs from the default value of 0xFFFF.

  Possible values are:

  0x0001 - no retransmissions at the baseband level should be performed since the minimum polling interval is 1.25 ms.

  0x0002 to 0xFFFE - Flush Timeout used by the baseband.

1. The default MTU was selected based on the payload carried by two baseband DH5 packets (2*341=682 octets) minus the baseband ACL headers (2*2=4 octets) and a 6-octet L2CAP header. Note that the L2CAP header length is 4 octets (see Section 3.3.1) but for historical reasons an L2CAP header length of 6 bytes is used.

0xFFFF - an infinite amount of retransmissions. This is also referred to as a 'reliable channel'. In this case, the baseband shall continue retransmissions until physical link loss is declared by link manager timeouts.

5.3 QUALITY OF SERVICE (QOS) OPTION

This option specifies a flow specification similar to RFC 1363[1]. Although the RFC flow specification addresses only the transmit characteristics, the Bluetooth QoS interface can handle the two directions (Tx and Rx) in the negotiation as described below.

If no QoS configuration parameter is negotiated the link shall assume the default parameters. The QoS option is type 0x03. This option shall not be used if the Extended Flow Specification option is used. The QoS option is negotiable.

In a configuration request, this option describes the outgoing traffic flow from the device sending the request. In a positive Configuration Response, this option describes the incoming traffic flow agreement to the device sending the response. In a negative Configuration Response, this option describes the preferred incoming traffic flow to the device sending the response.

L2CAP implementations are only required to support 'Best Effort' service, support for any other service type is optional. Best Effort does not require any guarantees. If no QoS option is placed in the request, Best Effort shall be assumed. If any QoS guarantees are required then a QoS configuration request shall be sent.

The remote device's Configuration Response contains information that depends on the value of the result field (see Section 4.5). If the request was for Guaranteed Service, the response shall include specific values for any wild card parameters (see Token Rate and Token Bucket Size descriptions) contained in the request. If the result is "Failure – unacceptable parameters", the response shall include a list of outgoing flow specification parameters and parameter values that would make a new Connection Request from the local device acceptable by the remote device. Both explicitly referenced in a Configuration Request or implied configuration parameters can be included in a Configuration Response. Recall that any missing configuration parameters from a Configuration Request are assumed to have their most recently accepted values.

If a configuration request contains any QoS option parameters set to "do not care" then the configuration response shall set the same parameters to "do not care". This rule applies for both Best Effort and Guaranteed Service.

1. Internet Engineering Task Force, "A Proposed Flow Specification", RFC 1363, September 1992.

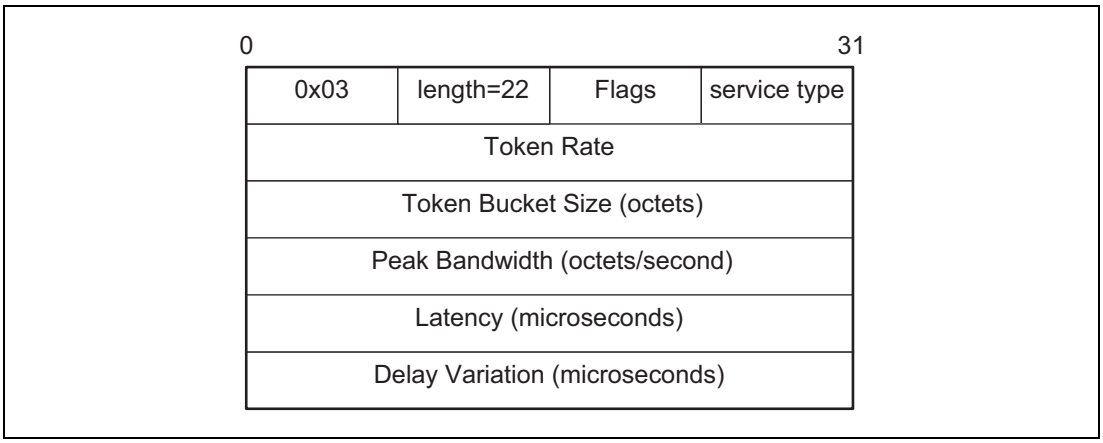


Figure 5.4: Quality of Service (QoS) option format containing Flow Specification

The option data fields are:

- *Flags (1 octet)*

  Reserved for future use.

- *Service Type (1 octet)*

  This field indicates the level of service required. Table 5.1 defines the different services available. The default value is ‘Best effort’.

  If ‘Best effort’ is selected, the remaining parameters should be treated as optional by the remote device. The remote device may choose to ignore the fields, try to satisfy the parameters but provide no response (QoS option omitted in the Response message), or respond with the settings it will try to meet.

  If ‘No traffic’ is selected, the remainder of the fields shall be ignored because there is no data being sent across the channel in the outgoing direction.

Value	Description
0x00	No traffic
0x01	Best effort (Default)
0x02	Guaranteed
Other	Reserved for Future Use

Table 5.1: Service type definitions

- *Token Rate (4 octets)*

  The value of this field represents the average data rate with which the application transmits data. The application may send data at this rate continuously. On a short time scale the application may send data in excess of the average data rate, dependent on the specified Token Bucket Size and Peak Bandwidth (see below). The Token Bucket Size and Peak Bandwidth allow the application to transmit data in a 'bursty' fashion.

The Token Rate signaled between two L2CAP peers is the data transmitted by the application and shall exclude the L2CAP protocol overhead. The Token Rate signaled over the interface between L2CAP and the Link Manager shall include the L2CAP protocol overhead. Furthermore the Token Rate value signaled over this interface may also include the aggregation of multiple L2CAP channels onto the same ACL logical transport.

The Token Rate is the rate with which traffic credits are provided. Credits can be accumulated up to the Token Bucket Size. Traffic credits are consumed when data is transmitted by the application. When traffic is transmitted, and there are insufficient credits available, the traffic is non-conformant. The Quality of Service guarantees are only provided for conformant traffic. For non-conformant traffic there may be insufficient resources such as bandwidth and buffer space. Furthermore non-conformant traffic may violate the QoS guarantees of other traffic flows.

The Token Rate is specified in octets per second. The value 0x00000000 indicates no token rate is specified. This is the default value and means “do not care”. When the Guaranteed service is selected, the default value shall not be used. The value 0xFFFFFFFF is a wild card matching the maximum token rate available. The meaning of this value depends on the service type. For best effort, the value is a hint that the application wants as much bandwidth as possible. For Guaranteed service the value represents the maximum bandwidth available at the time of the request.

- *Token Bucket Size (4 octets)*

  The Token Bucket Size specifies a limit on the 'burstiness' with which the application may transmit data. The application may offer a burst of data equal to the Token Bucket Size instantaneously, limited by the Peak Bandwidth (see below). The Token Bucket Size is specified in octets.

  The Token Bucket Size signaled between two L2CAP peers is the data transmitted by the application and shall exclude the L2CAP protocol overhead. The Token Bucket Size signaled over the interface between L2CAP and Link Manager shall include the L2CAP protocol overhead. Furthermore the Token Bucket Size value over this interface may include the aggregation of multiple L2CAP channels onto the same ACL logical transport.

  The value of 0x00000000 means that no token bucket is needed; this is the default value. When the Guaranteed service is selected, the default value shall not be used. The value 0xFFFFFFFF is a wild card matching the maximum token bucket available. The meaning of this value depends on the service type. For best effort, the value indicates the application wants a bucket as big as possible. For Guaranteed service the value represents the maximum L2CAP SDU size.

  The Token Bucket Size is a property of the traffic carried over the L2CAP channel. The Maximum Transmission Unit (MTU) is a property of an L2CAP implementation. For the Guaranteed service the Token Bucket Size shall be smaller or equal to the MTU.

- *Peak Bandwidth (4 octets)*

The value of this field, expressed in octets per second, limits how fast packets from applications may be sent back-to-back. Some systems can take advantage of this information, resulting in more efficient resource allocation.

The Peak Bandwidth signaled between two L2CAP peers specifies the data transmitted by the application and shall exclude the L2CAP protocol overhead. The Peak Bandwidth signaled over the interface between L2CAP and Link Manager shall include the L2CAP protocol overhead. Furthermore the Peak Bandwidth value over this interface may include the aggregation of multiple L2CAP channels onto the same ACL logical transport.

The value of 0x00000000 means "don't care." This states that the device has no preference on incoming maximum bandwidth, and is the default value. When the Guaranteed service is selected, the default value shall not be used.

- *Access Latency (4 octets)*

  The value of this field is the maximum acceptable delay of an L2CAP packet to the air-interface. The precise interpretation of this number depends on over which interface this flow parameter is signaled. When signaled between two L2CAP peers, the Access Latency is the maximum acceptable delay between the instant when the L2CAP SDU is received from the upper layer and the start of the L2CAP SDU transmission over the air. When signaled over the interface between L2CAP and the Link Manager, it is the maximum delay between the instant the first fragment of an L2CAP PDU is stored in the Host Controller buffer and the initial transmission of the L2CAP packet on the air.

  Thus the Access Latency value may be different when signaled between L2CAP and the Link Manager to account for any queuing delay at the L2CAP transmit side. Furthermore the Access Latency value may include the aggregation of multiple L2CAP channels onto the same ACL logical transport.

  The Access Latency is expressed in microseconds. The value 0xFFFFFFFF means “do not care” and is the default value. When the Guaranteed service is selected, the default value shall not be used.

- *Delay Variation (4 octets)*

  The value of this field is the difference, in microseconds, between the maximum and minimum possible delay of an L2CAP SDU between two L2CAP peers. The Delay Variation is a purely informational parameter. The value 0xFFFFFFFF means “do not care” and is the default value.

5.4 RETRANSMISSION AND FLOW CONTROL OPTION

This option specifies whether retransmission and flow control is used. If the feature is used both incoming and outgoing parameters are specified by this option. The Retransmission and Flow Control option contains both negotiable parameters and non-negotiable parameters. The mode parameter controls both incoming and outgoing data flow (i.e. both directions have to agree) and is negotiable. The other parameters control incoming data flow and are non-negotiable.

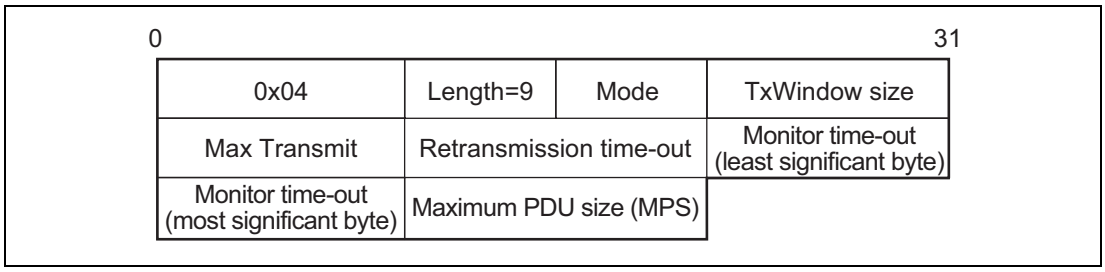


Figure 5.5: Retransmission and Flow Control option format

The option data fields are:

- *Mode (1 octet)*

  The field contains the requested mode of the link. Possible values are shown in Table 5.2.

Value	Description
0x00	L2CAP Basic Mode
0x01	Retransmission mode
0x02	Flow control mode
0x03	Enhanced Retransmission mode
0x04	Streaming mode
Other	Reserved for future use

Table 5.2: Mode definitions

  The Basic L2CAP mode is the default. If Basic L2CAP mode is requested then all other parameters shall be ignored.

  Enhanced Retransmission mode should be enabled if a reliable channel has been requested. Enhanced Retransmission mode shall only be sent to an L2CAP entity that has previously advertised support for the mode in its Extended Feature Mask (see Section 4.12).

  Streaming mode should be enabled if a finite L2CAP Flush Time-Out is set on an L2CAP connection. Streaming mode shall only be sent to a device that has previously advertised support for the mode in the Extended Feature Mask (see Section 4.12).

Flow Control mode and Retransmission mode shall only be used for backwards compatibility with L2CAP entities that do not support Enhanced Retransmission mode or Streaming mode.

- *TxWindow size (1 octet)*

  This field specifies the size of the transmission window for Flow Control mode, Retransmission mode, and Enhanced Retransmission mode. The range is 1 to 32 for Flow Control mode and Retransmission mode. The range is 1 to 63 for Enhanced Retransmission mode.

  In Retransmission mode and Flow Control mode this parameter should be negotiated to reflect the buffer sizes allocated for the connection on both sides. In general, the Tx Window size should be made as large as possible to maximize channel utilization. Tx Window size also controls the delay on flow control action. The transmitting device can send as many PDUs fit within the window.

  In Enhanced Retransmission mode this value indicates the maximum number of I-frames that the sender of the option can receive without acknowledging some of the received frames. It is not negotiated. It is an informational parameter that each L2CAP entity can specify separately. In general, the TxWindow size should be made as large as possible to maximize channel utilization. The transmitting L2CAP entity can send as many PDUs as will fit within the receiving L2CAP entity's TxWindow. TxWindow size values in a Configuration Response indicate the maximum number of packets the sender can send before it requires an acknowledgment. In other words it represents the number of unacknowledged packets the send can hold. The value sent in a Configuration Response shall be less than or equal to the TxWindow size sent in the Configuration Request. The receiver of this option in the Configuration Response may use this value as part of its acknowledgment algorithm.

  In Streaming mode this value is reserved for future use.

- *MaxTransmit (1 octet)*

  This field controls the number of transmissions of a single I-frame that L2CAP is allowed to try in Retransmission mode and Enhanced Retransmission mode. The minimum value is 1 (one transmission is permitted).

  MaxTransmit controls the number of retransmissions that L2CAP is allowed to try in Retransmission mode and Enhanced Retransmission mode before accepting that a packet and the channel is lost. When a packet is lost after being transmitted MaxTransmit times the channel shall be disconnected by sending a Disconnect request (see Section 4.6). In Enhanced Retransmission mode MaxTransmit controls the number of retransmissions for I-frames and S-frames with P-bit set to 1. The sender of the option in a Configuration Request specifies the value that shall be used by the receiver of the option. MaxTransmit values in a Configuration Response shall be ignored. Lower values might be appropriate for services requiring low latency. Higher values will be suitable for a link requiring robust operation. A value of 1 means that no retransmissions will be

made but also means that the channel will be disconnected as soon as a packet is lost. MaxTransmit shall not be set to zero in Retransmission mode. In Enhanced Retransmission mode a value of zero for MaxTransmit means infinite retransmissions.

In Streaming mode this value is reserved for future use.

- *Retransmission time-out (2 octets)*

  This is the value in milliseconds of the retransmission time-out (this value is used to initialize the RetransmissionTimer).

  The purpose of this timer in retransmission mode is to activate a retransmission in some exceptional cases. In such cases, any delay requirements on the channel may be broken, so the value of the timer should be set high enough to avoid unnecessary retransmissions due to delayed acknowledgments. Suitable values could be 100's of milliseconds and up.

  The purpose of this timer in flow control mode is to supervise I-frame transmissions. If an acknowledgment for an I-frame is not received within the time specified by the RetransmissionTimer value, either because the I-frame has been lost or the acknowledgment has been lost, the timeout will cause the transmitting side to continue transmissions. Suitable values are implementation dependent.

  The purpose of this timer in Enhanced Retransmission mode is to detect lost I-frames and initiate appropriate error recovery. The value used for the Retransmission time-out is specified in Section 8.6.2. The value sent in a Configuration Request is also specified in Section 8.6.2. A value for the Retransmission time-out shall be sent in a positive Configuration Response and indicates the value that will be used by the sender of the Configuration Response.

  In Streaming mode this value is reserved for future use.

- *Monitor time-out (2 octets)*

  In Retransmission mode this is the value in milliseconds of the interval at which S-frames should be transmitted on the return channel when no frames are received on the forward channel. (this value is used to initialize the MonitorTimer, see below).

  This timer ensures that lost acknowledgments are retransmitted. Its main use is to recover Retransmission Disable Bit changes in lost frames when no data is being sent. The timer shall be started immediately upon transitioning to the open state. It shall remain active as long as the connection is in the open state and the retransmission timer is not active. Upon expiration of the Monitor timer an S-frame shall be sent and the timer shall be restarted. If the monitor timer is already active when an S-frame is sent, the timer shall be restarted. An idle connection will have periodic monitor traffic sent in both directions. The value for this time-out should also be set to 100's of milliseconds or higher.

  In Enhanced Retransmission mode the Monitor time-out is used to detect lost S-frames with P-bit set to 1. If the time-out occurs before a response

with the F-bit set to 1 is received the S-frame is resent. The value used for the Monitor time-out is specified in Section 8.6.3. The value sent in a Configuration Request is also specified in Section 8.6.2. A value for the Monitor time-out shall be sent in a positive Configuration Response and indicates the value that will be used by the sender of the Configuration Response.

In Streaming mode this value is reserved for future use.

- *Maximum PDU payload Size - MPS (2 octets)*

  The maximum size of payload data in octets that the L2CAP layer entity sending the option in a Configuration Request is capable of accepting, i.e. the MPS corresponds to the maximum PDU payload size. Values used for MPS should take into account all possible Controllers to which the channel might be moved given that the MPS value cannot be renegotiated once the channel is created. Each device specifies the value separately. An MPS value sent in a positive Configuration Response is the actual MPS the receiver of the Configuration Request will use on this channel for traffic flowing into the local device. An MPS value sent in a positive Configuration Response shall be equal to or smaller than the value sent in the Configuration Request.

When using Retransmission mode and Flow Control mode the settings are configured separately for the two directions of an L2CAP connection. For example, in operating with an L2CAP entity implementing an earlier version of the core specification, an L2CAP connection can be configured as Flow Control mode in one direction and Retransmission mode in the other direction. If Basic L2CAP mode is configured in one direction and Retransmission mode or Flow control mode is configured in the other direction on the same L2CAP channel then the channel shall not be used.

Note: This asymmetric configuration only occurs during configuration.

When using Enhanced Retransmission mode or Streaming mode, both directions of the L2CAP connection shall be configured to the same mode. A precedence algorithm shall be used by both devices so a mode conflict can be resolved in a quick and deterministic manner.

There are two operating states:

- A device has a preferred mode but is willing to use another mode (known as "state 1"), and
- A device requires a specific mode (known as "state 2"). This includes cases where channels are created over AMP-U logical links or ACL-U logical links operating as described in Section 7.10.

In state 1, Basic L2CAP mode has the highest precedence and shall take precedence over Enhanced Retransmission mode and Streaming mode. Enhanced Retransmission mode has the second highest precedence and shall take precedence over all other modes except Basic L2CAP mode. Streaming

mode shall have the next level of precedence after Enhanced Retransmission mode.

In state 2, a layer above L2CAP requires Enhanced Retransmission mode or Streaming mode. In this case, the required mode takes precedence over all other modes.

A device does not know in which state the remote device is operating so the state 1 precedence algorithm assumes that the remote device may be a state 2 device. If the mode proposed by the remote device has a higher precedence (according to the state 1 precedence) then the algorithm will operate such that creation of a channel using the remote device's mode has higher priority than disconnecting the channel.

The algorithm for state 1 devices is divided into two parts. Part one covers the case where the remote device proposes a mode with a higher precedence than the state 1 local device. Part two covers the case where the remote device proposes a mode with a lower precedence than the state 1 local device. Part one of the algorithm is as follows:

- When the remote device receives the Configuration Request from the local device it will either reject the local device's Configuration Request by sending a negative Configuration Response or disconnect the channel. The negative Configuration Response will contain the remote device's desired mode.
- Upon receipt of the negative Configuration Response the local device shall either send a second Configuration Request proposing the mode contained in the remote device's negative Configuration Response or disconnect the channel.
- When the local device receives the Configuration Request from the remote device it shall send a positive Configuration Response or disconnect the channel.
- If the mode in the remote Device's negative Configuration Response does not match the mode in the remote device's Configuration Request then the local device shall disconnect the channel.

Part two of the algorithm is as follows:

- When the local device receives the Configuration Request from the remote device it shall reject the Configuration Request by sending a negative Configuration Response proposing its desired mode. The local device's desired mode shall be the same mode it sent in its Configuration Request. Upon receiving the negative Configuration Response the remote device will either send a second Configuration Request or disconnect the channel.
- If the local device receives a second Configuration Request from the remote device that does not contain the desired mode then the local device shall disconnect the channel.

- If the local device receives a negative Configuration Response then it shall disconnect the channel.

An example of the algorithm for state 1 devices is as follows:

- The remote device proposes Basic L2CAP mode in a Configuration Request and the local device proposes Enhanced Retransmission mode or Streaming mode. The remote device rejects the local device's Configuration Request by sending a negative Configuration Response proposing Basic mode. The local device will send a second Configuration Request proposing Basic L2CAP mode or disconnect the channel. If the local device sends a second Configuration Request that does not propose Basic L2CAP mode then the remote device will disconnect the channel. If the local device rejects the remote device's Configuration Request then the remote device will disconnect the channel.

The algorithm for state 2 devices is as follows:

- If the local device proposes a mode in a Configuration Request and the remote device proposes a different mode or rejects the local device's Configuration Request then the local device shall disconnect the channel.

For Enhanced Retransmission mode and Streaming mode the Retransmission time-out and Monitor Time-out parameters of the Retransmission and Flow Control option parameters may be changed but all other parameters shall not be changed in a subsequent reconfiguration after the channel has reached the OPEN state.

5.5 FRAME CHECK SEQUENCE (FCS) OPTION

This option is used to specify the type of Frame Check Sequence (FCS) that will be included on S/I-frames that are sent. It is non-negotiable. The FCS option shall only be used when the mode is being, or is already configured to Enhanced Retransmission mode or Streaming mode. Note: The FCS option can be reconfigured only when the mode is Enhanced Retransmission mode or Streaming mode. Implementations may reconfigure the FCS when L2CAP channels are moved between Controllers. The Frame Check Sequence option is type 0x05. "No FCS" shall only be used if both L2CAP entities send the FCS Option with value 0x00 (No FCS) in a configuration request. If one L2CAP entity sends the FCS Option with "No FCS" in a configuration request and the other L2CAP sends the FCS Option with a value other than "No FCS" then the default shall be used. If one or both L2CAP entities do not send the FCS option in a configuration request then the default shall be used.

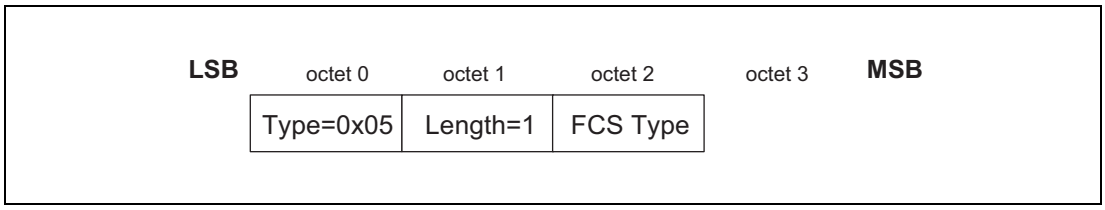


Figure 5.6: FCS option format

The FCS types are shown in Table 5.3

Value	Description
0x00	No FCS
0x01	16-bit FCS defined in section 3.3.5 (default)
Other	Reserved for Future Use

Table 5.3: FCS types

Value of 0x00 is set when the sender wishes to omit the FCS from S/I-frames.

This option shall only be sent if the peer L2CAP entity has indicated support for the FCS Option in the Extended Features Mask (see Section 4.12).

5.6 EXTENDED FLOW SPECIFICATION OPTION

This option specifies a flow specification for requesting a desired Quality of Service (QoS) on a channel. It is non-negotiable. The Extended Flow Specification shall be supported on all channels created over AMP-U logical links. Optionally, Extended Flow Specification may be supported on channels created over ACL-U logical links (see Section 7.10). If both devices show support for Extended Flow Specification for BR/EDR in the Extended Feature mask (see Table 4.12) then all channels created between the two devices shall use an Extended Flow Specification. The Quality of Service option and Flush Timeout option shall not be used if the Extended Flow Specification is used.

The parameters in the Extended Flow Specification option specify the traffic stream in the outgoing direction (transmitted traffic). Extended Flow Specification option is type 0x06.

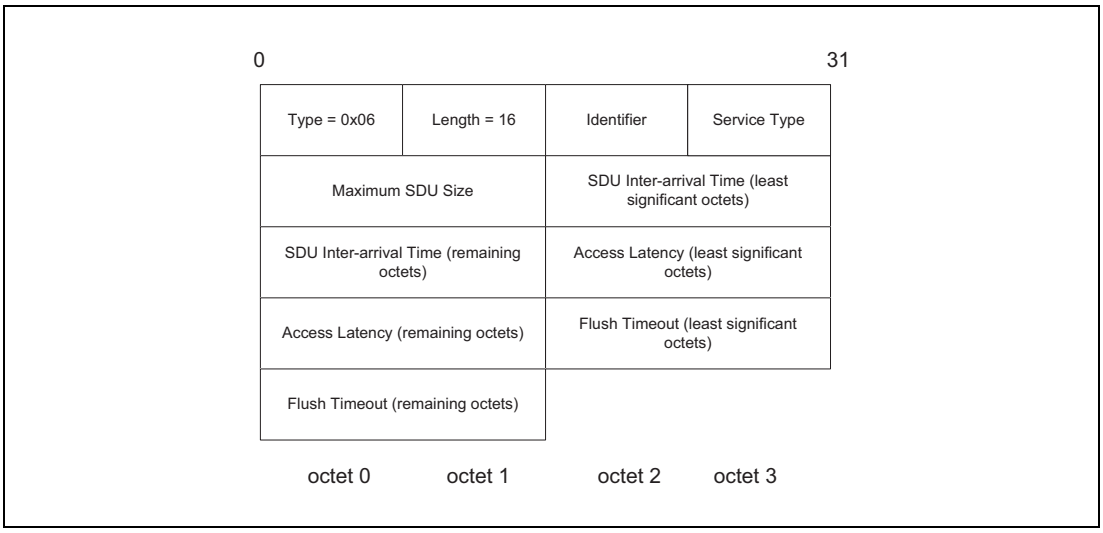


Figure 5.7: Extended Flow Specification option format

If no Extended Flow Specification is provided by the upper layer, an Extended Flow Specification with following default values shall be used:

Qos Parameter	Default Value
Identifier	0x01
Service Type	Best Effort
Maximum SDU size	0xFFFF
SDU Inter-arrival Time	0xFFFFFFFF
Access Latency	0xFFFFFFFF
Flush Timeout	0xFFFFFFFF

Table 5.4: Default Values for Extended Flow Specification

For a Best Effort channel no latency, air-time or bandwidth guarantees shall be assumed.

The parameters of the Extended Flow Specification are shown in Table 5.5:

QoS parameter	Parameter Size in Octets	Unit
Identifier	1	na
Service Type	1	na
Maximum SDU Size	2	octets
SDU Inter-arrival Time	4	microseconds

Table 5.5: Traffic parameters for L2CAP QoS configuration

QoS parameter	Parameter Size in Octets	Unit
Access Latency	4	microseconds
Flush Timeout	4	microseconds

Table 5.5: Traffic parameters for L2CAP QoS configuration

- *Identifer (1 octet)*

  This field provides a unique identifier for the flow specification. This identifier is used by some Controllers in the process of setting up the QoS request. Each active flow specification sent by a device to configure an L2CAP channel shall have a unique Identifier. An Identifier can be reused when the L2CAP channel associated with the flow spec is disconnected. The Identifier shall be unique within the scope of a physical link. Extended Flow Specifications for channels on different physical links may have the same Identifier. The Identifier for an Extended Flow Specification with Service Type Best Effort shall be 0x01.

  Note: Since the Identifier for an Extended Flow Specification with Service Type Best Effort is fixed to 0x01 it is possible to generate a Best Effort Extended Flow Specification for the remote device without performing the Lockstep Configuration process. (The Lockstep Configuration process is described in Section 7.1.3). This allows a Best Effort channel created over the ACL-U logical link without using the Lockstep configuration procedure to be moved to an AMP-U logical link. It is not possible to move a Guaranteed channel created over the ACL-U logical link to an AMP-U logical link unless the Lockstep configuration procedure is used during channel creation. This is because the Identifier for the remote device's Extended Flow Specification with Service Type Guaranteed is not known.

- *Service Type (1 octet)*

  This field indicates the level of service required. Table 5.6 defines the different Service Types values. The default value is 'Best effort'. If 'Best effort' is selected then Access Latency and Flush Timeout shall both be set to 0xFFFFFFFF. Maximum SDU size and SDU Inter-arrival Time are used to indicate the maximum data rate that the application can deliver to L2CAP for transmission. This is useful for high speed Controllers so they do not reserve more bandwidth than the application can deliver. The remote device should respond with lower settings indicating the maximum rate at which it can receive data (for example, maximum rate data it can write to a mass storage device, etc.). Values of 0xFFFF for Maximum SDU size and 0xFFFFFFFF for SDU Inter-arrival time are used when the actual values are not known. If Maximum SDU size is set to 0xFFFF then SDU Inter-arrival time shall be set to 0xFFFFFFFF, if SDU Inter-arrival time is set to 0xFFFFFFFF then Maximum SDU size shall be set to 0xFFFF. This tells the Controller to allocate as much bandwidth as possible.

If “Guaranteed” is selected the QoS parameters can be used to identify different types of Guaranteed traffic.

- **Guaranteed bandwidth** traffic is traffic with a minimum data rate but no particular latency requested. Latency will be related to the link supervision timeout. For this type of traffic Access Latency is set to 0xFFFFFFFF.
- **Guaranteed Latency** traffic is traffic with only latency requirements. For this type of traffic SDU Inter-arrival time is set to 0xFFFFFFFF. HID interrupt channel and AVRCP are examples of this type of traffic.
- **Both Guaranteed Latency and Bandwidth** traffic has both a latency and bandwidth requirement. An example is Audio/Video streaming.

If 'No Traffic' is selected the remainder of the fields shall be ignored because there is no data being sent across the channel in the outgoing direction.

Value	Description
0x00	No Traffic
0x01	Best effort (Default)
0x02	Guaranteed
Other	Reserved for Future Use

Table 5.6: Service Type definitions

A channel shall not be configured as “Best Effort” in one direction and “Guaranteed” in the other direction. If a channel is configured in this way it shall be disconnected. A channel may be configured as “No Traffic” in one direction and “Best Effort” in the other direction. The “No Traffic” refers to the application traffic not the Enhanced Retransmission mode supervisory traffic. A channel configured in this way is considered to have a service type of Best Effort. A channel may be configured as “No Traffic” in one direction and “Guaranteed” in the other direction. A channel configure in this way is considered to have a service type of Guaranteed.

Once configured the service type of a channel shall not be changed during reconfiguration.

- *Maximum SDU Size (2 octets)*

  The Maximum SDU Size parameter specifies the maximum size of the SDUs transmitted by the application. If the Service Type is “Guaranteed” then traffic submitted to L2CAP with a larger size is considered non-conformant. QoS guarantees are only provided for conformant traffic.

- *SDU Inter-arrival time (4 octets)*

  The SDU Inter-arrival time parameter specifies the time between consecutive SDUs generated by the application. For streaming traffic, SDU Inter-arrival time should be set to the average time between SDUs. For variable rate traffic and best effort traffic, SDU Inter-arrival time should be set to the minimum time between SDUs. If the Service Type is “Guaranteed”

then traffic submitted to L2CAP with a smaller interval, is considered non-conformant. QoS guarantees are only provided for conformant traffic.

- *Access Latency (4 octets)*

  The Access Latency parameter specifies the maximum delay between consecutive transmission opportunities on the air-interface for the connection. Note that access latency is based on the time base of the Controller, which may or may not be synchronous to the time base being used by the Host or the application.

  For streaming traffic (for example, A2DP), the Access Latency should be set to indicate the time budgeted for transmission of the data over the air, and would normally be roughly equal to the Flush Timeout minus the duration of streaming data which can be stored in the receive side application buffers.

  For non-streaming, bursty traffic (i.e. HID and AVRCP), the Access Latency parameter value sent in the L2CAP Configuration Request should be set to the desired latency, minus any HCI transport delays and any other stack delays that may be expected on the device and on target Host systems. The remote device receiving the L2CAP Configuration Request may send an Access Latency parameter value in the L2CAP Configuration Response which is equal to or lower than the value it received. The remote device may send a lower value to account for other traffic it may be carrying, or overhead activities it may be carrying out.

  If HCI is used then the Host should take into account the latency of the HCI transport when determining the value for the Access Latency. For example if the application requires an Access Latency of 20ms and the HCI transport has a latency of 5 ms then the value for Access Latency should be 15ms.

- *Flush Timeout (4 Octets)*

  The Flush Timeout defines a maximum period after which all segments of the SDU are flushed from L2CAP and the Controller. A Flush Timeout value of 0xFFFFFFFF indicates that data will not be discarded by the transmitting side, even if the link becomes congested. Note that in this case data is treated as reliable, and is never flushed. The device receiving the L2CAP Configuration Request with Flush Timeout set to 0xFFFFFFFF should not modify this parameter. The Flush Timeout for a “Best Effort” channel shall be set to 0xFFFFFFFF.

  However, if the Traffic Type is “Guaranteed” and the transmit side buffer is limited, then the Flush Timeout parameter given in the L2CAP Configuration Request may be set to a value corresponding to the duration of streaming data which the transmit buffer can hold before it must begin discarding data. The side receiving the L2CAP Configuration Request may then set the Flush Timeout parameter in the L2CAP Configuration Response to a lower value if the receive side buffer is smaller than the transmit side buffer. Note that the total available buffer space is typically a combination of application buffers, any buffers maintained by the L2CAP implementation, and HCI buffers provided by the Controller.

  The Flush Timeout should normally be set to a value which is larger than the Access Latency, and which also accounts for buffers maintained by the application on the receive side such as de-jitter buffers used in audio and video streaming applications. In general, the Flush Timeout value should be selected to ensure that the Flush Timeout expires when the application buffers are about to be exhausted.

  Flush Timeout may be set to 0x00000000 to indicate that no retransmissions are to occur. Data may be flushed immediately after transmission in this case. This behavior is useful in applications such as gaming where the tolerable latency is on the order of a few milliseconds, and hence the information contained in a packet will become stale very rapidly. In such applications, it is preferable to send “fresher” data if the last SDU submitted for transmission was not transmitted as a result of interference.

5.7 EXTENDED WINDOW SIZE OPTION

This option is used to negotiate the maximum extended window size. The Extended Window Size option is type 0x07 and is non-negotiable.

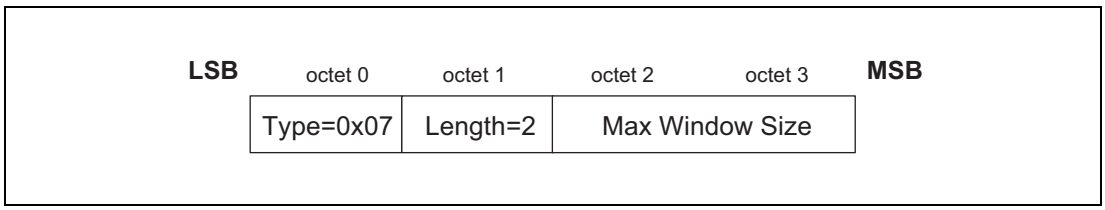


Figure 5.8: Extended Window Size option format

The allowable values for the Maximum Extended Window Size are:

Value	Description
0x0000	Invalid value for Enhanced Retransmission mode Valid for Streaming mode
0x0001 - 0x3FFF	Valid maximum window size (frames) for Enhanced Retransmission mode. Invalid for Streaming mode
Other	Reserved for Future Use

Table 5.7: Extended Window Size values

This option shall only be sent if the peer L2CAP entity has indicated support for the Extended Window size feature in the Extended Features Mask (see Section 4.12).

This option shall be ignored if the channel is configured to use Basic L2CAP Mode (see Section 5.4).

For Enhanced Retransmission mode, this option has the same directional semantics as the Retransmission and Flow Control option (see Section 5.4). The sender of a Configuration Request command containing this option is suggesting the maximum window size (possibly based on its own internal L2CAP receive buffer resources) that the peer L2CAP entity should use when sending data.

For Streaming mode, this option is used to enable use of the Extended Control Field and if sent, shall have a value of 0.

If this option is successfully configured then the Maximum Window Size negotiated using the Retransmission and Flow Control option (see Section 5.4) shall be ignored.

If this option is successfully configured in either direction then both L2CAP entities shall use the Extended Control Fields in all S/I-frames (see Section 3.3.2).

If the option is only configured in one direction then the maximum window size for the opposite direction shall be taken from the maximum window size value in the existing Retransmission and Flow Control option. In this configuration both L2CAP entities shall use the extended control fields in all S/I-frames.

6 STATE MACHINE

This section is informative. The state machine does not necessarily represent all possible scenarios.

6.1 GENERAL RULES FOR THE STATE MACHINE:

- It is implementation specific, and outside the scope of this specification, how the transmissions are triggered.
- “Ignore” means that the signal can be silently discarded.

The following states have been defined to clarify the protocol; the actual number of states and naming in a given implementation is outside the scope of this specification:

- CLOSED – channel not connected.
- WAIT_CONNECT – a connection request has been received, but only a connection response with indication “pending” can be sent.
- WAIT_CONNECT_RSP – a connection request has been sent, pending a positive connect response.
- CONFIG – the different options are being negotiated for both sides; this state comprises a number of substates, see Section 6.1.3
- OPEN – user data transfer state.
- WAIT_DISCONNECT – a disconnect request has been sent, pending a disconnect response.
- WAIT_CREATE – a channel creation request has been received, but only a response with indication “pending” can be sent. This state is similar to WAIT_CONNECT.
- WAIT_CREATE_RSP – a channel creation request has been sent, pending a channel creation response. This state is similar to WAIT_CONNECT_RSP.
- WAIT_MOVE – a request to move the current channel to another Controller has been received, but only a response with indication “pending” can be sent.
- WAIT_MOVE_RSP – a request to move a channel to another Controller has been sent, pending a move response
- WAIT_MOVE_CONFIRM – a response to the move channel request has been sent, waiting for a confirmation of the move operation by the initiator side
- WAIT_CONFIRM_RSP – a move channel confirm has been sent, waiting for a move channel confirm response.

In the following state tables and descriptions, the L2CAP_Data message corresponds to one of the PDU formats used on connection-oriented data channels as described in section 3, including PDUs containing B-frames, I-frames, S-frames.

Some state transitions and actions are triggered only by internal events effecting one of the L2CAP entity implementations, not by preceding L2CAP signaling messages. It is implementation-specific and out of the scope of this specification, how these internal events are realized; just for the clarity of specifying the state machine, the following abstract internal events are used in the state event tables, as far as needed:

- *OpenChannel_Req* – a local L2CAP entity is requested to set up a new connection-oriented channel.
- *OpenChannel_Rsp* – a local L2CAP entity is requested to finally accept or refuse a pending connection request.
- *ConfigureChannel_Req* – a local L2CAP entity is requested to initiate an outgoing configuration request.
- *CloseChannel_Req* – a local L2CAP entity is requesed to close a channel.
- *SendData_Req* – a local L2CAP entity is requested to transmit an SDU.
- *ReconfigureChannel_Req* – a local L2CAP entity is requested to reconfigure the parameters of a connection-oriented channel.
- *OpenChannelCntrl_Req* – a local L2CAP entity is requested to set up a new connection over a Controller identified by a Controller ID.
- *OpenChannelCntrl_Rsp* – a local L2CAP entity is requested to internally accept or refuse a pending connection over a Controller identified by a Controller ID.
- *MoveChannel_Req* – a local L2CAP entity is requested to move the current channel to another Controller.
- *ControllerLogicalLinkInd* – a Controller indicates the acceptance or rejection of a logical link request with an Extended Flow Specification.

There is a single state machine for each L2CAP connection-oriented channel that is active. A state machine is created for each new L2CAP_ConnectReq received. The state machine always starts in the CLOSED state.

To simplify the state event tables, the RTX and ERTX timers, as well as the handling of request retransmissions are described in Section 6.1.7 and not included in the state tables.

L2CAP messages not bound to a specific data channel and thus not impacting a channel state (e.g. L2CAP_InformationReq, L2CAP_EchoReq) are not covered in this section.

The following states and transitions are illustrated in Figure 6.1.

6.1.1 CLOSED state

Event	Condition	Action	Next State
OpenChannel_req	-	Send L2CAP_ ConnectReq	WAIT_ CONNECT_RSP
L2CAP_ConnectReq	Normal, connection is possible	Send L2CAP_ ConnectRsp (success)	CONFIG (substate WAIT_CONFIG)
L2CAP_ConnectReq	Need to indicate pending	Send L2CAP_ ConnectRsp (pending)	WAIT_CONNECT
L2CAP_ConnectReq	No resource, not approved, etc.	Send L2CAP_ ConnectRsp (refused)	CLOSED
L2CAP_ConnectRsp	-	Ignore	CLOSED
L2CAP_ConfigReq	-	Send L2CAP_ CommandReject (with reason Invalid CID)	CLOSED
L2CAP_ConfigRsp	-	Ignore	CLOSED
L2CAP_ DisconnectReq	-	Send L2CAP_ DisconnectRsp	CLOSED
L2CAP_DisconnectRsp	-	Ignore	CLOSED
L2CAP_Data	-	Ignore	CLOSED
OpenChannelCntrl_ Req		Send L2CAP_ CreateChanReq	WAIT_ CREATE_RSP
L2CAP_ CreateChanReq	Normal, connection is possible	Send L2CAP_CreateChanRsp (success)	CONFIG
L2CAP_ CreateChanReq	Need to indicate pending	Send L2CAP_CreateChanRsp (pending)	WAIT_CREATE
L2CAP_ CreateChanReq	No resource, not approved	Send L2CAP_CreateChanRsp (refused)	CLOSED
L2CAP_ CreateChanRsp		Ignore	CLOSED
L2CAP_MoveChanReq		Ignore	CLOSED
L2CAP_MoveChanRsp		Ignore	CLOSED
L2CAP_ MoveChanConfirm		Ignore	CLOSED
L2CAP_ MoveChanConfirmRsp		Ignore	CLOSED

Table 6.1: CLOSED state event table

Notes. The L2CAP_ConnectReq message is not mentioned in any of the other states apart from the CLOSED state, as it triggers the establishment of a new channel, thus the branch into a new instance of the state machine.

6.1.2 WAIT_CONNECT_RSP state

Event	Condition	Action	Next State
L2CAP_ConnectRsp	Success indicated in result	Send L2CAP_ConfigReq	CONFIG (substate WAIT_CONFIG)
L2CAP_ConnectRsp	Result pending	-	WAIT_CONNECT_RSP
L2CAP_ConnectRsp	Remote side refuses connection	-	CLOSED
L2CAP_ConfigReq	-	Send L2CAP_CommandReject (with reason Invalid CID)	WAIT_CONNECT_RSP
L2CAP_ConfigRsp	-	Ignore	WAIT_CONNECT_RSP
L2CAP_DisconnectRsp	-	Ignore	WAIT_CONNECT_RSP
L2CAP_Data	-	Ignore	WAIT_CONNECT_RSP
L2CAP_CreateChanReq		Ignore	WAIT_CONNECT_RSP
L2CAP_CreateChanRsp		Ignore	WAIT_CONNECT_RSP
L2CAP_MoveChanReq		Ignore	WAIT_CONNECT_RSP
L2CAP_MoveChanRsp		Ignore	WAIT_CONNECT_RSP
L2CAP_MoveChanConfirm		Ignore	WAIT_CONNECT_RSP
L2CAP_MoveChanConfirmRsp		Ignore	WAIT_CONNECT_RSP

Table 6.2: WAIT_CONNECT_RSP state event table

Notes. An L2CAP_DisconnectReq message is not included here, since the Source and Destination CIDs are not available yet to relate it correctly to the state machine of a specific channel.

6.1.3 WAIT_CONNECT state

Event	Condition	Action	Next State
OpenChannel_Rsp	Pending connection request is finally acceptable	Send L2CAP_Connect_Rsp (success)	CONFIG (substate WAIT_CONFIG)
OpenChannel_Rsp	Pending connection request is finally refused	Send L2CAP_Connect_Rsp (refused)	CLOSED
L2CAP_ConnectRsp	-	Ignore	WAIT_CONNECT
L2CAP_ConfigRsp	-	Ignore	WAIT_CONNECT
L2CAP_DisconnectRsp	-	Ignore	WAIT_CONNECT
L2CAP_Data	-	Ignore	WAIT_CONNECT
L2CAP_ CreateChanReq		Ignore	WAIT_CONNECT
L2CAP_ CreateChanRsp		Ignore	WAIT_CONNECT
L2CAP_MoveChanReq		Ignore	WAIT_CONNECT
L2CAP_MoveChanRsp		Ignore	WAIT_CONNECT
L2CAP_ MoveChanConfirm		Ignore	WAIT_CONNECT
L2CAP_ MoveChanConfirmRsp		Ignore	WAIT_CONNECT

Table 6.3: WAIT_CONNECT state event table

Notes. An L2CAP_DisconnectReq or L2CAP_ConfigReq message is not included here, since the Source and Destination CIDs are not available yet to relate it correctly to the state machine of a specific channel.

6.1.4 CONFIG state

Two configuration processes exist as described in Section 7.1. The configuration processes are the Standard process and the Lockstep process.

In the Standard and Lockstep configuration processes both L2CAP entities initiate a configuration request during the configuration process. This means that each device adopts an initiator role for the outgoing configuration request, and an acceptor role for the incoming configuration request. Configurations in both directions may occur sequentially, but can also occur in parallel.

In the Lockstep configuration process both L2CAP entities send Configuration Request packets and receive Configuration Response packets with a pending result code before submitting the flow specifications to their local Controllers. A final Configuration Response packet is sent by each L2CAP entity indicating the response from its local Controller.

The following substates are distinguished within the CONFIG state:

- WAIT_CONFIG – a device has sent or received a connection response, but has neither initiated a configuration request yet, nor received a configuration request with acceptable parameters.
- WAIT_SEND_CONFIG – for the initiator path, a configuration request has not yet been initiated, while for the response path, a request with acceptable options has been received.
- WAIT_CONFIG_REQ_RSP – for the initiator path, a request has been sent but a positive response has not yet been received, and for the acceptor path, a request with acceptable options has not yet been received.
- WAIT_CONFIG_RSP – the acceptor path is complete after having responded to acceptable options, but for the initiator path, a positive response on the recent request has not yet been received.
- WAIT_CONFIG_REQ – the initiator path is complete after having received a positive response, but for the acceptor path, a request with acceptable options has not yet been received.
- WAIT_IND_FINAL_RSP – for both the initiator and acceptor, the Extended Flow Specification has been sent to the local Controller but neither a response from Controller nor the final configuration response has yet been received.
- WAIT_FINAL_RSP – the device received an indication from the Controller accepting the Extended Flow Specification and has sent a positive response. It is waiting for the remote device to send a configuration response.
- WAIT_CONTROL_IND – the device has received a positive response and is waiting for its Controller to accept or reject the Extended Flow Specification.

According to Section 6.1.1 and Section 6.1.2, the CONFIG state is entered via WAIT_CONFIG substate from either the CLOSED state, the WAIT_CONNECT state, or the WAIT_CONNECT_RSP state. The CONFIG state is left for the OPEN state if both the initiator and acceptor paths complete successfully.

For better overview, separate tables are given: Table 6.4 shows the success transitions; therein, transitions on one of the minimum paths (no previous non-success transitions) are shaded. Table 6.5 shows the non-success transitions within the configuration process, and Table 6.6 shows further transition cause by events not belonging to the configuration process itself. The following configuration states and transitions are illustrated in Figure 6.2.

Previous state	Event	Condition	Action	Next State
WAIT_CONFIG	*ConfigureChannel_Req*	Standard process	Send L2CAP_ConfigReq	WAIT_CONFIG_REQ_RSP
WAIT_CONFIG	*ConfigureChannel_Req*	Lockstep process	Send L2CAP_Config Req (Ext Flow Spec plus other options)	WAIT_CONFIG_REQ_RSP
WAIT_CONFIG	L2CAP_ConfigReq	Options acceptable Standard process	Send L2CAP_ConfigRsp (success)	WAIT_SEND_CONFIG
WAIT_CONFIG	L2CAP_ConfigReq	Options acceptable Lockstep process	Send L2CAP_ConfigRsp (pending)	WAIT_SEND_CONFIG
WAIT_CONFIG_REQ_RSP	L2CAP_ConfigReq	Options acceptable	Send L2CAP_ConfigRsp (success)	WAIT_CONFIG_RSP
WAIT_CONFIG_REQ_RSP	L2CAP_ConfigRsp	Remote side accepts options	(continue waiting for configuration request)	WAIT_CONFIG_REQ
WAIT_CONFIG_REQ	L2CAP_ConfigReq	Options acceptable Standard process	Send L2CAP_ConfigRsp (success)	OPEN
WAIT_CONFIG_REQ	L2CAP_ConfigReq	Options acceptable Lockstep process	Send L2CAP_ConfigRsp (pending)	WAIT_IND_FINAL_RSP
WAIT_SEND_CONFIG	*ConfigureChannel_Req*	-	Send L2CAP_ConfigReq	WAIT_CONFIG_RSP
WAIT_CONFIG_RSP	L2CAP_ConfigRsp	Remote side accepts options Standard process	-	OPEN

Table 6.4: CONFIG state event table

Previous state	Event	Condition	Action	Next State
WAIT_CONFIG_RSP	L2CAP_ConfigRsp	Remote side accepts option Lockstep proc		WAIT_IND_FINAL_RSP
WAIT_IND_FINAL_RSP	ControllerLogicalLinkInd	Reject	Send L2CAP_ConfigRsp (fail)	WAIT_CONFIG
WAIT_IND_FINAL_RSP	ControllerLogicalLinkInd	Accept	Send L2CAP_ConfigRsp (success)	WAIT_FINAL_RSP
WAIT_IND_FINAL_RSP	L2CAP_ConfigRsp	Remote side fail		WAIT_CONFIG
WAIT_IND_FINAL_RSP	L2CAP_ConfigRsp	Remote side success		WAIT_CONTROL_IND
WAIT_FINAL_RSP	L2CAP_ConfigRsp	Remote side fail		WAIT_CONFIG
WAIT_FINAL_RSP	L2CAP_ConfigRsp	Remote side success		OPEN
WAIT_CONTROL_IND	ControllerLogicalLinkInd	Reject	Send L2CAP_ConfigRsp (fail)	WAIT_CONFIG
WAIT_CONTROL_IND	ControllerLogicalLinkInd	Accept	Send L2CAP_ConfigRsp (success)	OPEN

Table 6.4: CONFIG state event table (Continued)

Previous state	Event	Condition	Action	Next State
WAIT_CONFIG	L2CAP_ConfigReq	Options not acceptable	Send L2CAP_ConfigRsp (fail)	WAIT_CONFIG
WAIT_CONFIG	L2CAP_ConfigRsp	-	Ignore	WAIT_CONFIG
WAIT_SEND_CONFIG	L2CAP_ConfigRsp	-	Ignore	WAIT_SEND_CONFIG
WAIT_CONFIG_REQ_RSP	L2CAP_ConfigReq	Options not acceptable	Send L2CAP_ConfigRsp (fail)	WAIT_CONFIG_REQ_RSP
WAIT_CONFIG_REQ_RSP	L2CAP_ConfigRsp	Remote side rejects options	Send L2CAP_ConfigReq (new options)	WAIT_CONFIG_REQ_RSP
WAIT_CONFIG_REQ	L2CAP_ConfigReq	Options not acceptable	Send L2CAP_ConfigRsp (fail)	WAIT_CONFIG_REQ
WAIT_CONFIG_REQ	L2CAP_ConfigRsp	-	Ignore	WAIT_CONFIG_REQ
WAIT_CONFIG_RSP	L2CAP_ConfigRsp	Remote side rejects options	Send L2CAP_ConfigReq (new options)	WAIT_CONFIG_RSP

Table 6.5: CONFIG state/substates event table: non-success transitions within configuration process

Previous state	Event	Condition	Action	Next State
CONFIG (any substate)	*CloseChannel_Req*	Any internal reason to stop	Send L2CAP_Disconnect Req	WAIT_DISCONNECT
CONFIG (any substate)	L2CAP_DisconnectReq	-	Send L2CAP_Disconnect Rsp	CLOSED
CONFIG (any substate)	L2CAP_DisconnectRsp	-	Ignore	CONFIG (remain in substate)
CONFIG (any substate)	L2CAP_Data	-	Process the PDU	CONFIG (remain in substate)

Table 6.6: CONFIG state/substates event table: events not related to configuration process

Previous state	Event	Condition	Action	Next State
CONFIG (any substate)	L2CAP_ CreateChanReq		Ignore	CONFIG (remain in sub-state)
CONFIG (any substate)	L2CAP_ CreateChanRsp		Ignore	CONFIG (remain in sub-state)
CONFIG (any substate)	L2CAP_ MoveChanReq		Ignore	CONFIG (remain in sub-state)
CONFIG (any substate)	L2CAP_ MoveChanRsp		Ignore	CONFIG (remain in sub-state)
CONFIG (any substate)	L2CAP_ MoveChanConfirm		Ignore	CONFIG (remain in sub-state)
CONFIG (any substate)	L2CAP_ MoveChanCon-firmRsp		Ignore	CONFIG (remain in sub-state)

Table 6.6: CONFIG state/substates event table: events not related to configuration process

Notes:

- Receiving data PDUs (L2CAP_Data) in CONFIG state should be relevant only in case of a transition to a reconfiguration procedure (from OPEN state). Discarding the received data is allowed only in Retransmission Mode and Enhanced Retransmission Mode. Discarding an S-frame is allowed but not recommended. If a S-frame is discarded, the monitor timer will cause a new S-frame to be sent after a time out.
- Indicating a failure in a configuration response does not necessarily imply a failure of the overall configuration procedure; instead, based on the information received in the negative response, a modified configuration request may be triggered.

6.1.5 OPEN state

Event	Condition	Action	Next State
SendData_req	-	Send L2CAP_Data packet according to configured mode	OPEN
ReconfigureChannel_Req	-	Complete outgoing SDU Send L2CAP_ConfigReq	CONFIG (substate WAIT_CONFIG_REQ_RSP)
CloseChannel_Req	-	Send L2CAP_DisconnectReq	WAIT_DISCONNECT
L2CAP_ConnectRsp	-	Ignore	OPEN
L2CAP_ConfigReq	Incoming config options acceptable	Complete outgoing SDU Send L2CAP_ConfigRsp (ok)	CONFIG (substate WAIT_SEND_CONFIG)
L2CAP_ConfigReq	Incoming config options not acceptable	Complete outgoing SDU Send L2CAP_ConfigRsp (fail)	OPEN
L2CAP_DisconnectReq	-	Send L2CAP_DisconnectRsp	CLOSED
L2CAP_DisconnectRsp	-	Ignore	OPEN
L2CAP_Data	-	Process the PDU	OPEN
MoveChannel_Req		Send L2CAP_MoveChanReq	WAIT_MOVE_RSP
L2CAP_CreateChanReq		Ignore	OPEN
L2CAP_CreateChanRsp		Ignore	OPEN
L2CAP_MoveChanReq	Logical Link create/modify is not needed	Send L2CAP_MoveChanRsp (success)	WAIT_MOVE_CONFIRM
L2CAP_MoveChanReq	Need to indicate pending (logical link create/modify is needed)	Send L2CAP_MoveChanRsp (pending)	WAIT_MOVE
L2CAP_MoveChanReq	No resource, not approved	Send L2CAP_MoveChanRsp (refused)	WAIT_MOVE_CONFIRM
L2CAP_MoveChanRsp		Ignore	OPEN

Table 6.7: OPEN state event table

Event	Condition	Action	Next State
L2CAP_ MoveChanConfirm		Ignore	OPEN
L2CAP_ MoveChanConfirmRsp		Ignore	OPEN

Table 6.7: OPEN state event table

Note: The outgoing SDU shall be completed from the view of the remote entity. Therefore all PDUs forming the SDU shall have been reliably transmitted by the local entity and acknowledged by the remote entity, before entering the configuration state.

6.1.6 WAIT_DISCONNECT state

Event	Condition	Action	Next State
L2CAP_ConnectRsp	-	Ignore	WAIT_DISCONNECT
L2CAP_ConfigReq	-	Send L2CAP_ CommandReject with reason Invalid CID	WAIT_DISCONNECT
L2CAP_ConfigRsp	-	Ignore	WAIT_DISCONNECT
L2CAP_DisconnectReq	-	Send L2CAP_ DisconnectRsp	CLOSED
L2CAP_DisconnectRsp	-	-	CLOSED
L2CAP_Data	-	Ignore	WAIT_DISCONNECT
L2CAP_ CreateChanReq		Ignore	WAIT_DISCONNECT
L2CAP_ CreateChanRsp		Ignore	WAIT_DISCONNECT
L2CAP_MoveChanReq		Ignore	WAIT_DISCONNECT
L2CAP_MoveChanRsp		Ignore	WAIT_DISCONNECT
L2CAP_ MoveChanConfirm		Ignore	WAIT_DISCONNECT
L2CAP_ MoveChanConfirmRsp		Ignore	WAIT_DISCONNECT

Table 6.8: WAIT_DISCONNECT state event table

6.1.7 WAIT_CREATE_RSP state

Event	Condition	Action	Next State
L2CAP_CreateChanReq		Ignore	WAIT_CREATE_RSP
L2CAP_CreateChanRsp	Success indicated in result	Send L2CAP_ConfigReq	CONFIG (substate WAIT_CONFIG)
L2CAP_CreateChanRsp	Result pending		WAIT_CREATE_RSP
L2CAP_CreateChanRsp	Remote side refuses connection		CLOSED
L2CAP_MoveChanReq		Ignore	WAIT_CREATE_RSP
L2CAP_MoveChanRsp		Ignore	WAIT_CREATE_RSP
L2CAP_MoveChanConfirm		Ignore	WAIT_CREATE_RSP
L2CAP_ MoveChanConfirmRsp		Ignore	WAIT_CREATE_RSP

Table 6.9: WAIT_CREATE_RSP state event table

6.1.8 WAIT_CREATE state

Event	Condition	Action	Next State
OpenChannelCntrl_Req	-	Ignore	WAIT_CREATE
OpenChannelCntrl_Rsp	Pending connection request is finally acceptable	Send L2CAP_ CreateChanRsp (success)	CONFIG
OpenChannelCntrl_Rsp	Pending connection request is finally refused	Send L2CAP_ CreateChanRsp (refused)	CLOSED
L2CAP_CreateChanReq	-	Ignore	WAIT_CREATE
L2CAP_CreateChanRsp	-	Ignore	WAIT_CREATE
L2CAP_MoveChanReq	-	Ignore	WAIT_CREATE
L2CAP_MoveChanRsp	-	Ignore	WAIT_CREATE
L2CAP_ MoveChanConfirm	-	Ignore	WAIT_CREATE
L2CAP_ MoveChanConfirmRsp	-	Ignore	WAIT_CREATE

Table 6.10: WAIT_CREATE state event table

6.1.9 WAIT_MOVE_RSP state

Event	Condition	Action	Next State
L2CAP_MoveChanReq	Prioritization algorithm (remain initiator)	Send L2CAP_MoveChanRsp (collision)	WAIT_MOVE_RSP
L2CAP_MoveChanReq	Prioritization algorithm (become responder) and logical link create/modify is needed)	Send L2CAP_MoveChanRsp (pending)	WAIT_MOVE
L2CAP_MoveChanReq	Prioritization algorithm (become responder) and logical link create/modify is not needed)	Send L2CAP_MoveChanRsp (success)	WAIT_MOVE_CONFIRM
L2CAP_CreateChanRsp	-	Ignore	WAIT_MOVE_RSP
L2CAP_CreateChanReq	-	Ignore	WAIT_MOVE_RSP
L2CAP_MoveChanRsp	Result pending	-	WAIT_MOVE_RSP
L2CAP_MoveChanRsp	Remote side refuses move and/or local side refuses move (create/modify logical link fails)	Send L2CAP_MoveChanConfirm (failure)	WAIT_CONFIRM_RSP
L2CAP_MoveChanRsp	Both remote side and local side accepts move (create/modify logical link succeeds)	Send L2CAP_MoveChanConfirm (success)	WAIT_CONFIRM_RSP
L2CAP_MoveChanConfirm	-	Ignore	WAIT_MOVE_RSP
L2CAP_MoveChanConfirmRsp	-	Ignore	WAIT_MOVE_RSP

Table 6.11: WAIT_MOVE_RSP state event table

6.1.10 WAIT_MOVE state

Event	Condition	Action	Next State
ControllerLogicalLinkInd	Create/modify logical link completed successfully	Send L2CAP_MoveChanRsp (success)	WAIT_MOVE_CONFIRM
ControllerLogicalLinkInd	Create/modify logical link completed with failure	Send L2CAP_MoveChanRsp (refused)	WAIT_MOVE_CONFIRM
L2CAP_CreateChanReq	-	Ignore	WAIT_MOVE
L2CAP_CreateChanRsp	-	Ignore	WAIT_MOVE
L2CAP_MoveChanReq	-	Ignore	WAIT_MOVE
L2CAP_MoveChanRsp	-	Ignore	WAIT_MOVE
L2CAP_MoveChanConfirm	-	Ignore	WAIT_MOVE
L2CAP_MoveChanConfirmRsp	-	Ignore	WAIT_MOVE

Table 6.12: WAIT_MOVE state event table

6.1.11 WAIT_MOVE_CONFIRM state

Event	Condition	Action	Next State
L2CAP_CreateChanReq	-	Ignore	WAIT_MOVE_CONFIRM
L2CAP_CreateChanRsp	-	Ignore	WAIT_MOVE_CONFIRM
L2CAP_MoveChanReq	-	Ignore	WAIT_MOVE_CONFIRM
L2CAP_MoveChanRsp	-	Ignore	WAIT_MOVE_CONFIRM
L2CAP_MoveChanConfirm	Result of move is success	Send L2CAP_MoveChanConfirmRsp	OPEN (on new Controller)
L2CAP_MoveChanConfirm	Result of move is failure	Send L2CAP_MoveChanConfirmRsp	OPEN (on old Controller)
L2CAP_MoveChanConfirmRsp	-	Ignore	WAIT_MOVE_CONFIRM

Table 6.13: WAIT_MOVE_CONFIRM state event table

6.1.12 WAIT_CONFIRM_RSP state

Event	Condition	Action	Next State
L2CAP_CreateChanReq	-	Ignore	WAIT_CONFIRM_RSP
L2CAP_CreateChanRsp	-	Ignore	WAIT_CONFIRM_RSP
L2CAP_MoveChanReq	-	Ignore	WAIT_CONFIRM_RSP
L2CAP_MoveChanRsp	-	Ignore	WAIT_CONFIRM_RSP
L2CAP_MoveChanConfirm	-	Ignore	WAIT_CONFIRM_RSP
L2CAP_ MoveChanConfirmRsp	Move succeeded		OPEN (on new Controller)
L2CAP_ MoveChanConfirmRsp	Move failed		OPEN (on old Controller)

Table 6.14: WAIT_CONFIRM_RSP state event table

6.2 TIMERS EVENTS

6.2.1 RTX

The Response Timeout eXpired (RTX) timer is used to terminate the channel when the remote endpoint is unresponsive to signaling requests. This timer is started when a signaling request (see Section 7) is sent to the remote device. This timer is disabled when the response is received. If the initial timer expires, a duplicate Request message may be sent or the channel identified in the request may be disconnected. If a duplicate Request message is sent, the RTX timeout value shall be reset to a new value at least double the previous value. When retransmitting the Request message, the context of the same state shall be assumed as with the original transmission. If a Request message is received that is identified as a duplicate (retransmission), it shall be processed in the context of the same state which applied when the original Request message was received.

Implementations have the responsibility to decide on the maximum number of Request retransmissions performed at the L2CAP level before terminating the channel identified by the Requests. The exception is fixed channel CIDs since they can never be terminated. The LE Peripheral may disconnect the link on the expiry of the RTX timer. The decision should be based on the flush timeout of the signaling link. The longer the flush timeout, the more retransmissions may be performed at the physical layer and the reliability of the channel improves, requiring fewer retransmissions at the L2CAP level.

For example, if the flush timeout is infinite, no retransmissions should be performed at the L2CAP level. When terminating the channel, it is not necessary to send a L2CAP_DisconnectReq and enter WAIT_DISCONNECT state. Channels can be transitioned directly to the CLOSED state.

The value of this timer is implementation-dependent but the minimum initial value is 1 second and the maximum initial value is 60 seconds. One RTX timer shall exist for each outstanding signaling request, including each Echo Request. The timer disappears on the final expiration, when the response is received, or the physical link is lost. The maximum elapsed time between the initial start of this timer and the initiation of channel termination (if no response is received) is 60 seconds.

6.2.2 ERTX

The Extended Response Timeout eXpired (ERTX) timer is used in place of the RTX timer when it is suspected the remote endpoint is performing additional processing of a request signal. This timer is started when the remote endpoint responds that a request is pending, e.g., when an L2CAP_ConnectRsp event with a “connect pending” result (0x0001) is received. This timer is disabled when the formal response is received or the physical link is lost. If the initial timer expires, a duplicate Request may be sent or the channel may be disconnected.

If a duplicate Request is sent, the particular ERTX timer disappears, replaced by a new RTX timer and the whole timing procedure restarts as described previously for the RTX timer.

The value of this timer is implementation-dependent but the minimum initial value is 60 seconds and the maximum initial value is 300 seconds. Similar to RTX, there MUST be at least one ERTX timer for each outstanding request that received a Pending response. There should be at most one (RTX or ERTX) associated with each outstanding request. The maximum elapsed time between the initial start of this timer and the initiation of channel termination (if no response is received) is 300 seconds. When terminating the channel, it is not necessary to send a L2CAP_DisconnectReq and enter WAIT_DISCONNECT state. Channels should be transitioned directly to the CLOSED state.

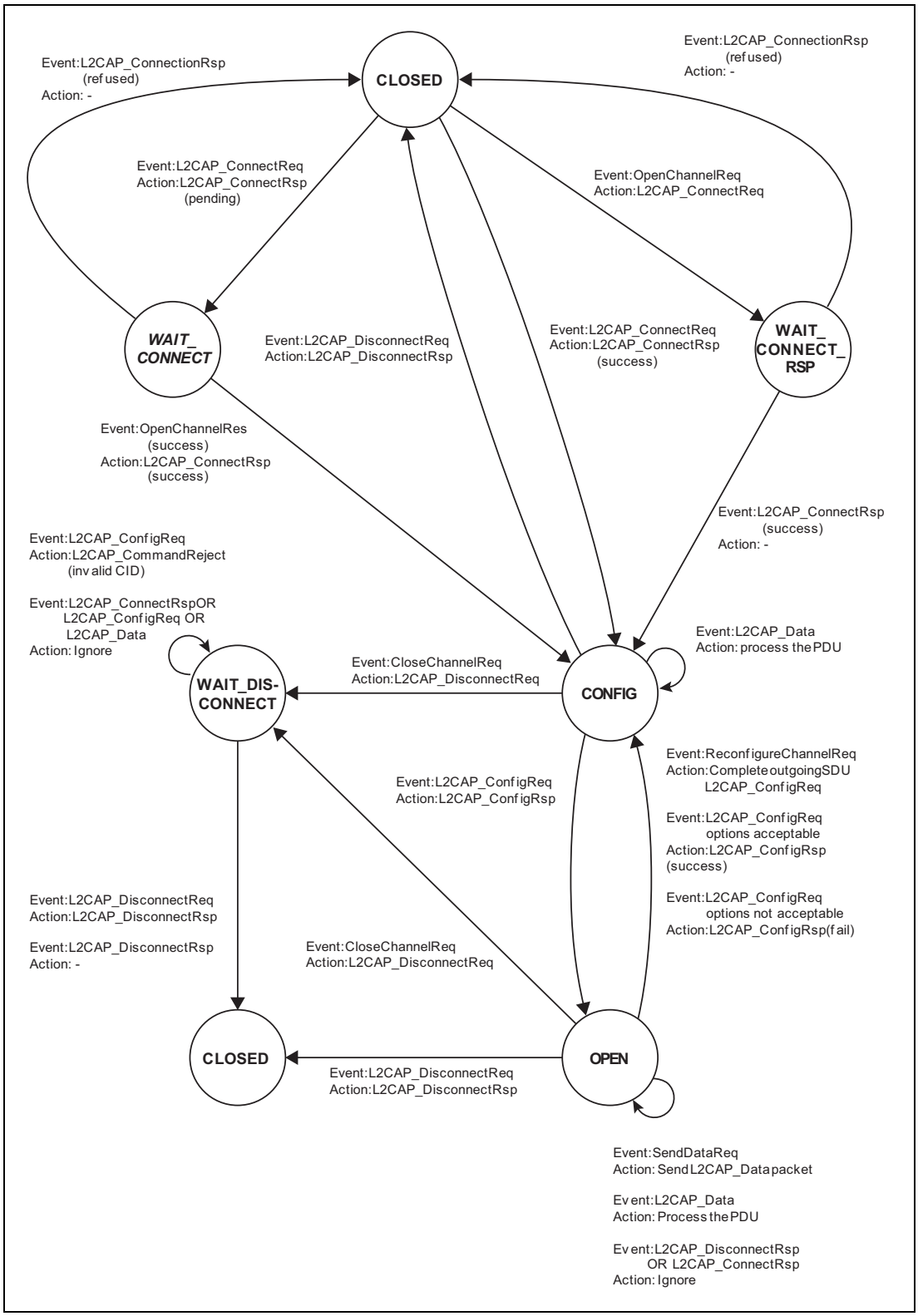


Figure 6.1: States and transitions

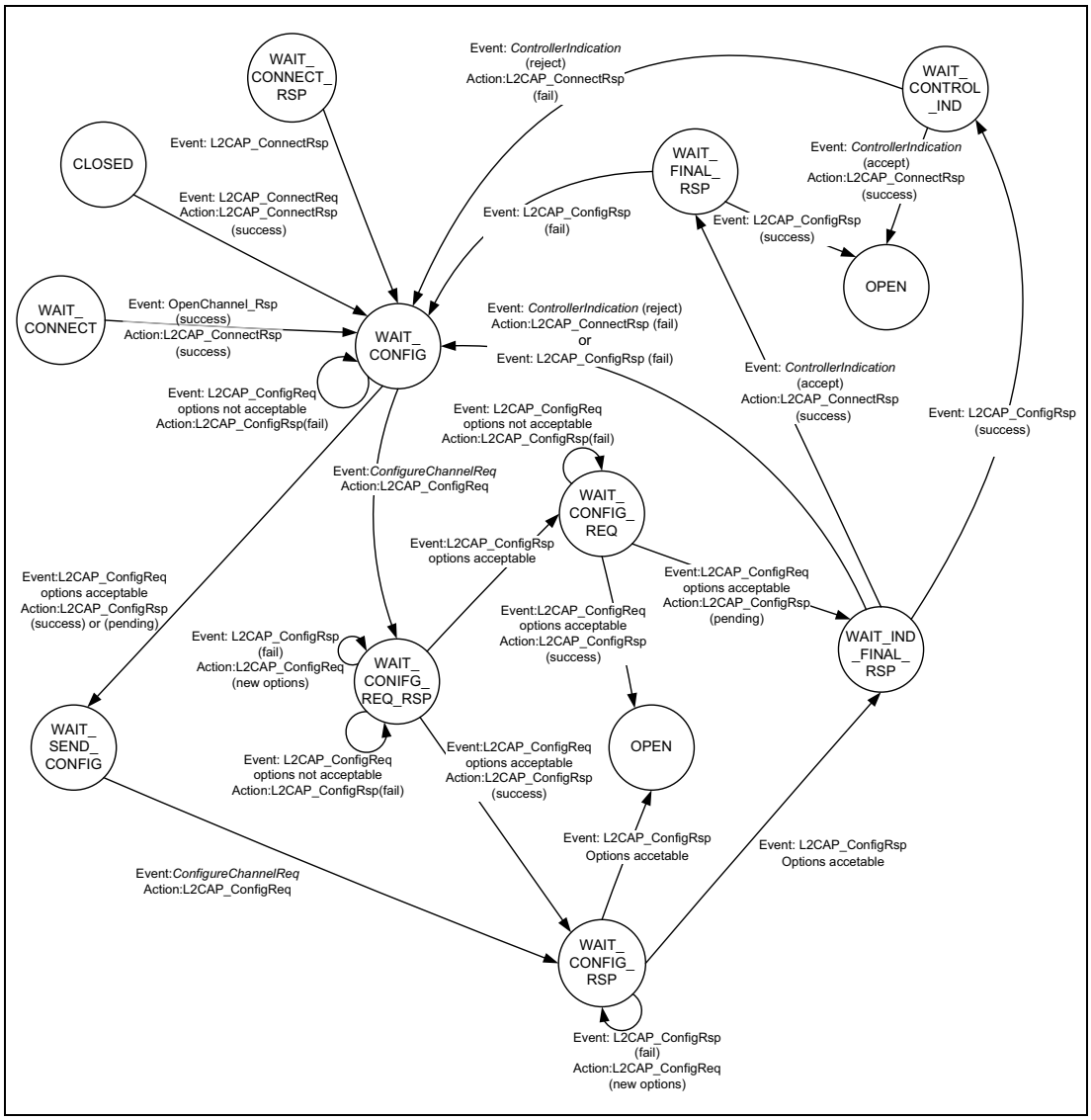


Figure 6.2: Configuration states and transitions

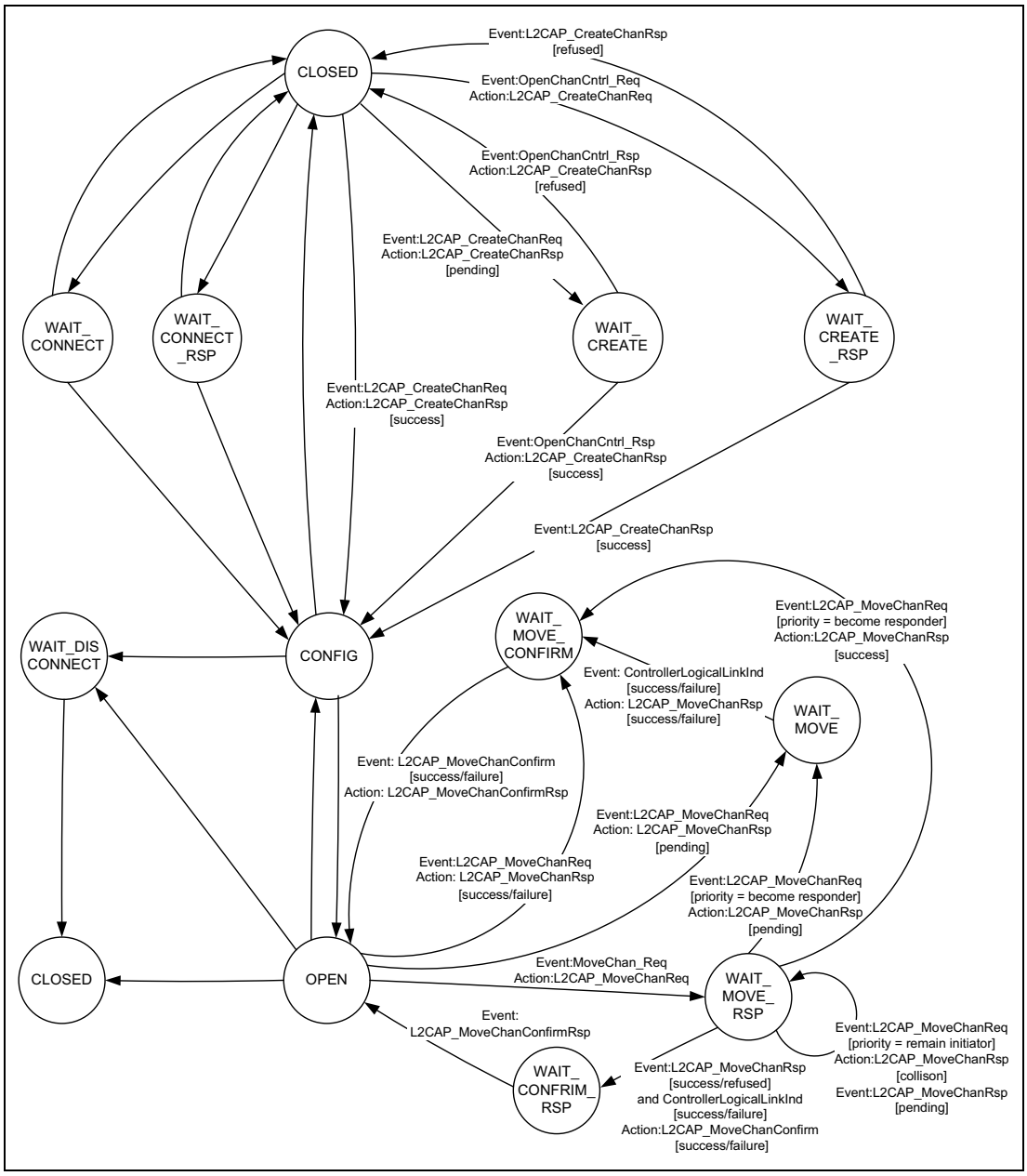


Figure 6.3: States and transitions–AMP enabled operation

Figure 6.3 is based on Figure 6.1. Only the new transitions show event/action labels. Transitions without labels are the same as in Figure 6.1.

7 GENERAL PROCEDURES

This section describes the general operation of L2CAP, including the configuration process, the handling and the processing of user data for transportation over the air interface. This section also describes the operation of L2CAP features including the delivery of erroneous packets, the flushing of expired data and operation in connectionless mode, operation collision resolution, aggregation of best effort flow specifications, and prioritizing data over HCI.

Procedures for the flow control and retransmission modes are described in Section 8.

7.1 CONFIGURATION PROCESS

Configuration consists of two processes, the Standard process and the Lockstep process. The Lockstep process shall be used if both L2CAP entities support the Extended Flow Specification option otherwise the Standard process shall be used.

For both processes, configuring the channel parameters shall be done independently for both directions. Both configurations may be done in parallel.

Each configuration parameter is one-directional. The configuration parameters describe the non default parameters the device sending a Configuration Request will accept. The configuration request cannot request a change in the parameters the device receiving the request will accept.

If a device needs to establish the value of a configuration parameter the remote device will accept, then it must wait for a configuration request containing that configuration parameter to be sent from the remote device.

The Lockstep process is used when the channel parameters include an Extended Flow Specification option. The Lockstep process can be divided into two phases. In the first phase, each L2CAP entity shall receive an Extended Flow Specification option along with all non-default parameters from its peer L2CAP entity and then present the pair of Extended Flow specifications (local and remote) to its local Controller. In the second phase, each L2CAP entity shall report the result from its local Controller to the peer L2CAP entity. The Lockstep process is described in Section 7.1.3. The Standard process is described in Section 7.1.4.

Both the Lockstep and Standard processes can be abstracted into the initial Request configuration path and a Response configuration path, followed by the reverse direction phase. Reconfiguration follows a similar two-phase process by requiring configuration in both directions.

During a reconfiguration session, all data traffic on the channel should be suspended pending the outcome of the configuration. If an L2CAP entity receives a Configuration Request while it is waiting for a response it shall not block sending the Configuration Response, otherwise the configuration process may deadlock.

7.1.1 Request Path

The Request Path can configure the following:

- requester's incoming MTU
- requester's outgoing flush timeout
- requester's outgoing QoS
- requester's incoming and outgoing flow and error control information
- requester's incoming and outgoing Frame Check Sequence option
- requester's outgoing QoS using Extended Flow Specification option
- requester's incoming Extended Window size option plus incoming and outgoing frame format.

Table 7.1 defines the configuration options that may be placed in a Configuration Request.

Parameter	Description
MTU	Incoming MTU information
FlushTO	Outgoing flush timeout[1]
QoS	Outgoing QoS information[1]
RFCMode	Incoming and outgoing Retransmission and Flow Control Mode
FCS	Incoming and outgoing Frame Check Sequence
ExtFlowSpec	Outgoing QoS information[1]
ExtWindow	Incoming Extended Window size plus incoming and outgoing frame format

Table 7.1: Parameters allowed in Request

1. FlushTO, QoS and ExtFlowSpec are considered QoS information. ExtFlowSpec is used instead of FlushTO and QoS when both devices support ExtFlowSpec.

The state machine for the configuration process is described in Section 6.

7.1.2 Response Path

The Response Path can configure the following:

- responder’s outgoing MTU, that is the remote side’s incoming MTU
- remote side’s flush timeout
- responder’s incoming QoS Flow Specification (remote side’s outgoing QoS Flow Specification)
- responder’s incoming and outgoing Flow and Error Control information
- responder's incoming QoS Extended Flow Specification (remote side's outgoing QoS Flow Specification)
- responder's outgoing Extended Window size.

For the Standard process, if a request-oriented parameter is not present in the Request message (reverts to last agreed value), the remote side may negotiate for a non-default value by including the proposed value in a negative Response message. Table 7.2 defines the configuration options that may be placed in a Configuration Response.

Parameter	Description
MTU	Outgoing MTU information
FlushTO	Incoming flush timeout [1]
QoS	Incoming QoS information[1]
RFCMode	Incoming and outgoing Retransmission and Flow Control Mode
ExtFlowSpec	Incoming QoS information[1]
ExtWindow	Outgoing Extended Window size

Table 7.2: Parameters allowed in Response

1. FlushTO, QoS and ExtFlowSpec are considered QoS information. ExtFlowSpec is used instead of FlushTO and QoS when both devices support ExtFLowSpec

7.1.3 Lockstep Configuration Process

Configuration Request packets are sent to establish or change the channel parameters including the QoS contract between two L2CAP entities. An Extended Flow Specification option along with any non-default parameters shall be sent in a Configuration Request following the sending or receipt of a Connect Response which accepts an L2CAP Connect Request for the channel being configured. Unlike the Standard process, negotiation involving the sending of multiple Configuration Request packets shall not be performed. In other words, only one Configuration Request packet shall be sent by each L2CAP entity during the Lockstep configuration process. The Lockstep process shall only be

used during channel reconfiguration when an Extended Flow Specification option is present in the Configuration Request packet used for reconfiguration.

The Extended Flow Specification shall be sent for all channels created on AMP-U logical links and shall only be sent for channels created on the ACL-U logical link if both the local and remote L2CAP entities have indicated support for the Extended Flow Specification for BR/EDR in their Extended Features masks. The Extended Features mask shall be obtained via the L2CAP Information Request/Response signaling mechanism (InfoType = 0x0002) prior to the issuance of the L2CAP Configuration Request. If a Configuration Request is sent containing the Extended Flow Specification option then the Quality of Service option and Flush Timeout option shall not be included.

Configuration Response packets shall be sent in reply to Configuration Request packets except when the error condition is covered by a Command Reject response. Although the L2CAP Configuration signaling mechanism allows for the use of wildcards, wildcard values are not supported in the Extended Flow Specification since each parameter represents a property of the traffic in one direction only, and no negotiation is intended to be performed at the L2CAP Configuration level.

The recipient of a Configuration Request shall perform all necessary checks with the Controller to validate that the requested QoS can be granted. In the case of a BR/EDR or BR/EDR/LE Controller the L2CAP layer performs the Controller checks. If HCI is used then the L2CAP entity should check that the requested QoS can be achieved over the HCI transport. In order to perform these checks, the recipient needs to have the QoS parameters for both directions. In order for each side to determine when to perform relevant Controller checks, each side will reply with a result “Pending” (0x0004). If no parameters are sent in the Configuration Response packet with result “Pending” then the parameters sent in the Configuration Request have been accepted without change. This Lockstep procedure results in both L2CAP entities performing the following:

- Receiving a Configuration Request containing the Extended Flow Specification option along with all non-default parameters
- Sending a Configuration Response with any modifications to the Extended Flow Specification option and allowed modifications to non-default parameters (result “Pending”)
- Sending a Configuration Request containing the Extended Flow Specification option along with all non-default parameters
- Receiving a Configuration Response containing any modifications to the Extended Flow Specification option and allowed modifications to non-default parameters (result “Pending”).

The ERTX timer is used when a Configuration Response is received with result “Pending” (see Section 6.2.2).

If a Configuration Response with result “success” is received before a Configuration Response with result “pending” is received the recipient shall disconnect the channel. This is a violation of the Lockstep configuration process.

If a device sends an Extended Flow Specification option in a Configuration Request with service type “Best Effort” and receives a Configuration Request with service type “Guaranteed,” the channel shall be disconnected. If a device sends an Extended Flow Specification in a Configuration Request with type “Guaranteed” and receives a Configuration Request with service type “Best Effort,” the channel shall be disconnected.

If the service type is “Best Effort” then values for certain parameters may be sent in a Configuration Response with result “Pending” to indicate the maximum bandwidth the sender of the Configuration Response is capable to receive. The values sent in a Configuration Response with result “Pending” and service type Best Effort shall be in accordance with Table 7.3.

Parameter	Changes permitted by responder
Maximum SDU Size	May decrease only
SDU Inter-arrival Time	May increase only
Access Latency	None
Flush Timeout	None

Table 7.3: Permitted parameter in L2CAP Configuration Response for Service Type “Best Effort”

After the Configuration Response is received with result “Pending,” L2CAP may issue the necessary checks with the Controller.

If the Controller cannot support the Extended Flow Specifications with service type “Guaranteed,” then the recipient of the Configuration Request shall send a Configuration Response indicating a result code of “Failure - flow spec rejected” (0x0005). If the Controller indicates that it can support the Extended Flow Specifications, then the recipient of the Configuration Request shall send a Configuration Response with result code of “Success” (0x0000) with no parameters.

If the Result of the Configuration Response is Failure (0x0005) for service type “Guaranteed” then an Extended Flow Specification option may be sent in the Configuration Response. The Extended Flow Specification parameters sent in the Configuration Response may be changed to reflect a QoS level that would be acceptable, but shall only be changed in accordance with Table 7.4.

If an L2CAP Configuration Response is received containing the Extended Flow Specification option with the same values sent earlier, the upper layer shall be notified of the error.

Parameter	Changes permitted by responder
Maximum SDU Size	None
SDU Inter-arrival Time	None
Access Latency	May decrease only
Flush Timeout	May decrease only (unless set to 0xFFFFFFFF, in which case no change is permitted)

Table 7.4: Permitted parameter changes in L2CAP Configuration Response for Service Type "Guaranteed"

7.1.4 Standard Configuration Process

For the Standard process the following general procedure shall be used for each direction:

1. Local device informs the remote device of the parameters that the local device will accept using a Configuration Request.
2. Remote device responds, agreeing or disagreeing with these values, including the default ones, using a Configuration Response.
3. The local and remote devices repeat steps (1) and (2) until agreement on all parameters is reached.

The decision on the amount of time (or messages) spent configuring the channel parameters before terminating the configuration is left to the implementation, but it shall not last more than 120 seconds.

There are two types of configuration parameters: negotiable and non-negotiable.

Negotiable parameters are those that a remote side receiving a Configuration Request can disagree with by sending a Configuration Response with the Unacceptable Parameters (0x0001) result code, proposing new values that can be accepted. Non-negotiable parameters are only informational and the recipient of a Configuration Request cannot disagree with them but can provide adjustments to the values in a positive Configuration Response. Section 5 identifies each parameter as negotiable or non-negotiable. Note: MTU is non-negotiable but can be rejected if a value lower than the mandated minimum is proposed (See Section 5.1).

The following rules shall be used for parameter negotiation in the Request Path:

1. An L2CAP entity shall send at least one Configuration Request packet as part of initial configuration or reconfiguration. If all default or previously agreed values are acceptable, a Configuration Request packet with no options shall be sent.
2. When an L2CAP entity receives a positive Configuration Response from the remote device it shall consider all configuration parameters explicitly

contained in the Configuration Request along with the default and previously agreed values not explicitly contained in the Configuration Request as accepted by the remote device.

3. When an L2CAP entity receives a negative Configuration Response and sends a new Configuration Request it shall include all the options it sent in the previous Configuration Request with the same values except the negotiable options that were explicitly rejected in the negative Configuration Response which will have new values. Note: The resending of all the options provides backwards compatibility with remote implementations that don't assume rule 4 when responding.
4. Negotiable options not included in a negative Configuration Response are considered accepted by the remote device. Note: For backwards compatibility if non-negotiable options are included in a negative Configuration Response, they should be processed as if the response was positive.

The following rules shall be used for parameter negotiation in the Response Path:

1. A positive Configuration Response accepts the values of all configuration parameters explicitly contained in the received Configuration Request and the default and previously agreed values not explicitly provided.
2. An L2CAP Entity shall send a negative Configuration Response to reject negotiable parameter values that are unacceptable, be it values explicitly provided in the received Configuration Request or previously agreed or default values. The rejected parameters sent in a negative Configuration Response shall have values that are acceptable to the L2CAP entity sending the negative Configuration Response.
3. All negotiable options being rejected shall be rejected in the same negative Configuration Response.
4. The only options allowed in a negative Configuration Response are the negotiable options being rejected. No wildcards or adjustments to non-negotiable options shall be in a negative Configuration Response.
5. Negotiable options not included in the negative Configuration Response are considered accepted.

7.2 FRAGMENTATION AND RECOMBINATION

Fragmentation is the breaking down of PDUs into smaller pieces for delivery from L2CAP to the lower layer. Recombination is the process of reassembling a PDU from fragments delivered up from the lower layer. Fragmentation and Recombination may be applied to any L2CAP PDUs.

7.2.1 Fragmentation of L2CAP PDUs

An L2CAP implementation may fragment any L2CAP PDU for delivery to the lower layers. If L2CAP runs directly over the Controller without HCI, then an implementation may fragment the PDU into multiple Controller packets for transmission over the air. If L2CAP runs above the HCI, then an implementation may send HCI transport sized fragments to the Controller. All L2CAP fragments associated with an L2CAP PDU shall be processed for transmission by the Controller before any other L2CAP PDU for the same logical transport shall be processed.

For example, in the BR/EDR Controller the two LLID bits defined in the first octet of baseband payload (also called the frame header) are used to signal the start and continuation of L2CAP PDUs. LLID shall be 10b for the first segment in an L2CAP PDU and 01b for a continuation segment. An illustration of fragmentation for a BR/EDR Controller is shown in Figure 7.1. An example of how fragmentation might be used in a device with HCI is shown in Figure 7.2.

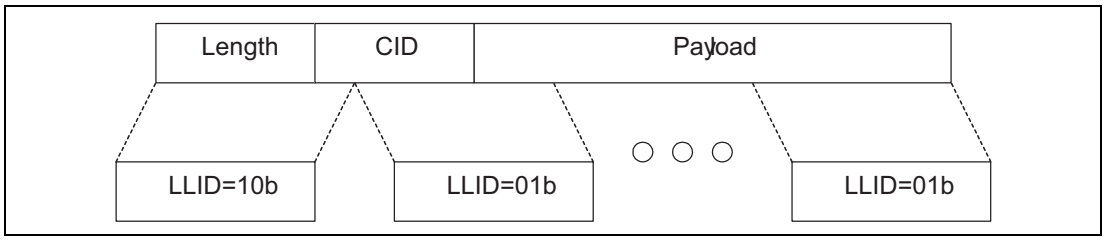


Figure 7.1: L2CAP fragmentation in a BR/EDR Controller

Note: The BR/EDR Link Controller is able to impose a different fragmentation on the PDU by using “start” and “continuation” indications as fragments are translated into baseband packets. Thus, both L2CAP and the BR/EDR Link Controller use the same mechanism to control the size of fragments.

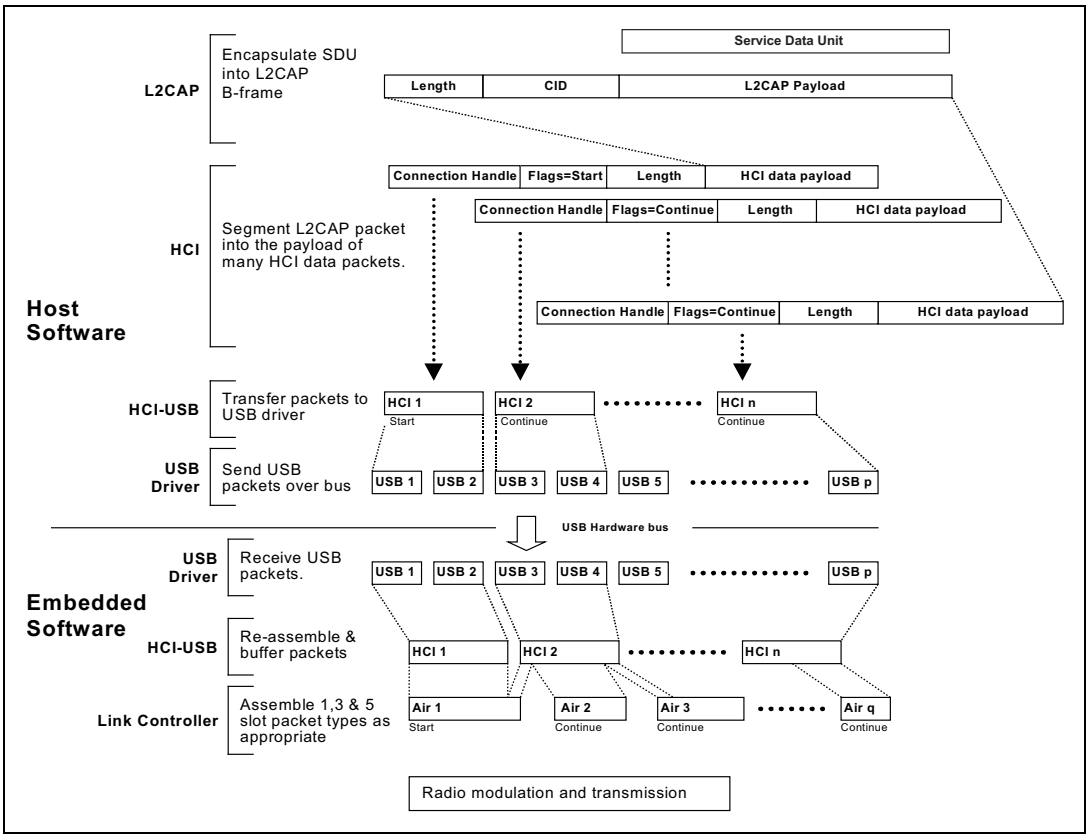


Figure 7.2: Example of fragmentation processes in a device with a BR/EDR Controller and USB HCI transport

7.2.2 Recombination of L2CAP PDUs

Controllers will attempt to deliver packets in sequence and without errors. Recombination of fragments may occur in the Controller but ultimately it is the responsibility of L2CAP to reassemble PDUs and SDUs and to check the length field of the SDUs. As the Controller receives packet fragments, it either signals the L2CAP layer on the arrival of each fragment, or accumulates a number of fragments (before the receive buffer fills up or a timer expires) before passing packets to the L2CAP layer.

An L2CAP implementation shall use the length field in the header of L2CAP PDUs, see Section 3, as a consistency check and shall discard any L2CAP PDUs that fail to match the length field. If channel reliability is not needed, packets with invalid lengths may be silently discarded. For reliable channels using Basic mode, an L2CAP implementation shall indicate to the upper layer that the channel has become unreliable. Reliable channels are defined by having an infinite flush timeout value as specified in Section 5.2. For higher data integrity L2CAP should be operated in the Enhanced Retransmission Mode.

7.3 ENCAPSULATION OF SDUs

All SDUs are encapsulated into one or more L2CAP PDUs.

In Basic L2CAP mode, an SDU shall be encapsulated with a minimum of L2CAP protocol elements, resulting in a type of L2CAP PDU called a Basic Information Frame (B-frame).

Segmentation and Reassembly operations are only used in Enhanced Retransmission mode, Streaming mode, Retransmission mode, and Flow Control mode. SDUs may be segmented into a number of smaller packets called SDU segments. Each segment shall be encapsulated with L2CAP protocol elements resulting in an L2CAP PDU called an Information Frame (I-frame).

The maximum size of an SDU segment shall be given by the Maximum PDU Payload Size (MPS). The MPS parameter may be exported using an implementation specific interface to the upper layer.

Note that this specification does not have a normative service interface with the upper layer, nor does it assume any specific buffer management scheme of a Host implementation. Consequently, a reassembly buffer may be part of the upper layer entity. It is assumed that SDU boundaries shall be preserved between peer upper layer entities.

7.3.1 Segmentation of L2CAP SDUs

In Flow Control, Streaming, or Retransmission modes, incoming SDUs may be broken down into segments, which shall then be individually encapsulated with L2CAP protocol elements (header and checksum fields) to form I-frames. I-frames are subject to flow control and may be subject to retransmission procedures. The header carries a 2 bit SAR field that is used to identify whether the I-frame is a 'start', 'end' or 'continuation' packet or whether it carries a complete, unsegmented SDU. Figure 7.3 illustrates segmentation and fragmentation.

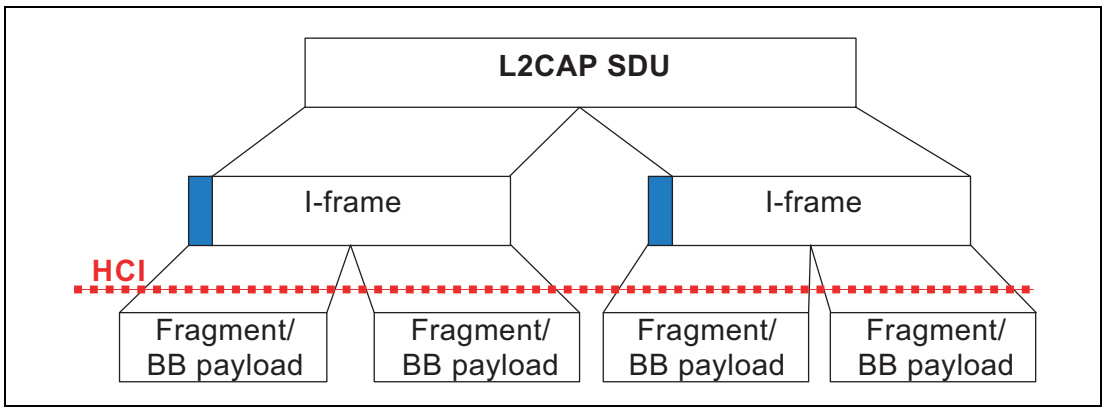


Figure 7.3: Segmentation and fragmentation of an SDU in a BR/EDR Controller

7.3.2 Reassembly of L2CAP SDUs

The receiving side uses the SAR field of incoming 'I-frames' for the reassembly process. The L2CAP SDU length field, present in the “start of SDU” I-frame, is an extra integrity check, and together with the sequence numbers may be used to indicate lost L2CAP SDUs to the application. Figure 7.3 illustrates segmentation and fragmentation.

7.3.3 Segmentation and fragmentation

Figure 7.4 illustrates the use of segmentation and fragmentation operations to transmit a single SDU. Note that while SDUs and L2CAP PDUs are transported in peer-to-peer fashion, the fragment size used by the Fragmentation and Recombination routines is implementation specific and may be different in the sender and the receiver. The over-the-air sequence of packet fragments as created by the sender is common to both devices.

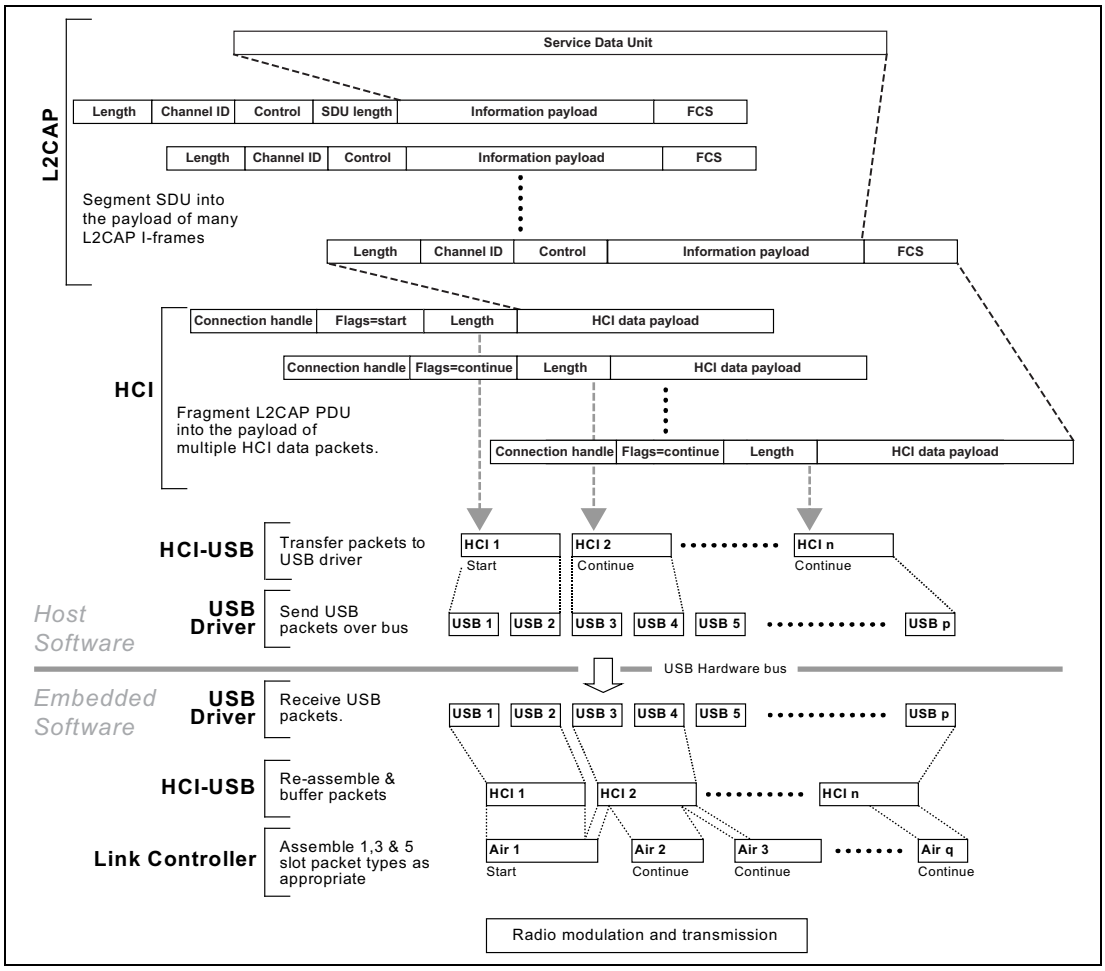


Figure 7.4: Example of segmentation and fragment processes in a device with a BR/EDR Controller and USB HCI Transport[1]

1. For simplicity, the stripping of any additional HCI and USB specific information fields prior to the creation of the baseband packets (Air_1, Air_2, etc.) is not shown in the figure.

7.4 DELIVERY OF ERRONEOUS L2CAP SDUS

Some applications may require corrupted or incomplete L2CAP SDUs to be delivered to the upper layer. If delivery of erroneous L2CAP SDUs is enabled, the receiving side will pass information to the upper layer on which parts of the L2CAP SDU (i.e., which L2CAP frames) have been lost, failed the error check, or passed the error check. If delivery of erroneous L2CAP SDUs is disabled, the receiver shall discard any L2CAP SDU segment with any missing frames or any frames failing the error checks. L2CAP SDUs whose length field does not match the actual frame length shall also be discarded.

7.5 OPERATION WITH FLUSHING ON ACL-U LOGICAL LINKS

In the L2CAP configuration using either the Flush Timeout option or the Extended Flow Specification option, the Flush timeout may be set separately per L2CAP channel, but in the BR/EDR baseband, the flush mechanisms operate per ACL logical transport.

When there is more than one L2CAP channel mapped to the same ACL logical transport, the automatic flush time-out does not discriminate between L2CAP channels. The automatic flush time-out also applies to unicast data sent via the L2CAP connectionless channel. The exception is packets marked as non-automatically-flushable via the Packet_Boundary_Flag in the HCI ACL Data Packet (see Section 1.1). The automatic flush time-out flushes a specific automatically-flushable L2CAP PDU. The HCI Flush command flushes all outstanding L2CAP PDUs for the ACL logical transport including L2CAP PDUs marked as non-automatically-flushable. Therefore, care has to be taken when using the Automatic Flush Time-out and the HCI Flush command. The HCI Enhanced Flush command should be used instead.

All packets associated with a reliable connection shall be marked as non-automatically-flushable (if it is mapped to an ACL logical transport with a finite automatic flush time-out) or L2CAP Enhanced Retransmission mode or Retransmission mode shall be used. In Enhanced Retransmission mode or Retransmission mode, loss of flushed L2CAP PDUs on the channel is detected by the L2CAP ARQ mechanism and they are retransmitted. Note that L2CAP Enhanced Retransmission mode or Retransmission mode might be used for other purposes such as the need for a residual error rate that is much smaller than the baseband can deliver. In this situation L2CAP Enhanced Retransmission mode or Retransmission mode and the Non-Flushable Packet Boundary Flag feature can be used at the same time.

If it is desired to send unicast data via the L2CAP connectionless channel which is not subject to automatic flushing, then the data should be marked as non-automatically flushable if it is mapped to an ACL logical transport with a finite automatic flush time-out. Unicast data sent via the L2CAP connectionless channel may be marked flushable.

There is only one automatic flush time-out setting per ACL logical transport. Therefore, all time bounded L2CAP channels on an ACL logical transport with an automatic flush time-out setting should configure the same flush time-out value at the L2CAP level. The flush time-out setting for the ACL logical transport also applies to unicast data sent via the L2CAP connectionless channel which are marked flushable.

If Automatic Flush Time-out is used, then it should be taken into account that it only flushes one L2CAP PDU. If one PDU has timed out and needs flushing, then other automatically-flushable packets on the same logical transport are also likely to need flushing. Therefore, flushing can be handled by the HCI Enhanced Flush command so that all outstanding automatically-flushable L2CAP PDUs are flushed.

When both reliable and isochronous data is to be sent over the same ACL logical transport, an infinite Automatic Flush Time-out can be used. In this case the isochronous data is flushed using the HCI Enhanced Flush command with Packet_Type set to “Automatically-Flushable Only,” thus preserving the reliable data.

7.6 CONNECTIONLESS DATA CHANNEL

In addition to connection-oriented channels, L2CAP also provides a connectionless channel. Data sent on the connectionless channel shall only be sent over the BR/EDR radio. The connectionless channel allows broadcast transmissions from the master device to all members of the piconet or unicast transmissions from either a master or slave to a single remote device. Data sent through the connectionless channel is sent in a best-effort manner. The connectionless channel provided by L2CAP has no quality of service.

While L2CAP itself does not provide retransmission for data sent via the connectionless channel, the baseband does provide an ARQ scheme for unicast data (see [Vol 2] Part B, Section 7.6). If a higher degree of reliability is desired for unicast data sent via the connectionless L2CAP channel than is provided by the baseband ARQ scheme then an ARQ scheme should be implemented at a higher layer.

No acknowledgment is provided by the baseband for broadcast transmissions and hence broadcast transmissions sent via the connectionless L2CAP channel are unreliable and hence might or might not reach each member of the piconet.

The receiving L2CAP entity may silently discard data received via the connectionless L2CAP channel if the data packet is addressed to a PSM and no application is registered to receive data on that PSM.

Note that L2CAP does not provide flow control for either connection-oriented L2CAP channels operating in Basic mode or for traffic on the connectionless L2CAP channel. Hence if data received by L2CAP is not accepted by the target

applications in a timely manner, congestion can occur in a receiving L2CAP implementation. For connection-oriented channels, the receiving L2CAP entity may elect to close a channel if the target application for that channel does not accept the data in a timely manner. Since this option is not available for unicast data received via the connectionless L2CAP channel, the receiving L2CAP entity may instead elect to de-register the application receiving the data or to disconnect the underlying physical link. An application shall be notified if it is de-registered. If the underlying physical link is disconnected then all applications utilizing that physical link shall be notified.

Unicast data shall only be sent via the connectionless L2CAP channel to a remote device if the remote device indicates support for Unicast Connectionless Data Reception in the L2CAP Extended Features Mask.[1] The L2CAP Extended Features Mask should be retrieved using the L2CAP Information Request signal to determine if Unicast Connectionless Data Reception is supported. Optionally, support for Unicast Connectionless Data Reception can be inferred from information obtained via a SDP or EIR. For example, if a service is found via SDP or EIR that is known to mandate the support of UCD, then it may be assumed that the device indicating support for the service supports Unicast Connectionless Data Reception.

Unicast data sent via the L2CAP connectionless channel are subject to automatic flushing and hence the packet boundary flags should be set appropriately if the Controller supports the Packet Boundary Flag feature. See Section 7.5 for further details. Since the receiving L2CAP entity has no mechanism to enable it to know whether received packets were originally marked as flushable or non-flushable on the transmitting device, the receiving L2CAP entity should treat all unicast packets received via the connectionless L2CAP packet as non-flushable.

If encryption is required for a given profile, then the profile or application shall ensure that authentication is performed and encryption is enabled prior to sending any unicast data on the connectionless L2CAP channel by utilizing Security Mode 4 as defined in GAP ([Vol 3] Part C, Section 5.2.2). There is no mechanism provided in this specification to prevent reception of unencrypted data on the connectionless L2CAP channel. An application which requires received data to be encrypted should ignore any unencrypted data it may receive over the connectionless channel.

Broadcast transmissions to the connectionless channel are sent with the broadcast LT_ADDR and hence may be received by any of the slaves in the piconet. If it is desirable to restrict the reception of the transmitted data to only a subset of the slaves in the piconet, then higher level encryption may be used to support private communication.

1. Note that the Unicast Connectionless Data Reception bit in the L2CAP Extended Features Mask does not in any way indicate support or lack of support for reception of broadcast data on the connectionless L2CAP channel even though both broadcast data and unicast data are sent and received using the same CID (0x0002). For historical reasons, there is no bit to indicate support for sending or receiving of broadcast data on the connectionless L2CAP channel.

The master will not receive transmissions broadcast on the connectionless channel. Therefore, higher layer protocols must loopback any broadcast data traffic being sent to the master device if required.

The connectionless data channel shall not be used with Enhanced Retransmission mode, Retransmission Mode or Flow Control Mode.

7.7 OPERATION COLLISION RESOLUTION

When two devices request the same operation by sending a request packet with the same code, a collision can occur. Some operations require collision resolution. The description of each operation in Section 4 will indicate if collision resolution is required. Both devices must know which request will be rejected. The following algorithm shall be used by both devices to determine which request to reject.

1. Set i=0 (representing the least significant octet of the BD_ADDR).
2. Compare the octet[i] of the BD_ADDR of both devices. If the octets are not equal go to step 4.
3. Increment i by 1. Go to step 2.
4. The device with the larger BD_ADDR octet shall reject the request from the other device.

7.8 AGGREGATING BEST EFFORT EXTENDED FLOW SPECIFICATIONS

There shall only be one pair of Extended Flow Specifications per logical link and only one “Best Effort” logical link per physical link. Thus, all Best Effort L2CAP channels running over the same physical link are aggregated into one logical link and the Best Effort Flow Specifications describing the traffic for each channel running over an AMP-U logical link shall be aggregated to a single pair of Extended Flow Specifications (one for each direction). The purpose of a Best Effort Flow Specification is to specify the maximum data rate of the data that can be delivered to the Controller from the Host and/or taken from the Controller by the Host in order to help the Controller to not over allocate bandwidth on the physical link. Since L2CAP performs admission control for BR/EDR and BR/EDR/LE Controllers it is not necessary to aggregate Best Effort channels for BR/EDR and BR/EDR/LE Controllers.

The two Extended Flow Specification parameters that are affected by Best Effort are Maximum SDU size and SDU Inter-arrival Time. A data rate is determined by dividing the Maximum SDU size by the SDU Inter-arrival time giving a value in bytes per second. The important value is the data rate and not the Maximum SDU size or SDU Inter-arrival time.

Best Effort aggregation shall occur when performing any of the three operations:

- Configuring a new Best Effort channel
- Disconnecting a Best Effort channel
- Moving a Best Effort a channel

During L2CAP channel configuration, the Extended Flow Specifications are exchanged and each L2CAP entity is allowed to modify the other's flow specification (lower the values). If a Best Effort logical link already exists (meaning there is at least one other Best Effort channel) then the new flow specifications shall be aggregated with the existing Best Effort aggregate before sending it to the Controller. When a Best Effort channel is moved or disconnected a new aggregate shall be created. If the new aggregate is different from the previous aggregate it shall be given to the Controller. The following guidelines are provided for aggregating Best Effort Flow specification parameters. Keep in mind that the data rate is the important value so the description shows how to aggregate data rates.

1. The value 0xFFFF is used for Maximum SDU Size and the value 0xFFFFFFFF is used for SDU Inter-arrival time to indicate that the actual values are unknown and maximum bandwidth is assumed. Therefore, if these values exist in an Extended Flow Specification then the aggregate becomes 0xFFFF and 0xFFFFFFFF for Maximum SDU Size and SDU Inter-arrival time respectively.
2. In general it is assumed that data rates provided by the local applications can be added together. For example if one application indicates a data rate of 100 bytes/s and a second application indicates a data rate of 100 bytes/s then the aggregate data rate from the two applications is 200 bytes/s. This is assumed for both directions.
3. The adjustments (sent in a Configuration Response) made by the remote device to an outgoing flow specification are assumed to be made on behalf of the application. These adjustments reduce the data rate of the outgoing flow specification. The reduced data rates can be added to data rates from other applications.
4. The final data rates shall be converted back into Maximum SDU Size and SDU Inter-arrival time to be passed to the Controller. Controllers may have a maximum PDU size or a “preferred” PDU size. When possible the “preferred” size should be used for the Maximum SDU size and the SDU Inter-arrival time should be set to a value that achieves the desired data rate. If the data rate cannot be achieved by using the “preferred” PDU size then an integer multiple of the preferred PDU size should be used.

7.9 PRIORITIZING DATA OVER HCI

In order for guaranteed channels to meet their guarantees, L2CAP should prioritize traffic over the HCI transport in devices that support HCI. Packets for Guaranteed channels should receive higher priority than packets for Best Effort channels.

7.10 SUPPORTING EXTENDED FLOW SPECIFICATION FOR BR/EDR AND BR/EDR/LE CONTROLLERS

If both the local L2CAP entity and the remote L2CAP entity indicate support for Extended Flow Specification for BR/EDR in the Extended Feature Mask then all channels created between the two devices shall send an Extended Flow Specification option and shall use the Lockstep configuration procedure. In addition all channels shall use Enhanced Retransmission mode or Streaming mode. If one or both L2CAP entities do not indicate support for Extended Flow Specification for BR/EDR in the Extended Feature Mask then the Lockstep configuration procedure shall not be used and the Extended Flow Specification option shall not be sent for channels created over the ACL-U logical link between the two devices.

The L2CAP entity shall perform admission control for Guaranteed channels during the Lockstep configuration procedure (see Section 7.1.3). Admission control is performed to determine if the requested Guaranteed QoS can be achieved by the BR/EDR or BR/EDR/LE Controller over an ACL-U logical link without compromising existing Guaranteed channels running on the Controller. If HCI is used then the L2CAP entity shall also verify that the QoS can be achieved over the HCI transport.

In performing admission control the L2CAP layer shall reject a Guaranteed QoS request that causes at least one of the following rules to be violated.

1. The total guaranteed data rate in both directions shall not exceed two times the highest Symmetric Max of an ACL-U logical link over the BR/EDR or BR/EDR/LE Controller (see [Vol 2] Part B, Section 6.7). For example for a Basic Rate Controller the highest Symmetric Max Rate is 433.9kb/s (DH5) from [Vol 2] Part B, Table 6.9. Two times that value is 867.8kb/s.
2. The total guaranteed data rate in any one direction shall not exceed the highest Asymmetric Max Rate of an ACL-U logical link (see [Vol 2] Part B, Section 6.7). For example the highest Asymmetric Max Rate for Basic Rate is 723.2kb/s (DH5 packet) from [Vol 2] Part B, Table 6.9.

The data rate of a Guaranteed channel is calculated by dividing the Maximum SDU size in an Extended Flow Specification by the SDU Inter-arrival time. Total guaranteed data rate in both directions is calculated by taking the sum of the data rates in both directions for all existing Guaranteed channels plus the data

rate in both directions of the requested Guaranteed channel (i.e. data rates from the both outgoing and incoming Extended Flow Specifications). Total guaranteed data rate for one direction is calculated by taking the sum of the data rates in one direction for all existing Guaranteed channels plus the data rate in the same direction of the requested Guaranteed channel.

An L2CAP entity should use additional information for admission control that may result in a Guaranteed QoS request being rejected even if none of the rules are violated. This allows the L2CAP entity to account for things such as CQDDR, SCO/eSCO channels, LMP traffic, page scanning, etc.

In order to meet the access latency and/or data rate required by a Guaranteed channel, the L2CAP entity should:

a) Prioritize traffic over the HCI transport in devices that support HCI.

b) Give conformant packets for Guaranteed channels higher priority than packets for Best Effort channels. Packets for Best Effort channels should have higher priority than non-conformant packets for Guaranteed channels. (See Section 5.6 for a discussion of non-conformant and conformant traffic).

c) Utilize the SAR feature to restrict the PDU sizes of Best Effort SDUs so that they do not prevent the Controller from sending the SDUs of the Guaranteed channel within the time periods required by its Extended Flow Specification.

When a channel is reconfigured the Lockstep configuration process is only used when an Extended Flow Specification option is present in the Configuration Request packet as described in Section 7.1.3.

8 PROCEDURES FOR FLOW CONTROL AND RETRANSMISSION

When Enhanced Retransmission mode, Streaming mode, Flow Control mode, or Retransmission mode is used, the procedures defined in this chapter shall be used, including the numbering of information frames, the handling of SDU segmentation and reassembly, and the detection and notification of frames with errors. Retransmission mode and Enhanced Retransmission mode also allow the sender to resend frames with errors on request from the receiver.

8.1 INFORMATION RETRIEVAL

Before attempting to configure Enhanced Retransmission mode, Streaming mode, Flow Control mode, or Retransmission mode on a channel, support for the suggested mode shall be verified by performing an information retrieval for the “Extended features supported” information type (0x0002). If the information retrieval is not successful or the “Extended features mask” bit is not set for the wanted mode, the mode shall not be suggested in a configuration request.

8.2 FUNCTION OF PDU TYPES FOR FLOW CONTROL AND RETRANSMISSION

Two frame formats are defined for Enhanced Retransmission mode, Streaming Mode, Flow Control Mode, and Retransmission mode (see Section 3.3). The I-frame is used to transport user information instead of the B-frame. The S-frame is used for supervision.

8.2.1 Information frame (I-frame)

I-frames are sequentially numbered frames containing information fields. I-frames also include some of the functionality of RR frames (see below).

8.2.2 Supervisory Frame (S-frame)

The S-frame is used to control the transmission of I-frames. For Retransmission mode and Flow Control mode, the S-frame has two formats: Receiver Ready (RR) and Reject (REJ). A description of how S-frames are used in Enhanced Retransmission mode is given in Section 8.6.1. S-frames are not used in Streaming mode. The following description of S-frames only applies to Retransmission mode and Flow Control mode.

8.2.2.1 Receiver Ready (RR)

The receiver ready (RR) S-frame is used to:

1. Acknowledge I-frames numbered up to and including ReqSeq - 1.
2. Enable or disable retransmission of I-frames by updating the receiver with the current status of the Retransmission Disable Bit.

The RR frame has no information field.

8.2.2.2 Reject (REJ)

The reject (REJ) S-frame is used to request retransmission of all I-frames starting with the I-frame with TxSeq equal to ReqSeq specified in the REJ. The value of ReqSeq in the REJ frame acknowledges I-frames numbered up to and including ReqSeq - 1. I-frames that have not been transmitted, shall be transmitted following the retransmitted I-frames.

When a REJ is transmitted, it triggers a REJ Exception condition. A second REJ frame shall not be transmitted until the REJ Exception condition is cleared. The receipt of an I-frame with a TxSeq equal to the ReqSeq of the REJ frame clears the REJ Exception. The REJ Exception condition only applies to traffic in one direction. Note: This means that only valid I-frames can be rejected.

8.3 VARIABLES AND SEQUENCE NUMBERS

The sending peer uses the following variables and Sequence numbers:

- TxSeq – the send Sequence number used to sequentially number each new I-frame transmitted.
- NextTxSeq – the Sequence number to be used in the next new I-frame transmitted.
- ExpectedAckSeq – the Sequence number of the next I-frame expected to be acknowledged by the receiving peer.

The receiving peer uses the following variables and Sequence numbers:

- ReqSeq – The Sequence number sent in an acknowledgment frame to request transmission of I-frame with TxSeq = ReqSeq and acknowledge receipt of I-frames up to and including (ReqSeq-1).
- ExpectedTxSeq – the value of TxSeq expected in the next I-frame.
- BufferSeq – When segmented I-frames are buffered this is used to delay acknowledgment of received I-frame so that new I-frame transmissions do not cause buffer overflow.

All variables have the range 0 to 63. Arithmetic operations on state variables (NextTXSeq, ExpectedTxSeq, ExpectedAckSeq, BufferSeq) and sequence numbers (TxSeq, ReqSeq) contained in this document shall be taken modulo 64.

To perform Modulo 64 operation on negative numbers multiples of 64 shall be added to the negative number until the result becomes non-negative.

8.3.1 Sending peer

8.3.1.1 Send sequence number TxSeq

I-frames contain TxSeq, the send sequence number of the I-frame. When an I-frame is first transmitted, TxSeq is set to the value of the send state variable NextTXSeq. TxSeq is not changed if the I-frame is retransmitted.

8.3.1.2 Send state variable NextTXSeq

The CID sent in the information frame is the destination CID and identifies the remote endpoint of the channel. A send state variable NextTxSeq shall be maintained for each remote endpoint. NextTxSeq is the sequence number of the next in-sequence I-frame to be transmitted to that remote endpoint. When the link is created NextTXSeq shall be initialized to 0.

The value of NextTxSeq shall be incremented by 1 after each in-sequence I-frame transmission, and shall not exceed ExpectedAckSeq by more than the maximum number of outstanding I-frames (TxWindow). The value of TxWindow shall be in the range 1 to 32 for Retransmission mode and Flow Control mode. The value of TxWindow shall be in the range of 1 to 63 for Enhanced Retransmission mode.

8.3.1.3 Acknowledge state variable ExpectedAckSeq

The CID sent in the information frame is the destination CID and identifies the remote endpoint of the channel. An acknowledge state variable ExpectedAckSeq shall be maintained for each remote endpoint. ExpectedAckSeq is the sequence number of the next in-sequence I-frame that the remote receiving peer is expected to acknowledge. (ExpectedAckSeq – 1 equals the TxSeq of the last acknowledged I-frame). When the link is created ExpectedAckSeq shall be initialized to 0.
Note that if the next acknowledgment acknowledges a single I-frame then its ReqSeq will be expectedAckSeq + 1.

If a valid ReqSeq is received from the peer then ExpectedAckSeq is set to ReqSeq. A valid ReqSeq value is one that is in the range ExpectedAckSeq ≤ ReqSeq ≤ NextTxSeq.

Note: The comparison with NextTXSeq must be ≤ in order to handle the situations where there are no outstanding I-frames.

These inequalities shall be interpreted in the following way: ReqSeq is valid, if and only if (ReqSeq-ExpectedAckSeq) mod 64 ≤ (NextTXSeq-ExpectedAckSeq) mod 64. Furthermore, from the description of NextTXSeq, it can be seen that (NextTXSeq-ExpectedAckSeq) mod 64 ≤ TxWindow.

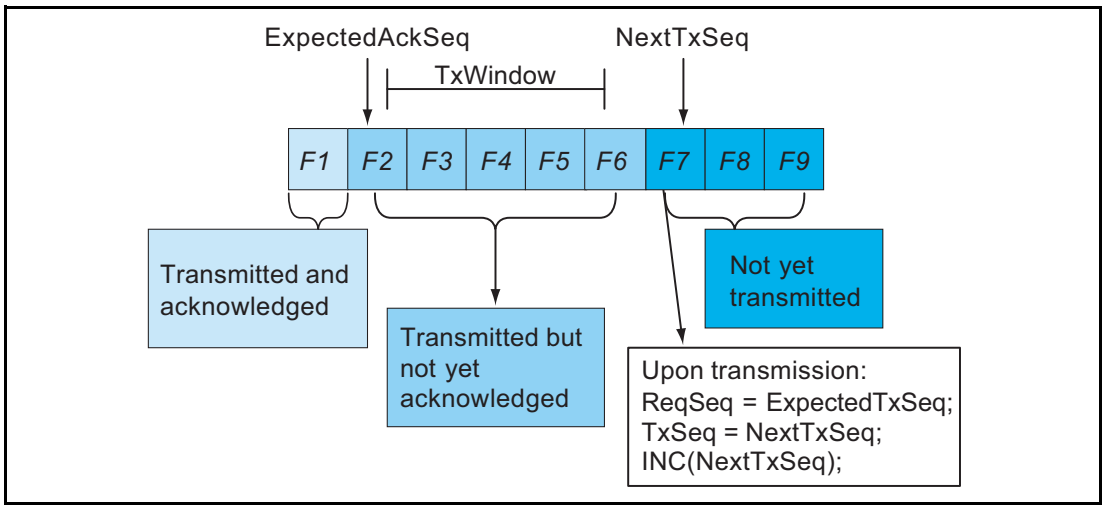


Figure 8.1: Example of the transmitter side

Figure 8.1 shows TxWindow=5, and three frames awaiting transmission. The frame with number *F7* may be transmitted when the frame with *F2* is acknowledged. When the frame with *F7* is transmitted, TxSeq is set to the value of NextTXSeq. After TxSeq has been set, NextTxSeq is incremented.

The sending peer expects to receive legal ReqSeq values, these are in the range ExpectedAckSeq up to and including NextTxSeq. Upon receipt of a ReqSeq value equal to the current NextTxSeq all outstanding I-frames have been acknowledged by the receiver.

8.3.2 Receiving peer

8.3.2.1 Receive sequence number ReqSeq

All I-frames and S-frames contain ReqSeq, the send Sequence number (TxSeq) that the receiving peer requests in the next I-frame.

When an I-frame or an S-frame is transmitted, the value of ReqSeq shall be set to the current value of the receive state variable ExpectedTxSeq or the buffer state variable BufferSeq. The value of ReqSeq shall indicate that the data link layer entity transmitting the ReqSeq has correctly received all I-frames numbered up to and including ReqSeq – 1.

Note: The option to set ReqSeq to BufferSeq instead of ExpectedTxSeq allows the receiver to impose flow control for buffer management or other purposes. In this situation, if BufferSeq<>ExpectedTxSeq, the receiver should also set the retransmission disable bit to 1 to prevent unnecessary retransmissions.

8.3.2.2 Receive state variable, ExpectedTxSeq

Each channel shall have a receive state variable (ExpectedTxSeq). The receive state variable is the sequence number (TxSeq) of the next in-sequence I-frame expected.

The value of the receive state variable shall be the last in-sequence, valid I-frame received.

8.3.2.3 Buffer state variable BufferSeq

Each channel may have an associated BufferSeq. BufferSeq is used to delay acknowledgment of frames until they have been pulled by the upper layers, thus preventing buffer overflow. BufferSeq and ExpectedTxSeq are equal when there is no extra segmentation performed and frames are pushed to the upper layer immediately on reception. When buffer space is scarce, for example when frames reside in the buffer for a period, the receiver may choose to set ReqSeq to BufferSeq instead of ExpectedTxSeq, incrementing BufferSeq as buffer space is released. The windowing mechanism will ensure that transmission is halted when ExpectedTxSeq - BufferSeq is equal to TxWindow.

Note: Owing to the variable size of I-frames, updates of BufferSeq may be based on changes in available buffer space instead of delivery of I-frame contents.

I-frames shall have sequence numbers in the range ExpectedTxSeq ≤ TxSeq < (BufferSeq + TxWindow).

On receipt of an I-frame with TxSeq equal to ExpectedTxSeq, ExpectedTxSeq shall be incremented by 1 regardless of how many I-frames with TxSeq greater than ExpectedTxSeq were previously received.

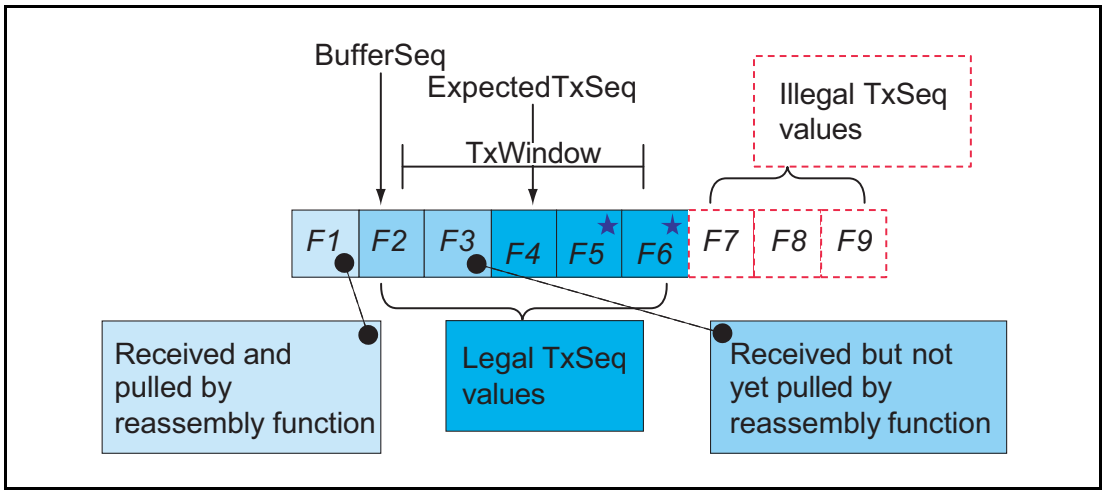


Figure 8.2: Example of the receiver side

Figure 8.2 shows TxWindow=5. *F1* is successfully received and pulled by the upper layer. BufferSeq shows that *F2* is the next I-frame to be pulled, and ExpectedTxSeq points to the next I-frame expected from the peer. An I-frame with TxSeq equal to 5 has been received thus triggering an SREJ or REJ exception. The star indicates I-frames received but discarded owing to the SREJ or REJ exception. They will be resent as part of the error recovery procedure.

In Figure 8.2 there are several I-frames in a buffer awaiting the SDU reassembly function to pull them and the TxWindow is full. The receiver would usually disable retransmission in Retransmission mode or Flow Control mode by setting the Retransmission Disable Bit to 1 and send an RR back to the sending side. This tells the transmitting peer that there is no point in performing retransmissions. Both sides will send S-frames to make sure the peer entity knows the current value of the Retransmission Disable Bit.

8.4 RETRANSMISSION MODE

8.4.1 Transmitting frames

A new I-frame shall only be transmitted when the TxWindow is not full. No I-frames shall be transmitted if the last RetransmissionDisableBit (R) received is set to one.

A previously transmitted I-frame may be retransmitted as a result of an error recovery procedure, even if the TxWindow is full. When an I-frame is retransmitted it shall always be sent with the same TxSeq value used in its initial transmission.

The state of the RetransmissionDisableBit (R) is stored and used along with the state of the RetransmissionTimer to decide the actions when transmitting I-frames. The RetransmissionTimer is running whenever I-frames have been sent but not acknowledged.

8.4.1.1 Last received R was set to zero

If the last R received was set to zero, then I-frames may be transmitted. If there are any I-frames which have been sent and not acknowledged then they shall be retransmitted when the RetransmissionTimer elapses. If the retransmission timer has not elapsed then a retransmission shall not be sent and only new I-frames may be sent.

a) If unacknowledged I-frames have been sent and the RetransmissionTimer has elapsed then an unacknowledged I-

frame shall be retransmitted. The RetransmissionTimer shall be restarted.

b) If unacknowledged I-frames have been sent, the Retransmission timer has not elapsed then a new I-frame shall be sent if one is waiting and no timer action shall be taken.

c) If no unacknowledged I-frames have been sent, and a new I-frame is waiting, then the new I-frame shall be sent, the RetransmissionTimer shall be started and if the Monitor Timer is running, it shall be stopped.

d) If no unacknowledged I-frames have been sent and no new I-frames are waiting to be transmitted, and the RetransmissionTimer is running, then the retransmission timer shall be stopped and the monitor timer shall be started.

The table below summarizes actions when the RetransmissionTimer is in use and R=0.

Unacknowledged I-frames sent = Retransmission Timer is running	**Retrans-mission Timer has elapsed**	**New I-frames are waiting**	**Transmit Action**	**Timer Action**
True	True	True or False	Retransmit un-acknowledged I-frame	Restart Retransmission Timer
True	False	True	Transmit new I-frame	No timer action
True	False	False	No transmit action	No Timer action
False	False	True	Transmit new I-frame	Restart Retransmis-sion Timer
False	False	False	No Transmit action	If MonitorTimer is not running then restart MonitorTimer

Table 8.1: Summary of actions when the RetransmissionTimer is in use and R=0

If the RetransmissionTimer is not in use, no unacknowledged I-frames have been sent and no new I-frames are waiting to be transmitted

a) If the MonitorTimer is running and has not elapsed then no transmit action shall be taken and no timer action shall be taken.

b) If the MonitorTimer has elapsed then an S-frame shall be sent and the MonitorTimer shall be restarted.

If any I-frames become available for transmission then the MonitorTimer shall be stopped, the RetransmissionTimer shall be started and the rules for when the RetransmissionTimer is in use shall be applied.

When an I-frame is sent ReqSeq shall be set to ExpectedTxSeq, TxSeq shall be set to NextTxSeq and NextTxSeq shall be incremented by one.

8.4.1.2 Last received R was set to one

If the last R received was set to one, then I-frames shall not be transmitted. The only frames which may be sent are S-frames. An S-frame shall be sent according to the rules below:

a) If the MonitorTimer is running and has not elapsed then no transmit action shall be taken and no timer action shall be taken.

b) If the MonitorTimer has elapsed then an S-frame shall be sent and the MonitorTimer shall be restarted.

8.4.2 Receiving I-frames

Upon receipt of a valid I-frame with TxSeq equal to ExpectedTxSeq, the frame shall be accepted for the SDU reassembly function. ExpectedTxSeq is used by the reassembly function.

The first valid I-frame received after an REJ was sent, with a TxSeq of the received I-frame equal to ReqSeq of the REJ, shall clear the REJ Exception condition.

The ReqSeq shall be processed according to Section 8.4.6.

If a valid I-frame with TxSeq ≠ ExpectedTxSeq is received then an exception condition shall be triggered which is handled according to Section 8.4.7.

8.4.3 I-frames pulled by the SDU reassembly function

When the L2CAP layer has removed one or more I-frames from the buffer, BufferSeq may be incremented in accordance with the amount of buffer space released. If BufferSeq is incremented, an acknowledgment shall be sent to the peer entity.

Note: Since the primary purpose of BufferSeq is to prevent buffer overflow, an implementation may choose to set BufferSeq in accordance with how many new incoming I-frames could be stored rather than how many have been removed.

The acknowledgment may either be an RR or an I-frame. The acknowledgment shall be sent to the peer L2CAP entity with ReqSeq equal to BufferSeq. When there are no I-frames buffered for pulling ExpectedTxSeq is equal to BufferSeq.

If the MonitorTimer is active then it shall be restarted to indicate that a signal has been sent to the peer L2CAP entity.

8.4.4 Sending and receiving acknowledgments

Either the MonitorTimer or the RetransmissionTimer shall be active while in Retransmission Mode. Both timers shall not be active concurrently.

8.4.4.1 Sending acknowledgments

Whenever an L2CAP entity transmits an I-frame or an S-frame, ReqSeq shall be set to ExpectedTxSeq or BufferSeq.

8.4.4.2 Receiving acknowledgments

On receipt of a valid S-frame or I-frame, the ReqSeq contained in the frame shall acknowledge previously transmitted I-frames. ReqSeq acknowledges I-frames with a TxSeq up to and including ReqSeq – 1.

The following rules shall be applied:

1. If the RetransmissionDisableBit changed value from 0 to 1 (stop retransmissions) then the receiving entity shall
    a) If the RetransmissionTimer is running then stop it and start the MonitorTimer.
    b) Store the state of the RetransmissionDisableBit received.

2. If the RetransmissionDisableBit changed value from 1 to 0 (start retransmissions) then the receiving entity shall
    a) Store the state of the RetransmissionDisableBit received.
    b) If there are any I-frames that have been sent but not acknowledged, then stop the MonitorTimer and start the RetransmissionTimer.
    c) Any buffered I-frames shall be transmitted according to Section 8.4.1.
3. If any unacknowledged I-frames were acknowledged by the ReqSeq contained in the frame, and the RetransmissionDisableBit equals 1 (retransmissions stopped), then the receiving entity shall
    a) Follow the rules in Section 8.4.1.
4. If any unacknowledged I-frames were acknowledged by the ReqSeq contained in the frame and the RetransmissionDisableBit equals 0 (retransmissions started) then the receiving entity shall
    a) If the RetransmissionTimer is running, then stop it.
    b) If any unacknowledged I-frames have been sent then the RetransmissionTimer shall be restarted.
    c) Follow the rules in Section 8.4.1.
    d) If the RetransmissionTimer is not running and the MonitorTimer is not running, then start the MonitorTimer.

On receipt of a valid S-frame or I-frame the ReqSeq contained in the frame shall acknowledge previously transmitted I-frames. ExpectedAckSeq shall be set to ReqSeq to indicate that the I-frames with TxSeq up to and including (ReqSeq - 1) have been acknowledged.

8.4.5 Receiving REJ frames

Upon receipt of a valid REJ frame, where ReqSeq identifies an I-frame not yet acknowledged, the ReqSeq acknowledges I-frames with TxSeq up to and including ReqSeq - 1. Therefore the REJ acknowledges all I-frames before the I-frame it is rejecting.

ExpectedAckSeq shall be set equal to ReqSeq to mark I-frames up to and including ReqSeq - 1 as received.

NextTXSeq shall be set to ReqSeq to cause transmissions of I-frames to resume from the point where TxSeq equals ReqSeq.

If ReqSeq equals ExpectedAckSeq then the REJ frame shall be ignored.

8.4.6 Waiting acknowledgments

A counter, TransmitCounter, counts the number of times an L2CAP PDU has been transmitted. This shall be set to 1 after the first transmission. If the RetransmissionTimer expires the following actions shall be taken:

1. If the TransmitCounter is less than MaxTransmit then:
    a) Increment the TransmitCounter
    b) Retransmit the last unacknowledged I-frame, according to Section 8.4.1.
2. If the TransmitCounter is equal to MaxTransmit this channel to the peer entity shall be assumed lost. The channel shall move to the CLOSED state and appropriate action shall be taken to report this to the upper layers.

8.4.7 Exception conditions

Exception conditions may occur as the result of physical layer errors or L2CAP procedural errors. The error recovery procedures which are available following the detection of an exception condition at the L2CAP layer in Retransmission Mode are defined in this section.

8.4.7.1 TxSeq Sequence error

A TxSeq sequence error exception condition occurs in the receiver when a valid I-frame is received which contains a TxSeq value which is not equal to the expected value, thus TxSeq is not equal to ExpectedTxSeq.

The TxSeq sequence error may be due to three different causes:

- *Duplicated I-frame*

  The duplicated I-frame is identified by a TxSeq in the range BufferSeq to ExpectedTxSeq – 1 (BufferSeq ≤TxSeq<ExpectedTxSeq). The ReqSeq and RetransmissionDisableBit shall be processed according to Section 8.4.4. The Information field shall be discarded since it has already been received.

- *Out-of-sequence I-frame*

  The out-of-sequence I-frame is identified by a TxSeq within the legal range. The ReqSeq and RetransmissionDisableBit shall be processed according to Section 8.4.4.

  A REJ exception is triggered, and an REJ frame with ReqSeq equal to ExpectedTxSeq shall be sent to initiate recovery. The received I-frame shall be discarded.

- *Invalid TxSeq*

  An invalid TxSeq value is a value that does not meet either of the above conditions. An I-frame with an invalid TxSeq is likely to have errors in the control field and shall be silently discarded.

8.4.7.2 ReqSeq Sequence error

An ReqSeq sequence error exception condition occurs in the transmitter when a valid S-frame or I-frame is received which contains an invalid ReqSeq value. An invalid ReqSeq is one that is not in the range ExpectedAckSeq ≤ ReqSeq ≤ NextTxSeq.

The L2CAP entity shall close the channel as a consequence of an ReqSeq Sequence error.

8.4.7.3 Timer recovery error

If an L2CAP entity fails to receive an acknowledgment for the last I-frame sent, then it will not detect an out-of-sequence exception condition and therefore will not transmit an REJ frame.

The L2CAP entity that transmitted an unacknowledged I-frame shall, on the expiry of the RetransmissionTimer, take appropriate recovery action as defined in Section 8.4.6.

8.4.7.4 Invalid frame

Any frame received which is invalid (as defined in Section 3.3.6) shall be discarded, and no action shall be taken as a result of that frame.

8.5 FLOW CONTROL MODE

When a link is configured to work in flow control mode, the flow control operation is similar to the procedures in retransmission mode, but all operations dealing with CRC errors in received packets are not used. Therefore

- REJ frames shall not be used in Flow Control Mode.
- The RetransmissionDisableBit shall always be set to zero in the transmitter, and shall be ignored in the receiver.

The behavior of flow control mode is specified in this section.

Assuming that the TxWindow size is equal to the buffer space available in the receiver (counted in number of I-frames), in flow control mode the number of unacknowledged frames in the transmitter window is always less than or equal to the number of frames for which space is available in the receiver. Note that a missing frame still occupies a place in the window.

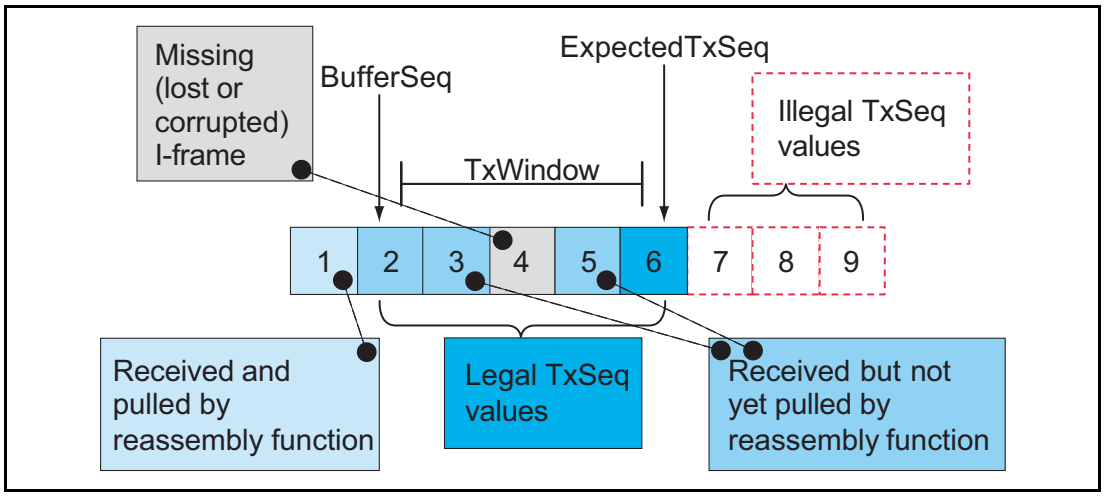


Figure 8.3: Overview of the receiver side when operating in flow control mode

8.5.1 Transmitting I-frames

A new I-frame shall only be transmitted when the TxWindow is not full.

Upon transmission of the I-frame the following actions shall be performed:

- If no unacknowledged I-frames have been sent then the MonitorTimer shall be stopped and the RetransmissionTimer shall be started.
- If any I-frames have been sent and not acknowledged then the RetransmissionTimer remains active and no timer operation is performed.

The control field parameter ReqSeq shall be set to ExpectedTxSeq, TxSeq shall be set to NextTXSeq and NextTXSeq shall be incremented by one.

8.5.2 Receiving I-frames

Upon receipt of a valid I-frame with TxSeq equal to ExpectedTxSeq, the frame shall be made available to the reassembly function. ExpectedTxSeq shall be incremented by one. An acknowledgment shall not be sent until the SDU reassembly function has pulled the I-frame.

Upon receipt of a valid I-frame with an out-of-sequence TxSeq (see Section 8.5.6) all frames with a sequence number less than TxSeq shall be assumed lost and marked as missing. The missing I-frames are in the range from ExpectedTxSeq (the frame that the device was expecting to receive) up to TxSeq-1, (the frame that the device actually received). ExpectedTxSeq shall be set to TxSeq +1. The received I-frame shall be made available for pulling by the reassembly function. The acknowledgment shall not occur until the SDU reassembly function has pulled the I-frame. The ReqSeq shall be processed according to Section 8.5.4.

8.5.3 I-frames pulled by the SDU reassembly function

When the L2CAP layer has removed one or more I-frames from the buffer, BufferSeq may be incremented in accordance with the amount of buffer space released. If BufferSeq is incremented, an acknowledgment shall be sent to the peer entity. If the MonitorTimer is active then it shall be restarted to indicate that a signal has been sent to the peer L2CAP entity.

Note: Since the primary purpose of BufferSeq is to prevent buffer overflow, an implementation may choose to set BufferSeq in accordance with how many new incoming I-frames could be stored rather than how many have been removed.

The acknowledgment may be an RR or an I-frame. The acknowledgment shall be sent to the peer L2CAP entity with ReqSeq equal to BufferSeq. When there is no I-frame buffered for pulling, ExpectedTxSeq is equal to BufferSeq.

8.5.4 Sending and receiving acknowledgments

One of the timers MonitorTimer or RetransmissionTimer shall always be active while in Flow Control mode. Both timers shall never be active concurrently.

8.5.4.1 Sending acknowledgments

Whenever a data link layer entity transmits an I-frame or a S-frame, ReqSeq shall be set to ExpectedTxSeq or BufferSeq.

8.5.4.2 Receiving acknowledgments

On receipt of a valid S-frame or I-frame the ReqSeq contained in the frame shall be used to acknowledge previously transmitted I-frames. ReqSeq acknowledges I-frames with a TxSeq up to and including ReqSeq – 1.

1. If any outstanding I-frames were acknowledged then
    a) Stop the RetransmissionTimer
    b) If there are still unacknowledged I-frames then restart the RetransmissionTimer, otherwise start the MonitorTimer.
    c) Transmit any I-frames awaiting transmission according to Section 8.5.1.

ExpectedAckSeq shall be set to ReqSeq to indicate that the I-frames with TxSeq up to and including ExpectedAckSeq have been acknowledged.

8.5.5 Waiting acknowledgments

If the RetransmissionTimer expires the following actions shall be taken:
The I-frame supervised by the RetransmissionTimer shall be considered lost, and ExpectedAckSeq shall be incremented by one.

1. If I-frames are waiting to be sent
    a) the RetransmissionTimer is restarted.
    b) I-frames awaiting transmission are transmitted according to Section 8.5.1.
2. If there are no I-frames waiting to be sent
    a) If there are still unacknowledged I-frames the RetransmissionTimer is restarted, otherwise the MonitorTimer is started.

8.5.6 Exception conditions

Exception conditions may occur as the result of physical layer errors or L2CAP procedural errors. The error recovery procedures which are available following the detection of an exception condition at the L2CAP layer in flow control only mode are defined in this section.

8.5.6.1 TxSeq Sequence error

A TxSeq sequence error exception condition occurs in the receiver when a valid I-frame is received which contains a TxSeq value which is not equal to the expected value, thus TxSeq is not equal to ExpectedTxSeq.

The TxSeq sequence error may be due to three different causes:

- *Duplicated I-frame*

  The duplicated I-frame is identified by a TxSeq in the range BufferSeq to ExpectedTxSeq – 1. The ReqSeq shall be processed according to Section 8.5.4. The Information field shall be discarded since it has already been received.

- *Out-of-sequence I-frame*

  The out-of-sequence I-frame is identified by a TxSeq within the legal range ExpectedTxSeq < TxSeq < (BufferSeq + TxWindow). The ReqSeq shall be processed according to Section 8.5.4.

  The missing I-frame(s) are considered lost and ExpectedTXSeq is set equal to TxSeq+1 as specified in Section 8.5.2. The missing I-frame(s) are reported as lost to the SDU reassembly function.

- *Invalid TxSeq*

  An invalid TxSeq value is a value that does not meet either of the above conditions and TxSeq is not equal to ExpectedTxSeq. An I-frame with an invalid TxSeq is likely to have errors in the control field and shall be silently discarded.

8.5.6.2 ReqSeq Sequence error

An ReqSeq sequence error exception condition occurs in the transmitter when a valid S-frame or I-frame is received which contains an invalid ReqSeq value. An invalid ReqSeq is one that is not in the range ExpectedAckSeq ≤ ReqSeq ≤ NextTXSeq.

The L2CAP entity shall close the channel as a consequence of an ReqSeq Sequence error.

An L2CAP entity that fails to receive an acknowledgment for an I-frame shall, on the expiry of the RetransmissionTimer, take appropriate recovery action as defined in Section 8.5.5.

8.5.6.3 Invalid frame

Any frame received that is invalid (as defined in Section 3.3.6) shall be discarded, and no action shall be taken as a result of that frame, unless the receiving L2CAP entity is configured to deliver erroneous frames to the layer above L2CAP. In that case, the data contained in invalid frames may also be added to the receive buffer and made available for pulling from the SDU reassembly function.

8.6 ENHANCED RETRANSMISSION MODE

Enhanced Retransmission mode operates as an HDLC balanced data link operational mode. Either L2CAP entity may send frames at any time without receiving explicit permission from the other L2CAP entity. A transmission may contain single or multiple frames and shall be used for I-frame transfer and/or to indicate status change.

8.6.1 Function Of PDU Types

Enhanced Retransmission mode uses I-frames to transfer upper layer information and S-frames for supervision. There are four S-frames defined: Receiver Ready (RR), Reject (REJ), Receiver Not Ready (RNR), and Selective Reject (SREJ). All frames formats in Enhanced Retransmission mode shall use the Enhanced Control Field.

8.6.1.1 Receiver Ready (RR)

The RR frame shall be used by an L2CAP entity to

1. Indicate that it is ready to receive I-frames
2. Acknowledge previously received I-frames numbered up to ReqSeq - 1 inclusive.

An RR with P-bit set to 1 (P=1) is used to indicate the clearance of any busy condition that was initiated by an earlier transmission of an RNR frame by the same L2CAP entity.

8.6.1.2 Reject (REJ)

The REJ frame shall be used by an L2CAP entity to request retransmission of I-frames starting with the frame numbered ReqSeq. I-frames numbered ReqSeq - 1 and below shall be considered acknowledged. Additional I-frames awaiting initial transmission may be transmitted following the retransmitted I-frame(s) up to the TxWindow size of the receiver.

At most only one REJ exception from a given L2CAP entity to another L2CAP entity shall be established at any given time. A REJ frame shall not be transmitted until an earlier REJ exception condition or all earlier SREJ

exception conditions have been cleared. The REJ exception condition shall be cleared upon the receipt of an I-frame with TxSeq equal to the ReqSeq of the REJ frame.

Two L2CAP entities may be in REJ exception conditions with each other at the same time.

8.6.1.3 Receiver Not Ready (RNR)

The RNR frame shall be used by an L2CAP entity to indicate a busy condition (i.e. temporary inability to receive I-frames). I-frames numbered up to ReqSeq - 1 inclusive shall be considered acknowledged. The I-frame numbered ReqSeq and any subsequent I-frames sent shall not be considered acknowledged. The acceptance status of these I-frames shall be indicated in subsequent transfers.

8.6.1.4 Selective Reject (SREJ)

The SREJ frame shall be used by an L2CAP entity to request retransmission of one I-frame. The ReqSeq shall indicate the TxSeq of the earliest I-frame to be retransmitted (not yet reported by a SREJ). If the P-bit is set to 1 then I-frames numbered up to ReqSeq -1 inclusive shall be considered acknowledged. If the P-bit is set to 0 then the ReqSeq field in the SREJ shall not indicate acknowledgment of I-frames.

Each SREJ exception condition shall be cleared upon receipt of an I-frame with TxSeq equal to the ReqSeq sent in the SREJ frame.

An L2CAP entity may transmit one or more SREJ frames with the P=0 before one or more earlier SREJ exception conditions initiated with SREJ(P=0) have been cleared. An L2CAP entity shall not transmit more than one SREJ with P=1 before all earlier SREJ exception conditions have been cleared. A SREJ frame shall not be transmitted if an earlier REJ exception condition has not been cleared. Likewise a REJ frame shall not be transmitted if one or more SREJ exception conditions have not been cleared. Only one I-frame shall be retransmitted in response to receiving a SREJ frame with P=0. Additional I-frames awaiting initial transmission may be transmitted following the retransmission of the specific I-frame requested by SREJ with P=1.

8.6.1.5 Functions of the Poll (P) and Final (F) bits.

P-bit set to 1 shall be used to solicit a response frame with the F-bit set to 1 from the remote L2CAP entity at the earliest respond opportunity. At most only one frame with a P=1 shall be outstanding in a given direction at a given time. Before an L2CAP entity issues another frame with P=1, it shall have received a response frame from the remote L2CAP entity with F=1. If no valid frame is received with F=1 within Monitor time-out period, the frame with P=1 may be retransmitted.

The Final bit shall be used to indicate the frame as a response to a soliciting poll (S-frame with P=1). The frame with F=1 shall not be retransmitted. The Monitor-timeout is not used to monitor lost frames with F=1. Additional frames with F=0 may be transmitted following the frame with F=1.

S-frames shall not be transmitted with both the F-bit and the P-bit set to 1 at the same time.

8.6.2 Rules For Timers

Timers are started upon transmission of a packet. Timers should be started when the corresponding packet leaves the Controller (transmitted or flushed). If the timer is not started when the packet leaves the Controller then it shall be started when the packet is delivered to the Controller. The specific rules for BR/EDR Controllers, BR/EDR/LE Controllers, and AMP Controllers are described in the following sections.

8.6.2.1 Timer Rules for ACL-U Logical Links

If a flush timeout does not exist on the ACL-U logical link for the channel using Enhanced Retransmission mode then the value for the Retransmission time-out shall be at least two seconds and the value for the Monitor time-out shall be at least twelve seconds.

If a flush timeout exists on the link for Enhanced Retransmission mode then the value for the Retransmission time-out shall be three times the value of flush timeout, subject to a minimum of 1 second and maximum of 2 seconds.

If a flush timeout exists on the link for Enhanced Retransmission mode and both sides of the link are configured to the same flush timeout value then the monitor time-out shall be set to a value at least as large as the Retransmission time-out otherwise the value of the Monitor time-out shall be six times the value of flush timeout, subject to a minimum of the retransmission timeout value and a maximum of 12 seconds.

If an L2CAP entity knows that a specific packet has been flushed instead of transmitted then it may execute proper error recovery procedures immediately.

When configuring a channel over an ACL-U logical link the values sent in a Configuration Request packet for Retransmission timeout and Monitor timeout shall be 0.

Note: If the link has a flush timeout and the Non-Flushable Packet Boundary Flag feature is used to mark the Enhanced Retransmission mode packets as non-flushable then the link does not have a flush timeout with regards to Enhanced Retransmission mode.

8.6.2.2 Timer Rules for AMP Controllers

AMP Controllers can be classified by their behavior as follows:

1. Attempt to send a packet until LSTO disconnects the physical link.
2. Attempt to send a packet until a Controller based retry counter is exceeded whereupon the packet is flushed.

Class 1 AMP Controllers are reliable. They will not lose packets though packets can be lost during a move operation. Class 2 AMP Controllers are not reliable and can lose packets. The Best Effort Flush Timeout field in the AMP Info (see [Vol 2] Part E, Section 7.5.8) can be used to determine the behavior of the Controller (i.e. class 1 or class 2). If the Best Effort Flush Timeout field in the AMP info is 0xFFFFFFFF then the class is 1 otherwise the class is 2. The Best Effort Flush Timeout field indicates the flush timeout that may be set on the Best Effort logical link.

For class 1 AMP Controllers the Retransmission and Monitor timers are not really needed. Packets should not be lost. Packets lost during the move operation will be detected by L2CAP and retransmitted as part of the move operation. Therefore, the Retransmission timeout and Monitor timeout shall be at least the value of the Link supervision timeout set on the link or can be turned off altogether. The values sent in a Configuration Request packet for Retransmission timeout and Monitor timeout shall be 0.

When configuring a channel the AMP-U logical link of a over a class 2 AMP Controller non-0 values for Retransmission timeout and Monitor timeout shall be sent in a Configuration Request packet. The non-0 values specify the “processing” time of received packets. Processing time includes the time it takes for a received packet to be passed from the device's Controller to the L2CAP layer plus the time to be processed by the L2CAP layer and a response submitted back to the Controller. The local device's processing time is used by the remote device in calculating the Retransmission timeout and Monitor timeout it will use. The timeout values that will actually be used by a device shall be sent in a Configuration Response packet.

As with BR/EDR and BR/EDR/LE Controllers, the method used for setting timer values for class 2 AMP Controllers depends on when timers are started. Timers are either started when the packet leaves the Controller or when the packet is delivered to the Controller.

The timeout values used for Class 2 AMP Controllers where timers are started when the packet leaves the Controller shall be at least the values received in the Configuration Request packet from the remote device (remote device's “processing” time).

For Class 2 AMP Controller where timers are started when the packet is delivered to the Controller the following rules shall be used:

1. The local L2CAP Entity shall set a flush timeout on the Best Effort logical link equal to the value provided by the local Controller in the Best Effort Flush Timeout field of AMP info structure.
2. The value of the Retransmission timeout and Monitor Timeout shall be the value of the flush timeout multiplied by three plus the corresponding processing time received in the Configuration Request packet from the remote device.

If an L2CAP entity knows that a specific packet has been flushed instead of transmitted then it may execute proper error recovery procedures immediately.

8.6.2.3 Timer Values used After a Move Operation

When a channel is moved from one Controller to another Controller the timeout values used after the move operation are based on the capabilities of the new Controller. The timeout values shall be set according to the following table:

Controller	Timeout Values
BR/EDR and BR/EDR/LE	Retransmission timeout – at least 2 seconds Monitor timeout – at least 12 seconds
Class 1 AMP Controller	Retransmission timeout – at least LSTO (or turned off) Monitor timeout – at least LSTO (or turned off)
Class 2 AMP Controller where timers are started when packets leave the Controller	Retransmission timeout – at least 500ms Monitor timeout – at least 500ms Note: 500ms is the default value for the “processing” time of received packets.
Class 2 AMP Controller where timers are started when packets are delivered to the Controller	Retransmission timeout – at least (local Controller "Best Effort” Flush Timeout * 3) + 500ms Monitor timeout – at least (local Controller “Best Effort” Flush Timeout * 3) + 500ms Note: 500ms is the default value for the “processing” time of received packets

Table 8.2: AMP Controller timeout values

When moving to a Class 2 AMP Controller, the Retransmission Timeout and Monitor timeout should be reconfigured after the move operation to get the actual value for the “processing” time of received packets.

8.6.3 General Rules for the State Machine

Enhanced Retransmission mode is specified using a pair of state machines, a Transmitter state machine and a Receiver state machine. The following rules apply to the state machine pair.

1. The state machine pair is informative but described using normative text in order to clearly specify the behavior of the protocol. Designers and implementers may choose any design / implementation technique they wish, but it shall behave in a manner identical to the external behavior of the specified state machines.
2. There is a single state machine pair for each active L2CAP channel configured to use Enhanced Retransmission mode.
3. Variables are used to limit the number of states by maintaining the state of particular conditions. The variables are defined in Section 8.6.5.2.
4. For some combinations of Event and Condition, the state tables provide alternative groups of actions. These alternatives are separated by horizontal lines in the Actions and Next State columns. The alternatives are mutually exclusive; selection of an alternate is done based upon (i) local status, (ii) a layer management action, or (iii) an implementation decision. There is no relationship between the order of the alternatives between events, nor is it implied that the same alternative must be selected every time the event occurs.
5. The state tables use timers. Any Start Timer action restarts the specified timer from its initial value, even if the timer is already running. When the timer reaches 0 the appropriate timer expired event is set and the timer stops. The Stop Timer action stops a timer if it is running.
6. Events not recognized in a particular state are assumed to remain pending until any masking flag is modified or a transition is made to a state where they can be recognized.
7. Some state transitions and actions are triggered by internal events (e.g. requests from the upper layer). It is implementation specific how these internal events are realized. They are used for clarity in specifying the state machine. All events including Internal events are described in Section 8.6.5.3.
8. The state machines specify the exact frames to be sent by transmitters but are relaxed on what receivers are allowed to accept as valid. For example there are cases where the transmitter is required to send a frame with P=1. The correct response is a frame with F=1 but in some cases the receiver is allowed to accept a frame with F=0 in addition to F=1.

8.6.4 State Diagram

The state diagram shows the states and the main transitions. Not all events are shown on the state diagram.

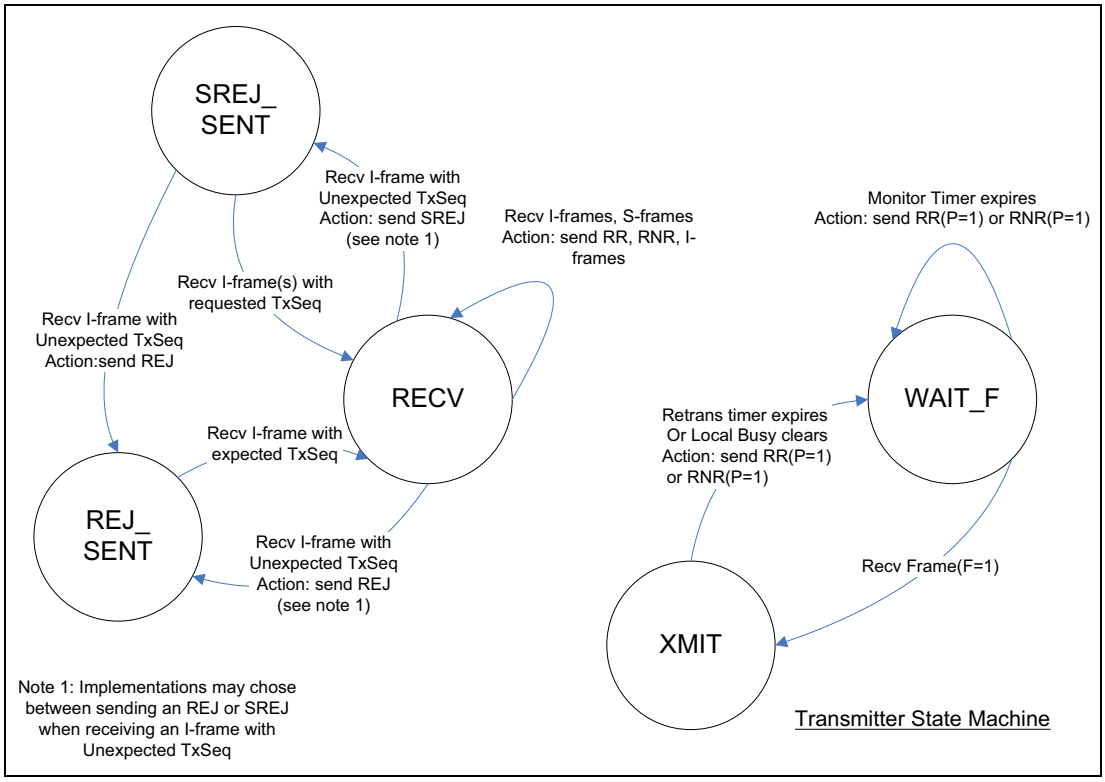


Figure 8.4: Receiver state machine

8.6.5 States Tables

8.6.5.1 State Machines

Enhanced Retransmission mode is described as a pair of state machine. The Receiver state machine handles all received frames while the Transmitter State machine handles all asynchronous events including requests from the upper layer and the expiration of timers.

The Receiver state machine “calls” the Transmitter state machine using the PassToTx action. This shows up in the Transmitter state machine as an event. When the Transmitter state machine is called it runs to completion before returning to the Receiver state machine. Running to completion means that all actions are executed and the Transmitter state is changed to the new state.

The Receiver and Transmitter state machine share variables and timers.

8.6.5.2 States

The following states have been defined to specify the protocol; the actual number of states and naming in a given implementation is outside the scope of this specification:

RECV—This is the main state of the Receiver state machine.

REJ_SENT—The L2CAP entity has sent a REJ frame to cause the remote L2CAP entity to resend I-frame(s). The L2CAP entity is waiting for the I-frame with a TxSeq that matches the ReqSeq sent in the REJ. Whether to send a REJ versus a SREJ is implementation dependent.

SREJ_SENT—The L2CAP entity has sent one or more SREJ frames to cause the remote L2CAP entity to resend missing I-frame(s). The local L2CAP entity is waiting for all requested I-frames to be received. If additional missing I-frames are detected while in SREJ_SENT then additional SREJ frames or a REJ frame can be sent to request those I-frames. Whether to send a SREJ versus a REJ is implementation dependent.

XMIT—This is the main state of the Transmitter state machine.

WAIT_F—Local busy has been cleared or the Retransmission timer has expired and an S-frame with P=1 has been sent. The local L2CAP entity is waiting for a frame with F=1. New I-frames cannot be sent while in the WAIT_F state to prevent the situation where retransmission of I-frames could result in the channel being disconnected.

8.6.5.3 Variables and Timers

Variables are used to limit the number of states and help clarify the state chart tables. Variables can be set to values, evaluated in conditions and compared in conditional statements. They are also used in the action descriptions. Below is a list of the operators, connectives and statements that can be used with variables.

Operator, connective or statement	Description
:=	Assignment operator. Used to set a variable to a value
=	Relational operator "equal"
>	Relational operator "greater than"
<	Relational operator "less than"
≥	Relational operator "greater than or equal"
≤	Relational operator "less than or equal"
+	Arithmetic operator "plus"

Table 8.3: Operators, connectives and statements used with variables

Operator, connective or statement	Description
mod	Modulo operator - returns the remainder of division of one number by another.
and	logical connective "and." It returns TRUE if both operands are TRUE otherwise it returns FALSE.
or	logical connective "or." It returns TRUE if either of its operands are TRUE otherwise it returns FALSE.
if (expression) **then {** statement **}**	Conditional Statement. If expression is TRUE then the statement is executed otherwise the statement is not executed. The statement is composed of one or more actions. All the actions in the statement are indented under the **if** … **then** clause and contained within braces “{ }”.
if (expression) **then {** statement1 **}** **else {** statement2 **}**	Conditional Statement. If expression is TRUE then statement1 is executed otherwise statement2 is executed. A statement is composed of one or more actions. All the actions in the statement1 are indented under the **if** … **then** clause and contained within braces “{ }”. All the actions of statement2 are indented under the else clause and contained within braces “{ }”.

Table 8.3: Operators, connectives and statements used with variables (Continued)

Enhanced Retransmission mode uses the following variables and sequence numbers described in Section 8.3:

- TxSeq
- NextTxSeq
- ExpectedAckSeq
- ReqSeq
- ExpectedTxSeq
- BufferSeq

In addition to the variables above the following variables and timers are used:

RemoteBusy—when set to TRUE RemoteBusy indicates that the local L2CAP entity has received an RNR from the remote L2CAP entity and considers the remote L2CAP entity as busy. When the remote device is busy it will likely discard I-frames sent to it. The RemoteBusy flag is set to FALSE when the local L2CAP Entity receives an RR, REJ or SREJ. When set to FALSE the local L2CAP entity considers the remote L2CAP entity able to accept I-frames. When the channel is created RemoteBusy shall be set to FALSE.

LocalBusy—when set to TRUE, LocalBusy indicates the local L2CAP entity is busy and will discard received I-frames. When set to FALSE the local L2CAP entity is not busy and is able to receive I-frames. When the channel is created LocalBusy shall be set to FALSE.

UnackedFrames—holds the number of unacknowledged I-frames. When the channel is created UnackedFrames shall be set to 0.

UnackedList—holds the unacknowledged I-frames so they can be retransmitted if necessary. I-frames in the list are accessed via their TxSeq number. For example UnackedList[5] accesses the I-frame with TxSeq 5.

PendingFrames—holds the number of pending I-frames. I-frames passed to L2CAP from the upper layer may be unable to be sent immediately because the remote L2CAP entity's TxWindow is full, is in a busy condition or the local L2CAP is in the incorrect state. When I-frames cannot be sent they are stored in a queue until conditions allow them to be sent. When the channel is created PendingFrames shall be set to 0.

SrejList—is a list of TxSeq values for I-frames that are missing and need to be retransmitted using SREJ. A SREJ has already been sent for each TxSeq on the list. When SrejList is empty it equals 0 (i.e. SrejList = 0). If SrejList is not empty it is greater than 0 (i.e. SrejList > 0).

RetryCount—holds the number of times an S-frame operation is retried. If an operation is tried MaxTransmit times without success the channel shall be closed.

RetryIframes[]—holds a retry counter for each I-frame that is sent within the receiving device's TxWindow. Each time an I-frame is retransmitted the corresponding counter within RetryIframes is incremented. When an attempt to retransmit the I-frame is made and the counter is equal to MaxTransmit then the channel shall be closed.

RNRsent—when set to TRUE it means that the local L2CAP entity has sent an RNR frame. It is used to determine if the L2CAP entity needs to send an RR to the remote L2CAP entity to clear the busy condition. When the channel is created RNRsent shall be set to FALSE.

RejActioned—is used to prohibit a frame with F=1 from causing I-frames already retransmitted in response to a REJ from being retransmitted again. RejActioned is set to TRUE if a received REJ is actioned when a frame sent with P=1 is unanswered. When the channel is created RejActioned shall be set to FALSE.

SrejActioned—is used in conjunction with SrejSaveReqSeq to prohibit a frame with F=1 from causing an I-frame already retransmitted in response to a SREJ from being retransmitted again. SrejActioned is set to TRUE if a received SREJ is actioned when a frame sent with P=1 is unanswered. When the channel is created SrejActioned shall be set to FALSE.

SrejSaveReqSeq—is used to save the ReqSeq of a SREJ frame that causes SrejActioned to be set to TRUE.

SendRej—when set to TRUE it indicates that the local L2CAP entity has determined that a REJ should be sent in the SREJ_SENT state while processing received I-frames. The sending of new SREJ frames is stopped. When the channel is created SendRej shall be set to FALSE.

BufferSeqSrej—is used while in the SREJ_SENT state to keep track of the value to which BufferSeq will be set upon exit of the SREJ_SENT state.

FramesSent—is used to keep track of the number I-frames sent by the Send-Data and Retransmit-I-frames actions.

MaxTxWin—contains the maximum window size plus 1. It is used in TxWindow modulo operations as the divisor and in state table conditions. This value shall be set to 16384 (0x4000) if the Extended Window Size option is used; otherwise it shall be set to 64.

RetransTimer—The Retransmission Timer is used to detect lost I-frames. When the channel is created the RetransTimer shall be off.

MonitorTimer—The Monitor Timer is used to detect lost S-frames. When the channel is created the MonitorTimer shall be off.

8.6.5.4 Events

Data-Request—The upper layer has requested that an SDU be sent. The SDU may need to be broken into multiple I-frames by L2CAP based on the MPS of the remote device and/or the maximum PDU allowed by the HCI or QoS requirements of the system.

Local-Busy-Detected—A local busy condition occurs when the local L2CAP entity is temporarily unable to receive, or unable to continue to receive, I-frames due to internal constraints. For example, the upper layer has not pulled received I-frames and the local L2CAP entity needs to send an acknowledgment to the remote L2CAP entity. The method for handling the detection of local busy is implementation specific. An implementation may wait to send an RNR to see if the busy condition will clear before the remote L2CAP entity's Retransmission timer expires. If the busy condition clears then frames can be acknowledged with an RR or I-frame. If the busy condition does not clear before the remote L2CAP entity's Retransmission timer expires then an RNR shall be sent in response to the RR or RNR poll sent by the remote L2CAP entity. Optionally an implementation may send an RNR as soon as the local busy condition is detected.

Local-Busy-Clear—The local busy condition clears when L2CAP has buffer space to receive more I-frames (i.e. SDU Reassembly function and/or upper layer has pulled I-frames) and if necessary the upper layer has cleared the busy condition.

Recv ReqSeqAndFbit—This is an event generated by the Receiver state machine. It contains the ReqSeq and F-bit value of a received frame. The value of the F-bit can be checked in a condition.

Recv Fbit—This is an event generated by the Receiver state machine. It contains the F-bit value of a received frame. The value of the F-bit can be checked in a condition.

RetransTimer-Expires—The Retransmission Timer has counted to down to 0 and stopped.

MonitorTimer-Expires—The Monitor Timer has counted down to 0 and stopped.

Recv I-frame—Receive an I-frame with any value for the F-bit.

Recv RR, REJ, RNR, SREJ (P=x) or **(F=x)**—Receive a specific S-frame (RR, REJ, etc.) with a specific value for the P and/or F bit. The F-bit and the P-bit shall not both be set to 1 in a transmitted S-frame so received S-frames with both P and F set to 1 should be ignored. If the P and/or F bit value is not specified in the event then either value is accepted.

Recv RRorRNR—Receive an RR or RNR with any value for the P-bit and F-bit.

Recv REJorSREJ—Receive an REJ or SREJ with any value for the P-bit and F-bit.

Recv frame—This is catch-all for all frames that are not explicitly declared as events in the state table.

8.6.5.5 Conditions

RemoteBusy = TRUE or FALSE—TRUE indicates the remote L2CAP entity is in a busy condition and FALSE indicates the remote L2CAP entity is not busy.

LocalBusy = TRUE or FALSE—TRUE indicates the local L2CAP entity is in a busy condition and FALSE indicates the local L2CAP entity is not busy.

RemWindow-Not-Full—The number of unacknowledged I-frames sent by L2CAP has not yet reached the TxWindow size of the remote L2CAP entity.

RemWindow-Full—The number of unacknowledged I-frames sent by the L2CAP entity has reached the TxWindow size of the remote L2CAP entity. No more I-frames shall be sent until one or more I-frames have been acknowledged.

RNRsent = TRUE or FALSE—**TRUE** indicates an RNR has been sent while a local busy condition exists. It is set to FALSE when the local busy condition clears.

F = 0 or 1—the F-bit of a received frame is checked. The F-bit of the received frame is available as part of the Recv ReqSeqAndFbit and Recv Fbit events.

RetryIframes[i] < or ≥ MaxTransmit—Compare the appropriate counter in RetryIframes after processing the ReqSeq in the receive frame to determine if it has reached MaxTransmit or not.

RetryCount < or ≥ MaxTransmit—Compare RetryCount to determine if it has reached MaxTransmit or not.

With-Expected-TxSeq—The TxSeq of a received I-frame is equal to ExpectedTxSeq.

With-Valid-ReqSeq—The ReqSeq of the received frame is in the range ExpectedAckSeq ≤ ReqSeq < NextTxSeq.

With-Valid-ReqSeq-Retrans—The ReqSeq of the received frame is in the range ExpectedAckSeq ≤ ReqSeq < NextTxSeq.

With-Valid-F-bit —The F-bit of a received frame is valid if it is 0 or if it is 1 and a frame sent with P=1 by the local L2CAP entity is unanswered (i.e. the local L2CAP entity send a frame with P=1 and has not yet received a frame with F=1 until receiving this one). If the Transmitter state machine is in the WAIT_F state then a frame sent with P=1 is unanswered.

With-unexpected-TxSeq—The TxSeq of the received I-frame is within the TxWindow of the L2CAP entity receiving the I-frame but has a TxSeq “greater” than ExpectedTxSeq where “greater” means later in sequence than ExpectedTxSeq.

With-duplicate-TxSeq—The TxSeq of the received I-frame is within the TxWindow of the L2CAP entity receiving the I-frame but has a TxSeq “less” than ExpectedTxSeq where “less” means earlier in the sequence than ExpectedTxSeq. In other words this is a frame that has already been received.

With-Invalid-TxSeq—The TxSeq of the received I-frame is not within the TxWindow of the L2CAP entity receiving the frame.

With-Invalid-ReqSeq—The ReqSeq of the received frame is not in the range ExpectedAckSeq ≤ ReqSeq < NextTxSeq.

With-Invalid-ReqSeq-Retrans—The ReqSeq of the received frame is not in the range ExpectedAckSeq ≤ ReqSeq < NextTxSeq.

Not-With-Expected-TxSeq—The TxSeq of the received I-frame is within the TxWindow of the L2CAP entity receiving the frame but is not equal to ExpectedTxSeq. It is either unexpected or a duplicate.

With-Expected-TxSeq-Srej—The TxSeq of the received I-frame is equal to the TxSeq at the head of SrejList.

SendRej = TRUE or FALSE—TRUE indicates that a REJ will be sent after all frames requested using SREJ have been received.

SrejList = or > 1—Determine if the number of items in SrejList is equal to or greater than 1.

With-Unexpected-TxSeq-Srej—The TxSeq of the received I-frame is equal to one of the values stored in SrejList but is not the TxSeq at the head. This indicates that one or more I-frames requested using SREJ are missing either because the SREJ was lost or the requested I-frame(s) were lost. Either way the SREJ frames must be resent to retrieve the missing I-frames.

With-duplicate-TxSeq-Srej—The TxSeq of the received I-frame is equal to a TxSeq of one of the saved I-frames indicating it is a duplicate.

8.6.5.6 Actions

Send-Data—This action is executed as a result of a Data-Request event. The number of I-frames sent without being acknowledged shall not exceed the TxWindow size of the receiving L2CAP entity (UnackedFrames is less than or equal to the remote L2CAP entity's TxWindow). Any I-frames that cannot be sent because they would exceed the TxWindow size are queued for later transmission. For each I-frame the following actions shall be carried out:

```
Send I-frame with TxSeq set to NextTxSeq and ReqSeq set
to BufferSeq.
UnackedList[NextTxSeq] := I-frame
UnackedFrames := UnackedFrames + 1
FramesSent := FramesSent + 1
RetryIframes[NextTxSeq] := 1
NextTxSeq := (NextTxSeq + 1) mod MaxTxWin
Start-RetransTimer
```

Pend-Data—This action is executed as a result of a Data-Request when it is not possible to send I-frames because the window is full, the remote L2CAP entity is in a busy condition or the local L2CAP entity is not in a state where I-frames can be sent (e.g. WAIT_F). The I-frame(s) are queued for later transmission.

Process-ReqSeq—the ReqSeq contained in the received frame shall acknowledge previously transmitted I-frames. ExpectedAckSeq shall be set to ReqSeq to indicate that the I-frames with TxSeq up to and including (ReqSeq—1) have been acknowledged. The acknowledged I-frames shall be removed from UnackedList, the retry counters for each acknowledged frame shall be set to 0 and the number of acknowledged frames shall be subtracted from UnackedFrames so that UnackedFrames shall contain the number of the remaining unacknowledged I-frames. Pending I-frames are now available to be

transmitted by the Send-Ack action. If UnackedFrames equals 0 then Stop-RetransTimer.

Send RR, RNR (P=x) or (F=x)—Send the specified S-frame with the specified value for the P-bit or F-bit. If a value for the P-bit or F-bit is not specified the value shall be 0. For example Send RR(P=1) means send an RR with the P-bit set to 1 and the F-bit set to 0. The ReqSeq field shall be set to BufferSeq. If an RNR is sent, RNRsent shall be set to TRUE.

Send REJ (P =x) or (F=x)—Send a REJ with the specified value for the P-bit or F-bit. The ReqSeq field shall be set to ExpectedTxSeq. If a value for the P-bit or F-bit is not specified the value shall be 0. Note that this will acknowledge previously received I-frames up to ExpectedTxSeq—1 and may allow the remote L2CAP entity to transmit new I-frames. If the local L2CAP entity is not in a position to acknowledge the previously received I-frames it may use SREJ(P=0) or RNR. It may also wait to send the REJ until it is able to acknowledge the I-frames.

Send RRorRNR (P=x) or (F=1)—Send an RR or RNR with the specified value for the P-bit or F-bit based on the value of LocalBusy. If a value for the P-bit or F-bit is not specified the value shall be 0. An RNR shall be sent if LocalBusy equals TRUE. If LocalBusy equals FALSE then an RR shall be sent.

Send IorRRorRNR(F=1)—Send I-frames, an RR or an RNR with the F-bit set to 1. The following algorithm shall be used:

```
FramesSent:=0
if LocalBusy = TRUE then {
    Send RNR(F=1)
}
if RemoteBusy = TRUE and UnackedFrames > 0 then {
    Start-RetransTimer
}
RemoteBusy := FALSE
Send-Pending-I-frames(see note)
if LocalBusy = FALSE and FramesSent = 0 then {
     Send RR(F=1)
}
```

Note: The SendIorRRorRNR(F=1) sends frames by invoking other actions. During the execution of SendIorRRorRNR multiple actions may be invoked. The first action invoked shall send the first or only frame with the F-bit set to 1. All other frames sent shall have the F-bit set to 0.

Send SREJ—Send one or more SREJ frames with P=0. For each missing I-frame starting with ExpectedTxSeq up to but not including the TxSeq of the

received I-frame, an SREJ frame is sent with ReqSeq set to the TxSeq of the missing frame. The TxSeq is inserted into the tail of SrejList. For example if ExpectedTxSeq is 3 and the received I-frame has a TxSeq of 5 there are two missing I-frames. An SREJ with ReqSeq 3 is sent followed by an SREJ with ReqSeq 4. TxSeq 3 is inserted first into SrejList followed by TxSeq 4. After all SREJ frames have been sent ExpectedTxSeq shall be set to the TxSeq of the received I-frame + 1 mod MaxTxWin.

Send SREJ(SrejList)—Send one or more SREJ frames with P=0. An I-frame was received that matches one of the TxSeq values in the SrejList but does not match the head of SrejList. This means I-frames requested via SREJ are still missing. For each TxSeq value starting with the head of SrejList and going backwards (i.e., from the head towards the tail) through the SrejList up to but not including the TxSeq of the received frame, an SREJ frame is sent with ReqSeq set to the TxSeq from SrejList. The TxSeq is removed from SrejList and reinserted into the tail of SrejList. Finally, remove the TxSeq of the received frame from the head of the list.

Send SREJ(SrejList-tail)(F=1)—Send a SREJ frame with F=1 and ReqSeq equal to the TxSeq at the tail of SrejList.

Start-RetransTimer—If the Monitor timer is not running then start the Retransmission Timer from its initial value (see Retransmission time-out in Section 5.4). If the Retransmission timer is already running it is restarted from its initial value. If the Monitor timer is running then the Retransmission timer is not started.

Start-MonitorTimer—Start the Monitor Timer from its initial value (see Monitor time-out in Section 5.4). If the timer is already running it is restarted from its initial value.

PassToTx—Pass the ReqSeq and F-bit value of a received frame to the Transmitter state machine. This will show up as a Recv ReqSeqAndFbit event in the Transmitter state machine.

PassToTxFbit—Pass the F-bit value of a received frame to the Transmitter state machine. This will show up as a Recv Fbit event in the Transmitter state machine.

Data-Indication—A received I-frame is passed to the SDU reassembly function. For the purpose of the state machine this operation is completed immediately so the Send_Ack action should be executed as one of the next actions. In some cases the SDU reassembly function cannot accept the I-frame so the I-frame will be stored within the L2CAP Entity consuming a portion of its TxWindow. When the I-frame is pulled by the SDU reassembly function the Send_Ack action should be executed. Before the Send_Ack action is executed BufferSeq is advanced as follows:

```
BufferSeq := (BufferSeq + 1) mod MaxTxWin
```

Increment-ExpectedTxSeq—ExpectedTxSeq is incremented as follows:

```
ExpectedTxSeq := (ExpectedTxSeq + 1) mod MaxTxWin
```

Stop-RetransTimer—the Retransmission timer is stopped.

Stop-MonitorTimer —the Monitor timer is stopped.

Send-Ack (F=x)—an acknowledgment with the specified value for the F-bit may be sent. Note that this action may occur in an action block with other actions that also send frames. If a frame has already been sent then it is not necessary to send additional frames. If the value for the F-bit is not specified it shall be set to 0. If the value specified is P then the F-bit shall be set equal to the value of the P-bit of the received frame being acknowledged. If more than one frame is sent in the acknowledgment only the first frame shall have an F-bit set to 1. An acknowledgment is an RR, RNR, or pending I-frame(s) (I-frames that have not been transmitted yet). If pending I-frames are available and are allowed to be sent then as many as allowed should be sent as an acknowledgment. Sending an RR or RNR as an acknowledgment for each received I-frame is not required. An implementation may wait to send an RR or RNR until a specific number of I-frames have been received, after a certain period of time has elapsed or some other algorithm. To keep data flowing it is recommended that an acknowledgment be sent before the TxWindow is full. It should also be noted that the maximum size of a remote L2CAP entity's unacknowledged I-frame list may be smaller than the local L2CAP entity's TxWindow. Therefore the local L2CAP entity should not expect the remote L2CAP entity to send enough frames to fill its TxWindow and should acknowledge I-frames accordingly. The following algorithm shall be used when sending an acknowledgment.

```
if LocalBusy == TRUE then {
    Send_RNR(F=x)
}
else if (RemoteBusy == FALSE) and Pending I-frames
Exist and RemWindow-Not-Full then {
    Send-Pending-I-frames (F=x)
}
else {
    Send_RR (F=x)
}
```

InitSrej—Initialize the variables used for processing SREJ as follows:

```
Clear SrejList - (remove all values)
SendRej := FALSE
BufferSeqSrej := BufferSeq
```

SaveIframeSrej—Save the received I-frame. Missing I-frame(s) will be retransmitted in response to SREJ frames. Implementations may want to save

the I-frame in its proper sequence order by leaving room for the missing I-frames.

StoreOrIgnore—If the local L2CAP entity has room to store the received I-frame then it may store it otherwise it shall discard it. If the received I-frame is stored, ExpectedTxSeq is advanced as follows:

```
ExpectedTxSeq := (ExpectedTxSeq + 1) mod MaxTxWin
```

PbitOutstanding—If the Transmitter state machine of the local L2CAP entity is in the WAIT_F state then return TRUE otherwise return FALSE.

Retransmit-I-frames—All the unacknowledged I-frames starting with the I-frame with TxSeq equal to the ReqSeq field of the received S-frame (REJ or RR) is retransmitted. If the P-bit of the received S-frame is 1 then the F-bit of the first I-frame sent shall be 1. If the P-bit of the received S-frame is 0 then the F-bit of the first I-frame sent shall be 0. The F-bit of all other unacknowledged I-frames sent shall be 0. The retry counter in RetryIframes[] for each retransmitted I-frame is incremented by 1. If a retry counter in RetryIframes[] is equal to MaxTransmit then the channel shall be closed. FramesSent shall be incremented by 1 for each frame sent. If the RetransTimer is not already running then perform the Start-RetransTimer action.

Retransmit-Requested-I-frame—The unacknowledged I-frame with TxSeq equal to the ReqSeq field of the received S-frame (SREJ) is retransmitted. If the P-bit of the received S-frame is 1 then the F-bit of the retransmitted I-frame shall be 1. If the P-bit of the received S-frame is 0 then the F-bit of the retransmitted I-frame shall be 0. The retry counter in RetryIframes[] corresponding to the retransmitted I-frame is incremented by 1. If the RetransTimer is not already running then perform the Start-RetransTimer action.

Send-Pending-I-frames (F=x)—If PbitOutstanding equals FALSE then send all pending I-frames that can be sent without exceeding the receiver's TxWindow using the Send-Data action. If a value for the F-bit is specified then the F-bit of the first I-frame sent shall be set to the specified value and the F-bit of all other I-frames sent shall be set to 0. If no value for the F-bit is specified then all I-frames sent shall have the F-bit set to 0. Pending I-frames are I-frames that have been given to the L2CAP entity by the upper layer but have not yet been transmitted. If one or more I-frames are sent and the RetransTimer is not already running then perform the Start-RetransTimer action.

Close Channel—Close the L2CAP channel as described in Section 4.6.

Ignore—the event may be silently discarded.

PopSrejList—Remove and discard the TxSeq from the head of SrejList.

Data-IndicationSrej—If the received I-frame fills a gap in a sequence of saved I-frames then all the saved I-frames in the sequence are passed to the SDU reassembly function. For the purpose of the state machine this operation is completed immediately. For example if the TxSeq of saved I-frames before receiving an I-frame is 2, 3, 5, 6, 9 and the received I-frame has a TxSeq of 4 then it fills the gap between 3 and 5 so the sequence 2, 3, 4, 5, 6 can be passed to the SDU reassembly function. When the I-frames are actually removed from the L2CAP entity receive buffers either by being processed immediately or when pulled by the SDU reassembly function, BufferSeqSrej is advanced as follows:

```
BufferSeqSrej := (BufferSeqSrej + 1) mod MaxTxWin
```

8.6.5.7 XMIT State Table

Event	Condition	Action	Next State
Data-Request	RemoteBusy = FALSE **and** RemWindow-Not-Full	Send-Data	XMIT
Data-Request	RemoteBusy = TRUE **or** RemWindow-Full	Pend-Data	XMIT
Local-Busy-Detected		LocalBusy := TRUE	XMIT
		LocalBusy := TRUE Send RNR	XMIT
Local-Busy-Clear	RNRsent = TRUE	LocalBusy := FALSE RNRsent := FALSE Send RR(P=1) RetryCount := 1 Stop-RetransTimer Start-MonitorTimer	WAIT_F
Local-Busy-Clear	RNRsent = FALSE	LocalBusy := FALSE RNRsent := FALSE	XMIT
Recv ReqSeqAndFbit		Process-ReqSeq	XMIT
Recv Fbit			XMIT
RetransTimer-Expires		Send RRorRNR(P=1) RetryCount := 1 Start-MonitorTimer	WAIT_F

Table 8.4: XMIT state table

8.6.5.8 WAIT_F State Table

Event	Condition	Action	Next State
Data-Request		Pend-Data	WAIT_F
Recv ReqSeqAndFbit	F = 1	Process-ReqSeq Stop-MonitorTimer **If** UnackedFrames > 0 **then {** Start-RetransTimer **}**	XMIT
Recv ReqSeqAndFbit	F = 0	Process-ReqSeq	WAIT_F
Recv Fbit	F = 1	Stop-MonitorTimer **If** UnackedFrames > 0 **then {** Start-RetransTimer **}**	XMIT
Recv Fbit	F = 0		WAIT_F
MonitorTimer-Expires	RetryCount < Max-Transmit	RetryCount := RetryCount+1 Send RRorRNR(P=1) Start-MonitorTimer	WAIT_F
MonitorTimer-Expires	RetryCount ≥ Max-Transmit	Close Channel	

Table 8.5: WAIT_F State Table

8.6.5.9 RECV State Table

Event	Condition	Action	Next State
Recv I-frame (F=0)	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** LocalBusy = FALSE	Increment-ExpectedTxSeq PassToTx Data-Indication Send-Ack(F=0)	RECV
Recv I-frame (F=1)	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** LocalBusy = FALSE	Increment-ExpectedTxSeq PassToTx Data-Indication **If** RejActioned = FALSE **then {** Retransmit-I-frames Send-Pending-I-frames **} else {** RejActioned := FALSE **}** Send-Ack(F=0)	RECV
Recv I-frame	With-duplicate-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** LocalBusy = FALSE	PassToTx	RECV
Recv I-frame	With-unexpected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** LocalBusy = FALSE	PassToTx SendREJ	REJ_SENT
		PassToTx InitSrej SaveIframeSrej SendSREJ	SREJ_SENT
Recv I-frame	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** LocalBusy = TRUE	PassToTx StoreOrIgnore	RECV
Recv I-frame	With-Valid-ReqSeq **and** Not-With_Expect-ed_TxSeq **and** With-Valid-F-bit **and** LocalBusy = TRUE	PassToTx	RECV
Recv RNR (P=0)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := TRUE PassToTx Stop-RetransTimer	RECV

Table 8.6: RECV_State table

Event	Condition	Action	Next State
Recv RNR (P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := TRUE PassToTx Stop-RetransTimer Send RRorRNR (F=1)	RECV
Recv RR(P=0)(F=0)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx **If** RemoteBusy = TRUE **and** UnackedFrames > 0 **then {** Start-RetransTimer **}** RemoteBusy := FALSE Send-Pending-I-frames	RECV
Recv RR(F=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned := FALSE **}** Send-Pending-I-frames	RECV
Recv RR(P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx Send IorRRorRNR(F=1)	RECV
Recv REJ (F=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-I-frames Send-Pending-I-frames **If** PbitOutstanding **then {** RejActioned := TRUE **}**	RECV
Recv REJ (F=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned :=FALSE **}** Send-Pending-I-frames]	RECV

Table 8.6: RECV_State table (Continued)

Event	Condition	Action	Next State
Recv SREJ (P=0) (F=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit Retransmit-Requested-I-frame **If** PbitOutstanding **then {** SrejActioned := TRUE SrejSaveReqSeq = ReqSeq **}**	RECV
Recv SREJ (P=0) (F=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit **If** SrejActioned = TRUE **and** SrejSaveReqSeq = ReqSeq **then {** SrejActioned := FALSE **} else {** Retransmit-Requested-I-frame **}**	RECV
Recv SREJ(P=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-Requested-I-frame Send-Pending-I-frames **If** PbitOutstanding **then {** SrejActioned = TRUE SrejSaveReqSeq := ReqSeq **}**	RECV
Recv REJ	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	
RECV SREJ	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] >= Max-Transmit	Close Channel	
Recv I-frame	(With-Invalid-TxSeq **and** TxWindow >(MaxTxWin/2) **or** With-Invalid-ReqSeq	Close Channel	
Recv I-frame	With-Invalid-TxSeq **and** TxWindow ≤ (MaxTx-Win/2)	Close Channel Ignore	 RECV
Recv RRorRNR	With-Invalid-ReqSeq	Close Channel	

Table 8.6: RECV_State table (Continued)

Event	Condition	Action	Next State
Recv REJorSREJ	With-Invalid-ReqSeq-Retrans	Close Channel	
Recv frame		Ignore	RECV

Table 8.6: RECV_State table (Continued)

8.6.5.10 REJ_SENT State Table

Event	Condition	Action	Next State
Recv I-frame (F=0)	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit	Increment-ExpectedTxSeq PassToTx Data-Indication Send-Ack (F=0)	RECV
Recv I-frame (F=1)	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit	Increment-ExpectedTxSeq PassToTx Data-Indication **If** RejActioned = FALSE **then {** Retransmit I-frames Send-Pending-I-frames **} else {** RejActioned := FALSE **}** Send-Ack (F=0)	RECV
Recv I-frame	With-Unexpected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx	REJ_SENT
Recv RR (F=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned := FALSE **}** Send-Pending-I-frames	REJ_SENT

Table 8.7: REJ_SENT State table

Event	Condition	Action	Next State
Recv RR (P=0)(F=0)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx **If** RemoteBusy = TRUE **and** UnackedFrames > 0 **then {** Start-RetransTimer **}** RemoteBusy := FALSE Send-Ack (F=0)	REJ_SENT
Recv RR (P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx **If** RemoteBusy = TRUE **and** UnackedFrames > 0 **then {** Start-RetransTimer **}** RemoteBusy := FALSE Send RR (F=1)	REJ_SENT
Recv RNR (P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := TRUE PassToTx Send RR (F=1)	REJ_SENT
Recv RNR (P=0)	With-Valid-ReqSeq and With-Valid-F-bit	RemoteBusy := TRUE PassToTx Send RR (F=0)	REJ_SENT
Recv REJ (F=0)	With-Valid-ReqSeq - Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-I-frames Send-Pending-I-frames **If** PbitOutstanding **then {** RejActioned := TRUE **}**	REJ_SENT
Recv REJ (F=1)	With-Valid-ReqSeq - Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned := FALSE **}** Send-Pending-I-frames	REJ_SENT

Table 8.7: REJ_SENT State table (Continued)

Event	Condition	Action	Next State
Recv SREJ (P=0) (F=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit Retransmit-Requested-I-frame **If** PbitOutstanding **then {** SrejActioned := TRUE SrejSaveReqSeq := ReqSeq **}**	REJ_SENT
Recv SREJ (P=0) (F=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit **If** SrejActioned = TRUE **and** SrejSaveReqSeq = ReqSeq **then {** SrejActioned := FALSE **} else {** Retransmit-Requested-I-frame **}**	REJ_SENT
Recv SREJ (P=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-Requested-I-frames Send-Pending-I-frames **If** PbitOutstanding **then {** SrejActioned := TRUE SrejSaveReqSeq := ReqSeq **}**	REJ_SENT
Recv REJ	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	
Recv SREJ (P=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	
RECV SREJ (P=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	

Table 8.7: REJ_SENT State table (Continued)

Event	Condition	Action	Next State
Recv I-frame	(With-Invalid-TxSeq **and** TxWindow > (MaxTx-Win/2)) **or** With-Invalid-ReqSeq	Close Channel	
Recv RRorRNR	With-Invalid-ReqSeq	Close Channel	
RecvREJorSREJ	With-Invalid-ReqSeq-Retrans	Close Channel	
Recv I-frame	With-Invalid-TxSeq	Close Channel	
	and TxWindow ≤ (MaxTx-Win/2) **and** With-Valid-ReqSeq	Ignore	REJ_SENT
Recv frame		*Ignore*	REJ_SENT

Table 8.7: REJ_SENT State table (Continued)

8.6.5.11 SREJ_SENT State Table

Event	Condition	Action	Next State
Recv I-frame	With-Expected-TxSeq-Srej **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** SendRej = FALSE **and** SrejList = 1	SaveIframeSrej PopSrejList PassToTx Data-IndicatioSrej BufferSeq := BufferSeqSrej Send-Ack (F=0)	RECV
Recv I-frame	With-Expected-TxSeq-Srej **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** SendRej = TRUE **and** SrejList = 1	SaveIframeSrej PopSrejList PassToTx Data-IndicationSrej BufferSeq := BufferSeqSrej Send REJ	REJ_SENT
Recv I-frame	With-Expected-TxSeq-Srej **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** SrejList > 1	SaveIframeSrej PopSrejList PassToTx Data-IndicationSrej	SREJ_SENT
Recv I-frame	With-Expected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit	SaveIframeSrej Increment-ExpectedTxSeq PassToTx	SREJ_SENT
Recv I-frame	With-Unexpected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** SendRej = FALSE	SaveIframeSrej PassToTx Send SREJ	SREJ_SENT
		PassToTx SendRej := TRUE	SREJ_SENT
Recv I-frame	With-Unexpected-TxSeq **and** With-Valid-ReqSeq **and** With-Valid-F-bit **and** SendRej = TRUE	PassToTx	SREJ_SENT
Recv I-frame	With-Unexpected-TxSeq-Srej **and** With-Valid-ReqSeq **and** With-Valid-F-bit	SaveIframeSrej PassToTx Send SREJ(SrejList)	SREJ_SENT

Table 8.8: SREJ_SENT State Table

Event	Condition	Action	Next State
Recv I-frame	With-duplicate-TxSeq-Srej **and** With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx	SREJ_SENT
Recv RR(F=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned := FALSE **}** Send-Pending-I-frames	SREJ_SENT
Recv RR(P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx **If** RemoteBusy = TRUE **and** UnackedFrames > 0 **then {** Start-RetransTimer **}** RemoteBusy := FALSE Send SREJ(SrejList-tail)(F=1)	SREJ_SENT
Recv RR(P=0)(F=0)	With-Valid-ReqSeq **and** With-Valid-F-bit	PassToTx **If** RemoteBusy = TRUE **and** UnackedFrames > 0 **then {** Start-RetransTimer **}** RemoteBusy := FALSE Send-Ack(F=0)	SREJ_SENT
Recv RNR(P=1)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := TRUE PassToTx Send SREJ(SrejList-tail)(F=1)	SREJ_SENT
Recv RNR(P=0)	With-Valid-ReqSeq **and** With-Valid-F-bit	RemoteBusy := TRUE PassToTx Send RR(F=0)	SREJ_SENT
Recv REJ (F=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-I-frames Send-Pending-I-frames **If** PbitOutstanding **then {** RejActioned := TRUE **}**	SREJ_SENT

Table 8.8: SREJ_SENT State Table (Continued)

Event	Condition	Action	Next State
Recv REJ (F=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < Max-Transmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx **If** RejActioned = FALSE **then {** Retransmit-I-frames **} else {** RejActioned := FALSE **}** Send-Pending-I-frames	SREJ_SENT
Recv SREJ(P=0) (F=0)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < MaxTransmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit Retransmit-Requested-I-frame **If** PbitOutstanding **then {** SrejActioned := TRUE SrejSaveReqSeq = ReqSeq **}**	SREJ_SENT
Recv SREJ(P=0) (F=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < MaxTransmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTxFbit **If** SrejActioned = TRUE **and** SrejSaveReqSeq = ReqSeq **then {** SrejActioned := FALSE **} else {** Retransmit-Requested-I-frame **}**	SREJ_SENT
Recv SREJ(P=1)	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] < MaxTransmit **and** With-Valid-F-bit	RemoteBusy := FALSE PassToTx Retransmit-Requested-I-frame Send-Pending-I-frames **If** PbitOutstanding **then {** SrejActioned := TRUE SrejSaveReqSeq = ReqSeq **}**	SREJ_SENT
Recv REJ	With-Valid-ReqSeq-Retrans **and** RetryIframes[i] ≥ MaxTransmit	Close Channel	

Table 8.8: SREJ_SENT State Table (Continued)

Event	Condition	Action	Next State
Recv SREJ(P=0)	With-Valid-ReqSeqRe-trans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	
Recv SREJ(P=1)	With-Valid-ReqSeqRe-trans **and** RetryIframes[i] ≥ Max-Transmit	Close Channel	
Recv I-frame	(With-Invalid-TxSeq **and** TxWindow > (Max-TxWin/2) or With-Invalid-ReqSeq	Close Channel	
Recv RRor-RNR	With-Invalid-ReqSeq	Close Channel	
Recv REJorSREJ	With-Invalid-ReqSeq-Retrans	Close Channel	
Recv I-frame	With-Invalid-TxSeq **and** TxWindow ≤ (Max-TxWin/2)	Close Channel	
		Ignore	SREJ_SENT
Recv frame	-	Ignore	SREJ_SENT

Table 8.8: SREJ_SENT State Table (Continued)

8.7 STREAMING MODE

When a link is configured to work in Streaming Mode, the frame format for outgoing data is the same as for Enhanced Retransmission mode but frames are not acknowledged. Therefore

- RR, REJ, RNR and SREJ frames shall not be used in Streaming Mode.
- The F-bit shall always be set to zero in the transmitter, and shall be ignored in the receiver.
- the MonitorTimer and RetransmissionTimer shall not be used in Streaming mode.

A channel configured to work in Streaming mode shall be configured with a finite value for the Flush Timeout on the transmitter.

8.7.1 Transmitting I-frames

When transmitting a new I-frame the control field parameter ReqSeq shall be set to 0, TxSeq shall be set to NextTXSeq and NextTXSeq shall be incremented by one.

8.7.2 Receiving I-frames

Upon receipt of a valid I-frame with TxSeq equal to ExpectedTxSeq, the frame shall be made available to the reassembly function. ExpectedTxSeq shall be incremented by one.

Upon receipt of a valid I-frame with an out-of-sequence TxSeq (see Section 8.7.3.1) all frames with a sequence number less than TxSeq shall be assumed lost and marked as missing. The missing I-frames are in the range from ExpectedTxSeq (the frame that the device was expecting to receive) up to and including TxSeq - 1. ExpectedTxSeq shall be set to TxSeq +1. The received I-frame shall be made available for pulling by the reassembly function. The ReqSeq shall be ignored.

Note: It is possible for a complete window size of I-frames to be missing and thus, no missing I-frames are detected. For example, when a window size of 63 is used this situation occurs when 63 I-frames in a row are missing. If the ability to not detect missing I-frames will cause problems for an application, it is recommended that the Extended Window Size option be used.

If there is no buffer space for the received I-frame an existing I-frame (i.e. the oldest) shall be discarded (flushed) freeing up buffer space for the new I-frame. The discarded I-frame shall be marked as missing.

8.7.3 Exception Conditions

Exception conditions may occur as the result of physical layer errors or L2CAP procedural errors. The error recovery procedures which are available following the detection of an exception condition at the L2CAP layer in Streaming mode are defined in this section.

8.7.3.1 TxSeq Sequence error

A TxSeq sequence error exception condition occurs in the receiver when a valid I-frame is received which contains a TxSeq value which is not equal to the expected value, thus TxSeq is not equal to ExpectedTxSeq.

The out-of-sequence I-frame is identified by a TxSeq that is greater than ExpectedTxSeq (TxSeq > ExpectedTXSeq). The ReqSeq shall be ignored. The missing I-frame(s) are considered lost and ExpectedTXSeq is set equal to TxSeq+1 as specified in Section 8.7.2. The missing I-frame(s) are reported as lost to the SDU reassembly function.

9 PROCEDURE FOR AMP CHANNEL CREATION AND HANDLING

When an AMP is used, the procedures defined in this chapter shall be used. Enhanced Retransmission mode is used on all reliable channels to ensure a reliable move channel operation and to ensure that user traffic with an infinite flush timeout is reliable even for AMPs that do not support infinite flush timeout. Streaming mode is used on all channels configured with a finite flush timeout.

9.1 CREATE CHANNEL

Create Channel Request is used to create a new L2CAP channel over a Controller. The channel will have the quality of service specified by a pair of Extended Flow Specifications exchanged during channel configuration. Channels shall only be created over the BR/EDR Controller if both L2CAP entities support Extended Flow Specification for BR/EDR. After configuration each device will have an outgoing (transmit traffic) flow specification and an incoming (received traffic) flow specification. Note: Where Extended Flow Specification for BR/EDR is not supported by one or both L2CAP entities, an L2CAP channel can be established with Connection Request.

All Best Effort channels created over the same AMP Physical link are aggregated over a single AMP Logical link, so if a Best Effort channel is requested over an AMP Physical link where a Best Effort logical link already exists then the Best Effort Extended Flow Specifications are aggregated into one pair of flow specifications and the flow specification of the AMP Logical link is modified using the HCI Flow Spec Modify command (in devices that support HCI). Section 7.8 describes how Best Effort Flow specifications are aggregated. A logical link is created for each Guaranteed channel and one for the first Best Effort channel of the AMP.

All channels created over the same BR/EDR physical link are aggregated over a single logical link. Aggregation of Best Effort Extended Flow Specifications is not necessary for channels created over ACL-U logical links so the term “modify the logical link” in the algorithm descriptions results in “no action” when the logical link is ACL-U. The L2CAP layer should perform admission control for Guaranteed channels created on ACL-U logical links (see Section 7.10 for a description of L2CAP admission control). The term “create a logical link” in the algorithm description refers to L2CAP performing admission control when the logical link is ACL-U.

Basic Algorithm:

1. Extended Flow specifications and other configuration parameters shall be exchanged via the Lockstep Configuration procedure.
2. If the service type of the Extended Flow Specifications are Best Effort (including the case where one is Best Effort and the other is “No Traffic”) then the Best Effort Algorithm shall be used otherwise the Guaranteed Algorithm shall be used. (See Section 5.6 for rules on setting the service type of Extended Flow Specifications).

Best Effort Algorithm:

1. If one or more Best Effort channels already exist for the Controller then Goto step 3
2. Tell the Controller to create a logical link passing the Extended Flow Specifications. Goto step 5
3. Aggregate the Extended Flow Specifications with all the other Best Effort Extended Flow specifications running on the same physical link as described in Section 7.8.
4. Tell the Controller to modify the logical link passing the aggregated Extended Flow Specifications.
5. If the Controller accepts the create/modify request and returns success then complete the L2CAP Configuration with result = success otherwise complete the L2CAP configuration with result = “Failure - flow spec rejected”

Guaranteed Algorithm

1. Tell the Controller to create a logical link passing the Extended Flow Specifications.
2. If the Controller accepts the create request and returns success, complete the L2CAP Configuration with result = success; otherwise, complete the L2CAP configuration with result = “Failure - flow spec rejected.”

If the Controller is a BR/EDR or BR/EDR/LE Controller and the Extended Flow Specification type is Guaranteed then L2CAP should perform admission control by determining if the requested QoS can be achieved by the Controller without compromising existing Guaranteed channels running on the Controller.

An example of the creation of the first Best Effort channel or a guaranteed channel is shown in Figure 9.1. An example of creation of a subsequent Best Effort channel is shown in Figure 9.2.

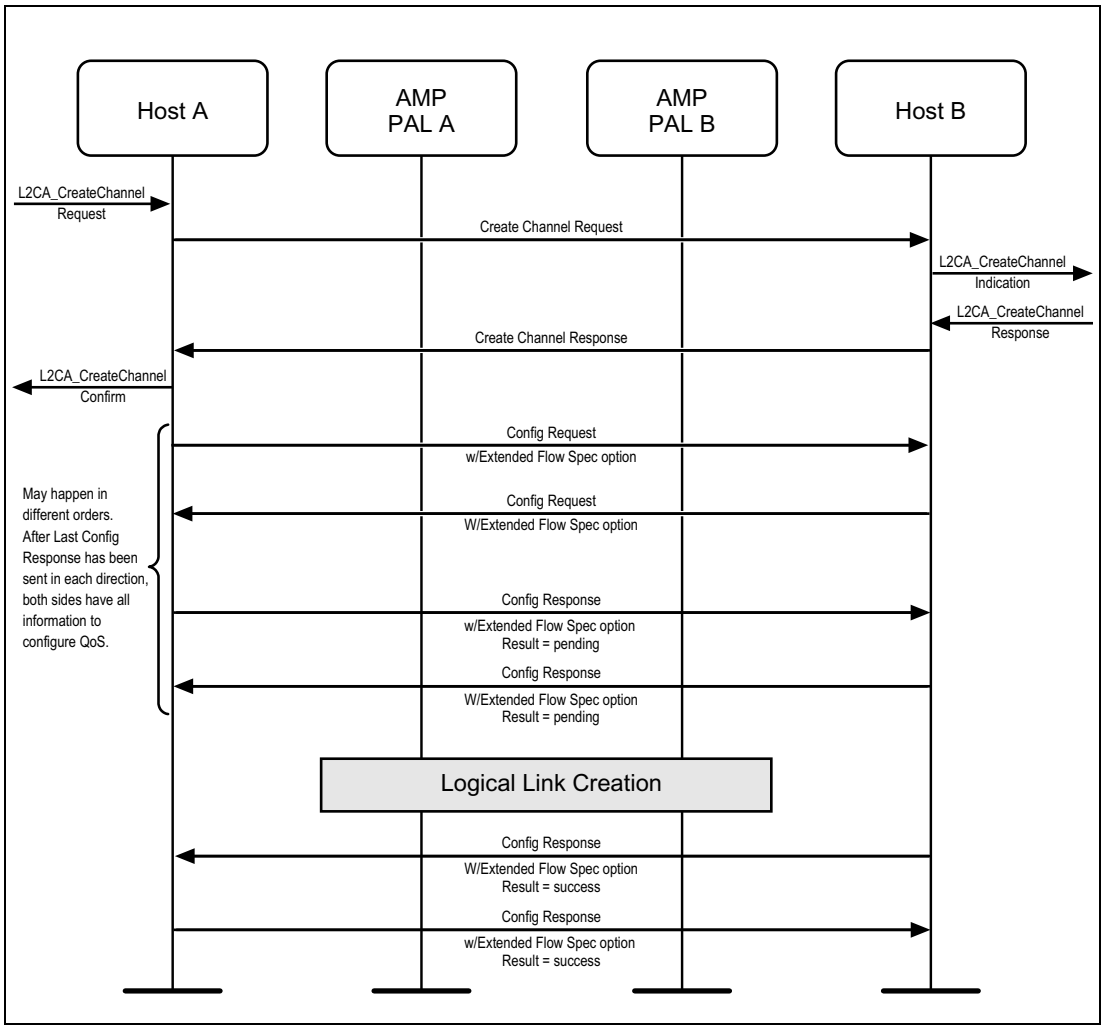


Figure 9.1: Creation of First Best Effort L2CAP channel or a Guaranteed L2CAP channel

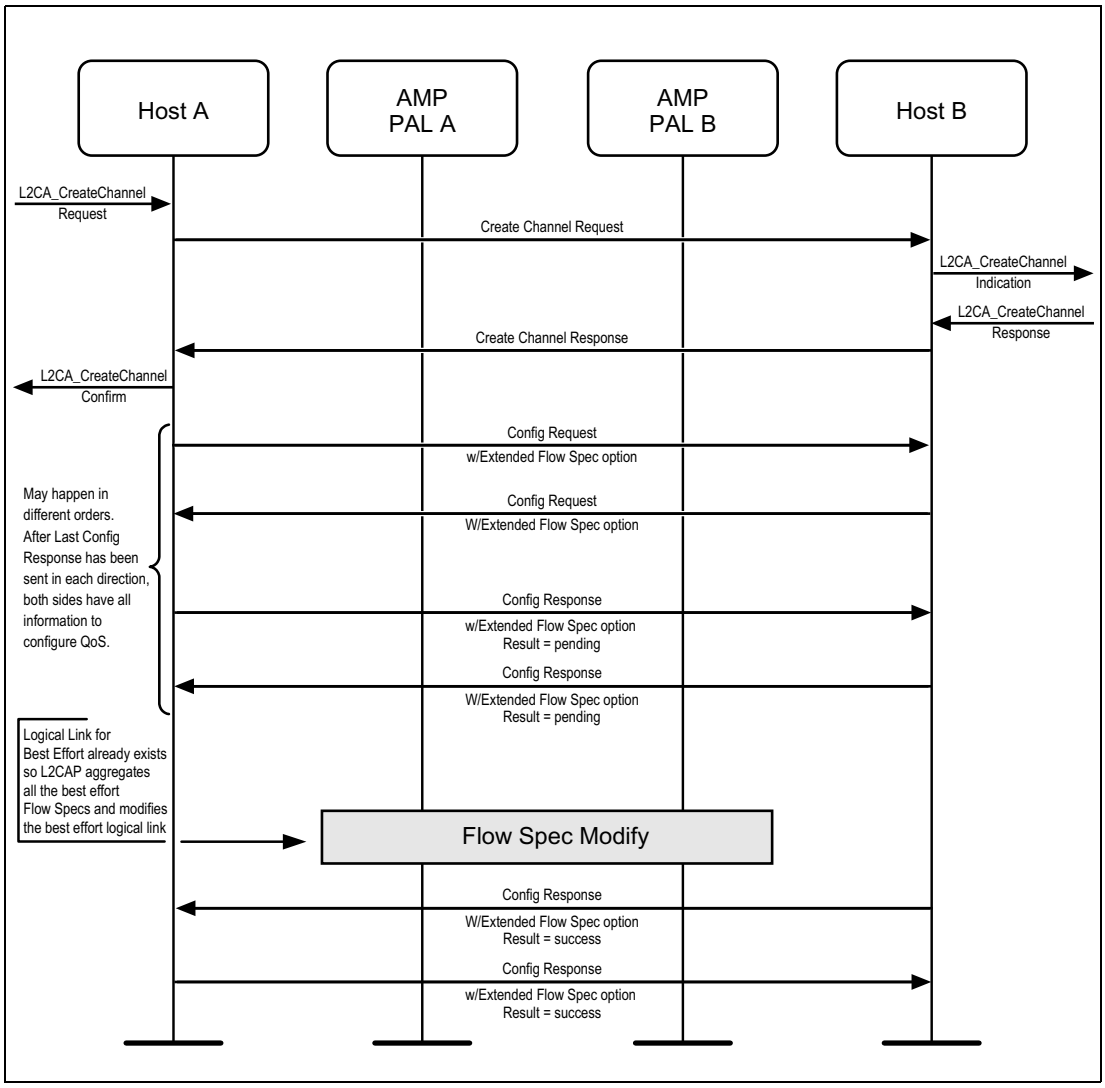


Figure 9.2: Creation of Subsequent Best Effort L2CAP channel

9.2 MOVE CHANNEL

Move Channel is used to move an L2CAP channel from one Controller to another. Moving a channel retains the existing channel configuration (MTU, QOS, etc.) and the CID. If reconfiguration is necessary then it may be done after a successful move channel operation. If a channel configured as Best Effort is moved, the Extended Flow Specification aggregate shall be recalculated (see Section 7.8 for the aggregation algorithm) for both the old and new Controllers in cases where an aggregate already exists or where a channel is moved to a Controller with an existing Best Effort channel. If the Extended Flow Specification aggregate are modified for a Controller then a logical link modify operation shall be performed for that Controller.

The two procedures for moving channels are based on the mode configured for the channel. One procedure is used for channels configured with Enhanced

Retransmission mode. Another procedure is used for channels configured with Streaming mode. The procedures are described in the following sections.

Note that the terms such as “logical link create” and “logical link modify” are used in the Move procedures. For AMP Controllers these terms refer to logical link operations (e.g. QoS admission control) performed by the Controller. For BR/EDR and BR/EDR/LE Controllers these terms refer to QoS admission control performed by L2CAP on behalf of the Controller.

9.2.1 Move Channel Protocol Procedure with Enhanced Retransmission Mode

1. When the L2CAP layer on the initiating device receives the L2CA_Move_Channel.request from the upper layer (application) it shall stop sending I-frames and S-frames. It shall continue to listen on the old Controller and follow the procedures in Section 9.2.1.1. The L2CAP layer on the initiating device shall send the Move Channel Request packet over the L2CAP signaling channel to the remote (responding) device.
2. When the L2CAP layer on the responding device receives the Move Channel Request packet it shall stop sending I-frames and S-frames. It shall still listen on the old Controller and follow the procedures in Section 9.2.1.1. It shall send a Move Channel Response packet to the other side. If a logical link must be created or modified (or admission control is required) the Move Channel Response packet shall contain a result code of “pending.” If a logical link does not need to be created or modified and the move operation is allowed then the Move Channel Response packet shall contain a result code of “success.” Otherwise, it shall contain the appropriate “refused” result code. If the response code sent in the Move Channel Response packet is “pending” then the L2CAP layer on the responding device shall attempt to create or modify a logical link on the new Controller for the channel. When the logical link create/modify operation is complete, the L2CAP layer on the responding device shall send a Move Channel Response packet to the other side with the result code indicating the success/failure of the logical link create/modify.
3. When the L2CAP layer on the initiating device receives the Move Channel Response packet it shall check the result code. If the result code in the Move Channel Response packet is “refused” it shall send a Move Channel Confirmation packet with result code “failure” to the other side. If the result code in the Move Channel Response packet is “pending” or “success” the L2CAP layer shall stop listening on the old Controller and attempt to create/modify a logical link on the new Controller for the channel. If the result code in the Move Channel Response packet is “pending” then it shall use the ERTX timer while waiting for a Move Channel Response packet with a “non-pending” result code from the responding device. When the logical link create/modify operation is complete and the L2CAP layer on the initiating

device has received a Move Channel Response packet from the responding device with a “non-pending” result code, it shall send a Move Channel Confirmation packet to conclude the Move Channel procedure. The result code in the Move Channel Confirmation packet indicates the success/failure of its own logical channel create/modify operation and the result code in the Move Channel Response packet from the responding device. If both are success then the result code sent in the Move Channel Confirmation packet shall be “success” otherwise it shall be “failure.”

4. When the L2CAP layer on the responding device receives the Move Channel Confirmation packet it shall send a Move Channel Confirmation Response and send an L2CA_Move_Channel_Confirm.indication to the upper layer with the result code contained in the Move Channel Confirmation packet. If the result code of the Move Channel Confirmation is success the L2CAP layer on the responding device shall listen on the new Controller if the result code is failure then it shall listen on the old Controller.
5. When the L2CAP layer on the initiating device receives the Move Channel Confirmation response packet it shall send an L2CAP_Move_Channel.confirm to the upper layer with the result code passed in the Move Channel Confirmation packet. If the result code sent in the Move Channel Confirmation packet is success then the L2CAP layer on the initiating device shall send an RR(P=1) on the new Controller and shall start listening on the new Controller. Before sending the RR(P=1) the L2CAP layer on the initiating device may initiate reconfiguration by sending a Configuration Request packet. If the result sent is failure then the L2CAP layer on the initiating device shall send an RR(P=1) on the old Controller and start listening on the old Controller.
6. When the L2CAP layer on the responding device receives the RR(P=1) packet it shall send an I-frame(F=1) with a TxSeq matching the ReqSeq in the RR(P=1) or an RR(F=1) if there are no I-frames to send. If the I-frame is a retransmission and the PDU size used for the new Controller is smaller than the PDU size used for the old Controller, the responding device shall segment the retransmitted I-frame to make it fit in the new PDU size. If the L2CAP layer on the responding device receives a Configuration Request packet before the RR(P=1) it shall perform reconfiguration. When the reconfiguration is complete it shall wait for the RR(P=1). If the L2CAP layer on the responding device desires to perform reconfiguration but receives the RR(P=1) it may send a Configuration Request packet instead of the RR(F=1) or I-frame(F=1) to initiate reconfiguration. After the reconfiguration is complete it shall send the RR(F=1) or I-frame(F=1).

7. When the L2CAP layer on the initiating device receives the I-frame(F=1) or RR(F=1) from the responding device, the move is complete. If it receives a Configuration Request packet before receiving the RR(F=1) or I-frame(F=1) it shall perform reconfiguration. When reconfiguration is complete it shall wait for the RR(F=1) or I-frame(F=1).

9.2.1.1 Enhanced Retransmission Mode Procedures During a Move Operation

1. Stop sending I-frames and S-frames and cancel all timers. Set the transmitter to the XMIT state and clear all retry counters.
2. Clear or reset any SREJ_SENT and REJ_SENT state specific variables including flushing any received out-of-sequence I-frames saved as part of being in the SREJ_SENT state. Set the receiver to the RECV state.
3. Process received I-frames in the RECV state including processing the ReqSeq and passing completed SDUs to the upper layer. Only process the ReqSeq of received S-frames. Do not change state.
4. Ignore all out-of-sequence I-frames keeping note of the TxSeq of the last in-sequence I-frame received.
5. If the initiating device is in a local busy condition then it should wait to send the Move Channel Confirmation packet until the local busy condition has cleared. If the responding device is in a local busy condition then it should send a Move Channel Response packet with result “pending” upon receiving the Move Channel Request packet and wait until the local busy condition is cleared before sending a Move Channel Response packet with a “non-pending” result.
6. The ReqSeq of the RR(P=1) sent by the initiating device shall be set to the TxSeq of the next I-frame after the last in-sequence I-frame received (noted in step 4). The ReqSeq of the RR(F=1) or I-frame(F=1) sent by the responding device shall be set to the TxSeq of the next frame after the last in-sequence I-frame received (noted in step 4).
7. The new Controller or HCI transport may require smaller PDU size than the old Controller. If this is the case then the L2CAP layer shall segment all retransmitted I-frames to fit the new PDU size.
8. After sending the RR(P=1) the initiating device should start the Monitor Timer and go to the WAIT_F state.
9. Timers shall be stopped during channel reconfiguration and restarted when reconfiguration is complete.

9.2.2 Move Channel Protocol Procedure with Streaming Mode (Initiator is Data Source)

1. When the L2CAP layer on the initiating device (data source) receives the L2CA_Move_Channel.request it shall stop sending L2CAP PDUs. The L2CAP layer on the initiating device shall send a Move Channel Request packet over the L2CAP signaling channel to the remote (responding) device.
2. When the L2CAP layer on the responding device receives the Move Channel Request packet it shall still listen on the old Controller for receive frames (timing could be such that packets from the initiating device are still in transit). It shall pass completely received SDUs up to the upper layer. It shall send a Move Channel Response packet to the other side. If a logical link must be created (or admission control is required) the Move Channel Response packet shall contain a result code of “pending.” If a logical link does not need to be created and the move operation is allowed then the Move Channel Response packet shall contain a result code of “success.” Otherwise it shall contain the appropriate “refused” result code. If the response code sent in the Move Channel Response packet is “pending” then the L2CAP layer on the responding device shall attempt to create a logical link on the new Controller for the channel. When the logical link create operation is complete, the L2CAP layer on the responding device shall send a Move Channel Response packet to the other side with the result code indicating the success/failure of the logical link create operation. It shall continue to listen on the old Controller.
3. When the L2CAP layer on the initiating device receives the Move Channel Response packet it shall check the result code. If the result code in the Move Channel Response packet is “refused” it shall send a Move Channel Confirmation packet with result code “failure” to the other side. If the result code in the Move Channel Response packet is “pending” or “success” the L2CAP layer shall attempt to create a logical link on the new Controller for the channel. If the result code in the Move Channel Response packet is “pending” then it shall use the ERTX timer while waiting for a Move Channel Response packet with a “non-pending” result code from the responding device. When the logical link create operation is complete and it has received a Move Channel Response packet from the responding device with a “non-pending” result code it shall send a Move Channel Confirmation packet and wait for a Move Channel Confirmation response packet. The result code in the Move Channel Confirmation indicates the success/failure of its own logical link create operation and the result code in the Move Channel Response packet from the responding device. If both are success then the result code sent in the Move Channel Confirmation shall be success otherwise it shall be failure.

4. When the L2CAP layer on the responding device receives the Move Channel Confirmation packet it shall send a Move Channel Confirmation response packet and send an L2CA_Move_Channel_Confirm.indication to the upper layer with the result code passed in the Move Channel Confirmation packet. If the result code of the Move Channel Confirmation is success it shall listen on the new Controller. If the result code is failure it shall listen on the old Controller.
5. When the L2CAP layer on the initiating device receives the Move Channel Confirmation response packet it shall send an L2CAP_Move_Channel.confirm to the upper layer with the result code passed in the Move Channel Confirmation packet. If the result sent in the Move Channel Confirmation is success then the initiating device shall send I-frames for the channel on the new Controller otherwise it shall send I-frames for the channel on the old Controller.

9.2.3 Move Channel Protocol Procedure with Streaming Mode (Initiator is Data Sink)

1. When the L2CAP layer on initiating device (data sink) receives the L2CAP_Move_Channel.request it shall send a Move Channel Request packet over the L2CAP signaling channel to the remote (responding) device. It shall continue listening on the old Controller.
2. When the L2CAP layer on the responding device receives the Move Channel Request packet it shall stop sending L2CAP PDUs and send a Move Channel Response packet to the other side. If a logical link must be created (or admission control is required) the Move Channel Response packet shall contain a result code of “pending.” If a logical link does not need to be created and the move operation is allowed then the Move Channel Response packet shall contain a result code of “success.” Otherwise it shall contain the appropriate “refused” result code. If the result code sent in the Move Channel Response packet is “pending” then the L2CAP layer on the responding device shall attempt to create a logical link on the new Controller for the channel. When the logical link create operation is complete, the L2CAP layer on the responding device shall send a Move Channel Response packet to the other side with the result code indicating the success/failure of the logical link create.
3. When the L2CAP layer on the initiating device receives the Move Channel Response packet it shall check the result code. If the result code in the Move Channel Response packet is “refused” it shall send a Move Channel Confirmation packet with result code “failure” to the other side. If the result code in the Move Channel Response packet is “pending” or “success” the L2CAP layer shall attempt to create a logical link on the new Controller for the channel. If the result code in the Move Channel Response packet is “pending” then it shall use the ERTX timer while waiting for a Move Channel Response packet with

a “non-pending” result code from the responding device. When the logical link create operation is complete and it has received a Move Channel Response packet from the responding device with a “non-pending” result code it shall send a Move Channel Confirmation packet and wait for a Move Channel Confirmation response packet. The result code in the Move Channel Confirmation indicates the success/failure of its own logical link create operation and the result code in the Move Channel Response packet from the responding device. If both are success then the result code sent in the Move Channel Confirmation shall be success otherwise it shall be failure. If the result sent is success then the initiating device shall listen on the new Controller otherwise it shall listen on the old Controller.

4. When the L2CAP layer on the responding device receives the Move Channel Confirmation packet it shall send a Move Channel Confirmation response packet and send an L2CA_Move_Channel_Confirm.indication to the upper layer. If the result code in the Move Channel Confirmation packet is success it shall send I-frames for the channel on the new Controller. If the result code is failure it shall send I-frames on for the channel the old Controller.
5. When the L2CAP layer on the initiating device receives the Move Channel Confirmation response packet it shall send an L2CA_Move_Channel.confirm to the upper layer with the result code passed in the Move Channel Confirmation packet.

Figure 9.3 and Figure 9.4 show examples of the move operation with Enhanced Retransmission mode active.

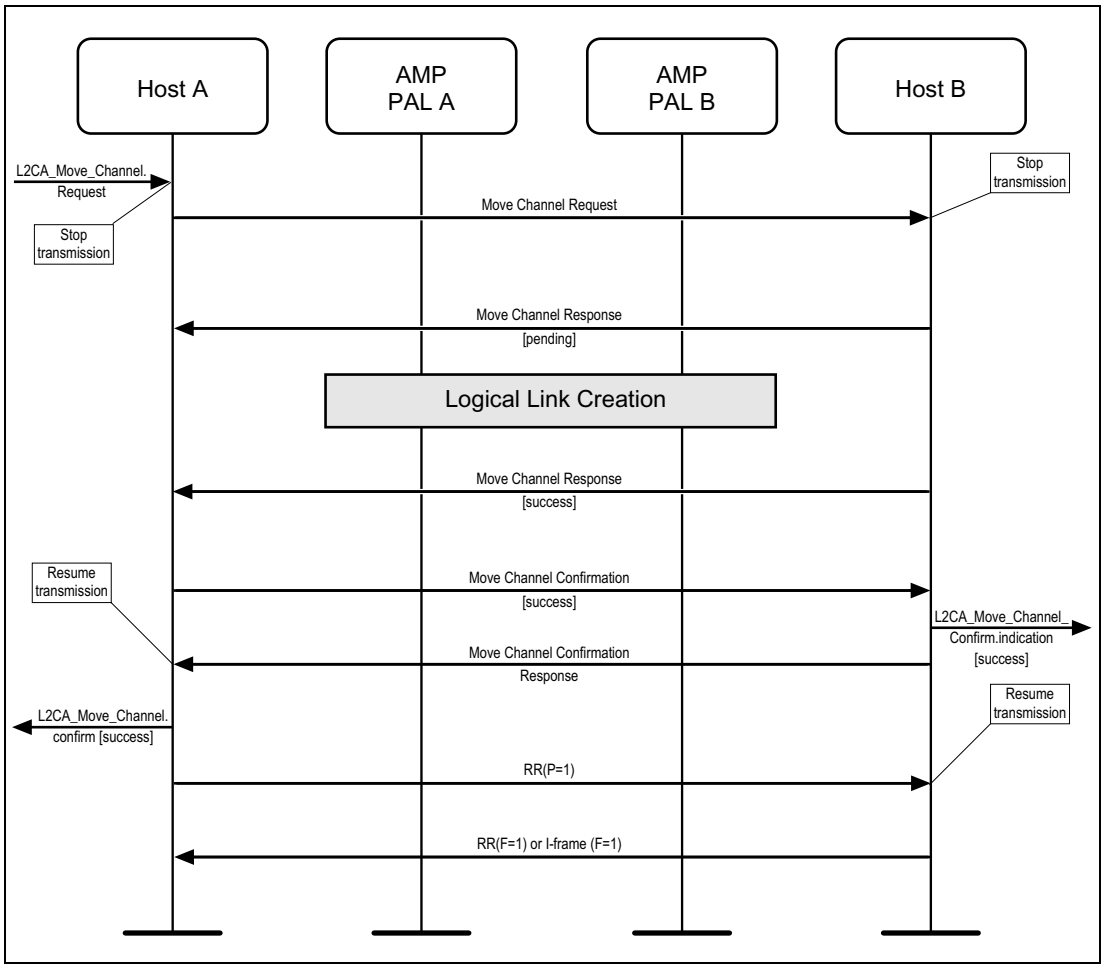


Figure 9.3: Move of a Best Effort L2CAP channel Enhanced Retransmission mode enabled to an AMP with no existing best effort logical link or move of any Guaranteed L2CAP channel

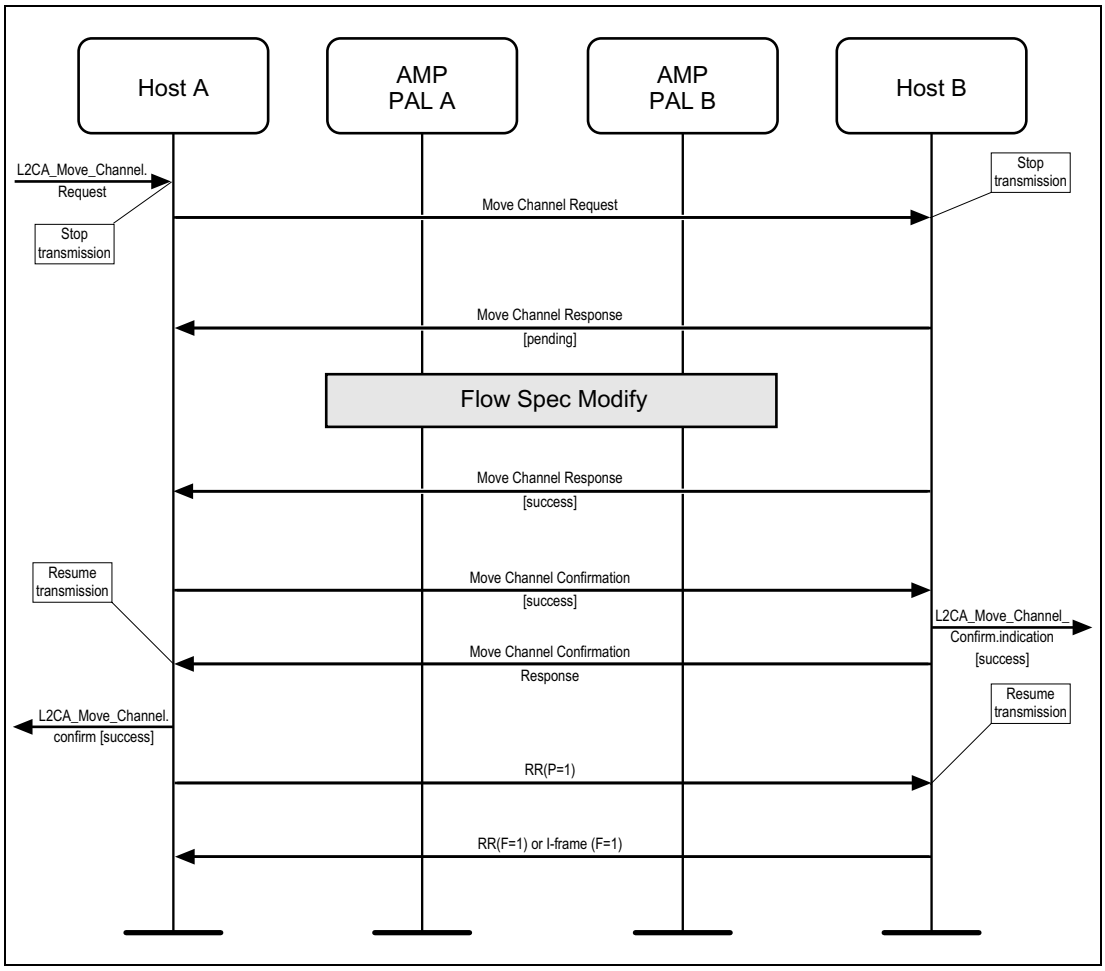


Figure 9.4: Move of a Best Effort L2CAP channel with Enhanced Retransmission mode enabled to an AMP where a best effort logical link exists

9.3 DISCONNECT CHANNEL

If a channel configured as Best Effort is disconnected the Extended Flow Specification aggregate shall be recalculated (see Section 7.8 for the aggregation algorithm) unless it is the last or only channel. If this is not the last or only Best Effort channel for the logical link then a logical link modify operation shall be performed otherwise the logical link should be disconnected. The ACL-U logical link between two devices should not be disconnected until all the L2CAP channels running over all logical links between the two devices have been disconnected.

10 PROCEDURES FOR CREDIT BASED FLOW CONTROL

10.1 LE CREDIT BASED FLOW CONTROL MODE

LE Credit Based Flow Control Mode is used for LE L2CAP connection oriented channels with flow control using a credit based scheme for L2CAP data (i.e. not signaling packets).

The number of credits (LE-frames) that can be received by a device on an L2CAP channel is determined during connection establishment. LE-frames shall only be sent on an L2CAP channel if the device has a credit count greater than zero for that L2CAP channel. For each LE-frame sent the device decreases the credit count for that L2CAP channel by one. The peer device may return credits for an L2CAP channel at any time by sending an LE Flow Control Credit packet. When a credit packet is received by a device it shall increment the credit count for that L2CAP channel by the value of the Credits field in this packet. The number of credits returned for an L2CAP channel may exceed the initial credits provided in the LE Credit Based Connection Request or Response packet. The device sending the LE Flow Control Credit packet shall ensure that the number of credits returned for an L2CAP channel does not cause the credit count to exceed 65535. The device receiving the credit packet shall disconnect the L2CAP channel if the credit count exceeds 65535. The device shall also disconnect the L2CAP channel if it receives an LE-frame on an L2CAP channel from the peer device that has a credit count of zero. If a device receives an LE Flow Control Credit packet with credit value set to zero, the packet shall be ignored. A device shall not send credit values of zero in LE Flow Control Credit packets.

If a connection request is received and there is insufficient authentication between the two devices, the connection shall be rejected with a result value of “Connection refused - insufficient authentication”. If a connection request is received and there is insufficient authorization between the two devices, the connection shall be rejected with a result value of “Connection refused - insufficient authorization”. If a connection request is received and the encryption key size is too short, the connection shall be rejected with a result value of “Connection refused – insufficient encryption key size”.

Note: When encryption is not enabled, the result value “Connection refused – insufficient authentication” does not indicate that MITM protection is required.

APPENDIX A CONFIGURATION MSCs

The examples in this appendix describe a sample of the multiple possible configuration scenarios that might occur.

Figure A.1 illustrates the basic configuration process. In this example, the devices exchange MTU information. All other values are assumed to be default.

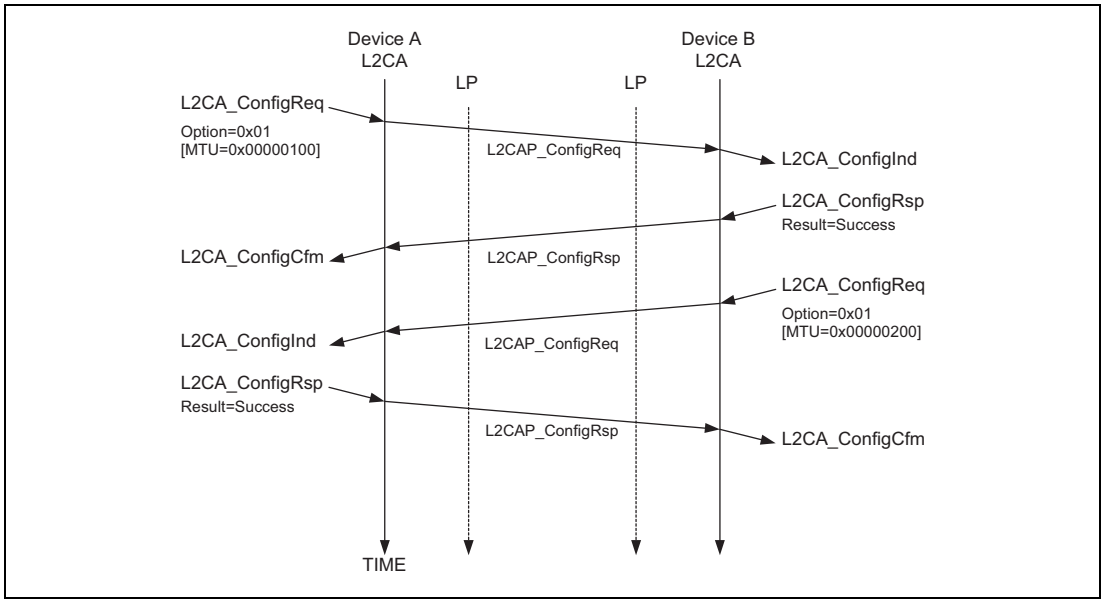


Figure A.1: Basic MTU exchange

Figure A.2 illustrates how two devices interoperate even though one device supports more options than the other does. Device A is an upgraded version. It uses a hypothetically defined option type 0x20 for link-level security. Device B rejects the command using the Configuration Response packet with result 'unknown parameter' informing Device A that option 0x20 is not understood. Device A then resends the request omitting option 0x20. Device B notices that it does not need to such a large MTU and accepts the request but includes in the response the MTU option informing Device A that Device B will not send an L2CAP packet with a payload larger than 0x80 octets over this channel. On receipt of the response, Device A could reduce the buffer allocated to hold incoming traffic.

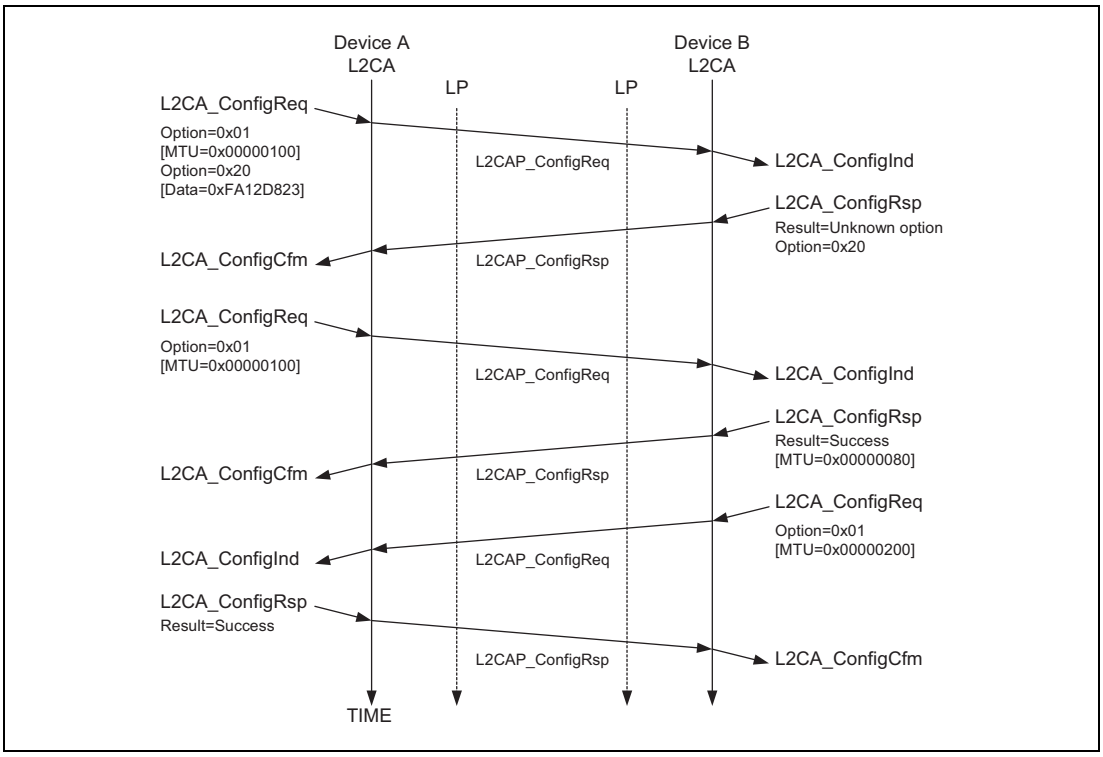


Figure A.2: Dealing with Unknown Options

Figure A.3 illustrates an unsuccessful configuration request. There are two problems described by this example. The first problem is that the configuration request is placed in an L2CAP packet that cannot be accepted by the remote device, due to its size. The remote device informs the sender of this problem using the Command Reject message. Device A then resends the configuration options using two smaller L2CAP_ConfigReq messages.

The second problem is an attempt to configure a channel with an invalid CID. For example device B may have no open connection on that CID (0x01234567 in this example case).

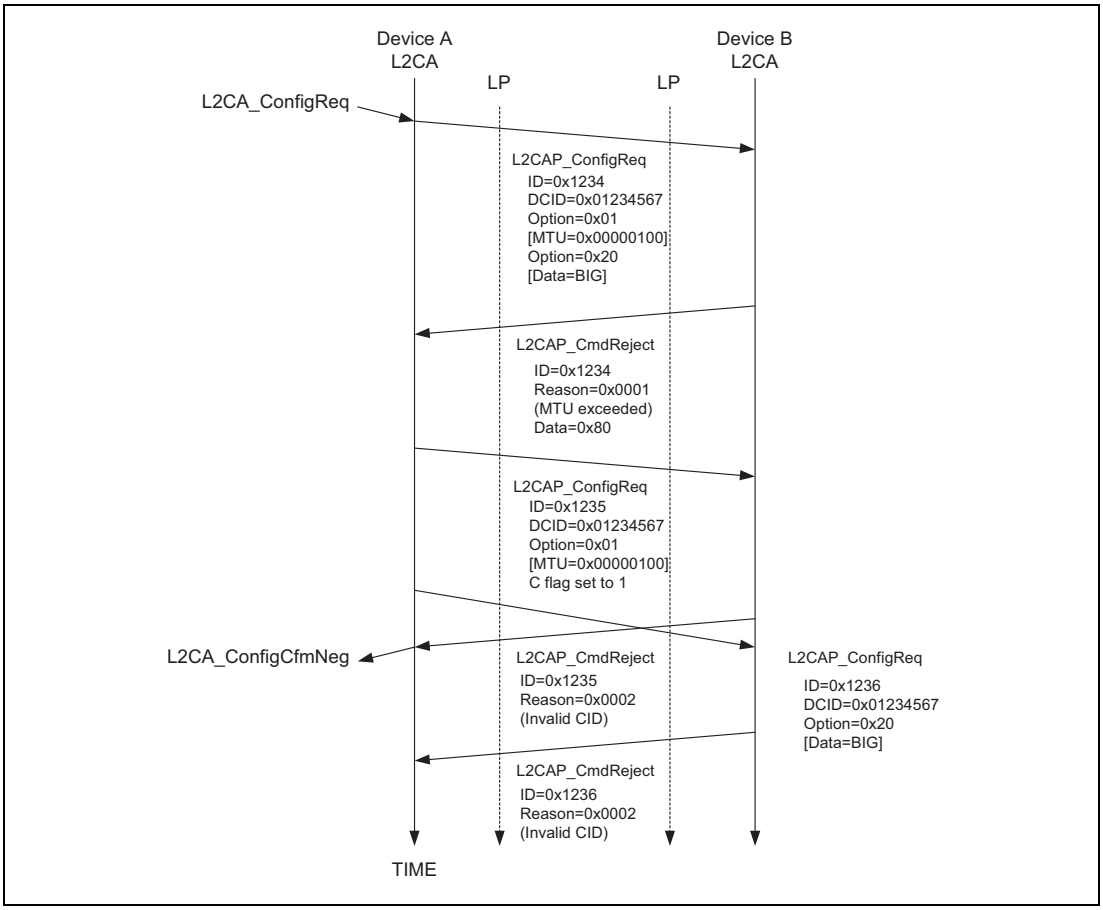


Figure A.3: Unsuccessful Configuration Request

SERVICE DISCOVERY PROTOCOL (SDP) SPECIFICATION

This specification defines a protocol for locating services provided by or available through a Bluetooth device.

CONTENTS

1 INTRODUCTION

1.1 GENERAL DESCRIPTION

The service discovery protocol (SDP) provides a means for applications to discover which services are available and to determine the characteristics of those available services.

1.2 MOTIVATION

Service Discovery in the Bluetooth environment, where the set of services that are available changes dynamically based on the RF proximity of devices in motion, is qualitatively different from service discovery in traditional network-based environments. The service discovery protocol defined in this specification is intended to address the unique characteristics of the Bluetooth environment. See Appendix A, for further information on this topic.

1.3 REQUIREMENTS

The following capabilities have been identified as requirements for version 1.0 of the Service Discovery Protocol.

1. SDP shall provide the ability for clients to search for needed services based on specific attributes of those services.
2. SDP shall permit services to be discovered based on the class of service.
3. SDP shall enable browsing of services without a priori knowledge of the specific characteristics of those services.
4. SDP shall provide the means for the discovery of new services that become available when devices enter RF proximity with a client device as well as when a new service is made available on a device that is in RF proximity with the client device.
5. SDP shall provide a mechanism for determining when a service becomes unavailable when devices leave RF proximity with a client device as well as when a service is made unavailable on a device that is in RF proximity with the client device.
6. SDP shall provide for services, classes of services, and attributes of services to be uniquely identified.
7. SDP shall allow a client on one device to discover a service on another device without consulting a third device.
8. SDP should be suitable for use on devices of limited complexity.
9. SDP shall provide a mechanism to incrementally discover information about the services provided by a device. This is intended to minimize the quantity of data that must be exchanged in order to determine that a particular service is not needed by a client.

10. SDP should support the caching of service discovery information by intermediary agents to improve the speed or efficiency of the discovery process.
11. SDP should be transport independent.
12. SDP shall function while using L2CAP as its transport protocol.
13. SDP shall permit the discovery and use of services that provide access to other service discovery protocols.
14. SDP shall support the creation and definition of new services without requiring registration with a central authority.

1.4 NON-REQUIREMENTS AND DEFERRED REQUIREMENTS

The Bluetooth SIG recognizes that the following capabilities are related to service discovery. These items are not addressed in SDP version 1.0. However, some may be addressed in future revisions of the specification.

1. SDP 1.0 does not provide access to services. It only provides access to information about services.
2. SDP 1.0 does not provide brokering of services.
3. SDP 1.0 does not provide for negotiation of service parameters.
4. SDP 1.0 does not provide for billing of service use.
5. SDP 1.0 does not provide the means for a client to control or change the operation of a service.
6. SDP 1.0 does not provide an event notification when services, or information about services, become unavailable.
7. SDP 1.0 does not provide an event notification when attributes of services are modified.
8. This specification does not define an application programming interface for SDP.
9. SDP 1.0 does not provide support for service agent functions such as service aggregation or service registration.

1.5 CONVENTIONS

1.5.1 Bit And Byte Ordering Conventions

When multiple bit fields are contained in a single byte and represented in a drawing in this specification, the more significant (high-order) bits are shown toward the left and less significant (low-order) bits toward the right.

Multiple-byte fields are drawn with the more significant bytes toward the left and the less significant bytes toward the right. Multiple-byte fields are transferred in network byte order. See Section 4.1.

2 OVERVIEW

2.1 SDP CLIENT-SERVER ARCHITECTURE

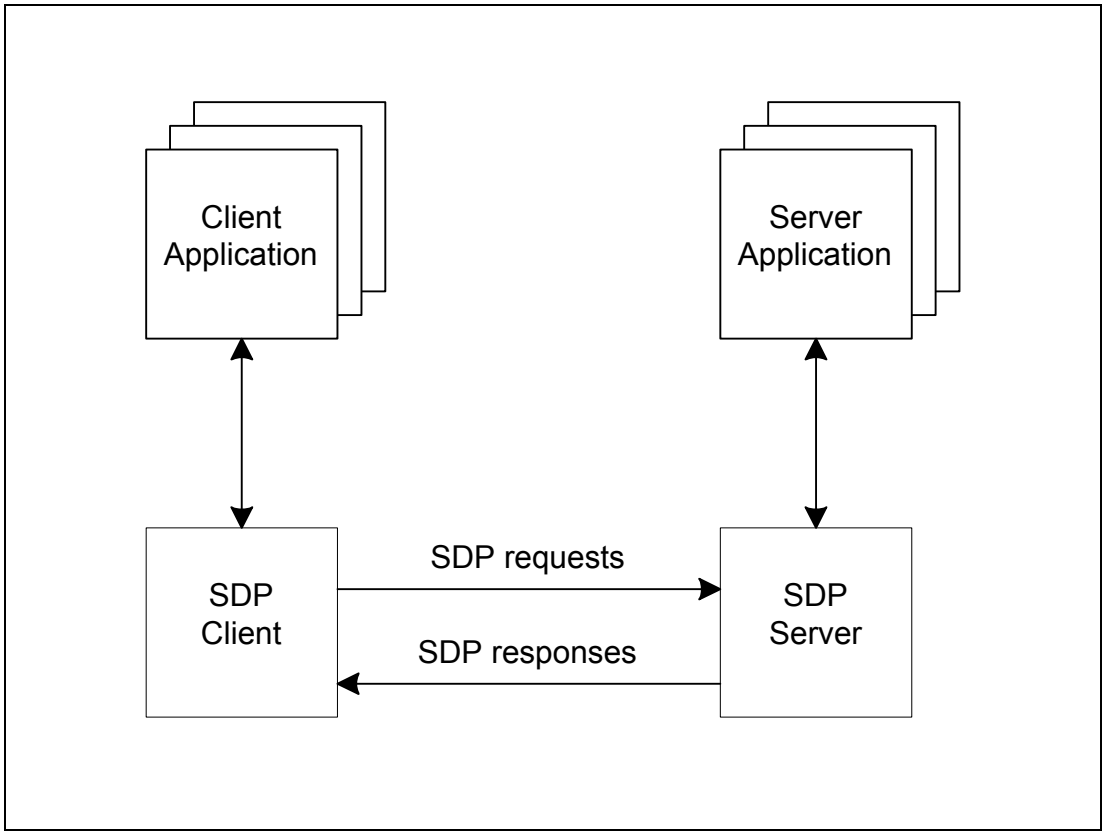


Figure 2.1: SDP Client-Server Interaction

The service discovery mechanism provides the means for client applications to discover the existence of services provided by server applications as well as the attributes of those services. The attributes of a service include the type or class of service offered and the mechanism or protocol information needed to utilize the service.

As far as the Service Discovery Protocol (SDP) is concerned, the configuration shown in Figure 2.1 can be simplified to that shown in Figure 2.2.

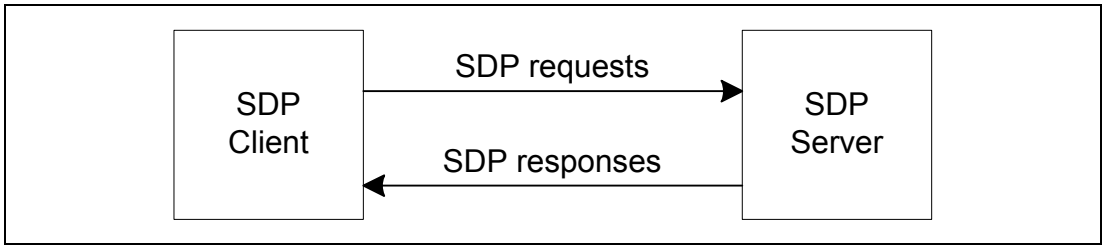


Figure 2.2: Simplified SDP Client-Server Interaction

SDP involves communication between an SDP server and an SDP client. The server maintains a list of service records that describe the characteristics of services associated with the server. Each service record contains information about a single service. A client can retrieve information from a service record maintained by the SDP server by issuing an SDP request.

If the client, or an application associated with the client, decides to use a service, it opens a separate connection to the service provider in order to utilize the service. SDP provides a mechanism for discovering services and their attributes (including associated service access protocols), but it does not provide a mechanism for utilizing those services (such as delivering the service access protocols).

If multiple applications on a device provide services, an SDP server can act on behalf of those service providers to handle requests for information about the services that they provide. Similarly, multiple client applications can utilize an SDP client to query servers on behalf of the client applications.

The set of SDP servers that are available to an SDP client will change dynamically based on the RF proximity of the servers to the client. When a server becomes available, a potential client must be notified by a means other than SDP so that the client can use SDP to query the server about its services. Similarly, when a server leaves proximity or becomes unavailable for any reason, there is no explicit notification via the service discovery protocol. However, the client can use SDP to poll the server and may infer that the server is not available if it no longer responds to requests.

Additional information regarding application interaction with SDP shall be contained in the Bluetooth Service Discovery Profile document.

2.2 SERVICE RECORD

A service is any entity that can provide information, perform an action, or control a resource on behalf of another entity. A service may be implemented as software, hardware, or a combination of hardware and software.

All of the information about a service that is maintained by an SDP server is contained within a single service record. The service record shall only be a list of service attributes.

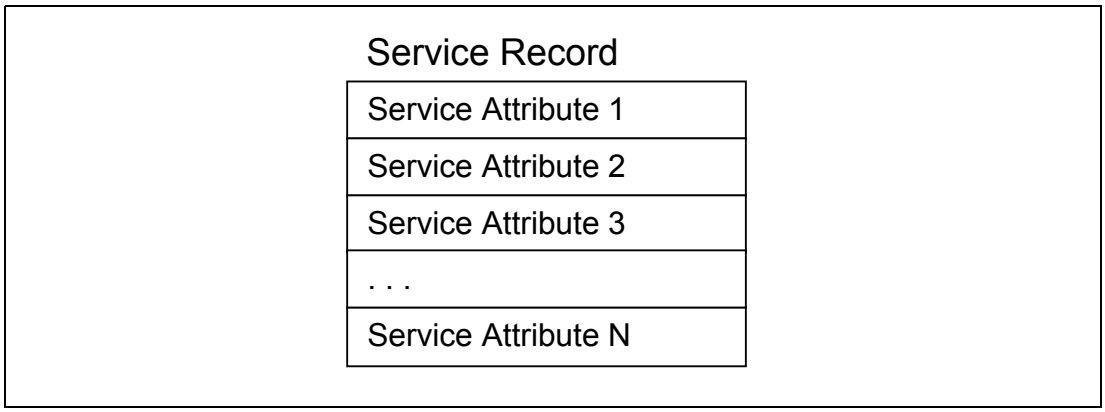


Figure 2.3: Service Record

A service record handle is a 32-bit number that shall uniquely identify each service record within an SDP server. It is important to note that, in general, each handle is unique only within each SDP server. If SDP server S1 and SDP server S2 both contain identical service records (representing the same service), the service record handles used to reference these identical service records are completely independent. The handle used to reference the service on S1 will be meaningless if presented to S2.

The service discovery protocol does not provide a mechanism for notifying clients when service records are added to or removed from an SDP server. While an L2CAP (Logical Link Control and Adaptation Protocol) connection is established to a server, a service record handle acquired from the server shall remain valid unless the service record it represents is removed. If a service is removed from the server, further requests to the server (during the L2CAP connection in which the service record handle was acquired) using the service's (now stale) record handle shall result in an error response indicating an invalid service record handle. An SDP server shall ensure that no service record handle values are re-used while an L2CAP connection remains established. Service record handles shall remain valid across successive L2CAP connections while the ServiceDatabaseState attribute value remains unchanged. Further, service record handles should remain valid until such time that the corresponding service is permanently removed or changes in an incompatible way. See the ServiceRecordState and ServiceDatabaseState attributes in Section 5.

A device may have a service record with a service record handle of 0x00000000 representing the SDP server itself. This service record contains attributes for the SDP server and the protocol it supports. For example, one of its attributes is the list of SDP protocol versions supported by the server.

2.3 SERVICE ATTRIBUTE

Each service attribute describes a single characteristic of a service. Some examples of service attributes are:

ServiceClassIDList	Identifies the type of service represented by a service record. In other words, the list of classes of which the service is an instance
ServiceID	Uniquely identifies a specific instance of a service
ProtocolDescriptorList	Specifies the protocol stack(s) that may be used to utilize a service
ProviderName	The textual name of the individual or organization that provides a service
IconURL	Specifies a URL that refers to an icon image that may be used to represent a service
ServiceName	A text string containing a human-readable name for the service
ServiceDescription	A text string describing the service

See Section 5.1, for attribute definitions that are common to all service records. Service providers can also define their own service attributes.

A service attribute consists of two components: an attribute ID and an attribute value.

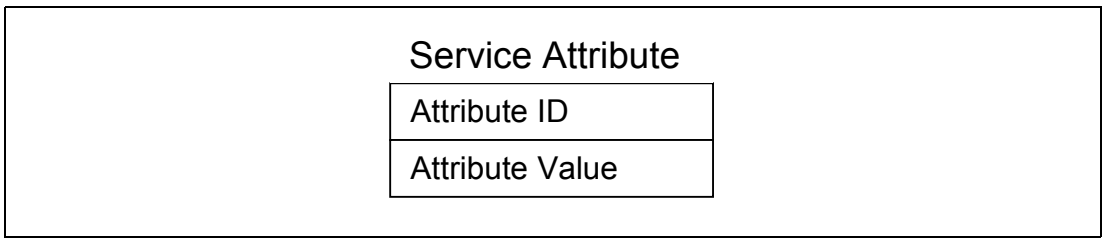


Figure 2.4: Service Attribute

2.3.1 Attribute ID

An attribute ID is a 16-bit unsigned integer that distinguishes each service attribute from other service attributes within a service record. The attribute ID also identifies the semantics of the associated attribute value.

A service class definition specifies each of the attribute IDs for a service class and assigns a meaning to the attribute value associated with each attribute ID. Each attribute ID is defined to be unique only within each service class.

All services belonging to a given service class assign the same meaning to each particular attribute ID. See Section 2.4.

In the Service Discovery Protocol, an attribute ID is represented as a data element. See Section 3.

2.3.2 Attribute Value

The attribute value is a variable length field whose meaning is determined by the attribute ID associated with it and by the service class of the service record in which the attribute is contained. In the Service Discovery Protocol, an attribute value is represented as a data element. (See Section 3.) Generally, any type of data element is permitted as an attribute value, subject to the constraints specified in the service class definition that assigns an attribute ID to the attribute and assigns a meaning to the attribute value. See Section 5, for attribute value examples.

2.4 SERVICE CLASS

Each service is an instance of a service class. The service class definition provides the definitions of all attributes contained in service records that represent instances of that class. Each attribute definition specifies the numeric value of the attribute ID, the intended use of the attribute value, and the format of the attribute value. A service record contains attributes that are specific to a service class as well as universal attributes that are common to all services.

Each service class is also assigned a unique identifier. This service class identifier is contained in the attribute value for the ServiceClassIDList attribute, and is represented as a UUID (see Section 2.5.1). Since the format and meanings of many attributes in a service record are dependent on the service class of the service record, the ServiceClassIDList attribute is very important. Its value shall be examined or verified before any class-specific attributes are used. Since all of the attributes in a service record must conform to all of the service's classes, the service class identifiers contained in the ServiceClassIDList attribute are related. Typically, each service class is a subclass of another class whose identifier is contained in the list. A service subclass definition differs from its superclass in that the subclass contains additional attribute definitions that are specific to the subclass.

When a new service class is defined that is a subclass of an existing service class, the new service class retains all of the attributes defined in its superclass. Additional attributes may be defined that are specific to the new service class. In other words, the mechanism for adding new attributes to some of the instances of an existing service class is to create a new service class that is a subclass of the existing service class.

If a Service Class UUID is exposed in the SDP database of a product, then the product containing the SDP record shall comply with the specification which defines the service corresponding to the UUID.

2.4.1 A Printer Service Class Example

A color postscript printer with duplex capability might conform to 4 ServiceClass definitions and have a ServiceClassIDList with UUIDs (See Section 2.5.1.) representing the following ServiceClasses:

DuplexColorPostscriptPrinterServiceClassID,
ColorPostscriptPrinterServiceClassID,
PostscriptPrinterServiceClassID,
PrinterServiceClassID

Note that this example is only illustrative. This is not necessarily a practical printer class hierarchy.

2.5 SEARCHING FOR SERVICES

The Service Search transaction allows a client to retrieve the service record handles for particular service records based on the values of attributes contained within those service records. Once an SDP client has a service record handle, it can request the values of specific attributes.

The capability search for service records based on the values of arbitrary attributes is not provided. Rather, the capability is provided to search only for attributes whose values are Universally Unique Identifiers[1] (UUIDs). Important attributes of services that can be used to search for a service are represented as UUIDs.

2.5.1 UUID

A UUID is a universally unique identifier that is guaranteed to be unique across all space and all time. UUIDs can be independently created in a distributed fashion. No central registry of assigned UUIDs is required. A UUID is a 128-bit value.

To reduce the burden of storing and transferring 128-bit UUID values, a range of UUID values has been pre-allocated for assignment to often-used, registered purposes. The first UUID in this pre-allocated range is known as the Bluetooth Base UUID and has the value 00000000-0000-1000-8000-00805F9B34FB, from the Bluetooth Assigned Numbers document. UUID values in the pre-allocated range have aliases that are represented as 16-bit or 32-bit values. These aliases are often called 16-bit and 32-bit UUIDs, but it is important to note that each actually represents a 128-bit UUID value.

The full 128-bit value of a 16-bit or 32-bit UUID may be computed by a simple arithmetic operation.

1. The format of UUIDs is specified in ITU-T Rec. X.667(10/2012), alternatively known as ISO/IEC 9834-8:2014.

128_bit_value = 16_bit_value * 2^{96} + Bluetooth_Base_UUID

128_bit_value = 32_bit_value * 2^{96} + Bluetooth_Base_UUID

A 16-bit UUID may be converted to 32-bit UUID format by zero-extending the 16-bit value to 32-bits. An equivalent method is to add the 16-bit UUID value to a zero-valued 32-bit UUID.

Note that two 16-bit UUIDs may be compared directly, as may two 32-bit UUIDs or two 128-bit UUIDs. If two UUIDs of differing sizes are to be compared, the shorter UUID must be converted to the longer UUID format before comparison.

2.5.2 Service Search Patterns

A service search pattern is a list of UUIDs used to locate matching service records. A service search pattern matches a service record if each and every UUID in the service search pattern is contained within any of the service record's attribute values. The UUIDs need not be contained within any specific attributes or in any particular order within the service record. The service search pattern matches if the UUIDs it contains constitute a subset of the UUIDs in the service record's attribute values. The only time a service search pattern does not match a service record is if the service search pattern contains at least one UUID that is not contained within the service record's attribute values. Note also that a valid service search pattern must contain at least one UUID.

2.6 BROWSING FOR SERVICES

Normally, a client searches for services based on some desired characteristic(s) (represented by a UUID) of the services. However, there are times when it is desirable to discover which types of services are described by an SDP server's service records without any a priori information about the services. This process of looking for any offered services is termed browsing. In SDP, the mechanism for browsing for services is based on an attribute shared by all service classes. This attribute is called the BrowseGroupList attribute. The value of this attribute contains a list of UUIDs. Each UUID represents a browse group with which a service may be associated for the purpose of browsing.

When a client desires to browse an SDP server's services, it creates a service search pattern containing the UUID that represents the root browse group. All services that may be browsed at the top level are made members of the root browse group by having the root browse group's UUID as a value within the BrowseGroupList attribute.

Normally, if an SDP server has relatively few services, all of its services will be placed in the root browse group. However, the services offered by an SDP server may be organized in a browse group hierarchy, by defining additional

browse groups below the root browse group. Each of these additional browse groups is described by a service record with a service class of BrowseGroupDescriptor.

A browse group descriptor service record defines a new browse group by means of its Group ID attribute. In order for a service contained in one of these newly defined browse groups to be browseable, the browse group descriptor service record that defines the new browse group must in turn be browseable. The hierarchy of browseable services that is provided by the use of browse group descriptor service records allows the services contained in an SDP server to be incrementally browsed and is particularly useful when the SDP server contains many service records.

2.6.1 Example Service Browsing Hierarchy

Here is a fictitious service browsing hierarchy that illuminates the manner in which browse group descriptors are used. Browse group descriptor service records are identified with (G); other service records with (S).

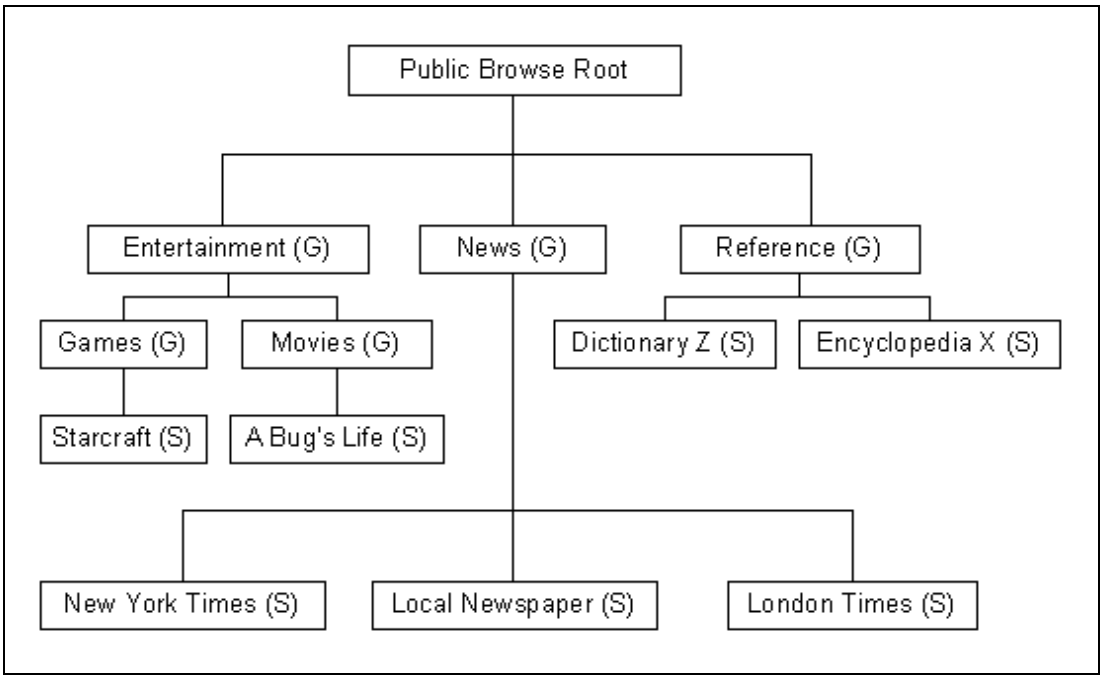


Figure 2.5: Service Browsing Hierarchy

This table shows the services records and service attributes necessary to implement the browse hierarchy.

Service Name	Service Class	Attribute Name	Attribute Value
Entertainment	BrowseGroupDescriptor	BrowseGroupList	PublicBrowseRoot
		GroupID	EntertainmentID
News	BrowseGroupDescriptor	BrowseGroupList	PublicBrowseRoot
		GroupID	NewsID
Reference	BrowseGroupDescriptor	BrowseGroupList	PublicBrowseRoot
		GroupID	ReferenceID
Games	BrowseGroupDescriptor	BrowseGroupList	EntertainmentID
		GroupID	GamesID
Movies	BrowseGroupDescriptor	BrowseGroupList	EntertainmentID
		GroupID	MoviesID
Starcraft	Video Game Class ID	BrowseGroupList	GamesID
A Bug's Life	Movie Class ID	BrowseGroupList	MovieID
Dictionary Z	Dictionary Class ID	BrowseGroupList	ReferenceID
Encyclopedia X	Encyclopedia Class ID	BrowseGroupList	ReferenceID
New York Times	Newspaper ID	BrowseGroupList	NewspaperID
London Times	Newspaper ID	BrowseGroupList	NewspaperID
Local Newspaper	Newspaper ID	BrowseGroupList	NewspaperID

Table 2.1: Service Browsing Hierarchy

3 DATA REPRESENTATION

Attribute values can contain information of various types with arbitrary complexity; thus enabling an attribute list to be generally useful across a wide variety of service classes and environments.

SDP defines a simple mechanism to describe the data contained within an attribute ID, attribute ID range, and attribute value. The primitive construct used is the data element.

3.1 DATA ELEMENT

A data element is a typed data representation. It consists of two fields: a header field and a data field. The header field, in turn, is composed of two parts: a type descriptor and a size descriptor. The data is a sequence of bytes whose length is specified in the size descriptor (described in Section 3.3) and whose meaning is (partially) specified by the type descriptor.

3.2 DATA ELEMENT TYPE DESCRIPTOR

A data element type is represented as a 5-bit type descriptor. The type descriptor is contained in the most significant (high-order) 5 bits of the first byte of the data element header. The following types have been defined.

Type Descriptor Value	Valid Size Descriptor Values	Type Description
0	0	Nil, the null type
1	0, 1, 2, 3, 4	Unsigned Integer
2	0, 1, 2, 3, 4	Signed twos-complement integer
3	1, 2, 4	UUID, a universally unique identifier
4	5, 6, 7	Text string
5	0	Boolean[1]
6	5, 6, 7	Data element sequence, a data element whose data field is a sequence of data elements
7	5, 6, 7	Data element alternative, data element whose data field is a sequence of data elements from which one data element is to be selected.
8	5, 6, 7	URL, a uniform resource locator
Other		Reserved for future use

Table 3.1: Data Element

1. False is represented by the value 0, and true is represented by the value 1. However, to maximize interoperability, any non-zero value received must be accepted as representing true.

3.3 DATA ELEMENT SIZE DESCRIPTOR

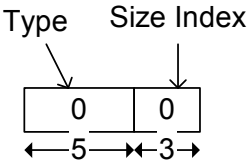
The data element size descriptor is represented as a 3-bit size index followed by 0, 8, 16, or 32 bits. The size index is contained in the least significant (low-order) 3 bits of the first byte of the data element header. The size index is encoded as follows.

Size Index	Additional bits	Data Size
0	0	1 byte. Exception: if the data element type is nil, the data size is 0 bytes.
1	0	2 bytes
2	0	4 bytes
3	0	8 bytes
4	0	16 bytes
5	8	The data size is contained in the additional 8 bits, which are interpreted as an unsigned integer.
6	16	The data size is contained in the additional 16 bits, which are interpreted as an unsigned integer.
7	32	The data size is contained in the additional 32 bits, which are interpreted as an unsigned integer.

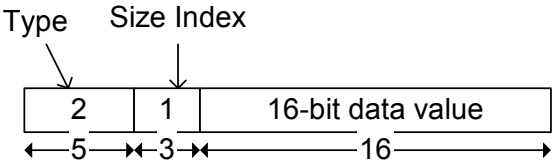
Table 3.2: Data Element Size

3.4 DATA ELEMENT EXAMPLES

Nil is represented as:



A 16-bit signed integer is represented as:



The 3 character ASCII string "Hat" is represented as:

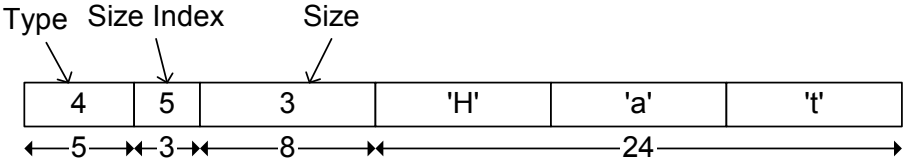


Figure 3.1: Data Element

4 PROTOCOL DESCRIPTION

SDP is a simple protocol with minimal requirements on the underlying transport. It can function over a reliable packet transport (or even unreliable, if the client implements timeouts and repeats requests as necessary).

SDP uses a request/response model where each transaction consists of one request protocol data unit (PDU) and one response PDU. In the case where SDP is used with the Bluetooth L2CAP transport protocol, no more than one SDP request PDU per connection to a given SDP server may be outstanding at a given instant. In other words, a client does not issue a further request to a server prior to receiving a response to the current request before issuing another request on the same L2CAP connection. Limiting SDP to sending one unacknowledged request PDU provides a simple form of flow control.

The protocol examples found in Appendix B, could be helpful in understanding the protocol transactions.

4.1 TRANSFER BYTE ORDER

The service discovery protocol shall transfer multiple-byte fields in standard network byte order (Big Endian), with more significant (high-order) bytes being transferred before less-significant (low-order) bytes.

4.2 PROTOCOL DATA UNIT FORMAT

Every SDP PDU consists of a PDU header followed by PDU-specific parameters. The header contains three fields: a PDU ID, a Transaction ID, and a ParameterLength. Each of these header fields is described here. Parameters may include a continuation state parameter, described below; PDU-specific parameters for each PDU type are described later in separate PDU descriptions.

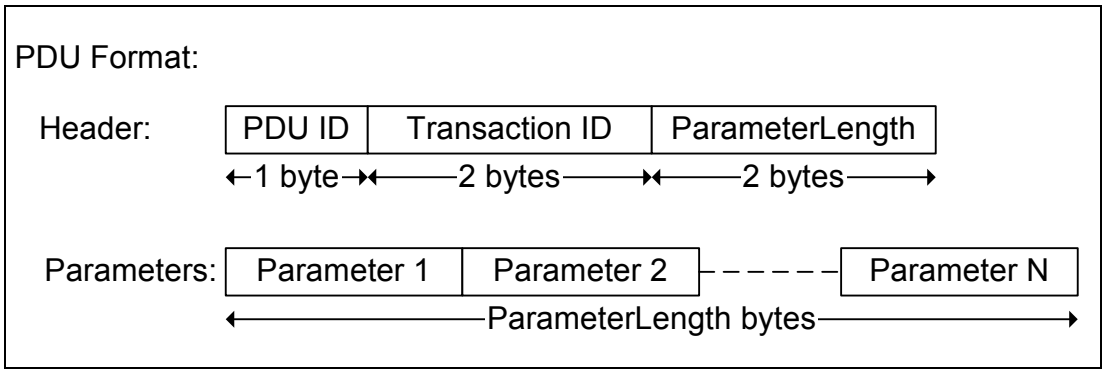


Figure 4.1: Protocol Data Unit Format

PDU ID: *Size: 1 Byte*

Value	Parameter Description
N	The PDU ID field identifies the type of PDU. I.e. its meaning and the specific parameters.
0x00	Reserved for future use
0x01	SDP_ErrorResponse
0x02	SDP_ServiceSearchRequest
0x03	SDP_ServiceSearchResponse
0x04	SDP_ServiceAttributeRequest
0x05	SDP_ServiceAttributeResponse
0x06	SDP_ServiceSearchAttributeRequest
0x07	SDP_ServiceSearchAttributeResponse
0x08-0xFF	Reserved for future use

TransactionID: *Size: 2 Bytes*

Value	Parameter Description
N	The TransactionID field uniquely identifies request PDUs and is used to match response PDUs to request PDUs. The SDP client can choose any value for a request's TransactionID provided that it is different from all outstanding requests. The TransactionID value in response PDUs is required to be the same as the request that is being responded to. Range: 0x0000 – 0xFFFF

ParameterLength: *Size: 2 Bytes*

Value	Parameter Description
N	The ParameterLength field specifies the length (in bytes) of all parameters contained in the PDU. Range: 0x0000 – 0xFFFF

4.3 PARTIAL RESPONSES AND CONTINUATION STATE

Some SDP requests may require responses that are larger than can fit in a single response PDU. In this case, the SDP server shall generate a partial response along with a continuation state parameter. The continuation state parameter can be supplied by the client in a subsequent request to retrieve the next portion of the complete response. The continuation state parameter is a variable length field whose first byte contains the number of additional bytes of continuation information in the field. The format of the continuation information is not standardized among SDP servers. Each continuation state parameter is meaningful only to the SDP server that generated it.

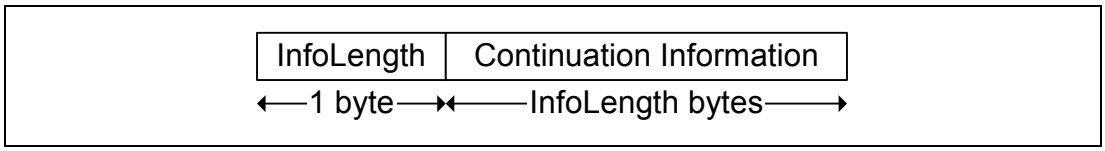


Figure 4.2: Continuation State Format

After a client receives a partial response and the accompanying continuation state parameter, it can re-issue the original request (with a new transaction ID) and include the continuation state in the new request indicating to the server that the remainder of the original response is desired. The maximum allowable value of the InfoLength field is 16 (0x10).

Note that, unless otherwise stated in a PDU response specification, an SDP server can split a response at any arbitrary boundary when it generates a partial response. The SDP server may select the boundary based on the contents of the reply, but is not required to do so. Therefore, length fields give the lengths as measured in the complete assembled record, not the length of the fields in the partial segment. When a service record is segmented into partial responses all attribute list values are relative to the complete record, not relevant to the partial record.

4.4 ERROR HANDLING

Each transaction consists of a request and a response PDU. Generally, each type of request PDU has a corresponding type of response PDU. However, if the server determines that a request is improperly formatted or for any reason the server cannot respond with the appropriate PDU type, it shall respond with an SDP_ErrorResponse PDU.

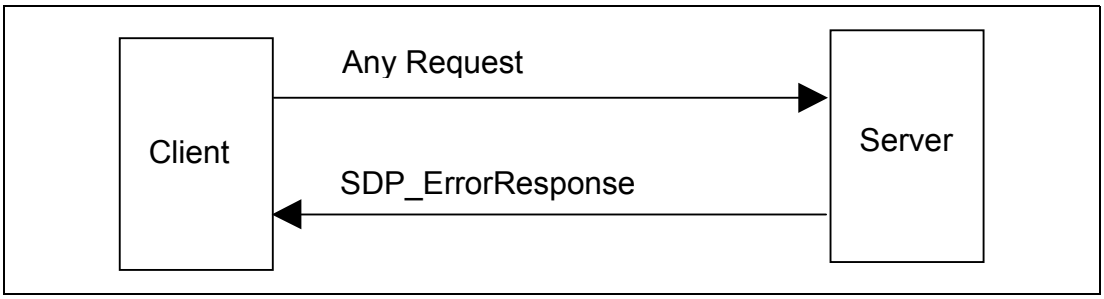


Figure 4.3: Error Handling

4.4.1 SDP_ErrorResponse PDU

PDU Type	PDU ID	Parameters
SDP_ErrorResponse	0x01	ErrorCode

Description:

The SDP server generates this PDU type in response to an improperly formatted request PDU or when the SDP server, for whatever reason, cannot generate an appropriate response PDU.

PDU Parameters:

ErrorCode: *Size: 2 Bytes*

Value	Parameter Description
N	The ErrorCode identifies the reason that an SDP_ErrorResponse PDU was generated.
0x0000	Reserved for future use
0x0001	Invalid/unsupported SDP version
0x0002	Invalid Service Record Handle
0x0003	Invalid request syntax
0x0004	Invalid PDU Size
0x0005	Invalid Continuation State
0x0006	Insufficient Resources to satisfy Request
0x0007-0xFFFF	Reserved for future use

Note: Invalid PDU size should be used, for example, if an incoming request PDU's length is inconsistent with the specification of that request PDU or the length parameter of an incoming request PDU is inconsistent with that request PDU's actual contents.

4.5 SERVICESEARCH TRANSACTION

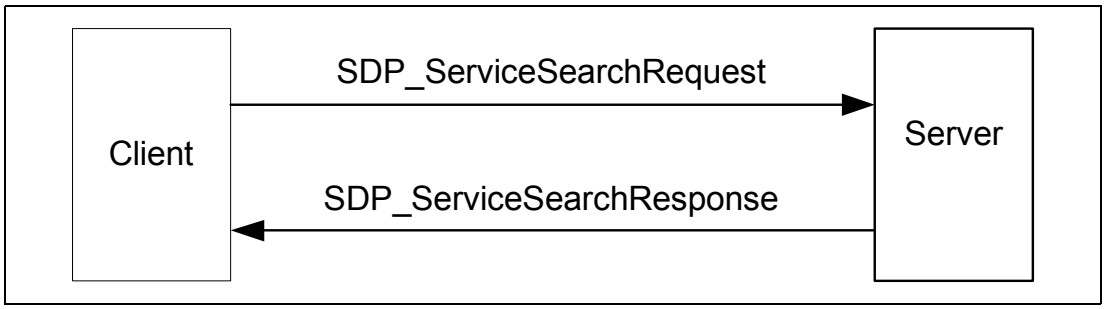


Figure 4.4: ServiceSearch Transaction

4.5.1 SDP_ServiceSearchRequest PDU

PDU Type	PDU ID	Parameters
SDP_ServiceSearchRequest	0x02	ServiceSearchPattern, MaximumServiceRecordCount, ContinuationState

Description:

The SDP client generates an SDP_ServiceSearchRequest to locate service records that match the service search pattern given as the first parameter of the PDU. Upon receipt of this request, the SDP server shall examine its service record data base and return an SDP_ServiceSearchResponse containing the service record handles of service records within its service record database that match the given service search pattern, or an appropriate error response.

Note that no mechanism is provided to request information for all service records. However, see Section 2.6 for a description of a mechanism that permits browsing for non-specific services without a priori knowledge of the services.

PDU Parameters:

ServiceSearchPattern: *Size: Varies*

Value	Parameter Description
Data Element Sequence	The ServiceSearchPattern is a data element sequence where each element in the sequence is a UUID. The sequence shall contain at least one UUID. The maximum number of UUIDs in the sequence is 12[1]. The list of UUIDs constitutes a service search pattern.

1. The value of 12 has been selected as a compromise between the scope of a service search and the size of a search request PDU. It is not expected that more than 12 UUIDs will be useful in a service search pattern.

MaximumServiceRecordCount: *Size: 2 Bytes*

Value	Parameter Description
N	MaximumServiceRecordCount is a 16-bit count specifying the maximum number of service record handles to be returned in the response(s) to this request. The SDP server shall not return more handles than this value specifies. If more than N service records match the request, the SDP server determines which matching service record handles to return in the response(s). Range: 0x0001-0xFFFF

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation state information that were returned in a previous response from the server. N is required to be less than or equal to 16. If no continuation state is to be provided in the request, N is set to 0.

4.5.2 SDP_ServiceSearchResponse PDU

PDU Type	PDU ID	Parameters
SDP_ServiceSearchResponse	0x03	TotalServiceRecordCount, CurrentServiceRecordCount, ServiceRecordHandleList, ContinuationState

Description:

The SDP server generates an SDP_ServiceSearchResponse upon receipt of a valid SDP_ServiceSearchRequest. The response contains a list of service record handles for service records that match the service search pattern given in the request. If a partial response is generated, it shall contain an integral number of complete service record handles; a service record handle value shall not be split across multiple PDUs.

PDU Parameters:

TotalServiceRecordCount: *Size: 2 Bytes*

Value	Parameter Description
N	The TotalServiceRecordCount is an integer containing the number of service records that match the requested service search pattern. If no service records match the requested service search pattern, this parameter is set to 0. N should never be larger than the MaximumServiceRecordCount value specified in the SDP_ServiceSearchRequest. When multiple partial responses are used, each partial response contains the same value for TotalServiceRecordCount. Range: 0x0000-0xFFFF

CurrentServiceRecordCount: *Size: 2 Bytes*

Value	Parameter Description
N	The CurrentServiceRecordCount is an integer indicating the number of service record handles that are contained in the next parameter. If no service records match the requested service search pattern, this parameter is set to 0. N should never be larger than the TotalServiceRecordCount value specified in the current response. Range: 0x0000-0xFFFF

ServiceRecordHandleList: *Size: (CurrentServiceRecordCount*4) Bytes*

Value	Parameter Description
List of 32-bit handles	The ServiceRecordHandleList contains a list of service record handles. The number of handles in the list is given in the CurrentServiceRecordCount parameter. Each of the handles in the list refers to a service record that matches the requested service search pattern. Note that this list of service record handles does not have the format of a data element. It contains no header fields, only the 32-bit service record handles.

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation information. If the current response is complete, this parameter consists of a single byte with the value 0. If a partial response is contained in the PDU, the ContinuationState parameter may be supplied in a subsequent request to retrieve the remainder of the response.

4.6 SERVICEATTRIBUTE TRANSACTION

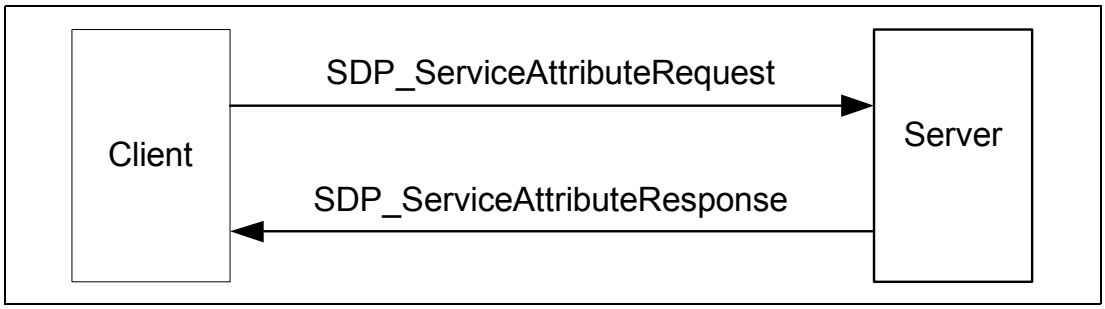


Figure 4.5: ServiceAttribute Transaction

4.6.1 SDP_ServiceAttributeRequest PDU

PDU Type	PDU ID	Parameters
SDP_ServiceAttributeRequest	0x04	ServiceRecordHandle, MaximumAttributeByteCount, AttributeIDList, ContinuationState

Description:

The SDP client generates an SDP_ServiceAttributeRequest to retrieve specified attribute values from a specific service record. The service record handle of the desired service record and a list of desired attribute IDs to be retrieved from that service record are supplied as parameters.

Command Parameters:

ServiceRecordHandle: *Size: 4 Bytes*

Value	Parameter Description
32-bit handle	The ServiceRecordHandle parameter specifies the service record from which attribute values are to be retrieved. The handle is obtained via a previous SDP_ServiceSearch transaction.

MaximumAttributeByteCount: *Size: 2 Bytes*

Value	Parameter Description
N	MaximumAttributeByteCount specifies the maximum number of bytes of attribute data to be returned in the response to this request. The SDP server shall not return more than N bytes of attribute data in the response PDU. If the requested attributes require more than N bytes, the SDP server determines how to segment the list. In this case the client may request each successive segment by issuing a request containing the continuation state that was returned in the previous response PDU. Note that in the case where multiple response PDUs are needed to return the attribute data, MaximumAttributeByteCount specifies the maximum size of the portion of the attribute data contained in each response PDU. Range: 0x0007-0xFFFF

AttributeIDList: *Size: Varies*

Value	Parameter Description
Data Element Sequence	The AttributeIDList is a data element sequence where each element in the list is either an attribute ID or a range of attribute IDs. Each attribute ID is encoded as a 16-bit unsigned integer data element. Each attribute ID range is encoded as a 32-bit unsigned integer data element, where the high order 16 bits are interpreted as the beginning attribute ID of the range and the low order 16 bits are interpreted as the ending attribute ID of the range. The attribute IDs contained in the AttributeIDList shall be listed in ascending order without duplication of any attribute ID values. Note that all attributes can be requested by specifying a range of 0x0000-0xFFFF.

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation state information that were returned in a previous response from the server. N shall be less than or equal to 16. If no continuation state is to be provided in the request, N shall be set to 0.

4.6.2 SDP_ServiceAttributeResponse PDU

PDU Type	PDU ID	Parameters
SDP_ServiceAttributeResponse	0x05	AttributeListByteCount, AttributeList, ContinuationState

Description:

The SDP server generates an SDP_ServiceAttributeResponse upon receipt of a valid SDP_ServiceAttributeRequest. The response contains a list of attributes (both attribute ID and attribute value) from the requested service record.

PDU Parameters:

AttributeListByteCount: *Size: 2 Bytes*

Value	Parameter Description
N	The AttributeListByteCount contains a count of the number of bytes in the AttributeList parameter. N shall never be larger than the MaximumAttributeByteCount value specified in the SDP_ServiceAttributeRequest. Range: 0x0002-0xFFFF

AttributeList: *Size: AttributeListByteCount*

Value	Parameter Description
Data Element Sequence	The AttributeList is a data element sequence containing attribute IDs and attribute values. The first element in the sequence contains the attribute ID of the first attribute to be returned. The second element in the sequence contains the corresponding attribute value. Successive pairs of elements in the list contain additional attribute ID and value pairs. Only attributes that have non-null values within the service record and whose attribute IDs were specified in the SDP_ServiceAttributeRequest are contained in the AttributeList. Neither an attribute ID nor an attribute value is placed in the AttributeList for attributes in the service record that have no value. The attributes are listed in ascending order of attribute ID value.

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation information. If the current response is complete, this parameter consists of a single byte with the value 0. If a partial response is given, the ContinuationState parameter may be supplied in a subsequent request to retrieve the remainder of the response.

If a partial response is generated, the response may be arbitrarily segmented into multiple PDUs (subject to the constraint imposed by the allowed range of values for the AttributeListByteCount parameter). Attributes in partial responses are not required to be integral.

4.7 SERVICESEARCHATTRIBUTE TRANSACTION

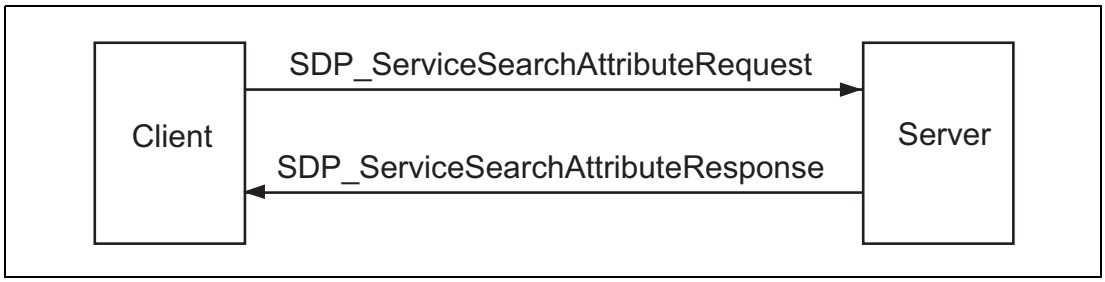


Figure 4.6: ServiceSearchAttribute Transaction

4.7.1 SDP_ServiceSearchAttributeRequest PDU

PDU Type	PDU ID	Parameters
SDP_ServiceSearchAttributeRequest	0x06	ServiceSearchPattern, MaximumAttributeByteCount, AttributeIDList, ContinuationState

Description:

The SDP_ServiceSearchAttributeRequest transaction combines the capabilities of the SDP_ServiceSearchRequest and the SDP_ServiceAttributeRequest into a single request. As parameters, it contains both a service search pattern and a list of attributes to be retrieved from service records that match the service search pattern. The SDP_ServiceSearchAttributeRequest and its response are more complex and can require more bytes than separate SDP_ServiceSearch and SDP_ServiceAttribute transactions. However, using SDP_ServiceSearchAttributeRequest can reduce the total number of SDP transactions, particularly when retrieving multiple service records.

Note that the service record handle for each service record is contained in the ServiceRecordHandle attribute of that service and may be requested along with other attributes.

PDU Parameters:

ServiceSearchPattern: *Size: Varies*

Value	Parameter Description
Data Element Sequence	The ServiceSearchPattern is a data element sequence where each element in the sequence is a UUID. The sequence must contain at least one UUID. The maximum number of UUIDs in the sequence is 12[1]. The list of UUIDs constitutes a service search pattern.

1. The value of 12 has been selected as a compromise between the scope of a service search and the size of a search request PDU. It is not expected that more than 12 UUIDs will be useful in a service search pattern.

MaximumAttributeByteCount: *Size: 2 Bytes*

Value	Parameter Description
N	MaximumAttributeByteCount specifies the maximum number of bytes of attribute data to be returned in the response to this request. The SDP server shall not return more than N bytes of attribute data in the response PDU. If the requested attributes require more than N bytes, the SDP server determines how to segment the list. In this case the client may request each successive segment by issuing a request containing the continuation state that was returned in the previous response PDU. Note that in the case where multiple response PDUs are needed to return the attribute data, MaximumAttributeByteCount specifies the maximum size of the portion of the attribute data contained in each response PDU. Range: 0x0007-0xFFFF

AttributeIDList: *Size: Varies*

Value	Parameter Description
Data Element Sequence	The AttributeIDList is a data element sequence where each element in the list is either an attribute ID or a range of attribute IDs. Each attribute ID is encoded as a 16-bit unsigned integer data element. Each attribute ID range is encoded as a 32-bit unsigned integer data element, where the high order 16 bits are interpreted as the beginning attribute ID of the range and the low order 16 bits are interpreted as the ending attribute ID of the range. The attribute IDs contained in the AttributeIDList shall be listed in ascending order without duplication of any attribute ID values. Note that all attributes may be requested by specifying a range of 0x0000-0xFFFF.

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation state information that were returned in a previous response from the server. N shall be less than or equal to 16. If no continuation state is to be provided in the request, N shall set to 0.

4.7.2 SDP_ServiceSearchAttributeResponse PDU

PDU Type	PDU ID	Parameters
SDP_ServiceSearchAttributeResponse	0x07	AttributeListsByteCount, AttributeLists, ContinuationState

Description:

The SDP server generates an SDP_ServiceSearchAttributeResponse upon receipt of a valid SDP_ServiceSearchAttributeRequest. The response contains a list of attributes (both attribute ID and attribute value) from the service records that match the requested service search pattern.

PDU Parameters:

AttributeListsByteCount: *Size: 2 Bytes*

Value	Parameter Description
N	The AttributeListsByteCount contains a count of the number of bytes in the AttributeLists parameter. N shall never be larger than the MaximumAttributeByteCount value specified in the SDP_ServiceSearchAttributeRequest. Range: 0x0002-0xFFFF

AttributeLists: *Size: Varies*

Value	Parameter Description
Data Element Sequence	The AttributeLists is a data element sequence where each element in turn is a data element sequence representing an attribute list. Each attribute list contains attribute IDs and attribute values from one service record. The first element in each attribute list contains the attribute ID of the first attribute to be returned for that service record. The second element in each attribute list contains the corresponding attribute value. Successive pairs of elements in each attribute list contain additional attribute ID and value pairs. Only attributes that have non-null values within the service record and whose attribute IDs were specified in the SDP_ServiceSearchAttributeRequest are contained in the AttributeLists. Neither an attribute ID nor attribute value is placed in AttributeLists for attributes in the service record that have no value. Within each attribute list, the attributes are listed in ascending order of attribute ID value.

ContinuationState: *Size: 1 to 17 Bytes*

Value	Parameter Description
Continuation State	ContinuationState consists of an 8-bit count, N, of the number of bytes of continuation state information, followed by the N bytes of continuation information. If the current response is complete, this parameter consists of a single byte with the value 0. If a partial response is given, the ContinuationState parameter may be supplied in a subsequent request to retrieve the remainder of the response.

If a partial response is generated, the response may be arbitrarily segmented into multiple PDUs (subject to the constraint imposed by the allowed range of values for the AttributeListByteCount parameter). Attributes in partial responses are not required to be integral.

5 SERVICE ATTRIBUTE DEFINITIONS

The service classes and attributes contained in this document are necessarily a partial list of the service classes and attributes supported by SDP. Only service classes that directly support the SDP server are included in this document. Additional service classes will be defined in other documents and possibly in future revisions of this document. Also, it is expected that additional attributes will be discovered that are applicable to a broad set of services; these may be added to the list of Universal attributes in future revisions of this document.

5.1 UNIVERSAL ATTRIBUTE DEFINITIONS

Universal attributes are those service attributes whose definitions are common to all service records. Note that this does not mean that every service record contains values for all of these service attributes. However, if a service record has a service attribute with an attribute ID allocated to a universal attribute, the attribute value shall conform to the universal attribute's definition.

Only two attributes are required to exist in every service record instance. They are the ServiceRecordHandle (attribute ID 0x0000) and the ServiceClassIDList (attribute ID 0x0001). All other service attributes are optional within a service record.

5.1.1 ServiceRecordHandle Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceRecordHandle	0x0000	32-bit unsigned integer

Description:

A service record handle is a 32-bit number that uniquely identifies each service record within an SDP server. It is important to note that, in general, each handle is unique only within each SDP server. If SDP server S1 and SDP server S2 both contain identical service records (representing the same service), the service record handles used to reference these identical service records are completely independent. The handle used to reference the service on S1 will, in general, be meaningless if presented to S2. Service record handle values 0x00000001-0x0000FFFF are reserved for future use.

5.1.2 ServiceClassIDList Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceClassIDList	0x0001	Data Element Sequence

Description:

The ServiceClassIDList attribute consists of a data element sequence in which each data element is a UUID representing the service classes that a given service record conforms to. The UUIDs should be listed in order from the most specific class to the most general class unless otherwise specified by the profile specifications defining the service classes. When profiles are enhanced, any new UUIDs should be added at the end of the ServiceClassIDList (after any existing UUIDs) to minimize interoperability issues with legacy implementations. The ServiceClassIDList shall contain at least one service class UUID.

5.1.3 ServiceRecordState Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceRecordState	0x0002	32-bit unsigned integer

Description:

The ServiceRecordState is a 32-bit integer that is used to facilitate caching of Service Attributes. If this attribute is contained in a service record, its value shall be changed when any other attribute value is added to, deleted from or changed within the service record. This permits a client to check the value of this single attribute. If its value has not changed since it was last checked, the client knows that no other attribute values within the service record have changed.

5.1.4 ServiceID Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceID	0x0003	UUID

Description:

The ServiceID is a UUID that universally and uniquely identifies the service instance described by the service record. This service attribute is particularly useful if the same service is described by service records in more than one SDP server.

5.1.5 ProtocolDescriptorList Attribute

Attribute Name	Attribute ID	Attribute Value Type
ProtocolDescriptorList	0x0004	Data Element Sequence or Data Element Alternative

Description:

The ProtocolDescriptorList attribute describes one or more protocol stacks that can be used to gain access to the service described by the service record.

If the ProtocolDescriptorList describes a single stack, it takes the form of a data element sequence in which each element of the sequence is a protocol descriptor. Each protocol descriptor is, in turn, a data element sequence whose first element is a UUID identifying the protocol and whose successive elements are protocol-specific parameters. Potential protocol-specific parameters are a protocol version number and a connection-port number. The protocol descriptors are listed in order from the lowest layer protocol to the highest layer protocol used to gain access to the service.

If it is possible for more than one kind of protocol stack to be used to gain access to the service, the ProtocolDescriptorList takes the form of a data element alternative where each member is a data element sequence as described in the previous paragraph.

Protocol Descriptors

A protocol descriptor identifies a communications protocol and provides protocol-specific parameters. A protocol descriptor is represented as a data element sequence. The first data element in the sequence shall be the UUID that identifies the protocol. Additional data elements optionally provide protocol-specific information, such as the L2CAP protocol/service multiplexer (PSM) and the RFCOMM server channel number (CN) shown below.

ProtocolDescriptorList Examples

These examples are intended to be illustrative. The parameter formats for each protocol are not defined within this specification.

In the first two examples, it is assumed that a single RFCOMM instance exists on top of the L2CAP layer. In this case, the L2CAP protocol specific information (PSM) points to the single instance of RFCOMM. In the last example, two different and independent RFCOMM instances are available on top of the L2CAP layer. In this case, the L2CAP protocol specific information (PSM) points to a distinct identifier that distinguishes each of the RFCOMM instances. See the L2CAP specification ([Vol 3] Part A, Section 4.2) for the range of allowed PSM values.

IrDA-like printer

((L2CAP, PSM=RFCOMM), (RFCOMM, CN=1), (PostscriptStream))

IP Network Printing

((L2CAP, PSM=RFCOMM), (RFCOMM, CN=2), (PPP), (IP), (TCP), (IPP))

Synchronization Protocol Descriptor Example

((L2CAP, PSM=0x1001), (RFCOMM, CN=1), (Obex), (vCal))

((L2CAP, PSM=0x1003), (RFCOMM, CN=1), (Obex), (otherSynchronisationApplication))

5.1.6 AdditionalProtocolDescriptorList Attribute

Attribute Name	Attribute ID	Attribute Value Type
AdditionalProtocolDescriptorList	0x000D	Data Element Sequence

Description:

The AdditionalProtocolDescriptorLists attribute contains a sequence of ProtocolDescriptorList-elements. Each element having the same format as the ProtocolDescriptorList described in section 5.1.5. The ordering of the elements is significant and should be specified and fixed in Profiles that make use of this attribute.

The AdditionalProtocolDescriptorLists attribute supports services that require more channels in addition to the service described in Section 5.1.5. If the AdditionalProtocolDescriptorLists attribute is included in a service record, the ProtocolDescriptorList attribute must be included.

AdditionalProtocolDescriptorList Examples

The following is just an illustrative example and is not meant to refer a real specified service or protocols.

```
Attribute    Attribute Value type            Attribute Value

ProtocolDescriptorList

   ProtocolDescriptor #0DataElementSequence

         ProtocolID    UUID       L2CAP

         Param: PSM    PSM        FooDataProtocol

   ProtocolDescriptor #1DataElementSequence

          ProtocolID           UUID       FooDataProtocol
```

```
AdditionalProtocolDescriptorLists

   ProtocolDescriptorList #0  DataElementSequence

   ProtocolDescriptor #0      DataElementSequence

              ProtocolID      UUID       L2CAP

              Param: PSM      PSM        FooControlProtocol

         ProtocolDescriptor #1DataElementSequence

              ProtocolID      UUID       FooControlProtocol
```

5.1.7 BrowseGroupList Attribute

Attribute Name	Attribute ID	Attribute Value Type
BrowseGroupList	0x0005	Data Element Sequence

Description:

The BrowseGroupList attribute consists of a data element sequence in which each element is a UUID that represents a browse group to which the service record belongs. The top-level browse group ID, called PublicBrowseRoot and representing the root of the browsing hierarchy, has the value 00001002-0000-1000-8000-00805F9B34FB (UUID16: 0x1002) from the Bluetooth Assigned Numbers document.

5.1.8 LanguageBaseAttributeIDList Attribute

Attribute Name	Attribute ID	Attribute Value Type
LanguageBaseAttributeIDList	0x0006	Data Element Sequence

Description:

In order to support human-readable attributes for multiple natural languages in a single service record, a base attribute ID is assigned for each of the natural languages used in a service record. The human-readable universal attributes are then defined with an attribute ID offset from each of these base values, rather than with an absolute attribute ID.

The LanguageBaseAttributeIDList attribute is a list in which each member contains a language identifier, a character encoding identifier, and a base attribute ID for each of the natural languages used in the service record. The LanguageBaseAttributeIDList attribute consists of a data element sequence in which each element is a 16-bit unsigned integer. The elements are grouped as triplets (threes).

The first element of each triplet contains an identifier representing the natural language. The language is encoded according to ISO 639:1988 (E/F): “Code for the representation of names of languages”.

The second element of each triplet contains an identifier that specifies a character encoding used for the language. Values for character encoding can be found in IANA's database[1], and have the values that are referred to as MIBEnum values. The recommended character encoding is UTF-8.

The third element of each triplet contains an attribute ID that serves as the base attribute ID for the natural language in the service record. Different service records within a server may use different base attribute ID values for the same language.

To facilitate the retrieval of human-readable universal attributes in a principal language, the base attribute ID value for the primary language supported by a service record shall be 0x0100. Also, if a LanguageBaseAttributeIDList attribute is contained in a service record, the base attribute ID value contained in its first element shall be 0x0100. If one or more human readable attributes are contained in a service record, the LanguageBaseAttributeIDList attribute should be included in that service record.

5.1.9 ServiceInfoTimeToLive Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceInfoTimeToLive	0x0007	32-bit unsigned integer

Description:

The ServiceTimeToLive attribute is a 32-bit integer that contains the number of seconds for which the information in a service record is expected to remain valid and unchanged. This time interval is measured from the time that the attribute value is retrieved from the SDP server. This value does not imply a guarantee that the service record will remain available or unchanged. It is simply a hint that a client can use to determine a suitable polling interval to re-validate the service record contents.

1. See http://www.isi.edu/in-notes/iana/assignments/character-sets

5.1.10 ServiceAvailability Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceAvailability	0x0008	8-bit unsigned integer

Description:

The ServiceAvailability attribute is an 8-bit unsigned integer that represents the relative ability of the service to accept additional clients. A value of 0xFF indicates that the service is not currently in use and is thus fully available, while a value of 0x00 means that the service is not accepting new clients. For services that support multiple simultaneous clients, intermediate values indicate the relative availability of the service on a linear scale.

For example, a service that can accept up to 3 clients should provide ServiceAvailability values of 0xFF, 0xAA, 0x55, and 0x00 when 0, 1, 2, and 3 clients, respectively, are utilizing the service. The value 0xAA is approximately (2/3) * 0xFF and represents 2/3 availability, while the value 0x55 is approximately (1/3)*0xFF and represents 1/3 availability. Note that the availability value is be approximated as

(1 - (current_number_of_clients / maximum_number_of_clients)) * 0xFF

When the maximum number of clients is large, this formula must be modified to ensure that ServiceAvailability values of 0x00 and 0xFF are reserved for their defined meanings of unavailability and full availability, respectively.

Note that the maximum number of clients a service can support may vary according to the resources utilized by the service's current clients.

A non-zero value for ServiceAvailability does not guarantee that the service will be available for use. It should be treated as a hint or an approximation of availability status.

5.1.11 BluetoothProfileDescriptorList Attribute

Attribute Name	Attribute ID	Attribute Value Type
BluetoothProfileDescriptorList	0x0009	Data Element Sequence

Description:

The BluetoothProfileDescriptorList attribute consists of a data element sequence in which each element is a profile descriptor that contains information about a Bluetooth profile to which the service represented by this service record conforms. Each profile descriptor is a data element sequence whose first element is the UUID assigned to the profile and whose second element is a 16-bit profile version number.

Each version of a profile is assigned a 16-bit unsigned integer profile version number, which consists of two 8-bit fields. The higher-order 8 bits contain the major version number field and the lower-order 8 bits contain the minor version number field. The initial version of each profile has a major version of 1 and a minor version of 0. When upward compatible changes are made to the profile, the minor version number will be incremented. If incompatible changes are made to the profile, the major version number will be incremented.

5.1.12 DocumentationURL Attribute

Attribute Name	Attribute ID	Attribute Value Type
DocumentationURL	0x000A	URL

Description:

This attribute is a URL which points to documentation on the service described by a service record.

5.1.13 ClientExecutableURL Attribute

Attribute Name	Attribute ID	Attribute Value Type
ClientExecutableURL	0x000B	URL

Description:

This attribute contains a URL that refers to the location of an application that can be used to utilize the service described by the service record. Since different operating environments require different executable formats, a mechanism has been defined to allow this single attribute to be used to locate an executable that is appropriate for the client device's operating environment. In the attribute value URL, the first byte with the value 0x2A (ASCII character '*') is to be replaced by the client application with a string representing the desired operating environment before the URL is to be used.

The list of standardized strings representing operating environments is contained in the Bluetooth Assigned Numbers document.

For example, assume that the value of the ClientExecutableURL attribute is http://my.fake/public/*/client.exe. On a device capable of executing SH3 WindowsCE files, this URL would be changed to http://my.fake/public/sh3-microsoft-wince/client.exe. On a device capable of executing Windows 98 binaries, this URL would be changed to http://my.fake/public/i86-microsoft-win98/client.exe.

5.1.14 IconURL Attribute

Attribute Name	Attribute ID	Attribute Value Type
IconURL	0x000C	URL

Description:

This attribute contains a URL that refers to the location of an icon that can be used to represent the service described by the service record. Since different hardware devices require different icon formats, a mechanism has been defined to allow this single attribute to be used to locate an icon that is appropriate for the client device. In the attribute value URL, the first byte with the value 0x2A (ASCII character '*') is to be replaced by the client application with a string representing the desired icon format before the URL is to be used.

The list of standardized strings representing icon formats is contained in the Bluetooth Assigned Numbers document.

For example, assume that the value of the IconURL attribute is http://my.fake/public/icons/*. On a device that prefers 24 x 24 icons with 256 colors, this URL would be changed to http://my.fake/public/icons/24x24x8.png. On a device that prefers 10 x 10 monochrome icons, this URL would be changed to http://my.fake/public/icons/10x10x1.png.

5.1.15 ServiceName Attribute

Attribute Name	Attribute ID Offset	Attribute Value Type
ServiceName	0x0000	String

Description:

The ServiceName attribute is a string containing the name of the service represented by a service record. It should be brief and suitable for display with an Icon representing the service. The offset 0x0000 is added to the attribute ID base (contained in the LanguageBaseAttributeIDList attribute) in order to compute the attribute ID for this attribute.

5.1.16 ServiceDescription Attribute

Attribute Name	Attribute ID Offset	Attribute Value Type
ServiceDescription	0x0001	String

Description:

This attribute is a string containing a brief description of the service. It should be less than 200 characters in length. The offset 0x0001 is added to the attribute ID base (contained in the LanguageBaseAttributeIDList attribute) in order to compute the attribute ID for this attribute.

5.1.17 ProviderName Attribute

Attribute Name	Attribute ID Offset	Attribute Value Type
ProviderName	0x0002	String

Description:

This attribute is a string containing the name of the person or organization providing the service. The offset 0x0002 is added to the attribute ID base (contained in the LanguageBaseAttributeIDList attribute) in order to compute the attribute ID for this attribute.

5.1.18 Reserved Universal Attribute IDs

Attribute IDs in the range of 0x000E – 0x01FF are reserved for use by SDP, if allocated the assigned numbers document will be updated.

5.2 SERVICEDISCOVERYSERVER SERVICE CLASS ATTRIBUTE DEFINITIONS

This service class describes service record that contains attributes of the service discovery server itself. The attributes listed in this section are only valid if the ServiceClassIDList attribute contains the ServiceDiscoveryServerServiceClassID. All of the universal attributes may be included in service records of the ServiceDiscoveryServer class.

5.2.1 ServiceRecordHandle Attribute

Described in the universal attribute definition for ServiceRecordHandle.

Value

A 32-bit integer with the value 0x00000000.

5.2.2 ServiceClassIDList Attribute

Described in the universal attribute definition for ServiceClassIDList.

Value

A UUID representing the ServiceDiscoveryServerServiceClassID.

5.2.3 VersionNumberList Attribute

Attribute Name	Attribute ID	Attribute Value Type
VersionNumberList	0x0200	Data Element Sequence

Description:

The VersionNumberList is a data element sequence in which each element of the sequence is a version number supported by the SDP server.

A version number is a 16-bit unsigned integer consisting of two fields. The higher-order 8 bits contain the major version number field and the low-order 8 bits contain the minor version number field. The initial version of SDP has a major version of 1 and a minor version of 0. When upward compatible changes are made to the protocol, the minor version number will be incremented. If incompatible changes are made to SDP, the major version number will be incremented. This guarantees that if a client and a server support a common major version number, they can communicate if each uses only features of the specification with a minor version number that is supported by both client and server.

5.2.4 ServiceDatabaseState Attribute

Attribute Name	Attribute ID	Attribute Value Type
ServiceDatabaseState	0x0201	32-bit unsigned integer

Description:

The ServiceDatabaseState is a 32-bit integer that is used to facilitate caching of service records. If this attribute exists, its value shall be changed when any of the other service records are added to or deleted from the server's database. If this value has not changed since the last time a client queried its value, the client knows that a) none of the other service records maintained by the SDP server have been added or deleted; and b) any service record handles acquired from the server are still valid. A client shall query this attribute's value when a connection to the server is established, prior to using any service record handles acquired during a previous connection.

Note that the ServiceDatabaseState attribute does not change when existing service records are modified, including the addition, removal, or modification of service attributes. A service record's ServiceRecordState attribute indicates when that service record is modified.

5.2.5 Reserved Attribute IDs

Attribute IDs in the range of 0x0202-0x02FF are reserved for future use.

5.3 BROWSEGROUPDESCRIPTOR SERVICE CLASS ATTRIBUTE DEFINITIONS

This service class describes the ServiceRecord provided for each BrowseGroupDescriptor service offered on a Bluetooth device. The attributes listed in this section are only valid if the ServiceClassIDList attribute contains the BrowseGroupDescriptorServiceClassID. Note that all of the universal attributes may be included in service records of the BrowseGroupDescriptor class.

5.3.1 ServiceClassIDList Attribute

Described in the universal attribute definition for ServiceClassIDList.

Value

A UUID representing the BrowseGroupDescriptorServiceClassID.

5.3.2 GroupID Attribute

Attribute Name	Attribute ID	Attribute Value Type
GroupID	0x0200	UUID

Description:

This attribute contains a UUID that can be used to locate services that are members of the browse group that this service record describes.

5.3.3 Reserved Attribute IDs

Attribute IDs in the range of 0x0201-0x02FF are reserved for future use.

6 SECURITY

In Security Mode 4, SDP should use no security but may use security (an authenticated or unauthenticated link key with encryption). See [Vol 3] Part C, Section 5.2.2).

APPENDIX A BACKGROUND INFORMATION

A.1 SERVICE DISCOVERY

As computing continues to move to a network-centric model, finding and making use of services that may be available in the network becomes increasingly important. Services can include common ones such as printing, paging, FAXing, and so on, as well as various kinds of information access such as teleconferencing, network bridges and access points, eCommerce facilities, and so on — most any kind of service that a server or service provider might offer. In addition to the need for a standard way of discovering available services, there are other considerations: getting access to the services (finding and obtaining the protocols, access methods, “drivers” and other code necessary to utilize the service), controlling access to the services, advertising the services, choosing among competing services, billing for services, and so on. This problem is widely recognized; many companies, standards bodies and consortia are addressing it at various levels in various ways. Service Location Protocol (SLP), Jini™, and Salutation™, to name just a few, all address some aspect of service discovery.

A.2 BLUETOOTH SERVICE DISCOVERY

Bluetooth Service Discovery Protocol (SDP) addresses service discovery specifically for the Bluetooth environment. It is optimized for the highly dynamic nature of Bluetooth communications. SDP focuses primarily on discovering services available from or through Bluetooth devices. SDP does not define methods for accessing services; once services are discovered with SDP, they can be accessed in various ways, depending upon the service. This might include the use of other service discovery and access mechanisms such as those mentioned above; SDP provides a means for other protocols to be used along with SDP in those environments where this can be beneficial. While SDP can coexist with other service discovery protocols, it does not require them. In Bluetooth environments, services can be discovered using SDP and can be accessed using other protocols defined by Bluetooth.

APPENDIX B EXAMPLE SDP TRANSACTIONS

The following are simple examples of typical SDP transactions. These are meant to be illustrative of SDP flows. The examples do not consider:

- Caching (in a caching system, the SDP client would make use of the ServiceRecordState and ServiceDatabaseState attributes);
- Service availability (if this is of interest, the SDP client should use the ServiceAvailability and/or ServiceTimeToLive attributes);
- SDP versions (the VersionNumberList attribute could be used to determine compatible SDP versions);
- SDP Error Responses (an SDP error response is possible for any SDP request that is in error); and
- Communication connection (the examples assume that an L2CAP connection is established).

The examples are meant to be illustrative of the protocol. The format used is `ObjectName[ObjectSizeInBytes] {SubObjectDefinitions}`, but this is not meant to illustrate an interface. The `ObjectSizeInBytes` is the size of the object in decimal. The `SubObjectDefinitions` (inside of `{}` characters) are components of the immediately enclosing object. Hexadecimal values shown as lower-case letters, such as for transaction IDs and service handles, are variables (the particular value is not important for the illustration, but each such symbol always represents the same value). Comments are included in this manner: `/* comment text */`

Numeric values preceded by “0x” are hexadecimal, while those preceded by “0b” are binary. All other numeric values are decimal.

B.1 SDP EXAMPLE 1 – ServiceSearchRequest

The first example is that of an SDP client searching for a generic printing service. The client does not specify a particular type of printing service. In the example, the SDP server has two available printing services. The transaction illustrates:

1. SDP client to SDP server: SDP_ServiceSearchRequest, specifying the PrinterServiceClassID (represented as a DataElement with a 32-bit UUID value of `ppp...ppp`) as the only element of the ServiceSearchPattern. The PrinterServiceClassID is assumed to be a 32-bit UUID and the data element type for it is illustrated. The TransactionID is illustrated as `tttt`.
2. SDP server to SDP client: SDP_ServiceSearchResponse, returning handles to two printing services, represented as `qqqqqqqq` for the first printing service and `rrrrrrrr` for the second printing service. The Transaction ID is the same value as supplied by the SDP client in the corresponding request (ττττ).

```
/* Sent from SDP Client to SDP server */
SDP_ServiceSearchRequest[15] {
  PDUID[1] {
    0x02
  }
  TransactionID[2] {
    0xtttt
  }
  ParameterLength[2] {
    0x000A
  }
  ServiceSearchPattern[7] {
    DataElementSequence[7] {
      0b00110 0b101 0x05
      UUID[5] {
        /* PrinterServiceClassID */
        0b00011 0b010 0xpppppppp
      }
    }
  }
  MaximumServiceRecordCount[2] {
    0x0003
  }
  ContinuationState[1] {
    /* no continuation state */
    0x00
  }
}


/* Sent from SDP server to SDP client */
SDP_ServiceSearchResponse[18] {
  PDUID[1] {
    0x03
  }
  TransactionID[2] {
    0xtttt
  }
  ParameterLength[2] {
    0x000D
  }
  TotalServiceRecordCount[2] {
    0x0002
  }
  CurrentServiceRecordCount[2] {
    0x0002
  }
  ServiceRecordHandleList[8] {
    /* print service 1 handle */
    0xqqqqqqqq
    /* print service 2 handle */
    0xrrrrrrrr
  }
  ContinuationState[1] {
    /* no continuation state */
```

```
    0x00
  }
}
```

B.2 SDP EXAMPLE 2 – ServiceAttributeTransaction

The second example continues the first example. In Example 1, the SDP client obtained handles to two printing services. In Example 2, the client uses one of those service handles to obtain the ProtocolDescriptorList attribute for that printing service. The transaction illustrates:

1. SDP client to SDP server: SDP_ServiceAttributeRequest, presenting the previously obtained service handle (the one denoted as `qqqqqqqq`) and specifying the ProtocolDescriptorList attribute ID (AttributeID 0x0004) as the only attribute requested (other attributes could be retrieved in the same transaction if desired). The TransactionID is illustrated as `uuuu` to distinguish it from the TransactionID of Example 1.
2. SDP server to SDP client: SDP_ServiceAttributeResponse, returning the ProtocolDescriptorList for the specified printing service. This protocol stack is assumed to be ((L2CAP), (RFCOMM, 2), (PostscriptStream)). The ProtocolDescriptorList is a data element sequence in which each element is, in turn, a data element sequence whose first element is a UUID representing the protocol, and whose subsequent elements are protocol-specific parameters. In this example, one such parameter is included for the RFCOMM protocol, an 8-bit value indicating RFCOMM server channel 2. The Transaction ID is the same value as supplied by the SDP client in the corresponding request (`uuuu`). The Attributes returned are illustrated as a data element sequence where the protocol descriptors are 32-bit UUIDs and the RFCOMM server channel is a data element with an 8-bit value of 2.

```
 /* Sent from SDP Client to SDP server */
SDP_ServiceAttributeRequest[17] {
  PDUID[1] {
    0x04
  }
  TransactionID[2] {
    0xuuuu
  }
  ParameterLength[2] {
    0x000C
  }
  ServiceRecordHandle[4] {
    0xqqqqqqqq
  }
  MaximumAttributeByteCount[2] {
    0x0080
  }
  AttributeIDList[5] {
    DataElementSequence[5] {
```

```
      0b00110 0b101 0x03
      AttributeID[3] {
        0b00001 0b001 0x0004
      }
    }
  }
  ContinuationState[1] {
    /* no continuation state */
    0x00
  }
}

/* Sent from SDP server to SDP client */
SDP_ServiceAttributeResponse[38] {
  PDUID[1] {
    0x05
  }
  TransactionID[2] {
    0xuuuu
  }
  ParameterLength[2] {
    0x0021
  }
  AttributeListByteCount[2] {
    0x001E
  }
  AttributeList[30] {
    DataElementSequence[30] {
      0b00110 0b101 0x1C
      Attribute[28] {
        AttributeID[3] {
          0b00001 0b001 0x0004
        }
        AttributeValue[25] {
          /* ProtocolDescriptorList */
          DataElementSequence[25] {
            0b00110 0b101 0x17
            /* L2CAP protocol descriptor */
            DataElementSequence[7] {
              0b00110 0b101 0x05
              UUID[5] {
                /* L2CAP Protocol UUID */
                0b00011 0b010 <32-bit L2CAP UUID>
              }
            }
            /* RFCOMM protocol descriptor */
            DataElementSequence[9] {
              0b00110 0b101 0x07
              UUID[5] {
                /* RFCOMM Protocol UUID */
                0b00011 0b010 <32-bit RFCOMM UUID>
              }
              /* parameter for server 2 */
              Uint8[2] {
                0b00001 0b000 0x02
              }
            }
```

```
            /* PostscriptStream protocol descriptor */
            DataElementSequence[7] {
              0b00110 0b101 0x05
              UUID[5] {
                /* PostscriptStream Protocol UUID */
                0b00011 0b010 <32-bit PostscriptStream UUID>
              }
            }
          }
        }
      }
    }
  }
  ContinuationState[1] {
    /* no continuation state */
    0x00
  }
}
```

B.3 SDP EXAMPLE 3 – ServiceSearchAttributeTransaction

The third example is a form of service browsing, although it is not generic browsing in that it does not make use of SDP browse groups. Instead, an SDP client is searching for available Synchronization services that can be presented to the user for selection. The SDP client does not specify a particular type of synchronization service. In the example, the SDP server has three available synchronization services: an address book synchronization service and a calendar synchronization service (both from the same provider), and a second calendar synchronization service from a different provider. The SDP client is retrieving the same attributes for each of these services; namely, the data formats supported for the synchronization service (vCard, vCal, ICal, etc.) and those attributes that are relevant for presenting information to the user about the services. Also assume that the maximum size of a response is 400 bytes. Since the result is larger than this, the SDP client will repeat the request supplying a continuation state parameter to retrieve the remainder of the response. The transaction illustrates:

1. SDP client to SDP server: SDP_ServiceSearchAttributeRequest, specifying the generic SynchronisationServiceClassID (represented as a data element whose 32-bit UUID value is `sss...sss`) as the only element of the ServiceSearchPattern. The SynchronisationServiceClassID is assumed to be a 32-bit UUID. The requested attributes are the ServiceRecordHandle (AttributeID 0x0000), ServiceClassIDList (AttributeID 0x0001), IconURL (AttributeID 0x000C), ServiceName (AttributeID 0x0100), ServiceDescription (AttributeID 0x0101), and ProviderName (AttributeID 0x0102) attributes; as well as the service-specific SupportedDataStores (AttributeID 0x0301). Since the first two attribute IDs (0x0000 and 0x0001) and three other attribute IDs(0x0100, 0x0101, and 0x0102 are consecutive, they are specified as attribute ranges. The TransactionID is illustrated as `vvvv` to distinguish it from the TransactionIDs of the other Examples.

Note that values in the service record's primary language are requested for the text attributes (ServiceName, ServiceDescription and ProviderName) so that absolute attribute IDs may be used, rather than adding offsets to a base obtained from the LanguageBaseAttributeIDList attribute.

2. SDP server to SDP client: SDP_ServiceSearchAttributeResponse, returning the specified attributes for each of the three synchronization services. In the example, each ServiceClassIDList is assumed to contain a single element, the generic SynchronisationServiceClassID (a 32-bit UUID represented as sss...sss). Each of the other attributes contain illustrative data in the example (the strings have illustrative text; the icon URLs are illustrative, for each of the respective three synchronization services; and the SupportedDataStore attribute is represented as an unsigned 8-bit integer where 0x01 = vCard2.1, 0x02 = vCard3.0, 0x03 = vCal1.0 and 0x04 = iCal). Note that one of the service records (the third for which data is returned) has no ServiceDescription attribute. The attributes are returned as a data element sequence, where each element is in turn a data element sequence representing a list of attributes. Within each attribute list, the ServiceClassIDList is a data element sequence while the remaining attributes are single data elements. The Transaction ID is the same value as supplied by the SDP client in the corresponding request (0xvvvv). Since the entire result cannot be returned in a single response, a non-null continuation state is returned in this first response.
3. Note that the total length of the initial data element sequence (487 in the example) is indicated in the first response, even though only a portion of this data element sequence (368 bytes in the example, as indicated in the AttributeLists byte count) is returned in the first response. The remainder of this data element sequence is returned in the second response (without an additional data element header).
4. SDP client to SDP server: SDP_ServiceSearchAttributeRequest, with the same parameters as in step 1, except that the continuation state received from the server in step 2 is included as a request parameter. The TransactionID is changed to 0xwww to distinguish it from previous request.
5. SDP server to SDP client: SDP_ServiceSearchAttributeResponse, with the remainder of the result computed in step 2 above. Since all of the remaining result fits in this second response, a null continuation state is included.

```
/* Part 1 -- Sent from SDP Client to SDP server */
SdpSDP_ServiceSearchAttributeRequest[33] {
  PDUID[1] {
    0x06
  }
  TransactionID[2] {
    0xvvvv
  }
  ParameterLength[2] {
    0x001C
```

```
  }
  ServiceSearchPattern[7] {
    DataElementSequence[7] {
      0b00110 0b101 0x05
      UUID[5] {
        /* SynchronisationServiceClassID */
        0b00011 0b010 0xssssssss
      }
    }
  }
  MaximumAttributeByteCount[2] {
    0x0190
  }
AttributeIDList[18] {
    DataElementSequence[18] {
      0b00110 0b101 0x10
      AttributeIDRange[5] {
        0b00001 0b010 0x00000001
      }
      AttributeID[3] {
        0b00001 0b001 0x000C
      }
      AttributeIDRange[5] {
        0b00001 0b010 0x01000102
      }
      AttributeID[3] {
        0b00001 0b001 0x0301
      }    }
  }
  ContinuationState[1] {
    /* no continuation state */
    0x00
  }
}

/* Part 2 -- Sent from SDP server to SDP client */
SdpSDP_ServiceSearchAttributeResponse[384] {
  PDUID[1] {
    0x07
  }
  TransactionID[2] {
    0xvvvv
  }
  ParameterLength[2] {
    0x017B
  }
  AttributeListByteCount[2] {
    0x0170
  }
  AttributeLists[368] {
    DataElementSequence[487] {
      0b00110 0b110 0x01E4
      DataElementSequence[178] {
        0b00110 0b101 0xB0
        Attribute[8] {
          AttributeID[3] {
            0b00001 0b001 0x0000
```

```
          }
          AttributeValue[5] {
            /* service record handle */
            0b00001 0b010 0xhhhhhhhh
          }
        }
        Attribute[10] {
          AttributeID[3] {
            0b00001 0b001 0x0001
          }
AttributeValue[7] {
          DataElementSequence[7] {
            0b00110 0b101 0x05
            UUID[5] {
              /* SynchronisationServiceClassID */
              0b00011 0b010 0xssssssss
            }
          }
        }
        Attribute[35] {
          AttributeID[3] {
            0b00001 0b001 0x000C
          }
          AttributeValue[32] {
            /* IconURL; '*' replaced by client application */
            0b01000 0b101 0x1E
            "http://Synchronisation/icons/*"
          }
        }
        Attribute[22] {
          AttributeID[3] {
            0b00001 0b001 0x0100
          }
          AttributeValue[19] {
            /* service name */
            0b00100 0b101 0x11
            "Address Book Sync"
          }
        }
        Attribute[59] {
          AttributeID[3] {
            0b00001 0b001 0x0101
          }
          AttributeValue[56] {
            /* service description */
            0b00100 0b101 0x36
            "Synchronisation Service for"
            " vCard Address Book Entries"
          }
        }
        Attribute[37] {
          AttributeID[3] {
            0b00001 0b001 0x0102
          }
          AttributeValue[34] {
            /* service provider */
```

```
          0b00100 0b101 0x20
          "Synchronisation Specialists Inc."
        }
      }
      Attribute[5] {
        AttributeID[3] {
          0b00001 0b001 0x0301
        }
        AttributeValue[2] {
          /* Supported Data Store 'phonebook' */
          0b00001 0b000 0x01
        }
      }
    }
    DataElementSequence[175] {
      0b00110 0b101 0xAD
      Attribute[8] {
        AttributeID[3] {
          0b00001 0b001 0x0000
        }
        AttributeValue[5] {
          /* service record handle */
          0b00001 0b010 0xmmmmmmmm
        }
      }
      Attribute[10] {
        AttributeID[3] {
          0b00001 0b001 0x0001
        }
                  AttributeValue[7] {
        DataElementSequence[7] {
          0b00110 0b101 0x05
          UUID[5] {
            /* SynchronisationServiceClassID */
            0b00011 0b010 0xssssssss
          }
        }
      }
      Attribute[35] {
        AttributeID[3] {
          0b00001 0b001 0x000C
        }
        AttributeValue[32] {
          /* IconURL; '*' replaced by client application */
          0b01000 0b101 0x1E
          "http://Synchronisation/icons/*"
        }
      }
      Attribute[21] {
        AttributeID[3] {
          0b00001 0b001 0x0100
        }
        AttributeValue[18] {
          /* service name */
          0b00100 0b101 0x10
          "Appointment Sync"
```

```
          }
        }
        Attribute[57] {
          AttributeID[3] {
            0b00001 0b001 0x0101
          }
          AttributeValue[54] {
            /* service description */
            0b00100 0b101 0x34
            "Synchronisation Service for"
            " vCal Appointment Entries"
          }
        }
        Attribute[37] {
          AttributeID[3] {
            0b00001 0b001 0x0102
          }
          AttributeValue[34] {
            /* service provider */
            0b00100 0b101 0x20
            "Synchronisation Specialists Inc."
          }
        }
        Attribute[5] {
          AttributeID[3] {
            0b00001 0b001 0x0301
          }
          AttributeValue[2] {
            /* Supported Data Store 'calendar' */
            0b00001 0b000 0x03
          }
        }
      }
    /* } Data element sequence of attribute lists */
    /* is not completed in this PDU. */
  }
  ContinuationState[9] {
    /* 8 bytes of continuation state */
    0x08 0xzzzzzzzzzzzzzzzz
  }
}

/* Part 3 -- Sent from SDP Client to SDP server */
SdpSDP_ServiceSearchAttributeRequest[41] {
  PDUID[1] {
    0x06
  }
  TransactionID[2] {
    0xwwww
  }
  ParameterLength[2] {
    0x0024
  }
  ServiceSearchPattern[7] {
    DataElementSequence[7] {
      0b00110 0b101 0x05
      UUID[5] {
```

```
        /* SynchronisationServiceClassID */
        0b00011 0b010 0xssssssss
      }
    }
  }
  MaximumAttributeByteCount[2] {
    0x0180
  }
    AttributeIDList[18] {
    DataElementSequence[18] {
      0b00110 0b101 0x10
      AttributeIDRange[5] {
        0b00001 0b010 0x00000001
      }
      AttributeID[3] {
        0b00001 0b001 0x000C
      }
      AttributeIDRange[5] {
        0b00001 0b010 0x01000102
      }
      AttributeID[3] {
        0b00001 0b001 0x0301
      }
    }
  }
  ContinuationState[9] {
    /* same 8 bytes of continuation state */
    /* received in part 2 */
    0x08 0xzzzzzzzzzzzzzzzz
  }
}

Part 4 -- Sent from SDP server to SDP client

SdpSDP_ServiceSearchAttributeResponse[115] {
  PDUID[1] {
    0x07
  }
  TransactionID[2] {
    0xwwww
  }
  ParameterLength[2] {
    0x006E
  }
  AttributeListByteCount[2] {
    0x006B
  }
  AttributeLists[107] {
    /* Continuing the data element sequence of */
    /* attribute lists begun in Part 2. */
      DataElementSequence[107] {
        0b00110 0b101 0x69
        Attribute[8] {
          AttributeID[3] {
            0b00001 0b001 0x0000
          }
          AttributeValue[5] {
```

```
      /* service record handle */
      0b00001 0b010 0xffffffff
    }
  }
  Attribute[10] {
    AttributeID[3] {
      0b00001 0b001 0x0001
    }
    AttributeValue[7] {
      DataElementSequence[7] {
        0b00110 0b101 0x05
        UUID[5] {
          /* SynchronisationServiceClassID */
          0b00011 0b010 0xssssssss
        }
      }
    }
  }
  Attribute[35] {
    AttributeID[3] {
      0b00001 0b001 0x000C
    }
    AttributeValue[32] {
      /* IconURL; '*' replaced by client application */
      0b01000 0b101 0x1E
      "http://DevManufacturer/icons/*"
    }
  }
  Attribute[18] {
    AttributeID[3] {
      0b00001 0b001 0x0100
    }
    AttributeValue[15] {
      /* service name */
      0b00100 0b101 0x0D
      "Calendar Sync"
    }
  }
  Attribute[29] {
    AttributeID[3] {
      0b00001 0b001 0x0102
    }
    AttributeValue[26] {
      /* service provider */
      0b00100 0b101 0x18
      "Device Manufacturer Inc."
    }
  }
  Attribute[5] {
    AttributeID[3] {
      0b00001 0b001 0x0301
    }
    AttributeValue[2] {
      /* Supported Data Store 'calendar' */
      0b00001 0b000 0x03
    }
  }
```

```
      }
    /* This completes the data element sequence */
    /* of attribute lists begun in Part 2. */
  }
  ContinuationState[1] {
    /* no continuation state */
    0x00
  }
}
```

GENERIC ACCESS PROFILE

This profile defines the generic procedures related to discovery of Bluetooth devices (idle mode procedures) and link management aspects of connecting to Bluetooth devices (connecting mode procedures). It also defines procedures related to use of different security levels. In addition, this profile includes common format requirements for parameters accessible on the user interface level.

CONTENTS

FOREWORD

Interoperability between devices from different manufacturers is provided for a specific service and use case, if the devices conform to a Bluetooth SIG-defined profile specification. A profile defines a selection of messages and procedures (generally termed *capabilities*) from the Bluetooth SIG specifications and gives a description of the air interface for specified service(s) and use case(s).

All defined features are process-mandatory. This means that, if a feature is used, it is used in a specified manner. Whether the provision of a feature is mandatory or optional is stated separately for both sides of the Bluetooth air interface.

1 INTRODUCTION

1.1 SCOPE

The purpose of the Generic Access Profile is:

To introduce definitions, recommendations and common requirements related to modes and access procedures that are to be used by transport and application profiles.

To describe how devices are to behave in standby and connecting states in order to guarantee that links and channels always can be established between Bluetooth devices, and that multi-profile operation is possible. Special focus is put on discovery, link establishment and security procedures.

To state requirements on user interface aspects, mainly coding schemes and names of procedures and parameters, that are needed to guarantee a satisfactory user experience.

This profile defines three device types based on the supported Core Configurations as defined in [Vol 0] Part B, Section 3.1. The device types are shown in Table 1.1:

Device Type	Description
BR/EDR	Devices that support the “Basic Rate” Core Configuration (see [Vol 0] Part B, Section 4.1)
LE only	Devices that support the “Low Energy” Core Configuration (see [Vol 0] Part B, Section 4.4)
BR/EDR/LE	Devices that support the “Basic Rate and Low Energy Combined” Core Configuration (see [Vol 0] Part B, Section 4.5)

Table 1.1: Device Types

The terms physical transport, physical link and physical channel as defined in [Vol 1] Part A, Section 3 are used in this specification.

The requirements for device types are shown in Table 1.2.

Device Types	Sections	Support
BR/EDR	1-8, 12, 15-18	C1
LE-only	1-3, 9-12, 15-18	C1
BR/EDR/LE	1-18	C1
C1: Mandatory to support only one device type		

Table 1.2: Requirements for device types

1.2 SYMBOLS AND CONVENTIONS

1.2.1 Requirement Status Symbols

In this document (especially in the profile requirements tables), the following symbols are used:

‘M’ for mandatory to support (used for capabilities that shall be used in the profile);

’O’ for optional to support (used for capabilities that can be used in the profile);

‘C’ for conditional support (used for capabilities that shall be used in case a certain other capability is supported);

‘E’ for excluded within profile role (used for capabilities that may be supported by the unit but shall never be used in the profile role);

’N/A’ for not applicable (in the given context it is impossible to use this capability).

Some excluded capabilities are capabilities that, according to the relevant Bluetooth specification, are mandatory. These are features that may degrade operation of devices following this profile. Therefore, these features shall never be activated while a unit is operating as a unit within this profile.

In this specification, the word *shall* is used for mandatory requirements, the word *should* is used to express recommendations and the word *may* is used for options.

1.2.2 Signaling diagram conventions

The following arrows are used in diagrams describing procedures:

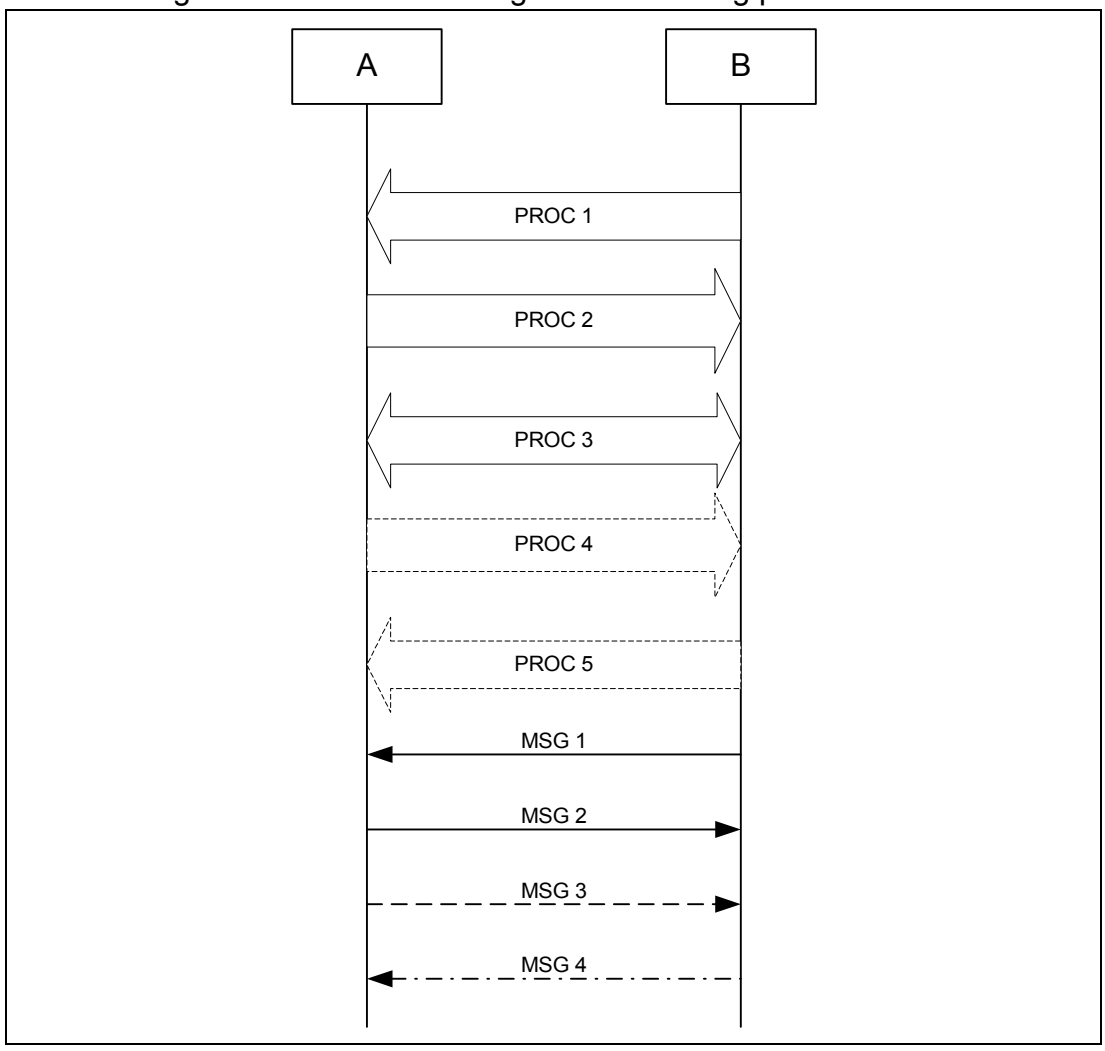


Figure 1.1: Arrows used in signaling diagrams

In Figure 1.1, the following cases are shown: PROC1 is a sub-procedure initiated by B. PROC2 is a sub-procedure initiated by A. PROC3 is a sub-procedure where the initiating side is undefined (may be both A or B). Dashed arrows denote optional steps. PROC4 indicates an optional sub-procedure initiated by A, and PROC5 indicates an optional sub-procedure initiated by B.

MSG1 is a message sent from B to A. MSG2 is a message sent from A to B. MSG3 indicates an optional message from A to B, and MSG4 indicates a conditional message from B to A.

1.2.3 Notation for Timers and Counters

Timers are introduced specific to this profile. To distinguish them from timers used in the Bluetooth protocol specifications and other profiles, these timers are named in the following format: 'T_{GAP}*(nnn)*'.

1.2.4 Notation for UUIDs

The use of « » (e.g. «Device Name») indicates a Bluetooth SIG-defined UUID.

2 PROFILE OVERVIEW

2.1 PROFILE STACK

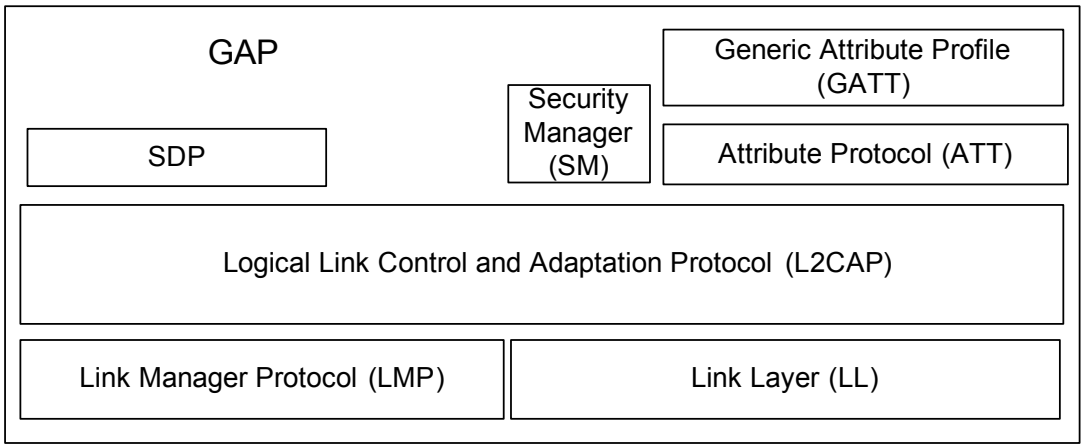


Figure 2.1: Relationship of GAP with lower layers of the Bluetooth architecture

The purpose of this profile is to describe:

- Profile roles
- Discoverability modes and procedures
- Connection modes and procedures
- Security modes and procedures

2.2 PROFILE ROLES

2.2.1 Roles when Operating over BR/EDR Physical Transport

In GAP, for describing the Bluetooth communication that occurs between two devices in the BR/EDR GAP role, the generic notation of the A-party (the *paging device* in case of link establishment, or *initiator* in case of another procedure on an established link) and the B-party (*paged device* or *acceptor*) is used. The A-party is the one that, for a given procedure, initiates device discovery, initiates the establishment of a physical link or initiates a transaction on an existing link.

This profile handles the procedures between two devices related to discovery and connecting (link and connection establishment) for the case where none of the two devices has any link established as well as the case where (at least) one device has a link established (possibly to a third device) before starting the described procedure.

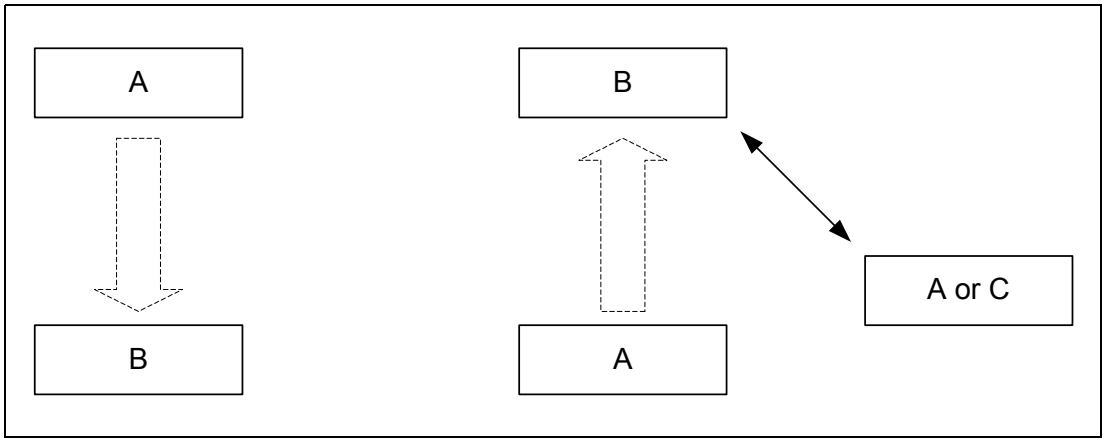


Figure 2.2: This profile covers procedures initiated by one device (A) towards another device (B) that may or may not have an existing Bluetooth link active

The initiator and the acceptor generally operate the generic procedures according to this profile or another profile referring to this profile. If the acceptor operates according to several profiles simultaneously, this profile describes generic mechanisms for how to handle this.

2.2.2 Roles when Operating over an LE Physical Transport

There are four GAP roles defined for devices operating over an LE physical transport:

- Broadcaster
- Observer
- Peripheral
- Central

Table 2.1 defines compliance requirements for Physical Layer and Link Layer functionalities for each GAP role when operating over an LE physical transport.

		GAP Roles When Operating Over an LE Physical Transport			
		Broadcaster	**Observer**	**Peripheral**	**Central**
Physical Layer functionality:					
• Transmitter Characteristics		M	O	M	M
• Receiver Characteristics		O	M	M	M
Link Layer functionality:					
States:					
• Standby State		M	M	M	M
• Advertising State		M	E	M	E
• Scanning State		E	M	E	M
• Initiating State		E	E	E	M
• Connection State	Slave Role	E	E	M	E
	Master Role	E	E	E	M
Advertising event types:					
• Connectable and scannable undirected event		E	E	M	E
• Connectable undirected event		E	E	O	E
• Connectable directed event		E	E	O	E
• Non-connectable and non-scannable undirected event		M	E	O	E
• Non-connectable and non-scannable directed event		O	E	O	E
• Scannable undirected event		O	E	O	E
• Scannable directed event		O	E	O	E
Scanning type:					
• Passive scanning		E	M	E	O
• Active scanning		E	O	E	C1
Link Layer control procedures:					
• Connection Update procedure		E	E	M	M
• Channel Map Update procedure		E	E	M	M

Table 2.1: GAP compliance requirements for Physical Layer and Link Layer functionalities for each GAP role when operating over an LE physical transport

	GAP Roles When Operating Over an LE Physical Transport			
	Broadcaster	**Observer**	**Peripheral**	**Central**
• Encryption procedure	E	E	O	O
• Master-initiated Feature Exchange procedure	E	E	M	M
• Slave-initiated Feature Exchange procedure	E	E	C2	C2
• Connection Parameters Request procedure	E	E	O	O
• Version Exchange procedure	E	E	M	M
• Termination procedure	E	E	M	M

C1: If passive scanning is supported then active scanning is optional, otherwise active scanning is mandatory.

C2: Mandatory if Connection Parameters Request procedure is supported, otherwise optional.

Table 2.1: GAP compliance requirements for Physical Layer and Link Layer functionalities for each GAP role when operating over an LE physical transport

2.2.2.1 Broadcaster Role

A device operating in the Broadcaster role is a device that sends advertising events as described in [Vol 6] Part B, Section 4.4.2. A device operating in the Broadcaster role is referred to as a Broadcaster and shall have a transmitter and may have a receiver.

2.2.2.2 Observer Role

A device operating in the Observer role is a device that receives advertising events as described in [Vol 6] Part B, Section 4.4.3. A device operating in the Observer role is referred to as an Observer and shall have a receiver and may have a transmitter.

2.2.2.3 Peripheral Role

Any device that accepts the establishment of an LE active physical link using any of the connection establishment procedures as defined in Section 9 is referred to as being in the Peripheral role. A device operating in the Peripheral role will be in the Slave role in the Link Layer Connection State as described in [Vol 6] Part B, Section 4.5. A device operating in the Peripheral role is referred to as a Peripheral. A Peripheral shall have both a transmitter and a receiver.

2.2.2.4 Central Role

A device that supports the Central role initiates the establishment of an LE active physical link. A device operating in the Central role will be in the Master role in the Link Layer Connection State as described in [Vol 6] Part B, Section 4.5. A device operating in the Central role is referred to as a Central. A Central shall have both a transmitter and a receiver.

2.2.2.5 Concurrent Operation in Multiple GAP Roles

A device may operate in multiple GAP roles concurrently if supported by the Controller. The Host should read the supported Link Layer States and State combinations from the Controller before any procedures or modes are used.

2.3 USER REQUIREMENTS AND SCENARIOS

The Bluetooth user should, where expected, be able to connect a Bluetooth device to any other Bluetooth device. Even if the two connected devices don't share any common application, it should be possible for the user to find this out using basic Bluetooth capabilities. When the two devices do share the same application but are from different manufacturers, the ability to connect them should not be blocked just because manufacturers choose to call basic Bluetooth capabilities by different names on the user interface level or implement basic procedures to be executed in different orders.

2.4 PROFILE FUNDAMENTALS

This profile states the requirements on names, values and coding schemes used for names of parameters and procedures experienced on the user interface level.

This profile defines modes of operation that are not service- or profile-specific, but that are generic and can be used by profiles referring to this profile, and by devices implementing multiple profiles.

This profile defines the general procedures that can be used for discovering identities, names and basic capabilities of other Bluetooth devices that are in a mode where they can be discovered. Only procedures where no channel or connection establishment is used are specified.

This profile defines the general procedure for how to create bonds (i.e., dedicated exchange of link keys) between Bluetooth devices.

This profile describes the general procedures that can be used for establishing connections to other Bluetooth devices that are in a mode that allows them to accept connections and service requests.

2.5 CONFORMANCE

Bluetooth devices shall conform to this profile to ensure basic interoperability.

Bluetooth devices that conform to another Bluetooth profile may use adaptations of the generic procedures as specified by that other profile. They shall, however, be compatible with devices compliant to this profile at least on the level of the supported generic procedures.

All capabilities indicated as mandatory for this profile shall be supported in the specified manner (process-mandatory). This also applies for all optional and conditional capabilities for which support is indicated. All mandatory capabilities, and optional and conditional capabilities for which support is indicated, are subject to verification as part of the Bluetooth qualification program.

3 USER INTERFACE ASPECTS

3.1 THE USER INTERFACE LEVEL

In the context of this specification, the user interface level refers to places (such as displays, dialog boxes, manuals, packaging, advertising, etc.) where users of Bluetooth devices encounters names, values and numerical representation of Bluetooth terminology and parameters.

This profile specifies the generic terms that should be used on the user interface level.

3.2 REPRESENTATION OF BLUETOOTH PARAMETERS

3.2.1 Bluetooth Device Address (BD_ADDR)

3.2.1.1 Definition

A BD_ADDR is the address used by a Bluetooth device as defined in Section 15.1. It is received from a remote device during the device discovery procedure.

3.2.1.2 Term on user interface level

When the Bluetooth address is referred to on UI level, the term Bluetooth Device Address' should be used.

3.2.1.3 Representation

On the baseband level the BD_ADDR is represented as 48 bits (see [Vol 2] Part B, Section 1.2). On the Link Layer the public and random device address are represented as 48-bit addresses.

On the UI level the Bluetooth address shall be represented as 12 hexadecimal characters, possibly divided into sub-parts separated by ':' (e.g., '000C3E3A4B69' or '00:0C:3E:3A:4B:69'). On the UI level any number shall have the MSB -> LSB (from left to right) 'natural' ordering.

3.2.2 Bluetooth Device Name (the user-friendly name)

3.2.2.1 Definition

The Bluetooth device name is the user-friendly name that a Bluetooth device exposes to remote devices. For a device supporting the BR/EDR device type, the name is a character string returned in the LMP_name_res in response to an LMP_name_req. For a device supporting the LE-only device type, the name is a character string held in the Device Name characteristic as defined in Section 12.1.

3.2.2.1.1 Bluetooth Device Name in a Device with BR/EDR/LE Device Type

A BR/EDR/LE device type shall have a single Bluetooth device name which shall be identical irrespective of the physical channel used to perform the name discovery procedure.

For the BR/EDR physical channel the name is received in the LMP_name_res. For the LE physical channel the name can be read from the Device Name characteristic as defined in Section 12.1.

Note: The Device Name Characteristic of the local device can be read by a remote device using ATT over BR/EDR if the local device supports ATT over BR/EDR.

3.2.2.2 Term on user interface level

When the Bluetooth device name is referred to on UI level, the term ‘Bluetooth Device Name’ should be used.

3.2.2.3 Representation

The Bluetooth device name can be up to 248 bytes (see [Vol 2] Part C, Section 4.3.5). It shall be encoded according to UTF-8 (therefore the name entered on the UI level may be restricted to as few as 62 characters if codepoints outside the range U+0000 to U+007F are used).

A device cannot expect that a general remote device is able to handle more than the first 40 characters of the Bluetooth device name. If a remote device has limited display capabilities, it may use only the first 20 characters.

3.2.3 Bluetooth Passkey (Bluetooth PIN)

3.2.3.1 Definition

The Bluetooth passkey may be used to authenticate two Bluetooth devices with each other during the creation of a mutual link key via the pairing procedure. The passkey may be used in the pairing procedures to generate the initial link key.

The PIN may be entered on the UI level but may also be stored in the device; e.g., in the case of a device without sufficient MMI for entering and displaying digits.

3.2.3.2 Terms at user interface level

When the Bluetooth PIN is referred to on UI level, the term ‘Bluetooth Passkey’ should be used.

3.2.3.3 Representation

There are a number of different representations of the Bluetooth passkey. At a high level there are two distinct representations: one used with the Secure Simple Pairing and Security Manager, and another used with legacy pairing (where it is generally referred to as the Bluetooth PIN).

For Secure Simple Pairing and Security Manager, the Bluetooth passkey is a 6-digit numerical value. It is represented as integer value in the range 0x00000000 – 0x000F423F (000000 to 999999). The numeric value may be used as the input to the Authentication Stage 1 for Secure Simple Pairing Passkey Entry (see [Vol 2] Part H, Section 7.2.3), or as the TK value in the Security Manager for the process defined in [Vol 3] Part H, Section 2.3.5.

For legacy pairing (see Section B.2), the Bluetooth PIN has different representations on different levels. PINBB is used on baseband level, and PINUI is used on user interface level. PINBB is the PIN used by [1] for calculating the initialization key during the Pairing Procedure.

PINUI is the character representation of the PIN that is entered on the UI level. The transformation from PINUI to PINBB shall be according to UTF-8. PINBB may be 128 bits (16 bytes).

PIN codes may be up to 16 characters. In order to take advantage of the full level of security all PINs should be 16 characters long. Variable PINs should be composed of alphanumeric characters chosen from within the Unicode range U+0000 to U+007F. If the PIN contains any decimal digits these shall be encoded using the Unicode Basic Latin characters (i.e., U+0030 to U+0039) (Note 1).

For compatibility with devices with numeric keypads, fixed PINs shall be composed of only decimal digits, and variable PINs should be composed of only decimal digits.

If a device supports entry of characters outside the Unicode range U+0000 to U+007F, other Unicode code points may be used (Note 2), except the Halfwidth and Fullwidth Forms (i.e., U+FF00 to U+FFEF) shall not be used (Note 3).

Examples:

User-entered code	Corresponding PIN_{BB}[0..length-1] (value as a sequence of octets in hexadecimal notation)
’0196554200906493’	length = 16, value = 0x30 0x31 0x39 0x36 0x35 0x35 0x34 0x32 0x30 0x30 0x39 0x30 0x36 0x34 0x39 0x33
’Børnelitteratur’	length = 16, value = 0x42 0xC3 0xB8 0x72 0x6e 0x65 0x6c 0x69 0x74 0x74 0x65 0x72 0x61 0x74 0x75 0x72

Note 1: This is to prevent interoperability problems since there are decimal digits at other code points (e.g., the Fullwidth digits at code points U+FF10 to U+FF19).

Note 2: Unicode characters outside the Basic Latin range (U+0000 to U+007F) encode to multiple bytes; therefore, when characters outside the Basic Latin range are used the maximum number of characters in the PINUI will be less than 16. The second example illustrates a case where a 15 character string encodes to 16 bytes because the character ø is outside the Basic Latin range and encodes to two bytes (0xC3 0xB8).

Note 3: This is to prevent interoperability problems since the Halfwidth and Fullwidth forms contain alternative variants of ASCII, Katakana, Hangul, punctuation and symbols. All of the characters in the Halfwidth and Fullwidth forms have other related Unicode characters; for example, U+3150 (Hangul Letter AE) can be used instead of U+FFC3 (Halfwidth Hangul Letter AE).

3.2.4 Class of Device

3.2.4.1 Definition

Class of device is a parameter received during the device discovery procedure on the BR/EDR physical transport, indicating the type of device. The Class of Device parameter is only used on BR/EDR and BR/EDR/LE devices using the BR/EDR physical transport.

3.2.4.2 Term on user interface level

The information within the Class of Device parameter should be referred to as ‘Bluetooth Device Class’ (i.e., the major and minor device class fields) and ‘Bluetooth Service Type’ (i.e., the service class field). The terms for the defined Bluetooth Device Types and Bluetooth Service Types are defined in [7].

When using a mix of information found in the Bluetooth Device Class and the Bluetooth Service Type, the term ‘Bluetooth Device Type’ should be used.

3.2.4.3 Representation

The Class of device is a bit field and is defined in [7]. The UI-level representation of the information in the Class of Device is implementation specific.

3.2.4.4 Usage

Some devices provide more than one service and a given service may be provided by different device types. Therefore, the device type does not have a one-to-one relationship with services supported. The major and minor device class field should not be used to determine whether a device supports any specific service(s). It may be used as an indication of devices that are most likely to support desired services before service discovery requests are made, and it may be used to guide the user when selecting among several devices that support the same service.

3.2.5 Appearance Characteristic

3.2.5.1 Definition

The Appearance characteristic contains a 16-bit number that can be mapped to an icon or string that describes the physical representation of the device during the device discovery procedure. It is a characteristic of the GAP service located on the device's GATT server. See Section 12.2.

3.2.5.2 Usage at user interface level

The Appearance characteristic value should be mapped to an icon or string or something similar that conveys to the user a visual description of the device. This allows the user to determine which device is being discovered purely by visual appearance. If a string is displayed, this string should be translated into the language selected by the user for the device.

3.2.5.3 Representation

The Appearance characteristic value shall be set to one of the 16-bit numbers assigned by the Bluetooth SIG and defined in [Core Specification Supplement], Part A, Section 1.12. The UI-level representation of the Appearance characteristic value is implementation specific.

3.3 PAIRING

Pairing over a BR/EDR physical link is defined on LMP level (LMP pairing, see Appendix B.2). Pairing over an LE physical link is defined by the Security Manager specification ([Vol 3] Part H, Section 2.3). Either the user initiates the bonding procedure and enters the passkey with the explicit purpose of creating a bond (and maybe also a secure relationship) between two Bluetooth devices, or the user is requested to enter the passkey during the establishment procedure since the devices did not share a common link key beforehand. In the first case, the user is said to perform “bonding (with entering of passkey)” and in the second case the user is said to “authenticate using the passkey.”

4 MODES – BR/EDR PHYSICAL TRANSPORT

Procedure	Ref.	Support
Discoverability modes:	4.1	
Non-discoverable mode		C1
Discoverable mode		O
Limited discoverable mode		C3
General discoverable mode		C4
Connectability modes:	4.2	
Non-connectable mode		O
Connectable mode		M
Bondable modes:	4.3	
Non-bondable mode		O
Bondable mode		C2
Synchronizability modes:	4.4	
Non-synchronizable mode		M
Synchronizable mode		O
C1: If limited discoverable mode is supported, non-discoverable mode is mandatory, otherwise optional.		
C2: If the bonding procedure is supported, support for bondable mode is mandatory, otherwise optional.		
C3: If Discoverable mode is supported, support for Limited Discoverable mode is mandatory, otherwise optional.		
C4: If Discoverable mode is supported, support for General Discoverable mode is mandatory, otherwise optional		

Table 4.1: Conformance requirements related to modes defined in this section

4.1 DISCOVERABILITY MODES

With respect to inquiry, a Bluetooth device shall be either in non-discoverable mode or in a discoverable mode. (The device shall be in one, and only one, discoverability mode at a time.) The two discoverable modes defined here are called limited discoverable mode and general discoverable mode. Inquiry is defined in [Vol 2] Part B, Section 8.4.

When a Bluetooth device is in non-discoverable mode it does not respond to inquiry.

A Bluetooth device is said to be made discoverable, or set into a discoverable mode, when it is in limited discoverable mode or in general discoverable mode. Even when a Bluetooth device is made discoverable, it may be unable to respond to inquiry due to other baseband activity (for example, reserved synchronous slots should have priority over response packets, so that synchronous links may prevent a response from being returned). A Bluetooth device that does not respond to inquiry is called a silent device.

After being made discoverable, the Bluetooth device shall be discoverable for at least $T_{GAP}(103)$.

The speed of discovery is dependent on the configuration of the inquiry scan interval and inquiry scan type of the Bluetooth device. The Host is able to configure these parameters based on trade-offs between power consumption, bandwidth and the desired speed of discovery.

4.1.1 Non-discoverable Mode

4.1.1.1 Definition

When a Bluetooth device is in non-discoverable mode, it shall never enter the INQUIRY_SCAN state.

4.1.1.2 Term on UI-level

Bluetooth device is ‘non-discoverable’ or in ’non-discoverable mode’.

4.1.2 Limited Discoverable Mode

4.1.2.1 Definition

The limited discoverable mode should be used by devices that need to be discoverable only for a limited period of time, during temporary conditions, or for a specific event. The purpose is to respond to a device that makes a limited inquiry (inquiry using the LIAC).

A Bluetooth device should not be in limited discoverable mode for more than $T_{GAP}(104)$. The scanning for the limited inquiry access code can be done either in parallel or in sequence with the scanning of the general inquiry access code. When in limited discoverable mode, one of the following options shall be used.

- *Parallel scanning*

  When a Bluetooth device is in limited discoverable mode and when discovery speed is more important than power consumption or bandwidth, it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(105)$ and that Interlaced Inquiry scan is used.

If, however, power consumption or bandwidth is important, but not critical, it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(102)$ and Interlaced Inquiry scan is used.

When power consumption or bandwidth is critical it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(102)$ and Non-interlaced Inquiry scan is used.

In all cases the Bluetooth device shall enter the INQUIRY_SCAN state at least once in $T_{GAP}(102)$ and scan for the GIAC and the LIAC for at least $T_{GAP}(101)$.

When either a SCO or eSCO link is in operation, it is recommended to use interlaced scan to significantly decrease the discoverability time.

- *Sequential scanning*

  When a Bluetooth device is in limited discoverable mode, it shall enter the INQUIRY_SCAN state at least once in $T_{GAP}(102)$ and scan for the GIAC for at least $T_{GAP}(101)$ and enter the INQUIRY_SCAN state more often than once in $T_{GAP}(102)$ and scan for the LIAC for at least $T_{GAP}(101)$.

  If an inquiry message is received when in limited discoverable mode, the entry into the INQUIRY_RESPONSE state takes precedence over the next entries into INQUIRY_SCAN state until the inquiry response is completed.

4.1.2.2 Conditions

When a device is in limited discoverable mode it shall set bit no 13 in the Major Service Class part of the Class of Device/Service field [7].

4.1.2.3 Term on UI-level

Bluetooth device is ‘discoverable’ or in ‘discoverable mode’.

4.1.3 General Discoverable Mode

4.1.3.1 Definition

The general discoverable mode shall be used by devices that need to be discoverable continuously or for no specific condition. The purpose is to respond to a device that makes a general inquiry (inquiry using the GIAC).

4.1.3.2 Conditions

When a Bluetooth device is in general discoverable mode and when discovery speed is more important than power consumption or bandwidth, it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(105)$ and that Interlaced Inquiry scan is used.

If, however, power consumption or bandwidth is important, but not critical, it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(102)$ and Interlaced Inquiry scan is used.

When power consumption or bandwidth is critical it is recommended that the Bluetooth device enter the INQUIRY_SCAN state at least every $T_{GAP}(102)$ and Non-interlaced Inquiry scan is used.

In all cases the Bluetooth device shall enter the INQUIRY_SCAN state at least once in $T_{GAP}(102)$ and scan for the GIAC for at least $T_{GAP}(101)$.

When either a SCO or eSCO link is in operation, it is recommended to use interlaced scan to significantly decrease the discoverability time.

A device in general discoverable mode shall not respond to a LIAC inquiry.

4.1.3.3 Term on UI-level

Bluetooth device is ‘discoverable’ or in ‘discoverable mode’.

4.2 CONNECTABILITY MODES

With respect to paging, a Bluetooth device shall be either in non-connectable mode or connectable mode. Paging is defined in [Vol 2] Part B, Section 8.3.

When a Bluetooth device is in non-connectable mode it does not respond to paging. When a Bluetooth device is in connectable mode it responds to paging.

The speed of connections is dependent on the configuration of the page scan interval and page scan type of the Bluetooth device. The Host is able to configure these parameters based on trade-offs between power consumption, bandwidth and the desired speed of connection.

4.2.1 Non-connectable Mode

4.2.1.1 Definition

When a Bluetooth device is in non-connectable mode it shall never enter the PAGE_SCAN state.

4.2.1.2 Term on UI-level

Bluetooth device is ‘non-connectable’ or in ‘non-connectable mode’.

4.2.2 Connectable Mode

4.2.2.1 Definition

When a Bluetooth device is in connectable mode it shall periodically enter the PAGE_SCAN state. The device makes page scan using the Bluetooth device address, BD_ADDR. Connection speed is a trade-off between power consumption / available bandwidth and speed. The Bluetooth Host is able to make these trade-offs using the Page Scan interval, Page Scan window, and Interlaced Scan parameters.

R0 page scanning should be used when connection speeds are critically important and when the paging device has a very good estimate of the Bluetooth clock. Under these conditions it is possible for paging to complete within two times the page scan window. Because the page scan interval is equal to the page scan window it is not possible for any other traffic to go over the Bluetooth link when using R0 page scanning. In R0 page scanning it is not possible to use interlaced scan. R0 page scanning is the highest power consumption mode of operation.

When connection times are critical but the other device either does not have an estimate of the Bluetooth clock or when the estimate is possibly out of date, it is better to use R1 page scanning with a very short page scan interval, $T_{GAP}(106)$, and Interlaced scan. This configuration is also useful to achieve

nearly the same connection speeds as R0 page scanning but using less power and leaving bandwidth available for other connections. Under these circumstances it is possible for paging to complete within $T_{GAP}(106)$. In this case the Bluetooth device shall page scan for at least $T_{GAP}(101)$.

When connection times are important but not critical enough to sacrifice significant bandwidth and/or power consumption it is recommended to use either $T_{GAP}(107)$ or $T_{GAP}(108)$ for the scanning interval. Using Interlaced scan will reduce the connection time by half but may use twice the power consumption. Under these circumstances it is possible for paging to complete within one or two times the page scanning interval depending on whether Interlaced Scan is used. In this case the Bluetooth device shall page scan for at least $T_{GAP}(101)$.

In all cases the Bluetooth device shall enter the PAGE_SCAN state at least once in $T_{GAP}(102)$ and scan for at least $T_{GAP}(101)$.

The page scan interval, page scan window size, and scan type for the six scenarios are described in Table 4.2:

Scenario	Page Scan Interval	Page Scan Window	Scan Type
R0 (1.28s)	$T_{GAP}(107)$	$T_{GAP}(107)$	Normal scan
Fast R1 (100ms)	$T_{GAP}(106)$	$T_{GAP}(101)$	Interlaced scan
Medium R1 (1.28s)	$T_{GAP}(107)$	$T_{GAP}(101)$	Interlaced scan
Slow R1 (1.28s)	$T_{GAP}(107)$	$T_{GAP}(101)$	Normal scan
Fast R2 (2.56s)	$T_{GAP}(108)$	$T_{GAP}(101)$	Interlaced scan
Slow R2 (2.56s)	$T_{GAP}(108)$	$T_{GAP}(101)$	Normal scan

Table 4.2: Page scan parameters for connection speed scenarios

When either a SCO or eSCO link is in operation, it is recommended to use interlaced scan to significantly decrease the connection time.

4.2.2.2 Term on UI-level

Bluetooth device is ‘connectable’ or in ‘connectable mode’.

4.3 BONDABLE MODES

With respect to bonding, a Bluetooth device shall be either in non-bondable mode or in bondable mode. In bondable mode the Bluetooth device accepts bonding initiated by the remote device, and in non-bondable mode it does not.

4.3.1 Non-bondable Mode

4.3.1.1 Definition

When a Bluetooth device is in non-bondable mode it shall not accept a pairing request that results in bonding. Devices in non-bondable mode may accept connections that do not request or require bonding.

A device in non-bondable mode shall respond to a received LMP_in_rand with LMP_not_accepted with the reason *pairing not allowed*.

When both devices support Secure Simple Pairing and the local device is in non-bondable mode, the local Host shall respond to an IO capability request where the Authentication_Requirements parameter requests dedicated bonding or general bonding with a negative response.

4.3.1.2 Term on UI-level

Bluetooth device is ‘non-bondable’ or in ‘non-bondable mode’ or “does not accept bonding”.

4.3.2 Bondable Mode

4.3.2.1 Definition

When a Bluetooth device is in bondable mode, and Secure Simple Pairing is not supported by either the local or remote device, the local device shall respond to a received LMP_in_rand with LMP_accepted (or with LMP_in_rand if it has a fixed PIN).

When both devices support Secure Simple Pairing, the local Host shall respond to a user confirmation request with a positive response.

4.3.2.2 Term on UI-level

Bluetooth device is ‘bondable’ or in ‘bondable mode’ or “accepts bonding”.

4.4 SYNCHRONIZABILITY MODES

A Bluetooth device shall be either in non-synchronizable mode or synchronizable mode. The synchronization train procedure is defined in [Vol 2] Part B, Section 2.7.2.

When a Bluetooth device is in synchronizable mode, it transmits timing and frequency information for its active Connectionless Slave Broadcast packets. When a Bluetooth device is non-synchronizable, timing and frequency information is not transmitted.

The Host is able to configure the Synchronization Train interval based on trade-offs between bandwidth, potential interference to other devices, power consumption, and the desired time for a slave to receive a synchronization train packet.

4.4.1 Non-synchronizable Mode

4.4.1.1 Definition

When a Bluetooth device is in non-synchronizable mode it shall never enter the **synchronization train** substate.

4.4.1.2 Term on UI-level

Bluetooth device is ‘non-synchronizable’ or in ‘non-synchronizable mode’.

4.4.2 Synchronizable Mode

4.4.2.1 Definition

When a Bluetooth device is in synchronizable mode, it shall enter the **synchronization train** substate using a synchronization train interval of T_{GAP}(Sync_Train_Interval).

After being made synchronizable, the Bluetooth device shall be synchronizable for at least T_{GAP}(Sync_Train_Duration).

5 SECURITY ASPECTS – BR/EDR PHYSICAL TRANSPORT

	Procedure	Ref.	Support
1	Authentication	5.1	M
2	Security modes	5.2	
	Security mode 1		E
	Security mode 2		O.1
	Security mode 3		E
	Security mode 4		M
O.1: Security Mode 2 may only be used for backwards compatibility when the remote device does not support Secure Simple Pairing.			

Table 5.1: Conformance requirements related to the generic authentication procedure and the security modes defined in this section

5.1 AUTHENTICATION

5.1.1 Purpose

The generic authentication procedure describes how the LMP-authentication and LMP-pairing procedures are used when authentication is initiated by one Bluetooth device towards another, depending on if a link key exists or not and if pairing is allowed or not.

5.1.2 Term on UI level

‘Bluetooth authentication’.

5.1.3 Procedure

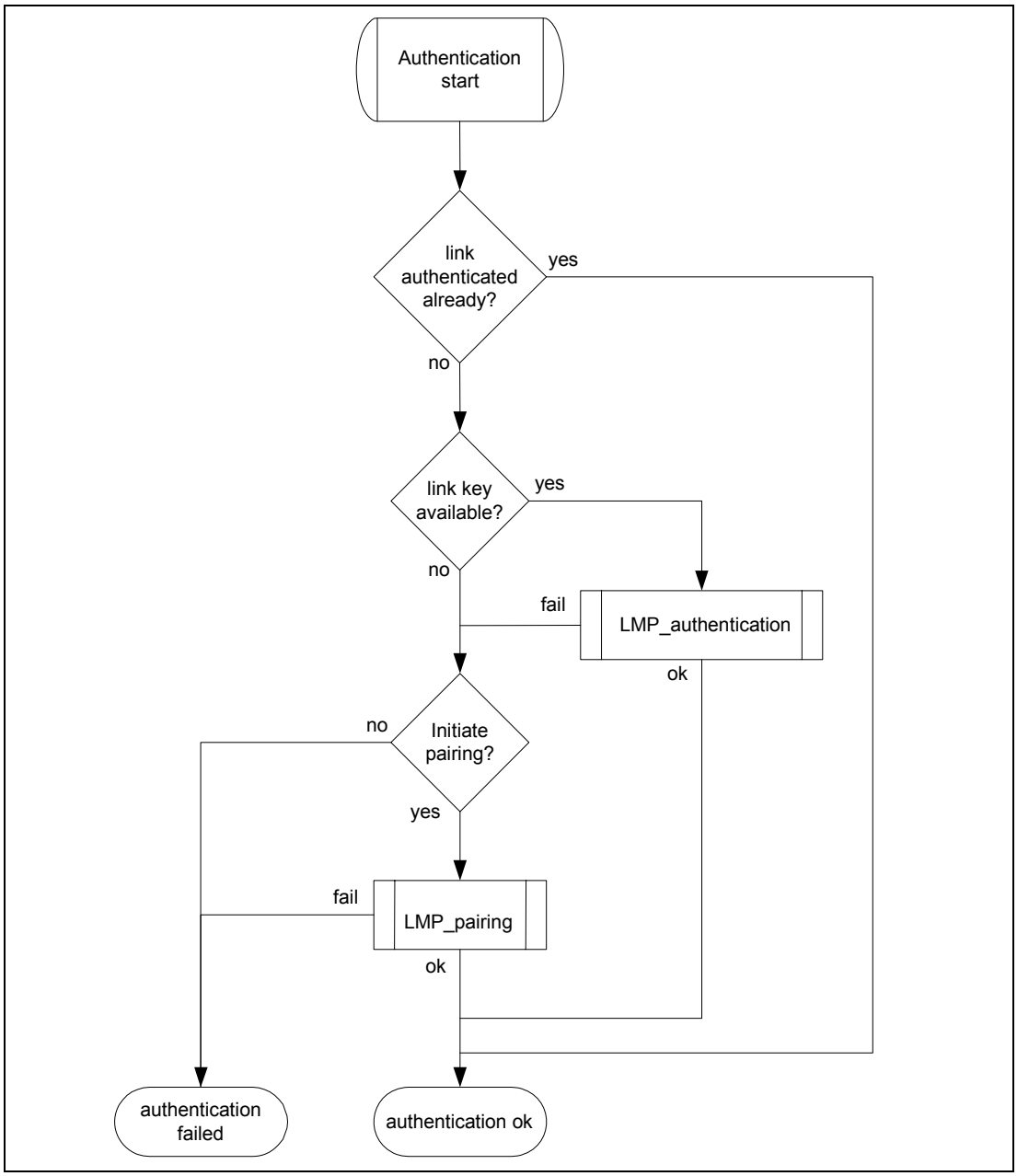


Figure 5.1: Definition of the generic authentication procedure

5.1.4 Conditions

The local device shall initiate authentication after link establishment. The remote device may initiate security during or after link establishment.

5.2 SECURITY MODES

The following flow chart provides an overview of the channel establishment procedures.

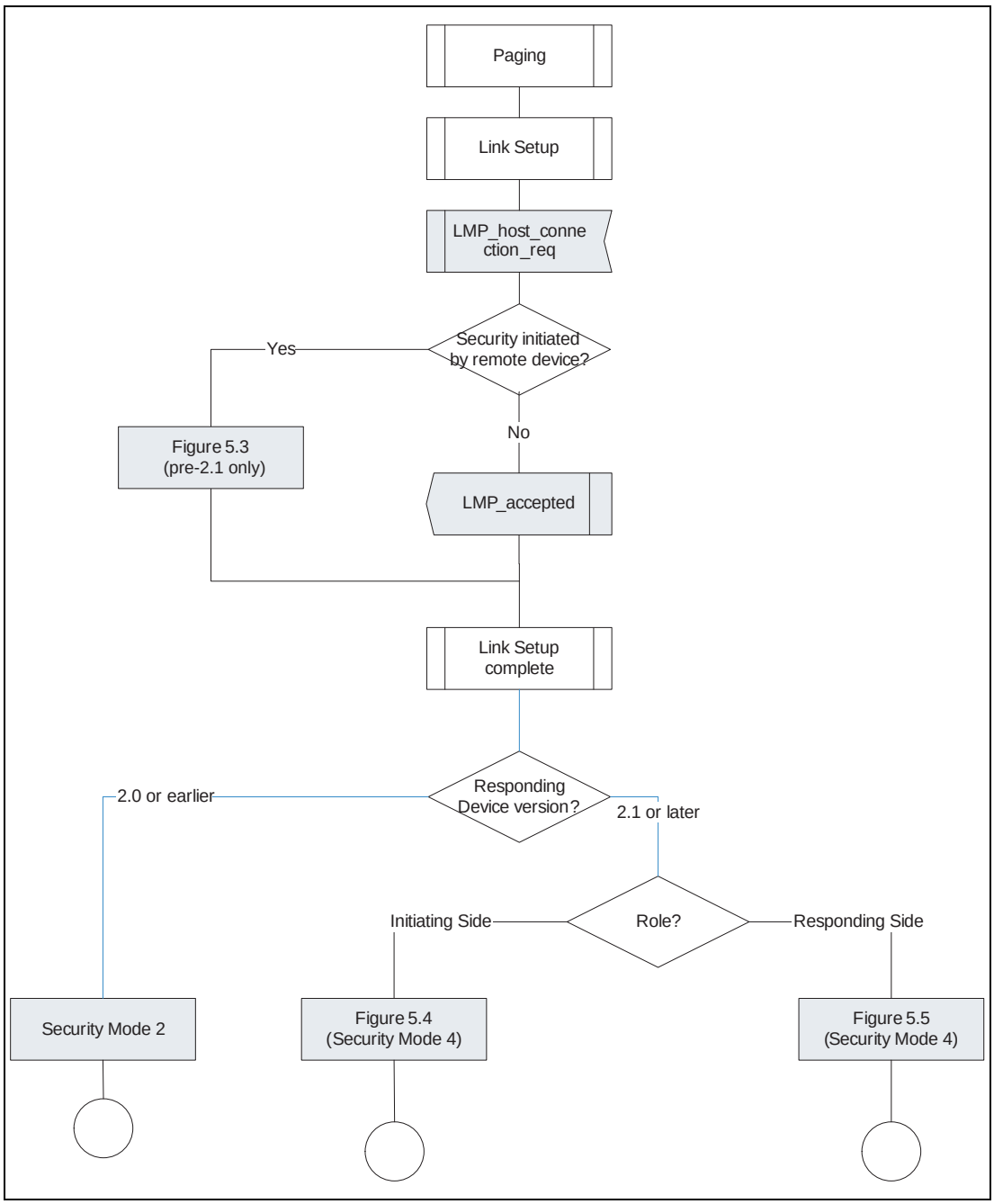


Figure 5.2: Channel establishment with security

A device may support two security modes simultaneously: security mode 2 for backwards compatibility with remote devices that do not support Secure Simple Pairing and security mode 4 for devices that support Secure Simple Pairing.

5.2.1 Legacy Security Modes

Legacy security modes apply to those devices with a Controller or a Host that does not support SSP.

5.2.1.1 Security mode 1 (non-secure)

When a remote Bluetooth device is in security mode 1 it will never initiate any security procedure (i.e., it will never send LMP_au_rand, LMP_in_rand or LMP_encryption_mode_req).

5.2.1.2 Security mode 2 (service level enforced security)

When a remote Bluetooth device is in security mode 2 it will not initiate any security procedure before a channel establishment request (L2CAP_ConnectReq) has been received or a channel establishment procedure has been initiated by itself. (The behavior of a device in security mode 2 is further described in [6].) Whether a security procedure is initiated or not depends on the security requirements of the requested channel or service.

A Bluetooth device in security mode 2 should classify the security requirements of its services using at least the following attributes:

- Authorization required
- Authentication required
- Encryption required

Note: Security mode 1 can be considered (at least from a remote device point of view) as a special case of security mode 2 where no service has registered any security requirements.

5.2.1.3 Security mode 3 (link level enforced security)

When a remote Bluetooth device is in security mode 3 it will initiate security procedures before it sends LMP_setup_complete.

A Bluetooth device in security mode 3 may reject the Host connection request (respond with LMP_not_accepted to the LMP_host_connection_req) based on settings in the Host (e.g., only communication with pre-paired devices allowed).

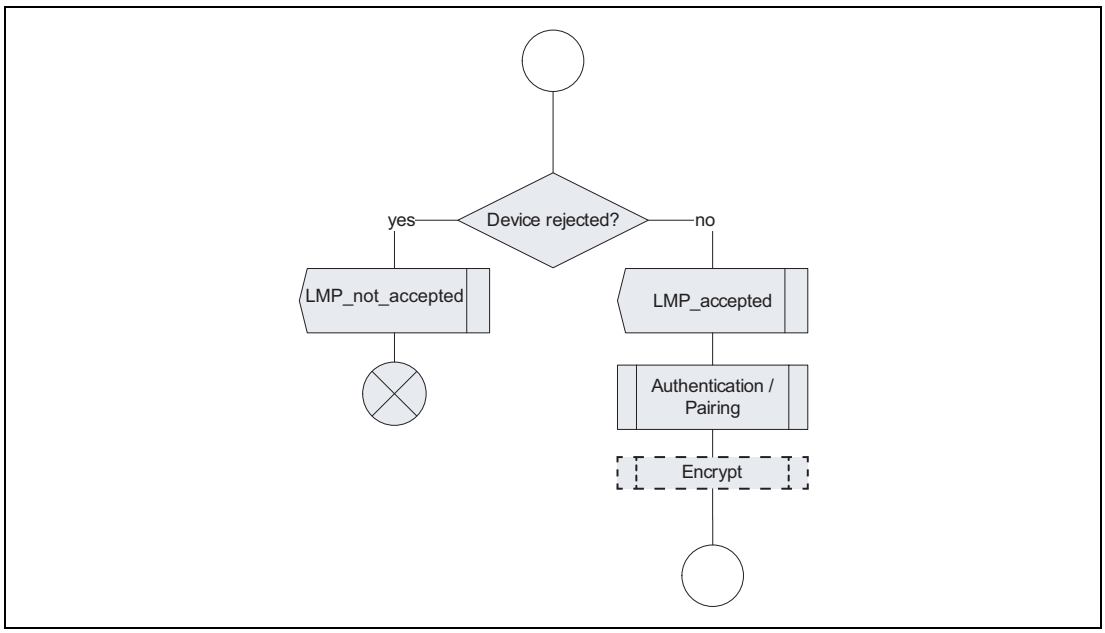


Figure 5.3: Security mode 3 with a legacy remote device

5.2.2 Security Mode 4 (service level enforced security)

A Bluetooth device in security mode 4 shall classify the security requirements of its services using at least the following attributes (in order of decreasing security):

- Authenticated link key required
- Unauthenticated link key required
- Security optional – SDP only. Limited to specific services (see Section 5.2.2.8).

An authenticated link key is a link key where either the numeric comparison, out-of-band, or passkey entry simple pairing association models were used. An authenticated link key has protection against man-in-the-middle (MITM) attacks. To ensure that an authenticated link key is created during the Simple Pairing procedure, the Authentication_Requirements parameter should be set to one of the MITM Protection Required options. An *unauthenticated link key* is a link key where the just works Secure Simple Pairing association model was used. An unauthenticated link key does not have protection against MITM attacks.

When both devices support Secure Simple Pairing, GAP shall require at least an unauthenticated link key and enabling encryption for all connections except those allowed to have security level 0 (see Section 5.2.2.8). A profile or protocol may define services that require more security (e.g., an authenticated link key) or no security (although unencrypted connections are only allowed when connecting to a service allowed to have security level 0). To allow an unauthenticated link key to be created during the Simple Pairing procedure, the Authentication_Requirements parameter may be set to one of the MITM Protection Not Required options.

When the device is in Bondable Mode, it shall enable Secure Simple Pairing mode prior to entering Connectable Mode or establishing a link.

A Bluetooth device in security mode 4 shall respond to authentication requests during link establishment when the remote device is in security mode 3 for backwards compatibility reasons.

A Bluetooth device in security mode 4 enforces its security requirements before it attempts to access services offered by a remote device and before it grants access to services it offers to remote devices. Service access may occur via L2CAP channels or via channels established by protocols above L2CAP such as RFCOMM.

For services transmitting unicast data over the connectionless L2CAP channel, the transmitting device shall enforce its security requirements prior to sending data. There is no mechanism for a device receiving data via the L2CAP connectionless channel to prevent unencrypted data from being received. Hence, Section 5.2.2.1 addresses unicast connectionless data transmission together with devices initiating connection-oriented channels while Section 5.2.2.2 covers only devices responding to requests for connection-oriented channel establishment but does not cover unicast connectionless data reception.

A device may be in a Secure Connections Only mode. When in Secure Connections Only mode, all services (except those allowed to have Security Mode 4, Level 0) available on the BR/EDR physical transport require Security Mode 4, Level 4. The device shall reject both new outgoing and incoming service level connections when the service requires Security Mode 4, Level 4 and either the physical transport does not support Secure Connections or unauthenticated pairing is being requested.
A device operating with a physical transport operating in Secure Connections Only mode may disconnect the ACL connection using error code 0x05 (Authentication Failure) when the physical transport that does not support Secure Connections, tries to access a service that requires Security Mode 4, Level 4.
Note: A device may operate several physical transports simultaneously - in this case all physical transports are required to enable Security Connections Only Mode simultaneously.

5.2.2.1 Security for Access to Remote Service (Initiating Side)

When the responding device does not support Secure Simple Pairing, it may disconnect the link while the initiating device is requesting the PIN to be entered by the user. This may occur due to the lack of an L2CAP channel being present for longer than an implementation-specific amount of time (e.g., a few seconds). When this occurs, the initiating device shall allow the user to complete entering the PIN and shall then re-page the remote device and restart the pairing procedure (see [Vol 2] Part C, Section 4.2.2) using the PIN entered.

5.2.2.1.1 Pairing Required for Access to Remote Service

When a Bluetooth device in security mode 4 initiates access to a remote service via a connection-oriented L2CAP channel and a sufficient link-key is not available, the local device shall perform pairing procedures and enable encryption before sending a channel establishment request (L2CAP_ConnectReq or a higher-layer channel establishment request such as that of RFCOMM).

When a Bluetooth device in security mode 4 transmits data to a remote service via the unicast connectionless L2CAP channel and a sufficient link-key is not available, the local device shall perform pairing procedures and enable encryption before transmitting unicast data on the connectionless L2CAP channel.

See Section 5.2.2.8 for details on determining whether or not a link key is sufficient.

If pairing does not succeed, the local device shall not send a channel establishment request. The local device may re-try pairing up to three (3) times. If pairing fails three consecutive times, the local device shall disconnect the ACL link with error code 0x05 - Authentication Failure.

If the link key generated is not at least as good as the expected or required type, the local device shall fail the establishment and may disconnect the ACL link with error code 0x05 - Authentication Failure.

5.2.2.1.2 Authentication Required for Access to Remote Service

When a Bluetooth device in security mode 4 initiates access to a remote service via a connection-oriented L2CAP channel and a sufficient link key is available for the remote device, it shall authenticate the remote device and enable encryption before sending a channel establishment request (L2CAP_ConnectReq or higher a layer-channel establishment request such as that of RFCOMM).

When a Bluetooth device in security mode 4 transmits unicast data to a remote service via the connectionless L2CAP channel and security is required for the application and a sufficient link-key is available then the local device shall

authenticate the remote device and enable encryption before transmitting unicast data on the L2CAP connectionless channel.

See Section 5.2.2.8 for details on determining whether or not a link key is sufficient.

If authentication is required by the service but does not succeed, or if a sufficient link-key is not available, then the local device shall not enable encryption and shall not send a channel establishment request and shall not send any unicast data via the L2CAP connectionless channel for that application. The Host may then notify the user and offer to perform pairing.

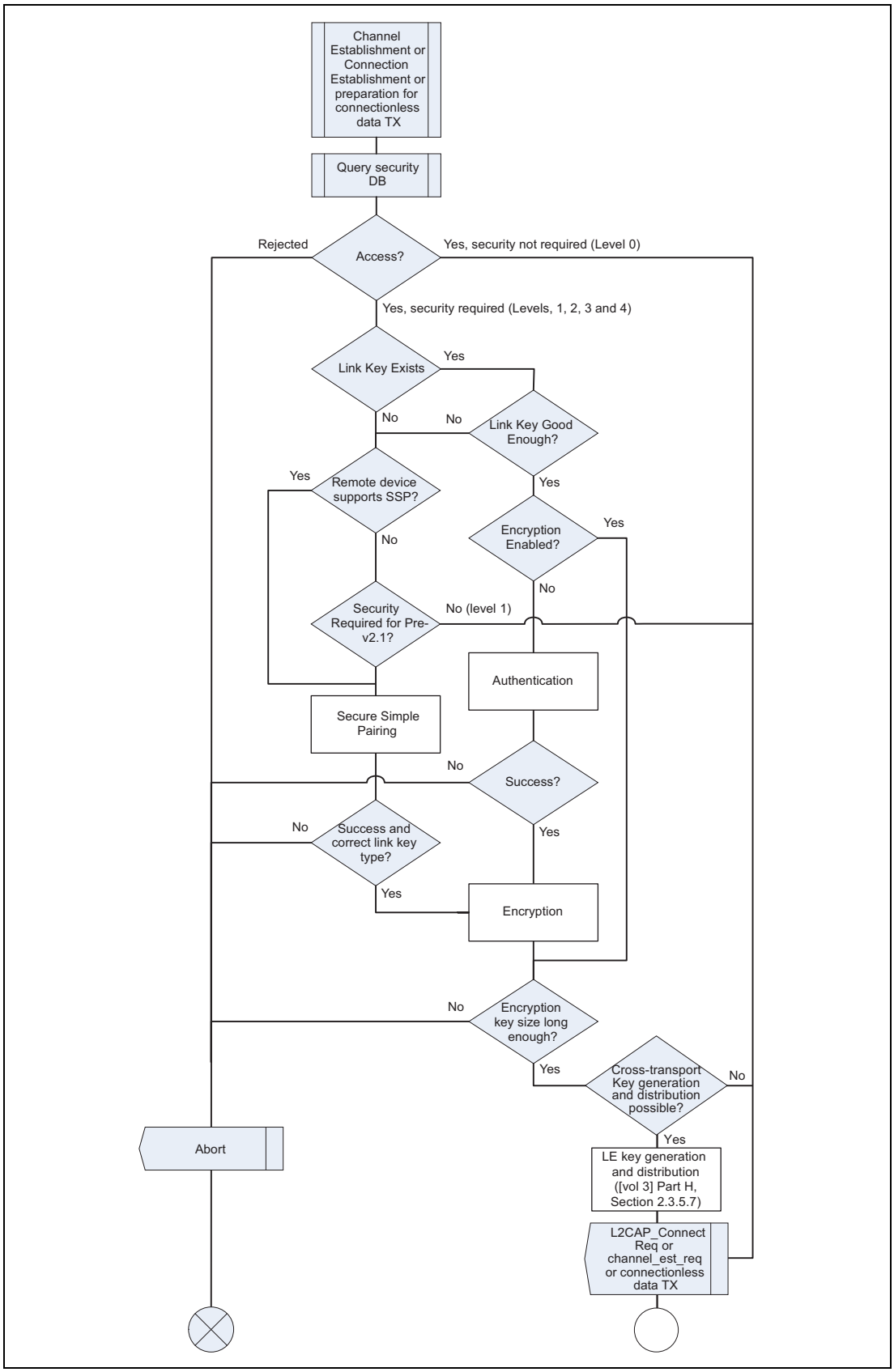


Figure 5.4: Channel establishment using security mode 4 for initiating side

5.2.2.1.3 Cross-transport Key Generation and Distribution

After encryption is enabled and both devices support cross-transport key generation, the master of the BR/EDR transport may perform LE key generation and distribution ([Vol 3] Part H, Section 2.3.5.7).

5.2.2.2 Security for Access to Local Service by Remote Device (Responding Side)

When a remote device attempts to access a service offered by a Bluetooth device that is in security mode 4 and a sufficient link key exists and authentication has not been performed the local device shall authenticate the remote device and enable encryption after the channel establishment request is received but before a channel establishment confirmation (L2CAP_ConnectRsp with result code of 0x0000 or a higher-level channel establishment confirmation such as that of RFCOMM) is sent.

When L2CAP is the channel establishment protocol being used for the requested service, an L2CAP_ConnectRsp signaling packet shall be sent by the responding device containing the result code 0x0001 (connection pending) following receipt of an L2CAP_ConnectReq and prior to initiating security procedures which can result in prompting the local user for input (e.g., pairing using a PIN or Secure Simple Pairing using either the Passkey entry or Numerical Comparison association models). This will stop the L2CAP RTX timer on the remote device (which may be as short as 1 second) and will invoke the ERTX timer on the remote device, which is a minimum duration of 60 seconds.

See [Vol 3] Part A, Section 6.1.7, for additional information on L2CAP RTX and ERTX timers. See also [Vol 3] Part A, Section 4.3 for additional information on the L2CAP_ConnectRsp signaling packet, and the defined result codes.

Higher layer channel establishment protocols should be designed to restrict timeouts to be 30 seconds or longer to allow for user input, or provide mechanisms to dynamically extend timeouts when user input may be required.

If authentication or pairing fails when a remote device is attempting to access a local service, the local device shall send a negative response to the channel establishment request (L2CAP_ConnectReq or channel_est_req) indicating a security issue if possible. If the channel establishment protocol is L2CAP, then the result code 0x0003 (connection refused - security block) shall be sent in the L2CAP_ConnectRsp signal.

If the remote device has indicated support for Secure Simple Pairing, a channel establishment request is received for a service other than SDP, and encryption has not yet been enabled, then the local device shall disconnect the ACL link with error code 0x05 - Authentication Failure.

5.2.2.2.1 Pairing Required for Access to Local Service by Remote Device

When a remote device attempts to access a service offered by a Bluetooth device that is in security mode 4 and pairing is required due to the link key being absent or insufficient, the local device shall perform pairing procedures and enable encryption after the channel establishment request is received and before a channel establishment confirmation (L2CAP_ConnectRsp with result code of 0x0000 or a higher-level channel establishment response such as that of RFCOMM) is sent.

See Section 5.2.2.6 for details on determining whether or not a link key is sufficient.

If pairing does not succeed, then the local device shall not send a channel establishment confirmation. The local device may retry pairing up to three (3) times. If pairing fails three consecutive times, then the local device shall disconnect the ACL link with error code 0x05 - Authentication Failure.

If the link-key generated is not at least as good as the expected or required type, then the local device shall fail the channel establishment and may disconnect the ACL link with error code 0x05 - Authentication Failure.

5.2.2.2.2 Authentication Required for Access to Local Service by Remote Device

See Section 5.2.2.6 for details on determining whether or not a link key is sufficient.

If authentication does not succeed, then the local device shall not send a channel establishment confirmation. The Host may at this point notify the user and offer to perform pairing.

A Bluetooth device in security mode 4 shall respond to authentication and pairing requests during link establishment when the remote device is in security mode 3 for backwards compatibility reasons. However, authentication of the remote device shall be performed after the receipt of the channel establishment request is received, and before the channel establishment response is sent.

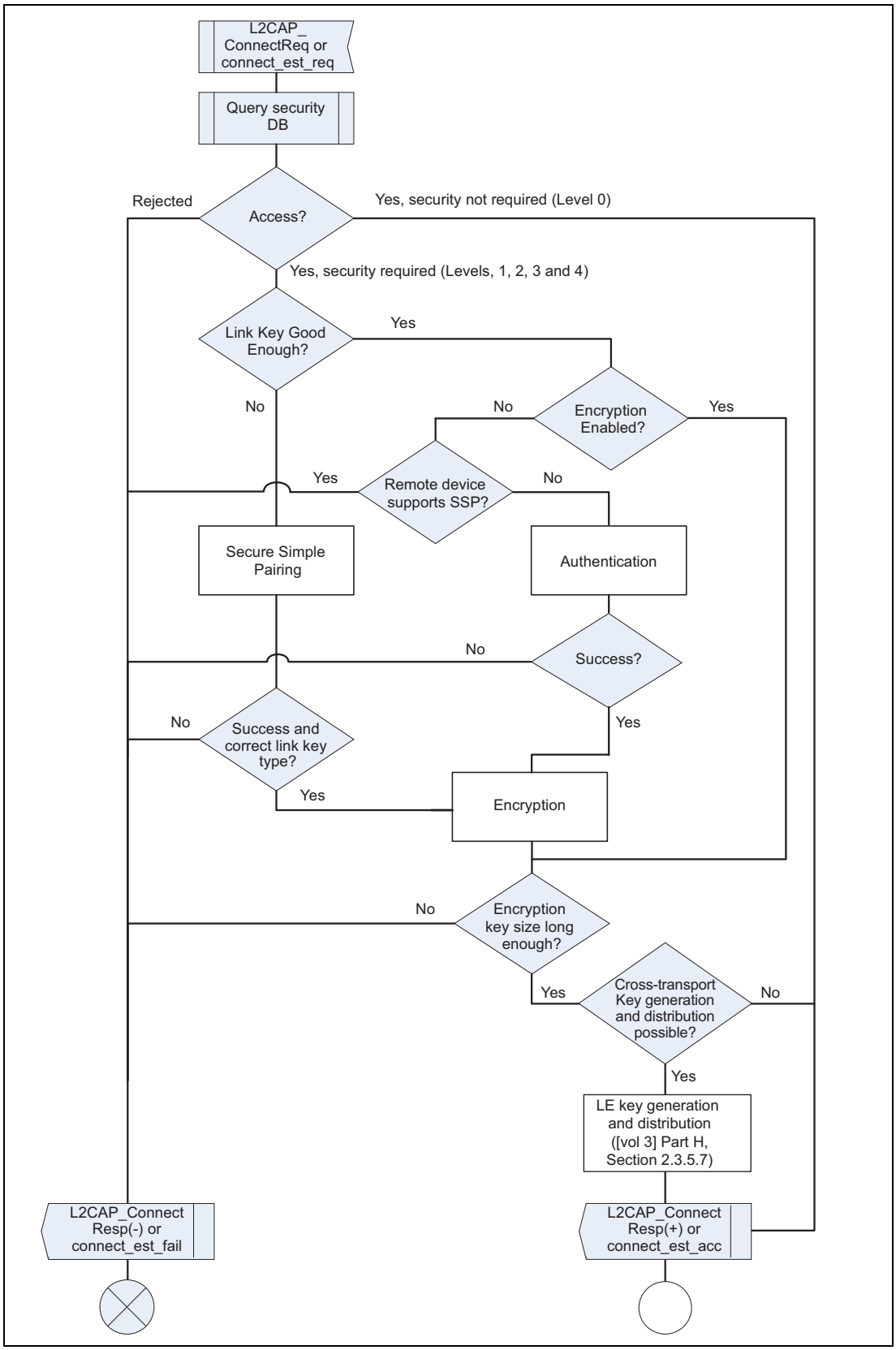


Figure 5.5: Channel establishment using security mode 4 for the responding side

5.2.2.2.3 Cross-transport Key Generation and Distribution

After encryption is enabled and both devices support cross-transport key generation, the master of the BR/EDR transport may perform LE key generation and distribution ([Vol 3] Part H, Section 2.3.5.7).

5.2.2.3 Simple Pairing after Authentication Failure

When both devices support Secure Simple Pairing all non-SDP connections are encrypted regardless of whether security was required or whether the devices are bonded or not. The initial connection between the two devices will result in a link key through Secure Simple Pairing. Depending on whether or not bonding was performed and the security policy of the initiating device, the link key may or may not be stored. When the link key is stored, subsequent connections to the same device will use authentication but this may fail if the remote device has deleted the link key. Table 5.2 defines what shall be done depending on the type of the link key and whether bonding was performed or not.

Link Key Type	Devices Bonded?	Action to take when Authentication Fails
Combination	No	Depends on security policy of the device: • Option 1: Automatically initiate pairing • Option 2: Notify user and ask if pairing is ok Option 2 is recommended.
Combination	Yes	Notify user of security failure
Unauthenticated	No	Depends on security policy of the device: • Option 1: Automatically initiate secure simple pairing • Option 2: Notify user and ask if secure simple pairing is ok. Option 1 is recommended.
Unauthenticated	Yes	Notify user of security failure
Authenticated	No	Depends on security policy of the device: • Option 1: Automatically initiate secure simple pairing • Option 2: Notify user and ask if secure simple pairing is ok Option 2 is recommended.
Authenticated	Yes	Notify user of security failure

Table 5.2: Simple Pairing after Authentication Failure

Note that non-bonded authenticated or unauthenticated link keys may be considered disposable by either device and may be deleted at any time.

5.2.2.4 IO Capabilities

Once a connection is established, if the Host determines that security is necessary and both devices support Secure Simple Pairing, the devices perform an IO capability exchange. The purpose of the IO capability exchange is to determine the authentication algorithm used in the Authentication Stage 1 phase of Simple Pairing.

The input and output capabilities are described in Table 5.3:

Capability	Description
No input	Device does not have the ability to indicate 'yes' or 'no'
Yes / No	Device has at least two buttons that are mapped easily to 'yes' and 'no' or the device has a mechanism whereby the user can indicate either 'yes' or 'no' (see note below).
Keyboard	Device has a numeric keyboard that can input the numbers '0' through '9' and a confirmation. Device also has two buttons that can be easily mapped to 'yes' and 'no' or the device has a mechanism whereby the user can indicate either 'yes' or 'no' (see Note below).

Table 5.3: User Input Capabilities

Note: 'yes' could be indicated by pressing a button within a certain time limit otherwise 'no' would be assumed.

Capability	Description
No output	Device does not have the ability to display or communicate a 6 digit decimal number
Numeric output	Device has the ability to display or communicate a 6 digit decimal number

Table 5.4: User Output Capabilities

5.2.2.5 Mapping of Input / Output Capabilities to IO Capability

The individual input and output capabilities are mapped to a single IO capability which is later used to determine which authentication algorithm will be used.

		Local Output Capability	
		No Output	**Numeric Output**
Local Input Capability	**No input**	NoInputNoOutput	DisplayOnly
	Yes / No	NoInputNoOutput	DisplayYesNo
	Keyboard	KeyboardOnly	DisplayYesNo

Table 5.5: IO Capability mapping

When a device has OOB authentication information from the remote device, it will indicate it in the LMP_IO_Capability_Res PDU. When either device has OOB information, the OOB association model will be used.

The Host may allow the Link Manager to ignore the IO capabilities and use the Numeric Comparison protocol with automatic accept by setting the Authentication_Requirements parameter to one of the MITM Protection *Not Required* options.

5.2.2.6 IO and OOB Capability Mapping to Authentication Stage 1 Method

Determining which association model to use in Authentication Stage 1 is performed in three steps. First, the devices look at the OOB Authentication Data Present parameter received in the remote IO capabilities. If either device has received OOB authentication data then the OOB association model is used. The event of receiving the OOB information is indicated by a device to its peer in the IO Capability Exchange step of simple pairing.

		Device A	
		Has not received remote OOB authentication data	**Has received remote OOB authentication table**
Device B	**Has not received remote OOB authentication data**	Use the IO capability mapping table	Use OOB association with ra = 0 rb from OOB
	Has received remote OOB authentication data	Use OOB association with ra from OOB rb = 0	Use OOB association with ra from OOB rb from OOB

Table 5.6: IO and OOB capability mapping

Second, if neither device has received OOB authentication data and if both devices have set the Authentication_Requirements parameter to one of the MITM Protection Not Required options, authentication stage 1 shall function as if both devices set their IO capabilities to DisplayOnly (e.g., Numeric comparison with automatic confirmation on both devices).

Finally, if neither device has received OOB authentication data and if one or both devices have set the Authentication_Requirements parameter to one of the *MITM Protection Required* options, the IO and OOB capabilities are mapped to the authentication stage 1 method as defined in the following table. A Host that has set the Authentication_Requirements parameter to one of the *MITM Protection Required* options shall verify that the resulting Link Key is an Authenticated Combination Key (see [Vol 2] Part E, Section 7.7.24). The table also lists whether the combination key results in an authenticated or unauthenticated link key.

		Device A (Initiator)			
		Display Only	**DisplayYesNo**	**KeyboardOnly**	**NoInputNoOutput**
Device B (Responder)	**DisplayOnly**	Numeric Comparison with automatic confirmation on both devices. Unauthenticated	Numeric Comparison with automatic confirmation on device B only. Unauthenticated	Passkey Entry: Responder Display, Initiator Input. Authenticated	Numeric Comparison with automatic confirmation on both devices. Unauthenticated
	DisplayYesNo	Numeric Comparison with automatic confirmation on device A only. Unauthenticated	Numeric Comparison: Both Display, Both Confirm. Authenticated	Passkey Entry: Responder Display, Initiator Input. Authenticated	Numeric Comparison with automatic confirmation on device A only and Yes/No confirmation whether to pair on device B. Device B does not show the confirmation value. Unauthenticated
	Keyboard Only	Passkey Entry: Initiator Display, Responder Input. Authenticated	Passkey Entry: Initiator Display, Responder Input. Authenticated	Passkey Entry: Initiator and Responder Input. Authenticated	Numeric Comparison with automatic confirmation on both devices. Unauthenticated
	NoInputNoOutput	Numeric Comparison with automatic confirmation on both devices. Unauthenticated	Numeric Comparison with automatic confirmation on device B only and Yes/No confirmation on whether to pair on device A. Device A does not show the confirmation value. Unauthenticated	Numeric Comparison with automatic confirmation on both devices. Unauthenticated	Numeric Comparison with automatic confirmation on both devices. Unauthenticated

Table 5.7: IO Capability Mapping to Authentication Stage 1

Note: The "DisplayOnly" IO capability only provides unidirectional authentication.

5.2.2.7 Out of Band (OOB)

An out of band mechanism may also be used to communicate discovery information as well as other information related to the pairing process.

The contents of the OOB data block are:

Mandatory contents:

- Length (2 bytes)
- BD_ADDR (6 bytes)

Optional contents:

- Class of Device (3 bytes)
- Simple Pairing Hash C (16 bytes)
- Simple Pairing Randomizer R (16 bytes)
- Local name (variable length)
- Other information

The length field includes all bytes in the OOB data block including the length field itself. The BD_ADDR will be a fixed field in the beginning of the OOB data block. Following the BD_ADDR will be zero or more EIR tag fields containing optional contents. The EIR tag format will be used for the optional contents.

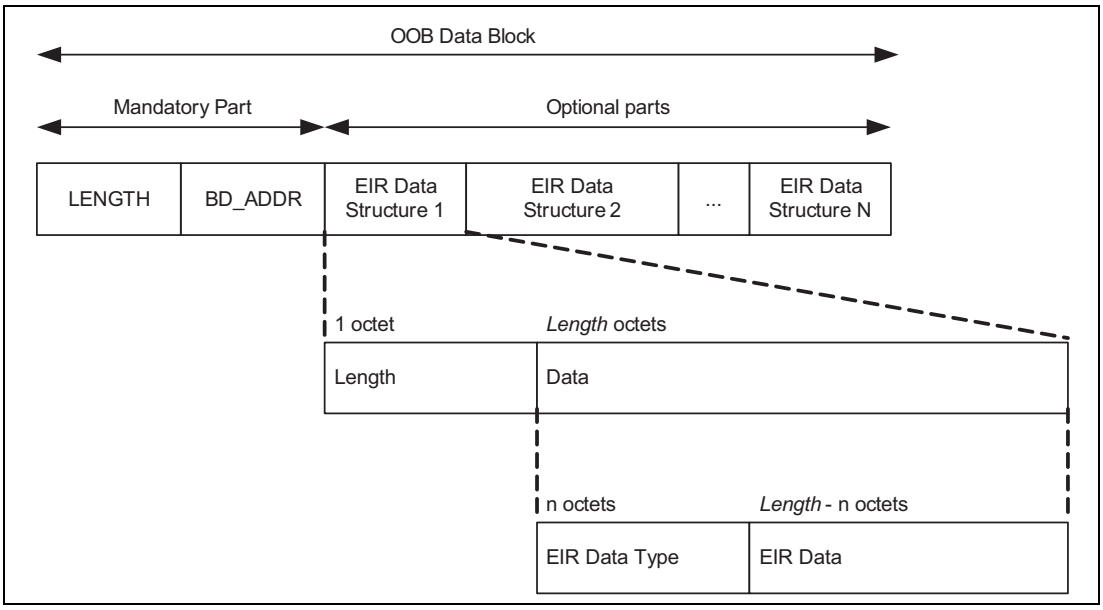


Figure 5.6: OOB Data Block Format

If Simple Pairing fails when one or both devices have OOB Authentication Data present, both devices shall discard the OOB Authentication Data and the device that originally initiated authentication shall re-initiate authentication. Note that although the user may get involved in authentication as defined by the IO capabilities of the two devices, falling back to the in-band association model will prevent deadlock conditions when one or both devices has stale OOB Authentication Data.

There is a MIME type defined for use with the OOB data format. The MIME type can be found from the following link: http://www.iana.org/assignments/media-types/application/vnd.bluetooth.ep.oob

5.2.2.8 Security Database

A Bluetooth device in security mode 4 shall classify the security requirements of its services using at least the following levels attributes (in order of decreasing security) for use when pairing with remote devices supporting Secure Simple Pairing:

- Level 4, for services with the following attributes or devices in Secure Connections Only Mode:

  MITM protection required

  128-bit equivalent strength for link and encryption keys required using FIPS approved algorithms (E0 not allowed, SAFER+ not allowed, and P-192 not allowed)

  User interaction acceptable
- Level 3, for services with the following attributes:

  MITM protection required

  Encryption required

  User interaction acceptable
- Level 2, for services with the following attributes:

  MITM protection not required

  Encryption required
- Level 1, for services with the following attributes:

  MITM protection not required

  Minimal user interaction desired
- Level 0: Service requires the following:

  MITM protection not required

  No encryption required

  No user interaction required

Security Mode 4 Level 0 shall only be used for:

a) L2CAP fixed signaling channels with CIDs 0x0001, 0x0003, and 0x003F

b) SDP

c) broadcast data sent on the connectionless L2CAP channel (CID 0x0002)

d) services with the combinations of Service Class UUIDs and L2CAP traffic types listed in [Core Specification Supplement], Part C.

The security level required for each service offered should be stored in a security database that is accessed to determine the type of link key that is required for access to the respective service. The security level required for service data transmitted on an L2CAP connection-oriented channel may differ from the security level required for service data transmitted on another L2CAP connection-oriented channel or on the connectionless L2CAP channel. Table 5.8 shows the type of link key required for each security level for both remote devices that support Secure Simple Pairing (v2.1 + EDR remote devices) and for those that do not (pre-v2.1 + EDR remote devices).

Security Level Required for Service	**Link Key type required for remote devices**	**Link Key type required for pre-v2.1 remote devices**	**Comments**
Level 4 • MITM protection required • Encryption required • User interaction acceptable	Authenticated (P-256 based Secure Simple Pairing and Secure Authentication)	NA	Highest Security Only possible when both devices support Secure Connections
Level 3 • MITM protection required • Encryption required • User interaction acceptable	Authenticated	Combination (16 digit PIN recommended)	High Security
Level 2 • MITM protection not necessary • Encryption desired	Unauthenticated	Combination	Medium Security
Level 1 • MITM protection not necessary • Encryption not necessary[1] • Minimal user interaction desired	Unauthenticated	None	Low Security

Table 5.8: Security Level mapping to link key requirements

Security Level Required for Service	Link Key type required for remote devices	Link Key type required for pre-v2.1 remote devices	Comments
Level 0 • MITM protection not necessary • Encryption not necessary • No user interaction desired	None	None	Permitted only for SDP and service data sent via either L2CAP fixed signaling channels or the L2CAP connectionless channel to PSMs that correspond to service class UUIDs which are allowed to utilize Level 0.

Table 5.8: Security Level mapping to link key requirements

1. Though encryption is not necessary for the service for Level 1, this specification mandates the use of encryption when the remote device is v2.1+EDR for all services other than SDP.

An *authenticated* link key is a link key where either the numeric comparison, out-of-band, or passkey entry simple pairing association models were used. An authenticated link key has protection against MITM attacks. To ensure that an authenticated link key is created during the Simple Pairing procedure, the Authentication_Requirements parameter should be set to one of the *MITM Protection Required* options.

An *unauthenticated* link key is a link key where the “Just Works” simple pairing association model was used (see [Vol 1] Part A, Section 5.2.4). An unauthenticated link key does not have protection against MITM attacks. To allow an unauthenticated link key to be created during the Simple Pairing procedure, the Authentication_Requirements parameter may be set to one of the *MITM Protection Not Required* options.

When both devices support Secure Simple Pairing and at least one device does not support Secure Connections, the strength of the link key is 96 effective bits. When both devices support Secure Connections, the strength of the link key is 128 effective bits. Secure Connections does not change the protection against MITM attacks.

A combination link key is a link key where the v2.0 pairing mechanism was used to generate the link-key (see [Vol 2] Part C, Section 4.2.2.4).

When both devices support Secure Simple Pairing, GAP shall require at least an unauthenticated link key and enable encryption for service traffic sent or received via connection-oriented L2CAP channels. A profile or protocol may define services that require more security (for example, an authenticated link key) or no security in the case of SDP or service traffic sent via the L2CAP connectionless channel for services that do not require security.

When the device is in Bondable Mode, it shall enable Secure Simple Pairing mode prior to entering Connectable Mode or establishing a link.

A Bluetooth device in security mode 4 shall respond to authentication and pairing requests during link establishment when the remote device is in security mode 3 for backwards compatibility reasons. See Section 5.2.1.3 for more information.

The remote Controller's and remote Host's support for Secure Simple Pairing shall be determined by the Link Manager Secure Simple Pairing (Host Support) feature bit.

A previously generated link key is considered “sufficient” if the link key type is of the type required for the service, or of a higher strength. Authenticated link keys are considered higher strength than Unauthenticated or Combination keys. Unauthenticated link keys are considered higher strength than Combination keys.

6 IDLE MODE PROCEDURES – BR/EDR PHYSICAL TRANSPORT

The inquiry and discovery procedures described here are applicable only to the device that initiates them (A). The requirements on the behavior of B is according to the modes specified in Section 4 and to [2].

	Procedure	Ref.	Support
1	General inquiry	6.1	C1
2	Limited inquiry	6.2	C1
3	Name discovery	6.3	O
4	Device discovery	6.4	O
5	Bonding	6.5	O
C1: If initiation of bonding is supported, support for at least one inquiry procedure is mandatory, otherwise optional. (Note: Support for LMP-pairing is mandatory [2].)			

6.1 GENERAL INQUIRY

6.1.1 Purpose

The purpose of the general inquiry procedure is to provide the initiator with the Bluetooth device address, clock, Class of Device, page scan mode, and extended inquiry response information of general discoverable devices (i.e., devices that are in range with regard to the initiator and are set to scan for inquiry messages with the General Inquiry Access Code). Also devices in limited discoverable mode will be discovered using general inquiry.

The general inquiry should be used by devices that need to discover devices that are made discoverable continuously or for no specific condition.

6.1.2 Term on UI level

‘Bluetooth Device Inquiry’.

6.1.3 Description

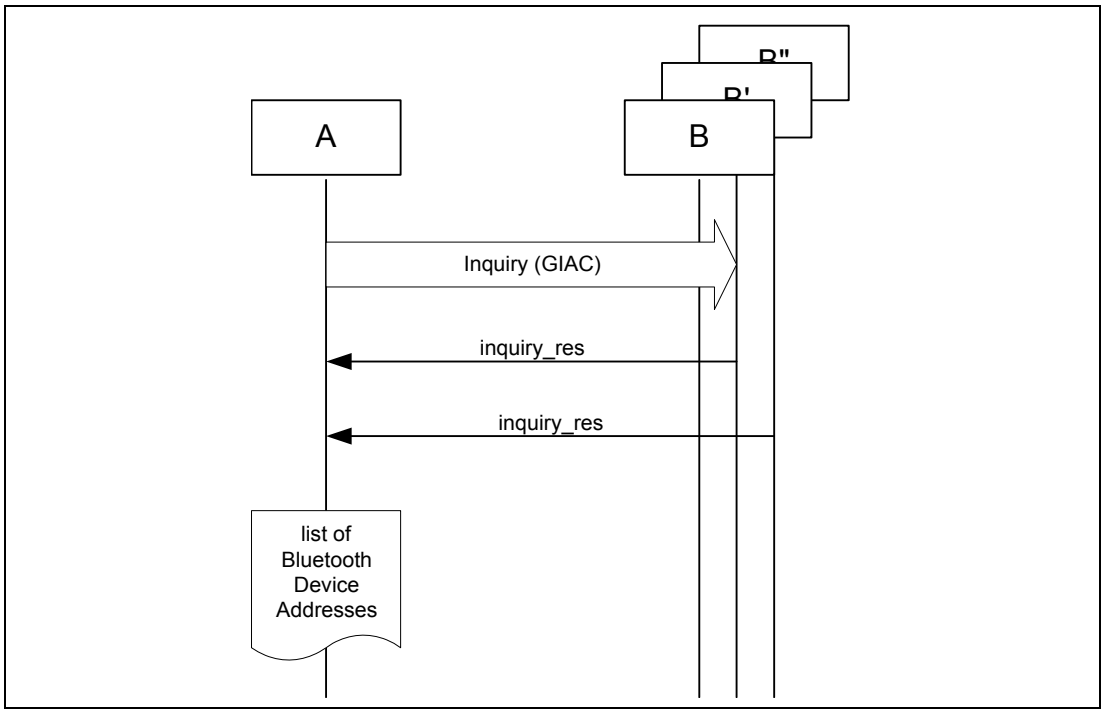


Figure 6.1: General inquiry, where B is a device in non-discoverable mode, B´ is a device in limited discoverable mode and B" is a device in general discoverable mode. (Note that all discoverable devices are discovered using general inquiry, independent of which discoverable mode they are in.)

6.1.4 Conditions

When general inquiry is initiated by a Bluetooth device, the INQUIRY state shall last $T_{GAP}(100)$ or longer, unless the inquirer collects enough responses and determines to abort the INQUIRY state earlier. The Bluetooth device shall perform inquiry using the GIAC.

In order for Device A to receive inquiry responses, the remote devices in range have to be made discoverable (limited or general).

6.2 LIMITED INQUIRY

6.2.1 Purpose

The purpose of the limited inquiry procedure is to provide the initiator with the Bluetooth device address, clock, Class of Device, page scan mode, and extended inquiry response information of limited discoverable devices. The latter devices are devices that are in range with regard to the initiator, and may be set to scan for inquiry messages with the Limited Inquiry Access Code, in addition to scanning for inquiry messages with the General Inquiry Access Code.

The limited inquiry should be used by devices that need to discover devices that are made discoverable only for a limited period of time, during temporary conditions or for a specific event. Since it is not guaranteed that the discoverable device scans for the LIAC, the initiating device may choose any inquiry procedure (general or limited). Even if the remote device that is to be discovered is expected to be made limited discoverable (e.g., when a dedicated bonding is to be performed), the limited inquiry should be done in sequence with a general inquiry in such a way that both inquiries are completed within the time the remote device is limited discoverable; i.e., at least $T_{GAP}(103)$.

6.2.2 Term on UI level

'Bluetooth Device Inquiry'.

6.2.3 Description

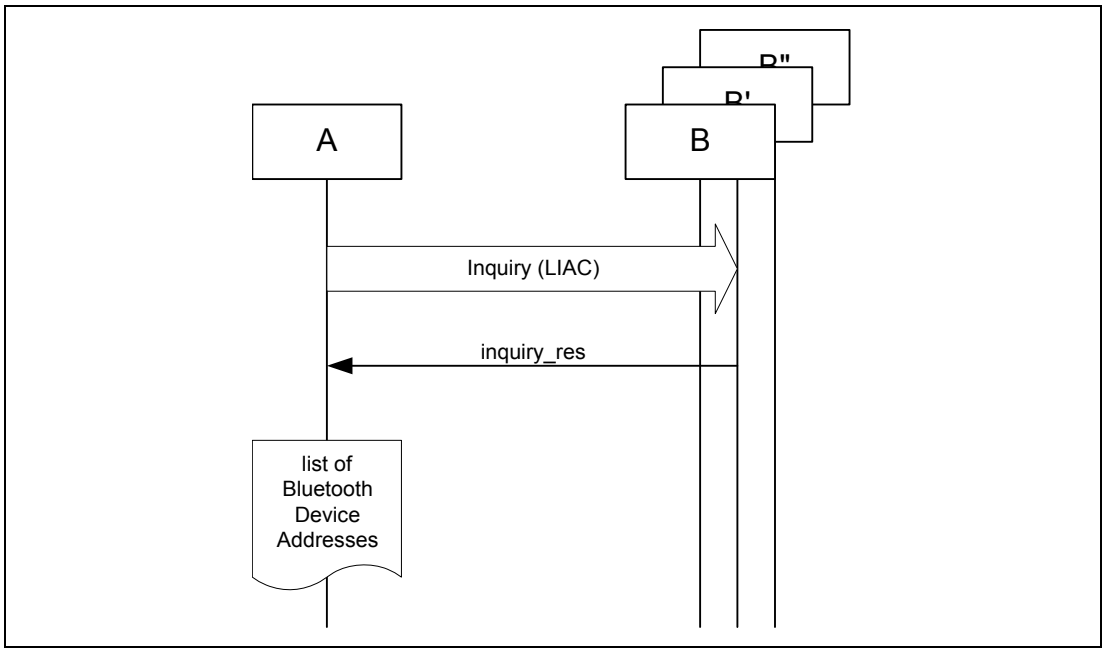


Figure 6.2: Limited inquiry where B is a device in non-discoverable mode, B' is a device in limited discoverable mode and B" is a device in general discoverable mode. (Note that only limited discoverable devices can be discovered using limited inquiry.)

6.2.4 Conditions

When limited inquiry is initiated by a Bluetooth device, the INQUIRY state shall last $T_{GAP}(100)$ or longer, unless the inquirer collects enough responses and determines to abort the INQUIRY state earlier. The Bluetooth device shall perform inquiry using the LIAC.

In order for Device A to receive inquiry responses, the remote devices in range has to be made limited discoverable.

6.3 NAME DISCOVERY

6.3.1 Purpose

The purpose of name discovery is to provide the initiator with the Bluetooth Device Name of connectable devices (i.e., devices in range that will respond to paging).

6.3.2 Term on UI level

'Bluetooth Device Name Discovery'.

6.3.3 Description

6.3.3.1 Name request

Name request is the procedure for retrieving the Bluetooth Device Name from a connectable Bluetooth device. It is not necessary to perform the full link establishment procedure (see 7.1) in order to just to get the name of another device.

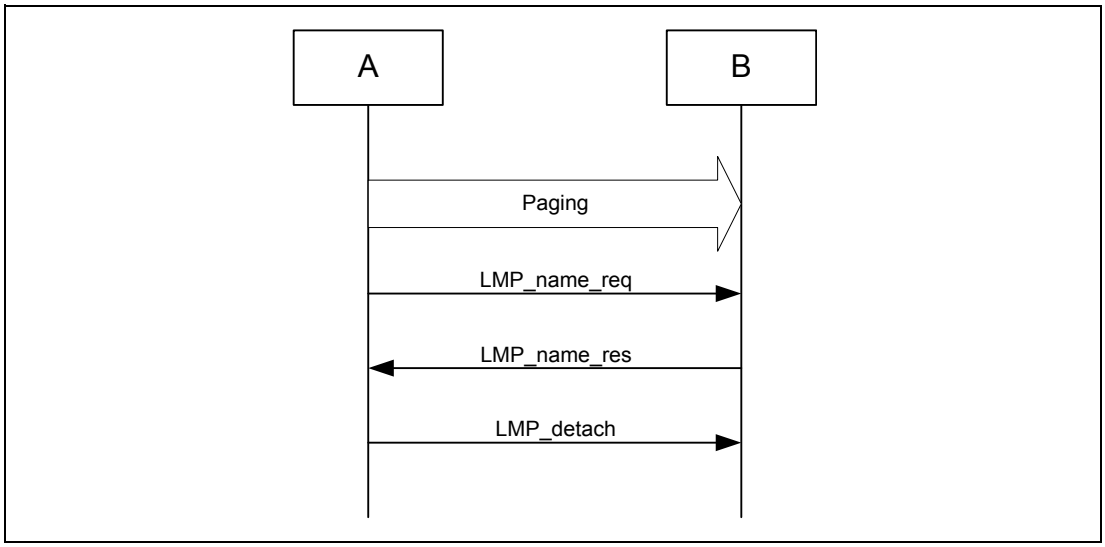


Figure 6.3: Name request procedure

6.3.3.2 Name discovery

Name discovery is the procedure for retrieving the Bluetooth Device Name from connectable Bluetooth devices by performing name request towards known devices (i.e., Bluetooth devices for which the Bluetooth Device Addresses are available).

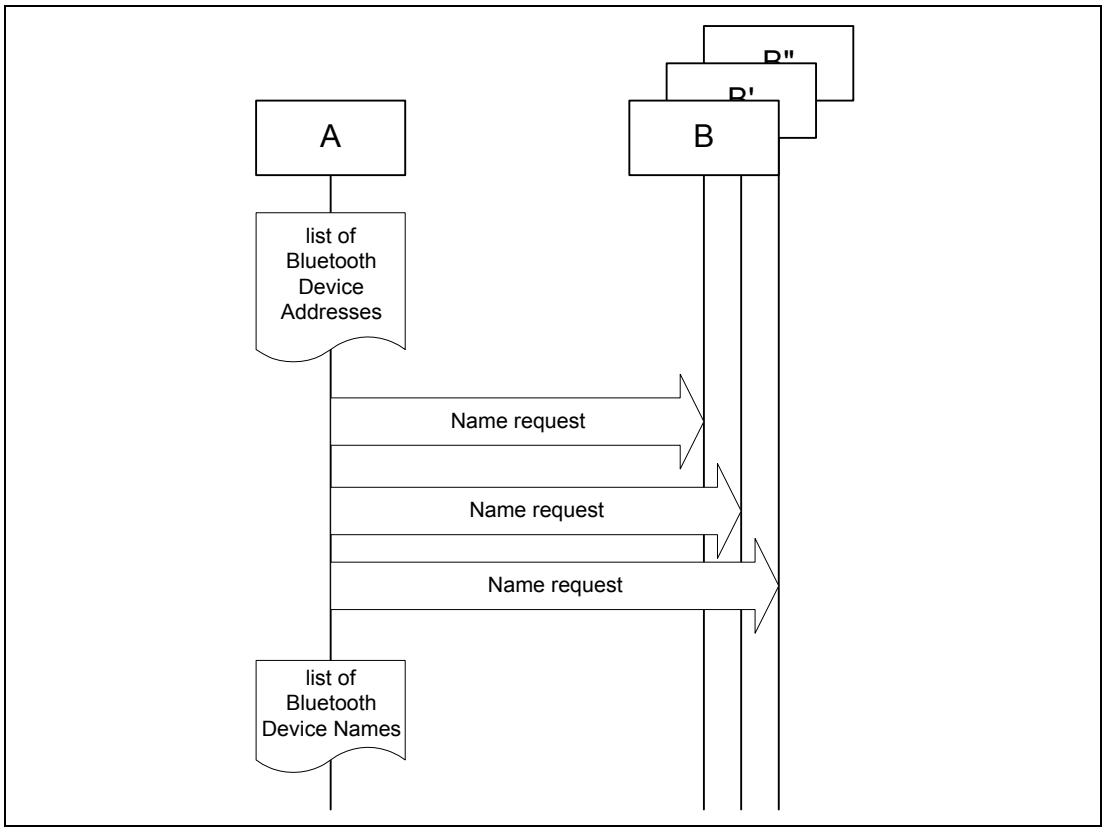


Figure 6.4: Name discovery procedure

6.3.4 Conditions

In the name request procedure, the initiator will use the Device Access Code of the remote device as retrieved immediately beforehand – normally through an inquiry procedure.

6.4 DEVICE DISCOVERY

This section only applies to a device of the BR/EDR and BR/EDR/LE device type.

6.4.1 Purpose

The purpose of device discovery is to provide the initiator with the Bluetooth Device Address, clock, Class of Device, used page scan mode, Bluetooth Device Name, and extended inquiry response information of discoverable devices.

6.4.2 Term on UI Level

'Bluetooth Device Discovery'.

6.4.3 Description

During the device discovery procedure, first an inquiry (either general or limited) is performed, and then name discovery is done towards some or all of the devices that responded to the inquiry. If the initiator of the device discovery receives a complete local name or a shortened local name that is considered long enough, via an extended inquiry response from a remote device, the initiator should not do a separate name discovery for that device.

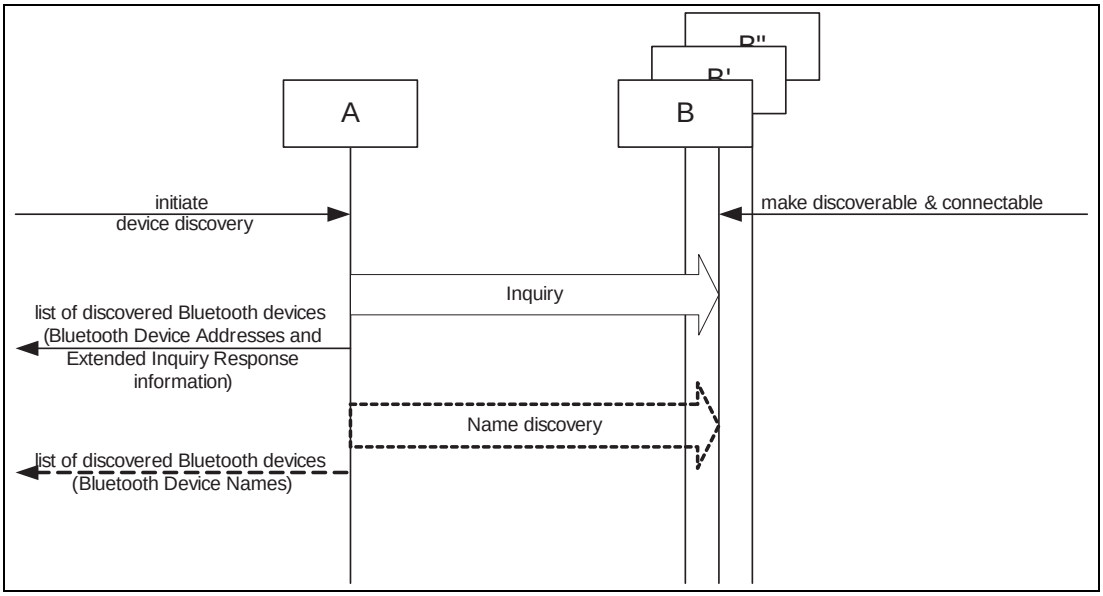


Figure 6.5: Device discovery procedure

6.4.4 Conditions

Conditions for both inquiry (general or limited) and name discovery must be fulfilled (i.e., devices discovered during device discovery must be both discoverable and connectable).

6.5 BONDING

6.5.1 Purpose

The purpose of bonding is to create a relation between two Bluetooth devices based on a common link key (a bond). The link key is created and exchanged (pairing) during the bonding procedure and is expected to be stored by both Bluetooth devices, to be used for future authentication. In addition to pairing, the bonding procedure can involve higher-layer initialization procedures.

6.5.2 Term on UI level

'Bluetooth Bonding'.

6.5.3 Description

Two forms of bonding are described in the following sections: General Bonding and Dedicated Bonding.

6.5.3.1 General Bonding

General Bonding refers to the process of performing bonding during connection setup or channel establishment procedures as a precursor to accessing a service.

When the devices that are performing General Bonding both support Secure Simple Pairing, the Authentication_Requirements parameter should be set to MITM Protection Not Required – General Bonding unless the security policy of an available local service requires MITM Protection in which case the Authentication_Requirements parameter shall be set to MITM Protection Required – General Bonding. 'No bonding' is used when the device is performing a Secure Simple Pairing procedure, but does not intend to retain the link key after the physical link is disconnected.

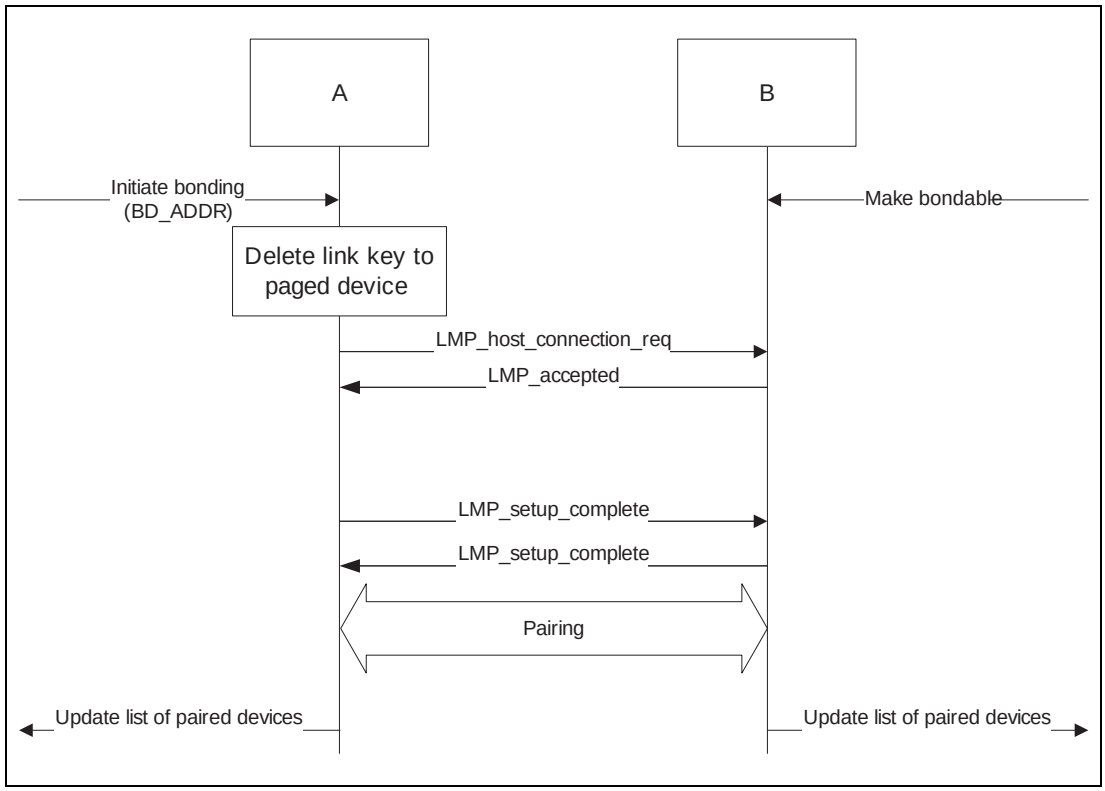


Figure 6.6: General description of general bonding as being the link establishment procedure executed under specific conditions on both devices, followed by authentication and an optional higher layer initialization process.

6.5.3.2 Dedicated Bonding

Dedicated Bonding refers to a procedure wherein one device connects to another only for the purpose of pairing without accessing a particular service. The main difference with dedicated bonding, as compared to a pairing done during link or channel establishment, is that for bonding it is the paging device (A) that must initiate the authentication.

When the devices that are performing Dedicated Bonding both support Secure Simple Pairing, the Authentication_Requirements parameter should be set to *MITM Protection Not Required – Dedicated Bonding* unless the security policy of an available local service requires MITM Protection in which case the Authentication Required parameter shall be set to *MITM Protection Required – Dedicated Bonding*. 'No bonding' is used when the device is performing a Secure Simple Pairing procedure, but does not intend to retain the link key after the physical link is disconnected.

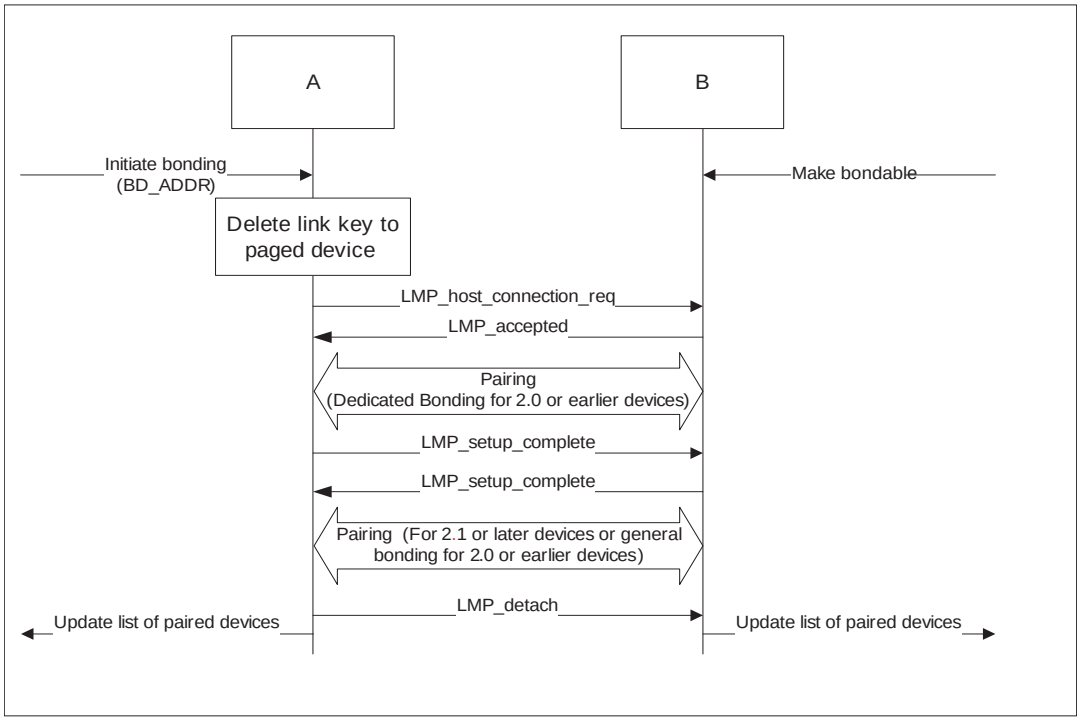


Figure 6.7: Dedicated Bonding as performed when the purpose of the procedure is only to create and exchange a link key between two Bluetooth devices

6.5.4 Conditions

Before bonding can be initiated, the initiating device (A) must know the Device Access Code of the device to pair with. This is normally done by first performing device discovery. A Bluetooth Device that can initiate bonding (A) should use limited inquiry, and a Bluetooth Device that accepts bonding (B) should support the limited discoverable mode.

Bonding is in principle the same as link establishment with the conditions:

- The paged device (B) shall be set into bondable mode. The paging device (A) is assumed to allow pairing since it has initiated the bonding procedure.
- The paging device (the initiator of the bonding procedure, A) shall initiate authentication.
- Before initiating the authentication part of the bonding procedure, the paging device should delete any link key corresponding to a previous bonding with the paged device.

7 ESTABLISHMENT PROCEDURES – BR/EDR PHYSICAL TRANSPORT

	Procedure	Ref.	Support in A	Support in B
1	Link establishment	7.1	M	M
2	Channel establishment	7.2	O	M
3	Connection establishment	7.3	O	O
4	Synchronization establishment	7.5	O	O

Table 7.1: Establishment procedures

The establishment procedures defined here do not include any discovery part. Before establishment procedures are initiated, the information provided during device discovery (in the FHS packet or the extended inquiry response packet of the inquiry response or in the response to a name request or in the synchronization train packet) must be available in the initiating device. This information is:

- The Bluetooth Device Address (BD_ADDR) from which the Device Access Code is generated
- The system clock of the remote device
- The page scan mode used by the remote device for Link establishment.

Additional information provided during device discovery that may be useful for making the decision to initiate an establishment procedure is:

- The Class of device
- The Device name
- The supported Service Classes.

7.1 LINK ESTABLISHMENT

7.1.1 Purpose

The purpose of the link establishment procedure is to establish a logical transport (of ACL type) between two Bluetooth devices using procedures from [1] and [2].

7.1.2 Term on UI Level

'Bluetooth link establishment'

7.1.3 Description

In this sub-section, the paging device (A) is in security mode 3. During link establishment, the paging device cannot distinguish if the paged device (B) is in security mode 1, 2 or 4.

7.1.3.1 B in security mode 1, 2, or 4

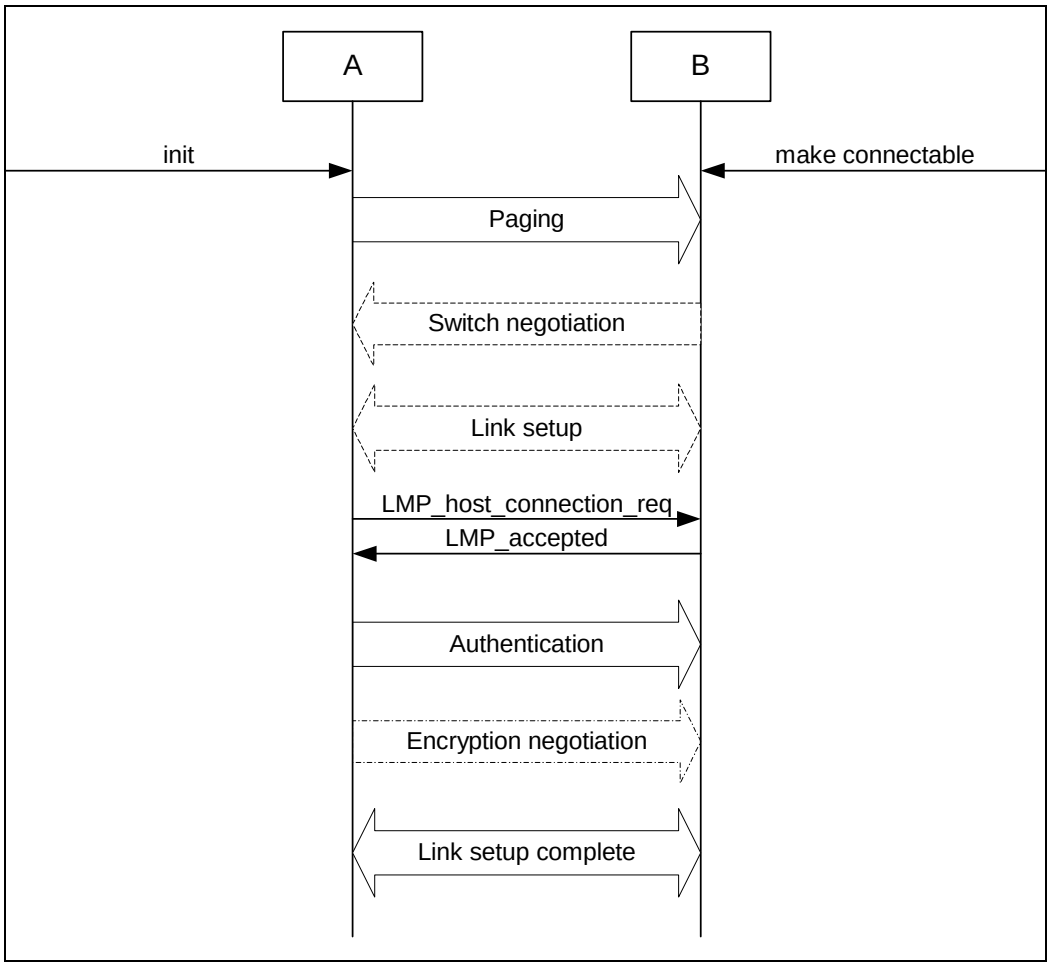


Figure 7.1: Link establishment procedure when the paging device (A) is in security mode 3 and the paged device (B) is in security mode 1, 2, or 4

7.1.3.2 B in security mode 3

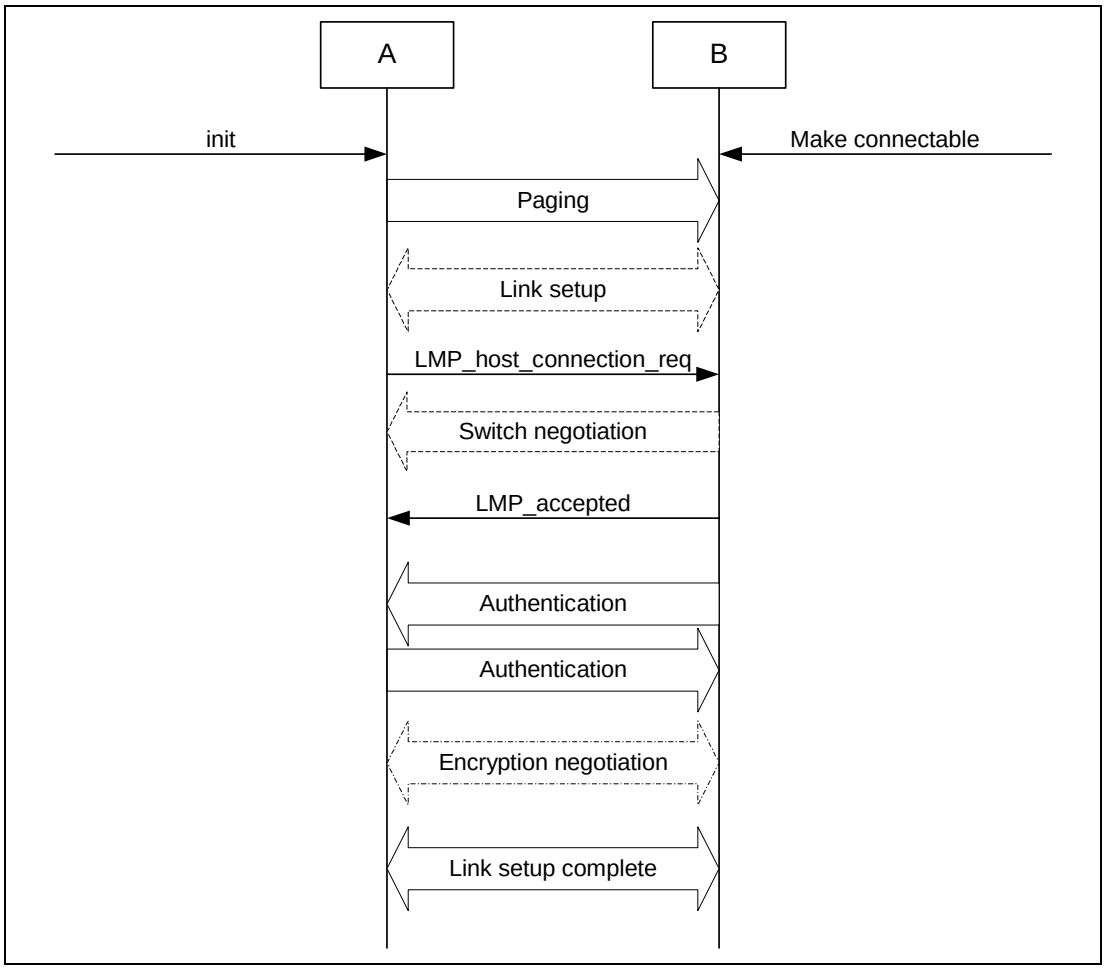


Figure 7.2: Link establishment procedure when both the paging device (A) and the paged device (B) are in security mode 3

7.1.4 Conditions

The paging procedure shall be according to [Vol 2] Part B, Section 8.3 and the paging device should use the Device Access Code and page mode received through a previous inquiry. When paging is completed, a physical link between the two Bluetooth devices is established.

If role switching is needed (normally it is the paged device that has an interest in changing the master/slave roles) it should be done as early as possible after the physical link is established. If the paging device does not accept the switch, the paged device has to consider whether to keep the physical link or not.

Both devices may perform link setup (using LMP procedures that require no interaction with the Host on the remote side). Optional LMP features can be used after having confirmed (using LMP_features_req) that the other device supports the feature.

When the paging device needs to go beyond the link setup phase, it issues a request to be connected to the Host of the remote device. If the paged device is in security mode 3, this is the trigger for initiating authentication.

The paging device shall send LMP_host_connection_req during link establishment (i.e., before channel establishment) and may initiate authentication only after having sent LMP_host_connection_req.

After an authentication has been performed, any of the devices can initiate encryption.

Further link configuration may take place after the LMP_host_connection_req. When both devices are satisfied, they send LMP_setup_complete.

Link establishment is completed when both devices have sent LMP_setup_complete.

7.2 CHANNEL ESTABLISHMENT

7.2.1 Purpose

The purpose of the channel establishment procedure is to establish a Bluetooth channel (L2CAP channel) between two Bluetooth devices using [1].

7.2.2 Term on UI level

'Bluetooth channel establishment'.

7.2.3 Description

In this sub-section, the initiator (A) is in security mode 3. During channel establishment, the initiator cannot distinguish if the acceptor (B) is in security mode 1 or 3.

7.2.3.1 B in security mode 2 or 4

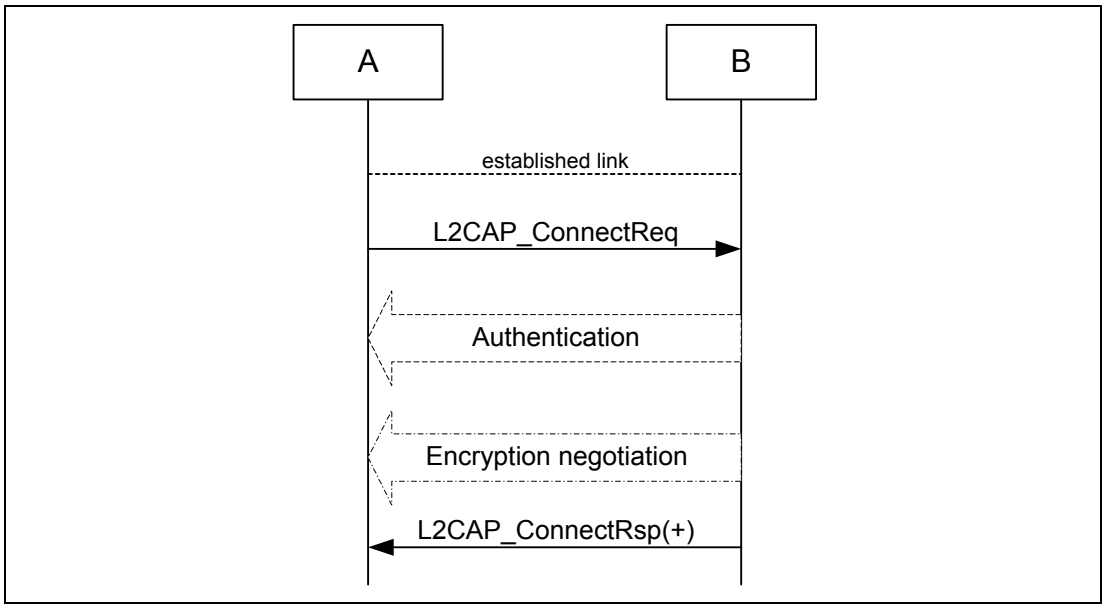


Figure 7.3: Channel establishment procedure when the initiator (A) is in security mode 3 and the acceptor (B) is in security mode 2 or 4

7.2.3.2 B in security mode 1 or 3

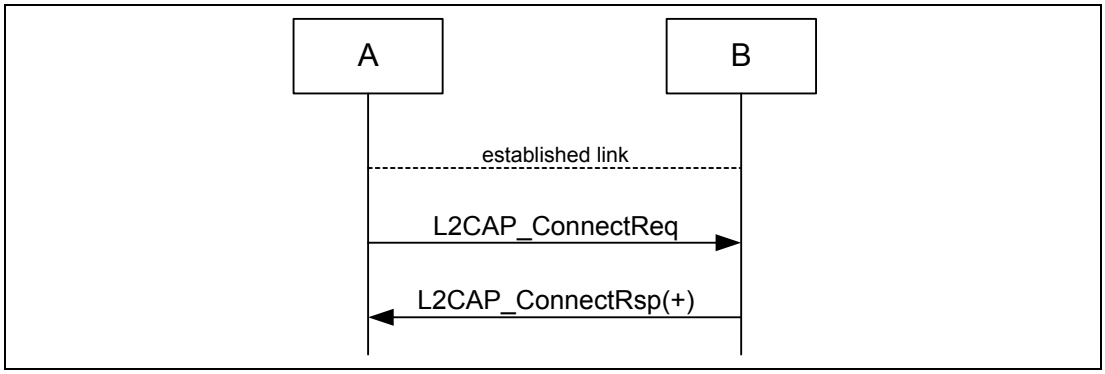


Figure 7.4: Channel establishment procedure when the initiator (A) is in security mode 3 and the acceptor (B) is in security mode 1 or 3

7.2.4 Conditions

Channel establishment starts after link establishment is completed when the initiator sends a channel establishment request (L2CAP_ConnectReq).

Depending on security mode, security procedures may take place after the channel establishment has been initiated.

Channel establishment is completed when the acceptor responds to the channel establishment request (with a positive L2CAP_ConnectRsp).

7.3 CONNECTION ESTABLISHMENT

7.3.1 Purpose

The purpose of the connection establishment procedure is to establish a connection between applications on two Bluetooth devices.

7.3.2 Term on UI level

'Bluetooth connection establishment'

7.3.3 Description

In this sub-section, the initiator (A) is in security mode 3. During connection establishment, the initiator cannot distinguish if the acceptor (B) is in security mode 1 or 3.

7.3.3.1 B in security mode 2 or 4

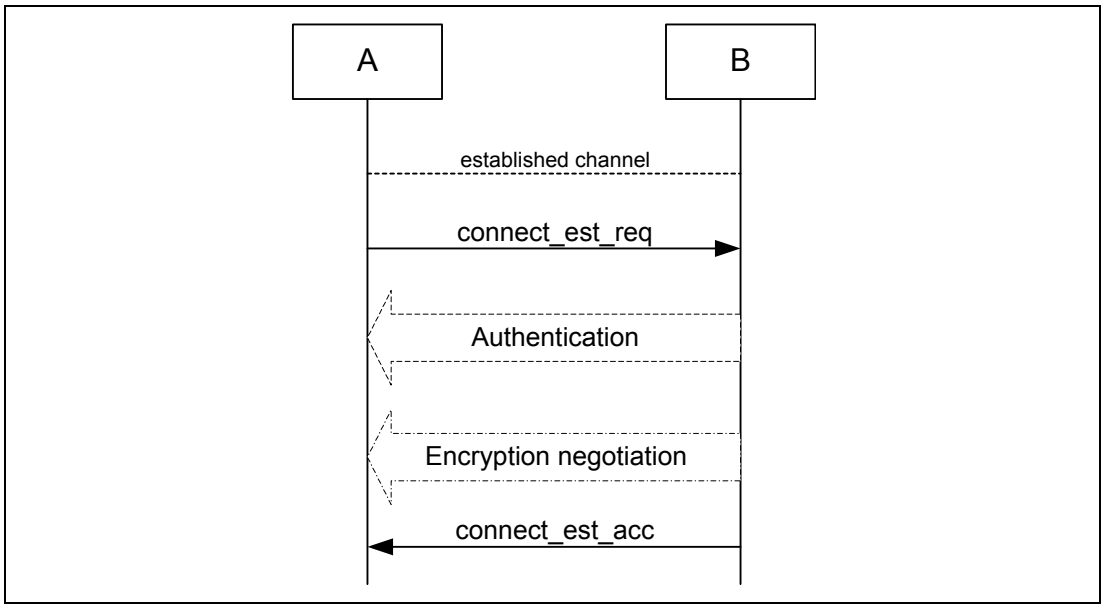


Figure 7.5: Connection establishment procedure when the initiator (A) is in security mode 3 and the acceptor (B) is in security mode 2 or 4

7.3.3.2 B in security mode 1 or 3

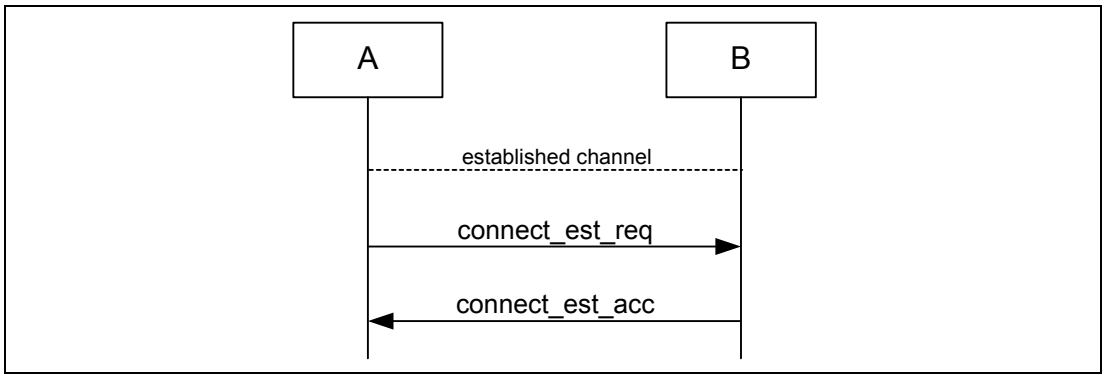


Figure 7.6: Connection establishment procedure when the initiator (A) is in security mode 3 and the acceptor (B) is in security mode 1 or 3

7.3.4 Conditions

Connection establishment starts after channel establishment is completed, when the initiator sends a connection establishment request (’connect_est_req’ is application protocol-dependent). This request may be a TCS SETUP message [4] in the case of a Bluetooth telephony application Cordless Telephony Profile, or initialization of RFCOMM and establishment of DLC [3] in the case of a serial port-based application Serial Port Profile (although neither TCS or RFCOMM use the term ‘connection’ for this).

Connection establishment is completed when the acceptor accepts the connection establishment request (’connect_est_acc’ is application protocol dependent).

7.4 ESTABLISHMENT OF ADDITIONAL CONNECTION

When a Bluetooth device has established one connection with another Bluetooth device, it may be available for establishment of:

- A second connection on the same channel, and/or
- A second channel on the same logical link, and/or
- A second physical link.

If the new establishment procedure is to be towards the same device, the security part of the establishment depends on the security modes used. If the new establishment procedure is to be towards a new remote device, the device should behave according to active modes independent of the fact that it already has another physical link established (unless allowed co-incident radio and baseband events have to be handled).

7.5 SYNCHRONIZATION ESTABLISHMENT

7.5.1 Purpose

The purpose of the Synchronization Establishment procedure is for a device to receive synchronization train packets using the procedures in [Vol 2] Part B, Section 2.7.3

7.5.2 Term on UI Level

'Bluetooth synchronization establishment'

7.5.3 Description

In Figure 7.7 the receiving device (B) is attempting to receive synchronization train packets from device (A).

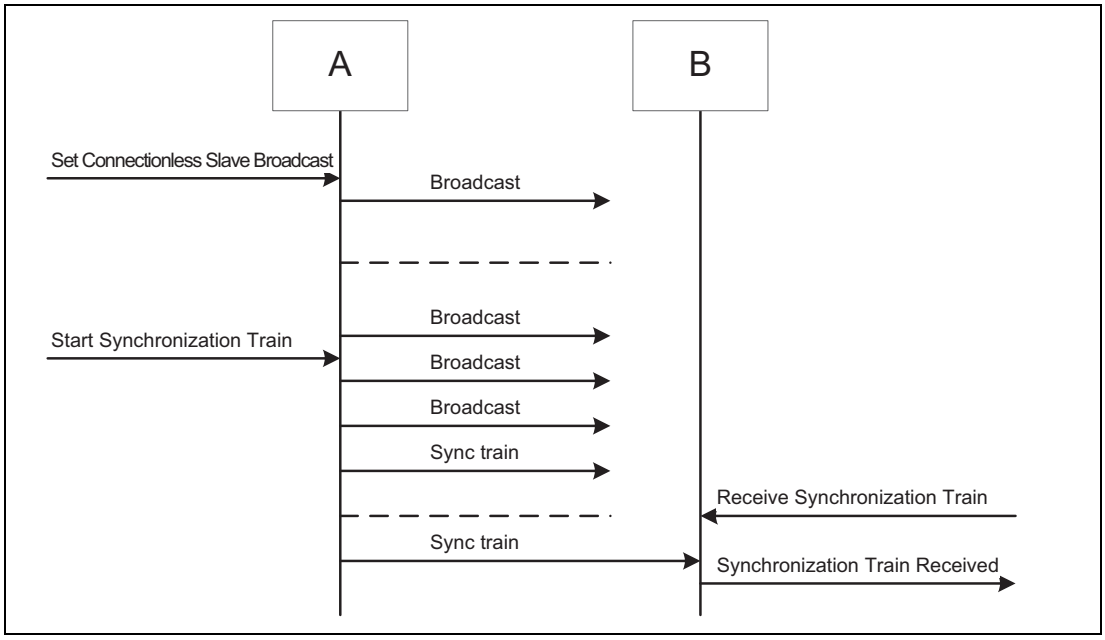


Figure 7.7: Synchronization establishment procedure

7.5.4 Conditions

After receiving a synchronization train packet, the receiving device can listen to and receive profile data sent via Connectionless Slave Broadcast by device A.

Note that devices A and B may go through a separate Link Establishment procedure any time they desire to establish an ACL logical transport between each other. They may also use Connectionless Slave Broadcast procedures with an ACL logical transport already established.

The receiving device shall enter the **synchronization scan** substate using a scan interval of T_{GAP}(Sync_Scan_Interval) and a scan window of T_{GAP}(Sync_Scan_Window).

8 EXTENDED INQUIRY RESPONSE DATA FORMAT

The extended inquiry response data format is shown in Figure 8.1. The data is 240 octets and consists of a significant part and a non-significant part. The significant part contains a sequence of data structures. Each data structure shall have a length field of one octet, which contains the Length value, and a data field of Length octets. The first n octets of the data field contain the extended inquiry response (EIR) data type. The content of the remaining Length - n octets in the data field depends on the value of the EIR data type and is called the EIR data. The non-significant part extends the extended inquiry response to 240 octets and shall contain all-zero octets.

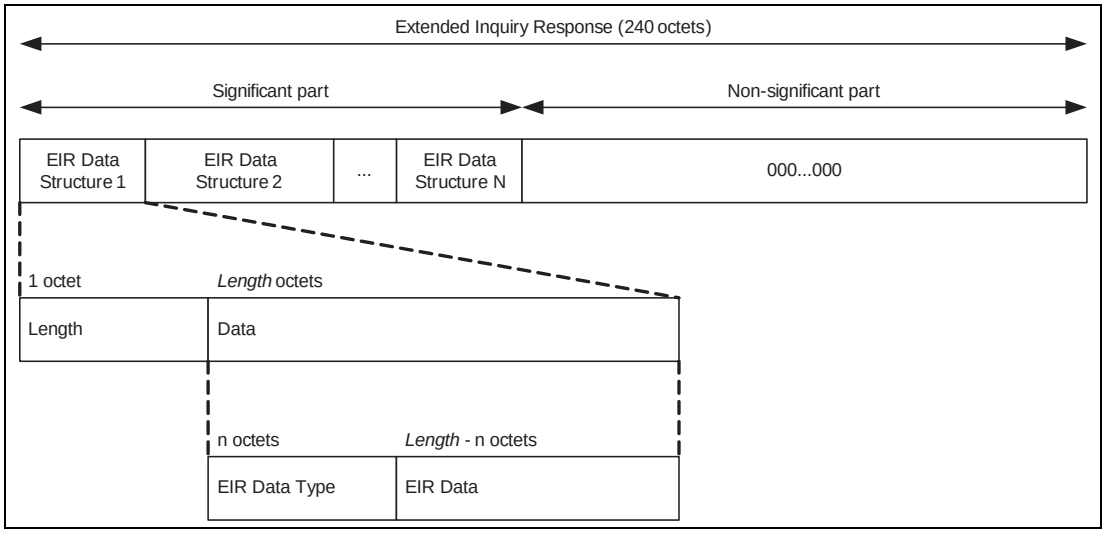


Figure 8.1: Extended Inquiry Response data format

The extended inquiry response data formats and meanings are defined in [Core Specification Supplement], Part A.The extended inquiry response data type values are defined in the Assigned Numbers document.

If the length field is set to zero, then the data field has zero octets. This shall only occur to allow an early termination of the tagged data.

To reduce interference, the Host should try to minimize the amount of EIR data such that the baseband can use a 1-slot or 3-slot EIR packet. This is advantageous because it reduces interference and maximizes the probability that the EIR packet will be received. If applications on a Host provide more than 240 bytes of extended inquiry response data, it is up to the Host to limit it to 240 octets.

The EIR data shall be sent during the inquiry response state. EIR data can contain device name, Tx power level, service class UUIDs, as well as manufacturer's data, as defined in [Core Specification Supplement], Part A. In selecting the packet type to be used, FEC (DM1 or DM3) should be considered to maximize the range.

The Host shall include the device name in the EIR data according to the following rules:

1. If the device does not have a device name (i.e., 0 octet) and
    a) If there is no other data to be sent in the EIR packet, the Host shall send a name tag with zero length and the type field set to indicate that this is the complete name (i.e., total of 2 octets with length = 1).
    b) If there is other important data to be sent in the EIR packet and a zero octet name tag will not fit, the Host may avoid sending the name tag.
2. If the device has a device name (greater than 0 octet) and
    a) If it is too long be included in the EIR packet (given the choice of packet type and any other data that is being sent), the Host may send a shortened version of the name (even 0 octet) and shall mark the name as 'shortened' to inform the receiver that a remote name request is required obtain the full name if the name is needed.
    b) If there are no other data to be sent in the EIR packet (given the choice of packet type selected), the Host shall maximize the length of the device name to be sent, this may be complete or shortened name (e.g., if DM1 packet is chosen and device name characters equates to greater than 15 octets, then Host sends first few characters that equates to 15 octets or less with shortened flag).

Note: It is not necessary to understand each and every EIR data type. If the Host does not understand a given EIR data type value it should just skip over Length octets and look for the next EIR data structure.

9 OPERATIONAL MODES AND PROCEDURES – LE PHYSICAL TRANSPORT

Several different modes and procedures may be performed simultaneously over an LE physical transport. The following modes and procedures are defined for use over an LE physical transport:

- Broadcast mode and observation procedure
- Discovery modes and procedures
- Connection modes and procedures
- Bonding modes and procedures
- Periodic advertising modes and procedure

Each of the above modes and procedures are independent from each other but are closely related since a combination of the modes and procedures are necessary for most devices to communicate with each other. Both the modes and procedures may be entered or executed respectively as a result of direct user action or autonomously by a device.

The Host shall configure the Controller with its local Link Layer feature information as defined in [Vol 6] Part B, Section 4.6 before performing any of the above modes and procedures.

The types of advertising used in these modes and procedures for each of the associated GAP roles are defined in Section 2.2.2 Table 2.1.

9.1 BROADCAST MODE AND OBSERVATION PROCEDURE

The broadcast mode and observation procedure allow two devices to communicate in a unidirectional connectionless manner using the advertising events. The requirements for a device operating in a specific GAP role to support the broadcast mode and observation procedure are defined in Table 9.1.

Broadcast Mode and Observation procedure	Ref.	Broadcaster	Observer
Broadcast mode	9.1.1	M	E
Observation procedure	9.1.2	E	M

Table 9.1: Broadcast mode and Observation procedure Requirements

9.1.1 Broadcast Mode

9.1.1.1 Definition

The broadcast mode provides a method for a device to send connectionless data in advertising events.

9.1.1.2 Conditions

A device in the broadcast mode shall send data using non-connectable advertising events.

A device in the broadcast mode may send non-connectable and non-scannable undirected or non-connectable and non-scannable directed advertising events anonymously by excluding the broadcaster's address.

The advertising data shall be formatted using the Advertising Data (AD) type format as defined in [Core Specification Supplement], Part A, Section 1.3. A device in the broadcast mode shall not set the ‘LE General Discoverable Mode’ flag or the ‘LE Limited Discoverable Mode’ flag in the Flags AD Type as defined in [Core Specification Supplement], Part A, Section 1.3.

Note: All data sent by a device in the broadcast mode is considered unreliable since there is no acknowledgment from any device that may have received the data.

The device may configure and enable multiple independent advertising sets. Each advertising set may have an independent advertising filter policy.

9.1.2 Observation Procedure

9.1.2.1 Definition

The observation procedure provides a method for a device to receive connectionless data from a device that is sending advertising events.

9.1.2.2 Conditions

A device performing the observation procedure may use passive scanning or active scanning to receive advertising events.

A device performing the observation procedure may use active scanning to also receive scan response data sent by any device in the broadcast mode that advertises using scannable advertising events.

When a device performing the observation procedure receives a resolvable private address in the advertising event, the device may resolve the private address by using the resolvable private address resolution procedure as defined in Section 10.8.2.3.

Note: In use cases where a device in the broadcast mode sends dynamic data, the receiving device should disable duplicate filtering capability in the Controller so that the Host receives all advertising packets received by the Controller.

9.2 DISCOVERY MODES AND PROCEDURES

All devices shall be in either non-discoverable mode or one of the discoverable modes. A device in the discoverable mode shall be in either the general discoverable mode or the limited discoverable mode. A device in the non-discoverable mode is not discoverable. Devices operating in either the general discoverable mode or the limited discoverable mode can be found by the discovering device. A device that is discovering other devices performs either the limited discovery procedure as defined in Section 9.2.5 or the general discovery procedure as defined in Section 9.2.6.

Some devices may only scan for advertising events using legacy advertising PDUs. It is therefore recommended that devices using advertising events with the extended advertising PDUs also use an advertising set with advertising events that use legacy advertising PDUs.

9.2.1 Requirements

Discovery modes and procedures	Ref.	Peripheral	Central
Non-Discoverable mode	9.2.2	M	E
Limited Discoverable mode	9.2.3	O	E
General Discoverable mode	9.2.4	C1	E
Limited Discovery procedure	9.2.5	E	O
General Discovery procedure	9.2.6	E	M
Name Discovery procedure	9.2.7	O	O
C1: if limited discoverable mode is not supported then general discoverable mode is mandatory, else optional.			

Table 9.2: Device discovery requirements

9.2.2 Non-Discoverable Mode

9.2.2.1 Description

A device configured in non-discoverable mode will not be discovered by any device that is performing either the general discovery procedure or the limited discovery procedure.

9.2.2.2 Conditions

A device in the non-discoverable mode may send advertising events. If the device sends advertising events, it shall not set the 'LE General Discoverable Mode' flag or 'LE Limited Discoverable Mode' flag in the Flags AD type (see [Core Specification Supplement], Part A, Section 1.3).

If the device sends advertising events, then it is recommended that the Host configures the Controller as follows:

- The Host should set the advertising filter policy for all advertising sets to either 'process scan and connection requests only from devices in the White List' or 'process scan and connection requests from all devices'.
- The Host should set the advertising intervals as defined in Section 9.3.11.

9.2.3 Limited Discoverable Mode

9.2.3.1 Description

Devices configured in the limited discoverable mode are discoverable for a limited period of time by other devices performing the limited or general device discovery procedure. The limited discoverable mode is typically used when a user performs a specific action to make the device discoverable for a limited period of time.

9.2.3.2 Conditions

While a device is in the Peripheral role the device may support the limited discoverable mode. While a device is only in the Broadcaster, Observer or Central role the device shall not support the limited discoverable mode.

A device in the limited discoverable mode shall send advertising event types with the advertising data including the Flags AD type as defined in [Core Specification Supplement], Part A, Section 1.3 with all the following flags set as described:

- The LE Limited Discoverable Mode flag set to one.
- The LE General Discoverable Mode flag set to zero.
- For a device of the LE-only device type with all the following flags set as described:
    a) The 'BR/EDR Not Supported' flag to set one.
    b) The 'Simultaneous LE and BR/EDR to Same Device Capable (Controller)' flag set to zero.
    c) The 'Simultaneous LE and BR/EDR to Same Device Capable (Host)' flag set to zero.

The advertising data should also include the following AD types to enable a faster connectivity experience:

- TX Power Level AD type defined in [Core Specification Supplement], Part A, Section 1.5.
- Local Name AD type defined in [Core Specification Supplement], Part A, Section 1.2.
- Service UUIDs AD type defined in [Core Specification Supplement], Part A, Section 1.1.
- Slave Connection Interval Range AD type as defined in [Core Specification Supplement], Part A, Section 1.9.

Devices shall remain in the limited discoverable mode no longer than T_{GAP}(lim_adv_timeout).

While a device is in limited discoverable mode the Host configures the Controller as follows:

- The Host shall set the advertising filter policy to ‘process scan and connection requests from all devices’.
- The Host should set the advertising intervals as defined in Section 9.3.11.

The device shall remain in limited discoverable mode until a connection is established or the Host terminates the mode.

If a device is in the limited discoverable mode and in the undirected connectable mode the advertising interval values should be set as defined in Section 9.3.4

A device in the limited discoverable mode shall not set both the LE Limited Discoverable Flag and the LE General Discoverable Flag to one.

Note: Host data used in legacy advertising events that change frequently should be placed in the advertising data and static data should be placed in the scan response data.

Note: The choice of advertising interval is a trade-off between power consumption and device discovery time.

The device may configure and enable multiple independent advertising sets. Each advertising set may have an independent advertising filter policy.

9.2.4 General Discoverable Mode

9.2.4.1 Description

Devices configured in general discoverable mode are intended to be discoverable by devices performing the general discovery procedure. The

general discoverable mode is typically used when the device is intending to be discoverable for a long period of time.

9.2.4.2 Conditions

While a device is in the Peripheral role the device may support the general discoverable mode. While a device is only in the Broadcaster, Observer or Central role the device shall not support the general discoverable mode.

A device in general discoverable mode shall send advertising events with the advertising data including the Flags AD data type as defined in [Core Specification Supplement], Part A, Section 1.3 with all the following flags set as described:

- The LE Limited Discoverable Mode flag set to zero.
- The LE General Discoverable Mode flag set to one.
- For a device of the LE-only device type with all the following flags set as described:
    a) The ‘BR/EDR Not Supported’ flag set to one.
    b) The ‘Simultaneous LE and BR/EDR to Same Device Capable (Controller)’ flag set to zero.
    c) The ‘Simultaneous LE and BR/EDR to Same Device Capable (Host)’ flag set to zero.

The advertising data should also include the following AD types to enable a faster connectivity experience:

- TX Power Level AD type as defined in [Core Specification Supplement], Part A, Section 1.5.
- Local Name AD type as defined in [Core Specification Supplement], Part A, Section 1.2.
- Service UUIDs AD type as defined in [Core Specification Supplement], Part A, Section 1.1.
- Slave Connection Interval Range AD type as defined in [Core Specification Supplement], Part A, Section 1.9.

While a device is in general discoverable mode the Host configures the Controller as follows:

- The Host shall set the advertising filter policy for all advertising sets to ‘process scan and connection requests from all devices’.
- The Host should set the advertising intervals as defined in Section 9.3.11.

The device shall remain in general discoverable mode until a connection is established or the Host terminates the mode.

If a device is in the general discoverable mode and in the directed connectable mode or the non-connectable mode, the advertising interval values should be set as defined in Section 9.3.3.

A device in the general discoverable mode shall not set both the LE Limited Discoverable Flag and the LE General Discoverable Flag to one.

Note: Host data used in legacy advertising events that change frequently should be placed in the advertising data and static data should be placed in the scan response data.

Note: The choice of advertising interval is a trade-off between power consumption and device discovery time.

9.2.5 Limited Discovery Procedure

9.2.5.1 Description

A device performing the limited discovery procedure receives the device address, advertising data and scan response data from devices in the limited discoverable mode only.

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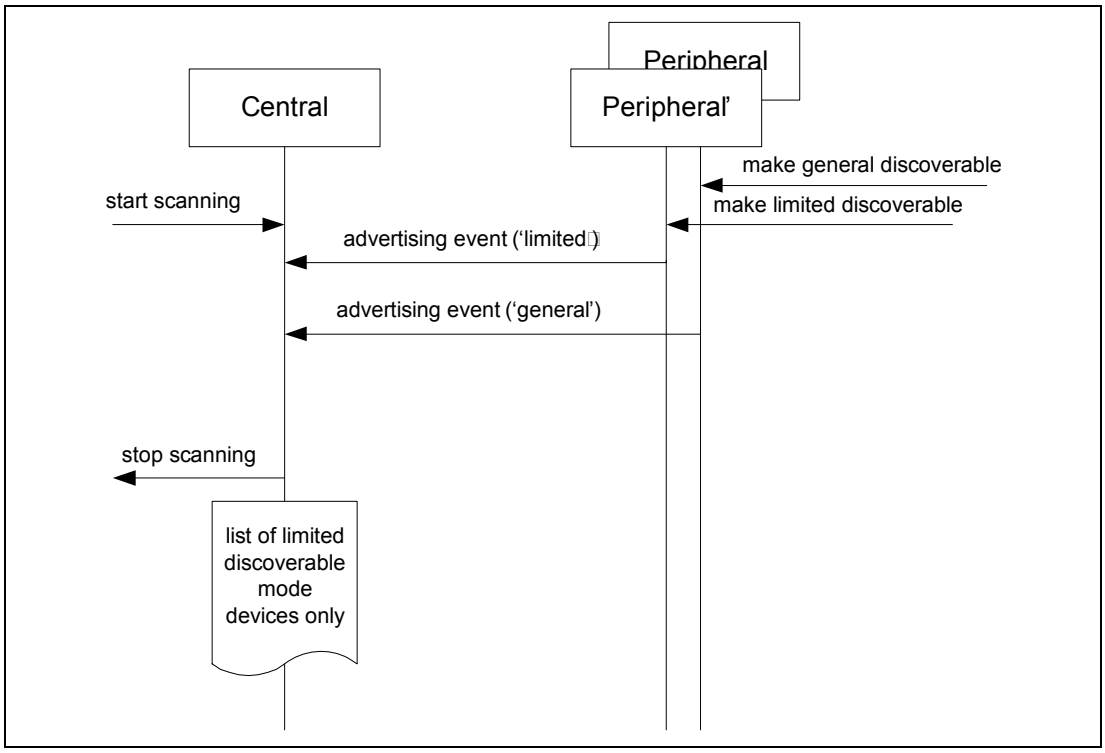

Figure 9.1: A Central performing limited discovery procedure discovering Peripherals in the limited discoverable mode

9.2.5.2 Conditions

While a device is in the Central role the device may support the limited discovery procedure. While a device is only in the Broadcaster, Observer or Peripheral role the device shall not support the limited discovery procedure.

It is recommended that the device scan on all the PHYs it supports.

When a Host performs the limited discovery procedure, the Host configures the Controller as follows:

1. The Host shall set the scanner filter policy to ‘process all advertising packets’.
2. The Host should set the scan interval and scan window as defined in Section 9.3.11.
3. The Host should configure the Controller to use active scanning.

The Host shall begin scanning for advertising packets and should continue for a minimum of T_{GAP}(lim_disc_scan_min) when scanning on the LE 1M PHY and T_{GAP}(lim_disc_scan_min_coded) when scanning on the LE Coded PHY, unless the Host ends the limited discovery procedure.

The Host shall check for the Flags AD type in the advertising data. If the Flags AD type is present and the LE Limited Discoverable Flag is set to one then the Host shall consider the device as a discovered device, otherwise the advertising data shall be ignored. The Flag AD type is defined in [Core Specification Supplement], Part A, Section 1.3. The advertising data of the discovered device may contain data with other AD types, e.g. Service UUIDs AD type, TX Power Level AD type, Local Name AD type, Slave Connection Interval Range AD type. The Host may use the data in performing any of the connection establishment procedures.

The Host shall ignore the 'Simultaneous LE and BR/EDR to Same Device Capable (Controller)' and 'Simultaneous LE and BR/EDR to Same Device Capable (Host)' bits in the Flags AD type.

9.2.6 General Discovery Procedure

9.2.6.1 Description

A device performing the general discovery procedure receives the device address, advertising data and scan response data from devices in the limited discoverable mode or the general discoverable mode.

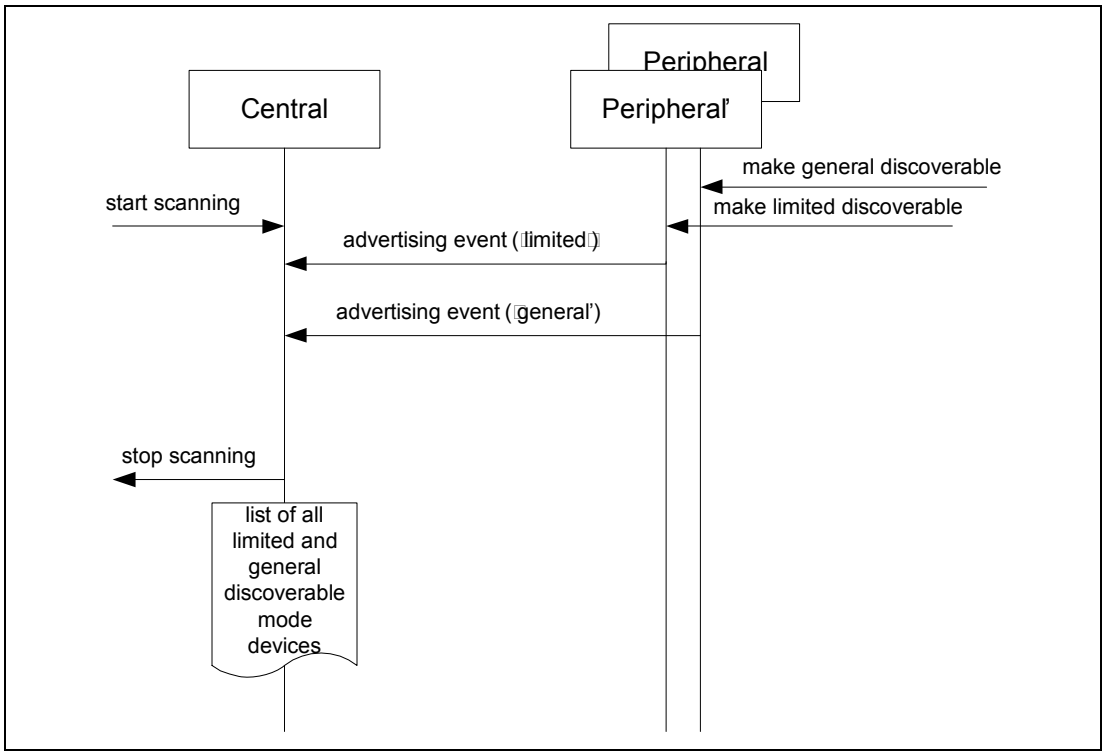

Figure 9.2: A Central performing general discovery procedure discovering Peripherals in the limited discoverable mode and general discoverable mode

9.2.6.2 Conditions

While a device is in the Central role the device shall support the general discovery procedure. While a device is only in the Broadcaster, Observer or Peripheral role the device shall not support the general discovery procedure.

It is recommended that the device scan on all the PHYs it supports.

When a Host performs the general discovery procedure, the Host configures the Controller as follows:

1. The Host shall set the scanner filter policy to 'process all advertising packets'.
2. The Host should set the scan interval and scan window as defined in Section 9.3.11.
3. The Host should configure the Controller to use active scanning.

The Host shall begin scanning for advertising packets and should continue for a minimum of T_{GAP}(gen_disc_scan_min) when scanning on the LE 1M PHY and T_{GAP}(gen_disc_scan_min_coded) when scanning on the LE Coded PHY. The procedure may be terminated early by the Host.

The Host shall check for the Flags AD type in the advertising data. If the Flags AD type (see [Core Specification Supplement], Part A, Section 1.3) is present and either the LE General Discoverable Mode flag is set to one or the LE Limited Discoverable Mode flag is set to one then the Host shall consider the device as a

discovered device, otherwise the advertising data shall be ignored. The advertising data of the discovered device may contain data with other AD types, e.g. Service UUIDs AD type, TX Power Level AD type, Local Name AD type, Slave Connection Interval Range AD type. The Host may use the data in performing any of the connection establishment procedures as defined in Section 9.3.

The Host shall ignore the 'Simultaneous LE and BR/EDR to Same Device Capable (Controller)' and 'Simultaneous LE and BR/EDR to Same Device Capable (Host)' bits in the Flags AD type.

9.2.7 Name Discovery Procedure

9.2.7.1 Description

The name discovery procedure is used to obtain the Bluetooth Device Name of a remote connectable device.

9.2.7.2 Conditions

If the complete device name is not acquired while performing either the limited discovery procedure or the general discovery procedure, then the name discovery procedure may be performed.

The name discovery procedure shall be performed as follows:

1. The Host shall establish a connection using one of the connection establishment procedures as defined in Section 9.3.
2. The Host shall read the device name characteristic using the GATT procedure Read Using Characteristic UUID [Vol 3] Part G, Section 4.8.2
3. The connection may be terminated after the GATT procedure has completed.

9.3 CONNECTION MODES AND PROCEDURES

The connection modes and procedures allow a device to establish a connection to another device.

When devices are connected, the parameters of the connection can be updated with the Connection Parameter Update procedure. The connected device may terminate the connection using the Terminate Connection procedure. The requirements for a device to support the connection modes and procedures are defined in Table 9.3.

9.3.1 Requirements

Connection Modes and Procedures	Ref.	Peripheral	Central	Broadcaster	Observer
Non-connectable mode	9.3.2	M	E	M	M
Directed connectable mode	9.3.3	O	E	E	E
Undirected connectable mode	9.3.4	M	E	E	E
Auto connection establishment procedure	9.3.5	E	O	E	E
General connection establishment procedure	9.3.6	E	O	E	E
Selective connection establishment procedure	9.3.7	E	O	E	E
Direct connection establishment procedure	9.3.8	E	M	E	E
Connection parameter update procedure	9.3.9	O	M	E	E
Terminate connection procedure	9.3.10	M	M	E	E

Table 9.3: Connection modes and procedures requirements[1]

1. Note: Requirements listed in the table above refer to the specific role a device is operating in. Devices supporting multiple roles are required to support the specified modes and procedures for a given role while operating in that role.

9.3.2 Non-Connectable Mode

9.3.2.1 Description

A device in the non-connectable mode shall not allow a connection to be established.

9.3.2.2 Conditions

While a device is in the Peripheral role the device shall support the non-connectable mode. A device in the Broadcaster or Observer role cannot establish a connection, therefore the device is considered to support the non-connectable mode.

A Peripheral device in the non-connectable mode may send non-connectable advertising events. In this case it is recommended that the Host configures the Controller as follows:

- The Host should set the advertising filter policy to either ‘process scan and connection requests only from devices in the White List’ or ‘process scan and connection requests from all devices’.
- The Host should set the advertising intervals as defined in Section 9.3.11.

The device may configure and enable multiple independent advertising sets. Each advertising set may have an independent advertising filter policy.

9.3.3 Directed Connectable Mode

9.3.3.1 Description

A device in the directed connectable mode shall accept a connection request from a known peer device performing the auto connection establishment procedure or the general connection establishment procedure.

9.3.3.2 Conditions

While a device is in the Peripheral role the device may support the directed connectable mode. This mode shall only be used if the device has a known peer device address. While a device is only in the Broadcaster, Observer, or the Central role the device shall not support the direct connectable mode.

A Peripheral device shall send connectable directed advertising events.

The device may configure and enable multiple independent advertising sets. Each advertising set may have an independent advertising filter policy.

9.3.4 Undirected Connectable Mode

9.3.4.1 Description

A device in the undirected connectable mode shall accept a connection request from a device performing the auto connection establishment procedure or the general connection establishment procedure.

9.3.4.2 Conditions

While a device is in the Peripheral role the device shall support the undirected connectable mode. While a device is only in the Broadcaster, Observer, or the Central role the device shall not support the undirected connectable mode.

A Peripheral device should follow the guidelines defined in Section 9.3.11. A Peripheral device shall send either connectable and scannable undirected advertising events or connectable undirected advertising events.

The device may configure and enable multiple independent advertising sets. Each advertising set may have an independent advertising filter policy.

9.3.5 Auto Connection Establishment Procedure

9.3.5.1 Description

The auto connection establishment procedure allows the Host to configure the Controller to autonomously establish a connection with one or more devices in the directed connectable mode or the undirected connectable mode. White Lists in the Controller are used to store device addresses. This procedure uses the initiator White List in the Controller. The Controller autonomously establishes a connection with a device with the device address that matches the address stored in the White List.

9.3.5.2 Conditions

While a device is in the Central role the device may support the auto connection establishment procedure. While a device is only in the Broadcaster, Observer, or Peripheral role the device shall not support the auto connection establishment procedure.

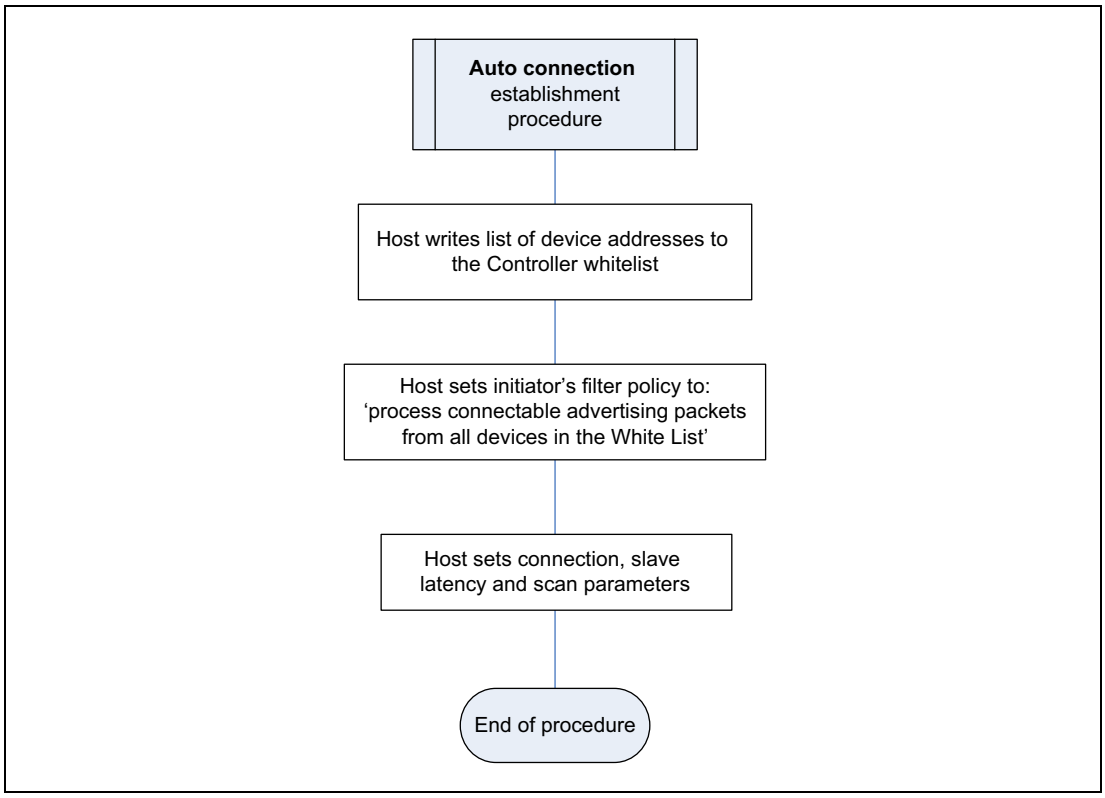

Figure 9.3: Flow chart for a device performing the auto connection establishment procedure

When a Host performs the auto connection establishment procedure, the Host configures the Controller as follows:

1. The Host shall write the list of device addresses that are to be auto connected to into the White List.
2. The Host shall set the initiator filter policy to 'process connectable advertising packets from all devices in the White List'.
3. The Host should set the scan interval and scan window as defined in Section 9.3.11.
4. The Host should set connection parameters as defined in Section 9.3.12.

This procedure is terminated when a connection is established or when the Host terminates the procedure.

9.3.6 General Connection Establishment Procedure

9.3.6.1 Description

The general connection establishment procedure allows the Host to establish a connection with a set of known peer devices in the directed connectable mode or the undirected connectable mode.

9.3.6.2 Conditions

While a device is in the Central role the device may support the general connection establishment procedure. While a device is only in the Broadcaster, Observer, or Peripheral role the device shall not support the general connection establishment procedure.

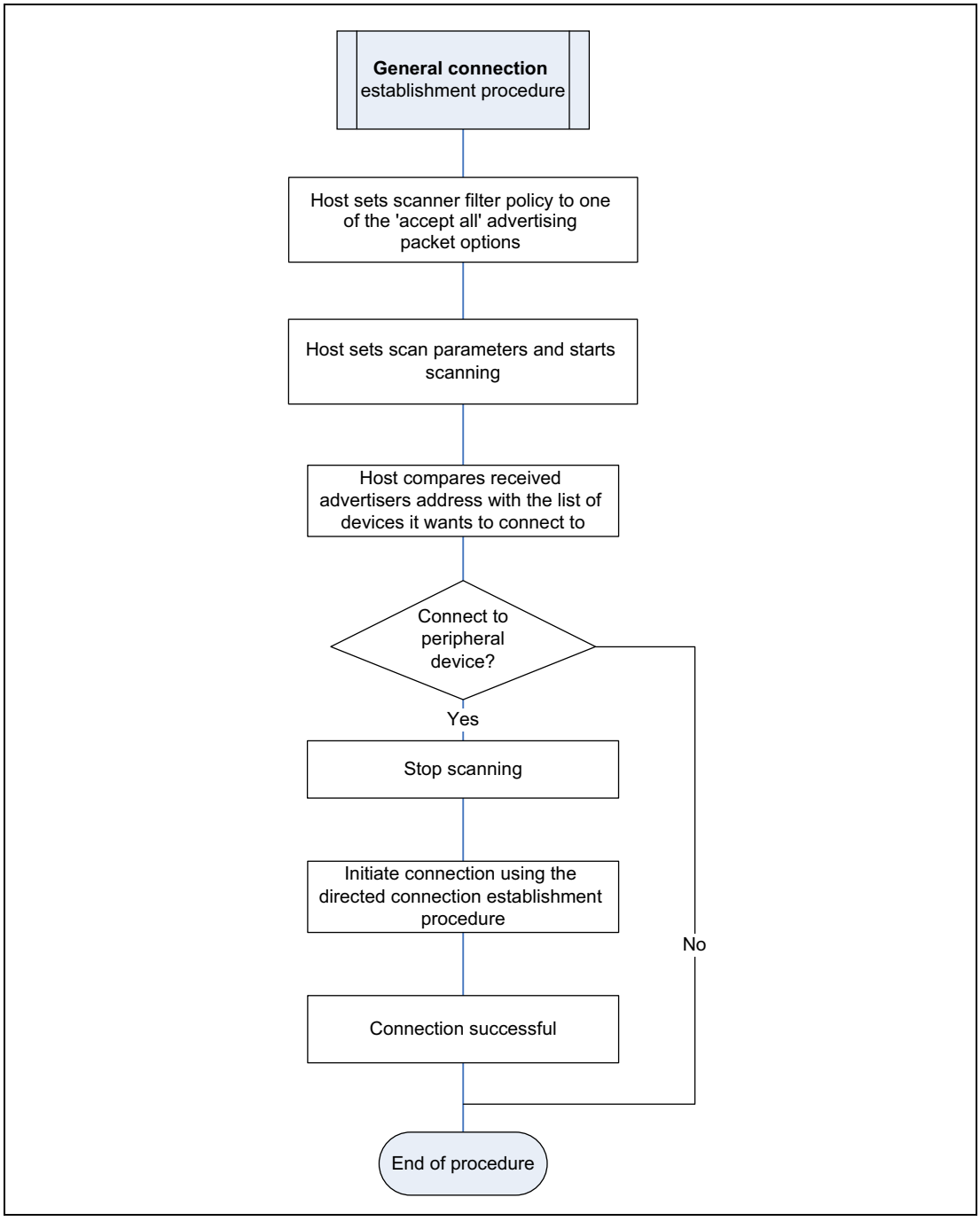

Figure 9.4: Flow chart for a device performing the general connection establishment procedure

When a Host performs the general connection establishment procedure, the Host configures the Controller as follows:

1. The Host shall set the scanner filter policy to one of the ‘accept all’ options as defined in [Vol 2] Part E, Section 7.8.10.
2. The Host should set the scan interval as defined in Section 9.3.11.
3. The Host should set the scan window as defined in Section 9.3.11.
4. The Host shall start scanning.
5. The Host should set connection parameters as defined in Section 9.3.12.

When the Host discovers a device to which the Host may attempt to connect, the Host shall stop the scanning, and initiate a connection using the direct connection establishment procedure.

This procedure is terminated when a connection is established or when the Host terminates the procedure.

9.3.7 Selective Connection Establishment Procedure

9.3.7.1 Description

The selective connection establishment procedure allows the Host to establish a connection with the Host selected connection configuration parameters with a set of devices addresses in the White List.

9.3.7.2 Conditions

While a device is in the Central role the device may support the selective connection establishment procedure. While a device is only in the Broadcaster, Observer, or the Peripheral role the device shall not support the selective connection establishment procedure. Figure 9.5 shows the flow chart for a device performing the selective connection establishment procedure.

When a Host performs the selective connection establishment procedure, the Host configures the Controller as follows:

1. The Host shall write the list of device addresses that are to be selectively connected into the White List.
2. The Host shall set the scanner filter policy to the 'accept only' option as defined in [Vol 2] Part E, Section 7.8.10.
3. The Host should set the scan interval as defined in Section 9.3.11.
4. The Host should set the scan window as defined in Section 9.3.11.
5. The Host shall start active scanning or passive scanning.

When the Host discovers one of the peer devices it is connecting to, the Host shall stop scanning, and initiate a connection using the direct connection establishment procedure with the connection configuration parameters for that peer device.

This procedure is terminated when a connection is established or when the Host terminates the procedure.

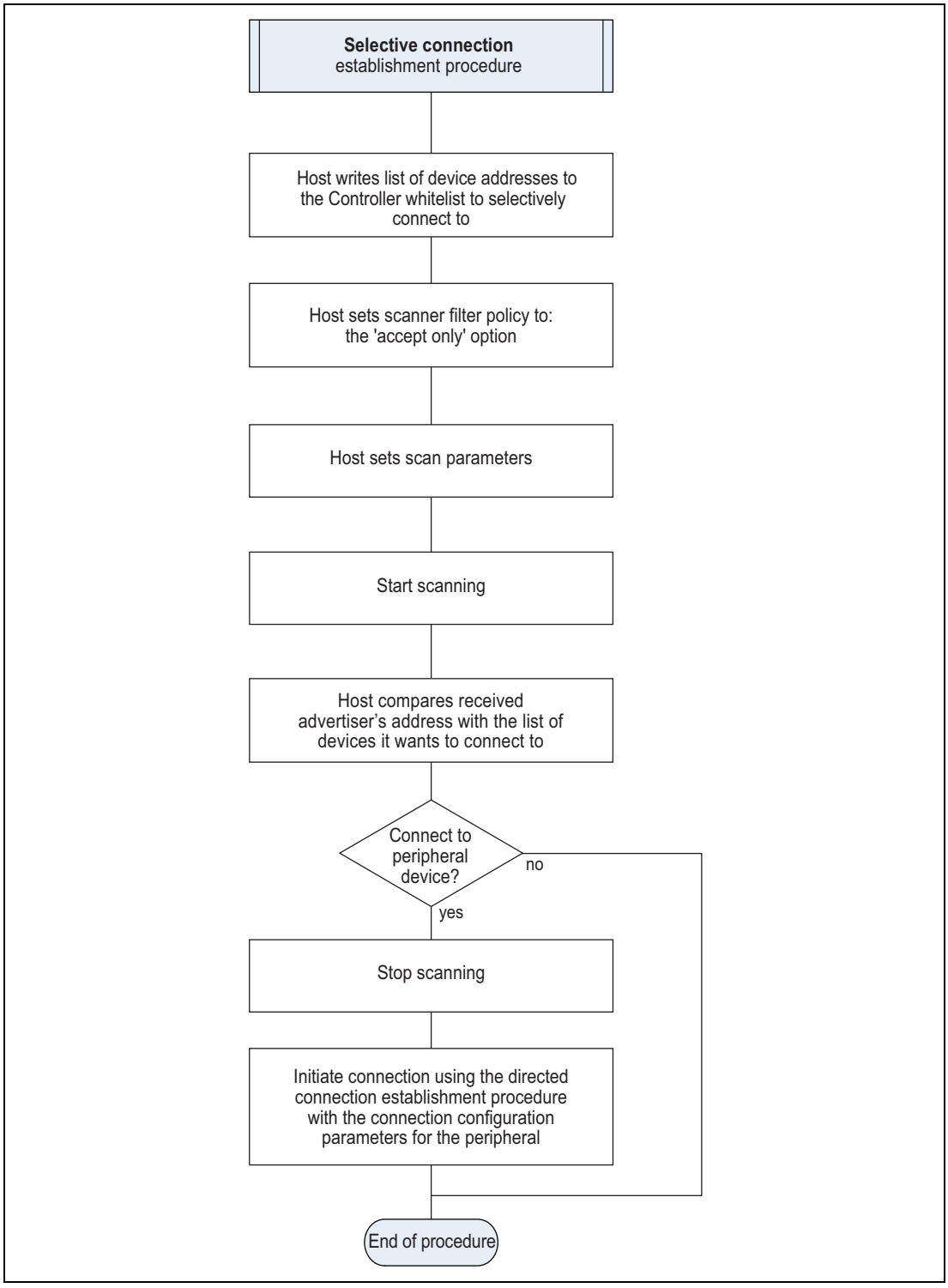

Figure 9.5: Flow chart for a device performing the selective connection establishment procedure

9.3.8 Direct Connection Establishment Procedure

9.3.8.1 Description

The direct connection establishment procedure allows the Host to establish a connection with the Host selected connection configuration parameters with a single peer device.

9.3.8.2 Conditions

While a device is in the Central role the device shall support the direct connection establishment procedure. While a device is only in the Broadcaster, Observer, or the Peripheral role the device shall not support the direct connection establishment procedure.

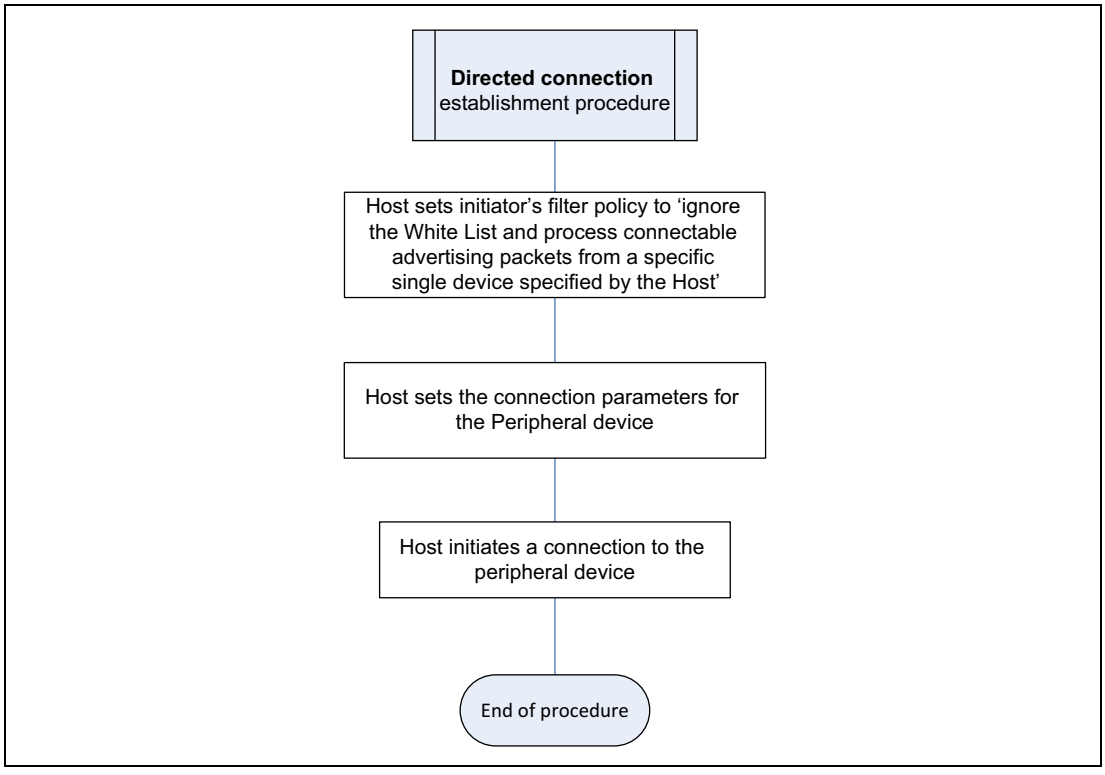

Figure 9.6: Flow chart for a device performing the directed connection establishment procedure

When a Host performs the direct connection establishment procedure, the Host configures the Controller as follows:

1. The Host shall set the initiator filter policy to 'ignore the White List and process connectable advertising packets from a specific single device specified by the Host'.
2. The Host shall set the peer address to the device address of the specific single device.
3. The Host should set connection parameters as defined in Section 9.3.12.

4. The Host shall initiate a connection.

This procedure is terminated when a connection is established or when the Host terminates the procedure.

9.3.9 Connection Parameter Update Procedure

9.3.9.1 Description

The connection parameter update procedure allows a Peripheral or Central to update the Link Layer connection parameters of an established connection.

9.3.9.2 Conditions

While a device is in the Central role the device shall support the connection parameter update procedure. While a device is only in the Peripheral role the device may support the connection parameter update procedure. While a device is in the Broadcaster or the Observer role the device shall not support the connection parameter update procedure.

A Central initiating the connection parameter update procedure shall use the Link Layer Connection Update procedure defined in [Vol 6] Part B, Section 5.1.1 with the required connection parameters if either the Central or the Peripheral does not support the Connection Parameters Request Link Layer Control procedure.

If both the Central and Peripheral support the Connection Parameters Request Link Layer control procedure, then the Central or Peripheral initiating the connection parameter update procedure shall use the Connection Parameters Request Link Layer Control procedure defined in [Vol 6] Part B, Section 5.1.7 with the required connection parameters.

If either the Central or the Peripheral does not support the Connection Parameters Request Link Layer Control procedure, then the Peripheral initiating the connection parameter update procedure shall use the L2CAP Connection Parameter Update Request command defined in [Vol 3] Part A, Section 4.20 with the required connection parameters. The Peripheral shall not send an L2CAP Connection Parameter Update Request command within T_{GAP}(conn_param_timeout) of an L2CAP Connection Parameter Update Response being received. When the Central accepts the Peripheral initiated Connection Parameter Update, the Central should initiate the Link Layer Connection Update procedure defined in [Vol 6] Part B, Section 5.1.1 with the required connection parameters within TGAP(conn_param_timeout).

If the requested or updated connection parameters are unacceptable to the Central or Peripheral then it may disconnect the connection with the error code 0x3B (Unacceptable Connection Parameters). Devices should be tolerant of connection parameters given to them by the remote device.

9.3.10 Terminate Connection Procedure

9.3.10.1 Description

The terminate connection procedure allows a Host to terminate the connection with a peer device.

9.3.10.2 Conditions

Centrals and Peripherals shall support the terminate connection procedure. Broadcasters and Observers shall not support the terminate connection procedure.

The Host initiating the terminate connection procedure shall use the Link Layer Termination Procedure defined in [Vol 6] Part B, Section 5.1.6.

9.3.11 Connection Establishment Timing Parameters

9.3.11.1 Description

The connection establishment timing parameters are used during initial connection establishment between a Central and a Peripheral device.

A Central device should use one of the GAP connection establishment procedures to initiate a connection to a Peripheral device in a connectable mode. The procedures and modes that may use these timing parameters are defined in Section 9.3.4 through Section 9.3.8.

9.3.11.2 Conditions

A Central device starting a GAP connection establishment procedure should use the recommended scan interval T_{GAP}(scan_fast_interval) and scan window T_{GAP}(scan_fast_window) for T_{GAP}(scan_fast_period) when scanning on the LE 1M PHY and should use scan interval T_{GAP}(scan_fast_interval_coded) and scan window T_{GAP}(scan_fast_window_coded) for T_{GAP}(scan_fast_period) when scanning on the LE Coded PHY.

A Central device that is background scanning should use the recommended scan interval T_{GAP}(scan_slow_interval1) and scan window T_{GAP}(scan_slow_window1) when scanning on the LE 1M PHY and should use scan interval T_{GAP}(scan_slow_interval1_coded) and scan window T_{GAP}(scan_slow_window1_coded) when scanning on the LE Coded PHY. Alternatively the central may use T_{GAP}(scan_slow_interval2) and scan window T_{GAP}(scan_slow_window2) when scanning on the LE 1M PHY and should use T_{GAP}(scan_slow_interval2_coded) and scan window T_{GAP}(scan_slow_window2_coded) when scanning on the LE Coded PHY.

A Peripheral device entering any of the following GAP Modes should use the recommended advertising interval T_{GAP}(adv_fast_interval1) for T_{GAP}(adv_fast_period) when advertising on the LE 1M PHY and should use T_{GAP}(adv_fast_interval1_coded) for T_{GAP}(adv_fast_period) when advertising on the LE Coded PHY:

- Undirected Connectable Mode
- Limited Discoverable Mode and sending connectable undirected advertising events
- General Discoverable Mode and sending connectable undirected advertising events
- Directed Connectable Mode and sending low duty cycle connectable directed advertising events

A Peripheral device when entering any of the following GAP Modes and sending non-connectable advertising events should use the recommended advertising interval T_{GAP}(adv_fast_interval2) for T_{GAP}(adv_fast_period) when advertising on the LE 1M PHY and should use T_{GAP}(adv_fast_interval2_coded) for T_{GAP}(adv_fast_period) when advertising on the LE Coded PHY:

- Non-Discoverable Mode
- Non-Connectable Mode
- Limited Discoverable Mode
- General Discoverable Mode

A Peripheral device that is background advertising in any GAP Mode other than GAP Directed Connectable Mode with high duty cycle connectable directed advertising events should use the recommended advertising interval T_{GAP}(adv_slow_interval) when advertising on the LE 1M PHY and should use T_{GAP}(adv_slow_interval_coded) when advertising on the LE Coded PHY.

Note: When advertising interval values of less than 100ms are used for non-connectable or scannable undirected advertising in environments where the advertiser can interfere with other devices, it is recommended that steps be taken to minimize the interference. For example, the advertising might be alternately enabled for only a few seconds and disabled for several minutes.

9.3.12 Connection Interval Timing Parameters

9.3.12.1 Description

The connection interval timing parameters are used within a connection. Initial connection interval is used to ensure procedures such as bonding, encryption setup and service discovery are completed quickly. The connection interval should be changed to the Peripheral Preferred Connection Parameters after initiating procedures are complete.

9.3.12.2 Conditions

The Central device should either read the Peripheral Preferred Connection Parameters characteristic (see Section 12.3) or retrieve the parameters from advertising data (see Section 12.3).

The connection interval should be set to T_{GAP}(initial_conn_interval) when establishing a connection on the LE 1M PHY and to T_{GAP}(initial_conn_interval_coded) when establishing a connection on the LE Coded PHY and slave latency should be set to zero. These parameters should be used until the Central device has no further pending actions to perform or until the Peripheral device performs a Connection Parameter Update procedure (see Section 9.3.9).

After the Central device has no further pending actions to perform and the Peripheral device has not initiated any other actions within T_{GAP}(conn_pause_central), then the Central device should invoke the Connection Parameter Update procedure (see Section 9.3.9) and change the connection intervals as defined in the Peripheral Preferred Connection Parameters.

If the Central device does not have the Peripheral Preferred Connection Parameters, then the Central device may choose the connection parameters to be used.

After the Peripheral device has no further pending actions to perform and the Central device has not initiated any other actions within T_{GAP}(conn_pause_central), then the Peripheral device may perform a Connection Parameter Update procedure (see Section 9.3.9). The Peripheral device should not perform a Connection Parameter Update procedure within T_{GAP}(conn_pause_peripheral) after establishing a connection.

At any time a key refresh or encryption setup procedure is required and the current connection interval is greater than T_{GAP}(initial_conn_interval) when connected on the LE 1M PHY or LE 2M PHY or greater than T_{GAP}(initial_conn_interval_coded) when connected on the LE Coded PHY, the key refresh or encryption setup procedure should be preceded with a Connection Parameter Update procedure (see Section 9.3.9). The connection interval should be set to T_{GAP}(initial_conn_interval) when connected on the LE 1M PHY and to LE 2M PHY and T_{GAP}(initial_conn_interval_coded) when connected on the LE Coded PHY and slave latency should be set to zero. This fast connection interval should be maintained until the key refresh or encryption setup procedure is complete. It should then switch to the Peripheral Preferred Connection Parameters.

9.4 BONDING MODES AND PROCEDURES

Bonding allows two connected devices to exchange and store security and identity information to create a trusted relationship. The security and identity information as defined in [Vol 3] Part H, Section 2.4.1 is also known as the bonding information. When the devices store the bonding information, it is known as the phrases ‘devices have bonded’ or ‘a bond is created’.

There are two modes for bonding, non-bondable mode and bondable mode. Bonding may only occur between two devices in bondable mode. The requirements for a device to support the bonding modes and procedure are defined in Table 9.4.

9.4.1 Requirements

Bonding	Ref.	Peripheral	Central
Non-Bondable mode	9.4.2	M	M
Bondable mode	9.4.3	O	O
Bonding procedure	9.4.4	O	O

Table 9.4: Bonding Compliance Requirements

9.4.2 Non-Bondable Mode

9.4.2.1 Description

A device in the non-bondable mode does not allow a bond to be created with a peer device.

9.4.2.2 Conditions

While a device is in the Peripheral or the Central role the device shall support the non-bondable mode. If a device does not support pairing as defined in the Security Manager section then it is considered to be in non-bondable mode.

If Security Manager pairing is supported, the Host shall set the Bonding_Flags to ‘No Bonding’ as defined in [Vol 3] Part H, Section 3.5.1 and bonding information shall not be exchanged or stored.

9.4.3 Bondable Mode

9.4.3.1 Description

A device in the bondable mode allows a bond to be created with a peer device in the bondable mode.

9.4.3.2 Conditions

The Host shall set the Bonding_Flags to ‘Bonding’ during the pairing procedure.

9.4.4 Bonding Procedure

9.4.4.1 Description

The bonding procedure may be performed when a non-bonded device tries to access a service that requires bonding. The bonding procedure may be performed for the purpose of creating a bond between two devices.

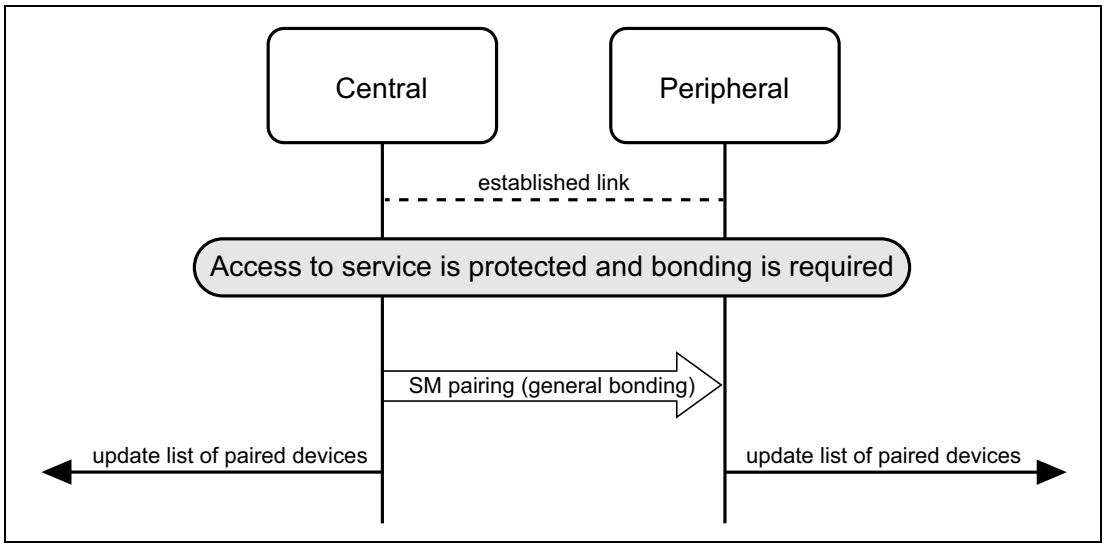

Figure 9.7: The Bonding procedure

9.4.4.2 Conditions

While a device is in the Peripheral or the Central role the device may support the Bonding procedure. While a device is in the Broadcaster or the Observer role the device shall not support the bonding procedure.

The Host of the Central initiates the pairing process as defined in [Vol 3] Part C, Section 2.1 with the Bonding_Flags set to Bonding as defined in [Vol 3] Part H, Section 3.5.1. If the peer device is in the bondable mode, the devices shall exchange and store the bonding information in the security database.

If a device supports the generation of resolvable private addresses as defined in Section 10.8.2.2 and generates a resolvable private address for its local address, it shall send Identity Information with SMP, including a valid IRK. If a device does not generate a resolvable private address for its own address and the Host sends Identity Information with SMP, the Host shall send an all-zero IRK. The Host can abort the pairing procedure if the authentication requirements are not sufficient to distribute the IRK.

9.5 PERIODIC ADVERTISING MODES AND PROCEDURE

The periodic advertising modes and procedure allow two or more devices to communicate in a unidirectional connectionless manner using extended advertising events and periodic advertising events. The requirements for a device operating in a specific GAP role to support periodic advertising synchronizability mode, periodic advertising mode, and periodic advertising synchronization procedure are defined in Table 9.5.

Mode and Procedures	Ref.	Broadcaster	Observer
Periodic Advertising Synchronizability mode	9.5.1	O	E
Periodic Advertising mode	9.5.2	C1	E
Periodic Advertising Synchronization Establishment procedure	9.5.3	E	O
C1: If Periodic Advertising Synchronization mode is supported, Periodic Advertising mode is mandatory; otherwise excluded.			

Table 9.5: Periodic Advertising modes and Periodic Advertising procedure requirements

9.5.1 Periodic Advertising Synchronizability Mode

9.5.1.1 Definition

The periodic advertising synchronizability mode provides a method for a device to send synchronization information about periodic advertising events.

9.5.1.2 Conditions

A device in the periodic advertising synchronizability mode shall send synchronization information for periodic advertising events in non-connectable and non-scannable extended advertising events.

9.5.2 Periodic Advertising Mode

9.5.2.1 Definition

The periodic advertising mode provides a method for a device to send advertising data at periodic and deterministic intervals.

9.5.2.2 Conditions

A device in the periodic advertising mode shall send periodic advertising events at the interval and using the frequency hopping sequence specified in the periodic advertising synchronization information.

9.5.3 Periodic Advertising Synchronization Establishment Procedure

9.5.3.1 Definition

The periodic advertising synchronization establishment procedure provides a method for a device to receive periodic advertising synchronization information and to synchronize to periodic advertisements.

9.5.3.2 Conditions

A device performing the periodic advertising synchronization establishment procedure shall scan for non-connectable and non-scannable advertising events containing synchronization information for periodic advertising events. When a device receives synchronization information for periodic advertising events, it may listen for periodic advertising events at the intervals and using the frequency hopping sequence specified in the synchronization information contained in the non-connectable and non-scannable extended advertising event.

10 SECURITY ASPECTS – LE PHYSICAL TRANSPORT

This section defines the modes and procedures that relate to the security of a connection. The following modes and procedures are defined:

- LE security mode 1
- LE security mode 2
- Authentication procedure
- Authorization procedure
- Connection data signing procedure
- Authenticate signed data procedure

Requirements for a device to support the LE security modes and procedures is shown in Table 10.1.

10.1 REQUIREMENTS

Security Modes and Procedures	Ref.	Broadcaster	Observer	Peripheral	Central
LE Security mode 1	10.2.1	E	E	O	O
LE Security mode 2	10.2.2	E	E	O	O
Authentication procedure	10.3	E	E	O	O
Authorization procedure	10.5	E	E	O	O
Connection data signing procedure	10.4.1	E	E	O	O
Authenticate signed data procedure	10.4.2	E	E	O	O

Table 10.1: Requirements related to security modes and procedures

10.2 LE SECURITY MODES

The security requirements of a device, a service or a service request are expressed in terms of a security mode and security level. Each service or service request may have its own security requirement. The device may also have a security requirement. A physical connection between two devices shall operate in only one security mode.

There are two LE security modes, LE security mode 1 and LE security mode 2.

10.2.1 LE Security Mode 1

LE security mode 1 has the following security levels:

1. No security (No authentication and no encryption)
2. Unauthenticated pairing with encryption
3. Authenticated pairing with encryption
4. Authenticated LE Secure Connections pairing with encryption using a 128-bit strength encryption key.

A connection operating in LE security mode 1 level 2 shall also satisfy the security requirements for LE security mode 1 level 1.

A connection operating in LE security mode 1 level 3 shall also satisfy the security requirements for LE security mode 1 level 2 or LE security mode 1 level 1.

A connection operating in LE security mode 1 level 3 shall also satisfy the security requirements for LE security mode 2.

A connection operating in LE security mode 1 level 4 shall also satisfy the security requirements for LE security mode 1 level 3 or LE security mode 1 level 2 or LE security mode 1 level 1.
A connection operating in LE security mode 1 level 4 shall also satisfy the security requirements for LE security mode 2.

10.2.2 LE Security Mode 2

LE security mode 2 has two security levels:

1. Unauthenticated pairing with data signing
2. Authenticated pairing with data signing

LE security mode 2 shall only be used for connection based data signing.

Data signing as defined in Section 10.4 shall not be used when a connection is operating in LE security mode 1 level 2, LE security mode 1 level 3, or LE security mode 1 level 4.

10.2.3 Mixed Security Modes Requirements

If there are requirements for both LE security mode 1 and LE security mode 2 level 2 for a given physical link then LE security mode 1 level 3 shall be used.

If there are requirements for both LE security mode 1 level 3 and LE security mode 2 for a given physical link then LE security mode 1 level 3 shall be used.

If there are requirements for both LE security mode 1 level 2 and LE security mode 2 level 1 for a given physical link then LE security mode 1 level 2 shall be used.

If there are requirements for both LE security mode 1 level 4 and any other security mode or level for a given physical link then LE security mode 1 level 4 shall be used.

10.2.4 Secure Connections Only Mode

A device may be in a Secure Connections Only mode. When in Secure Connections Only mode only security mode 1 level 4 shall be used except for services that only require security mode 1 level 1.

The device shall only accept new outgoing and incoming service level connections for services that require Security Mode 1, Level 4 when the remote device supports LE Secure Connections and authenticated pairing is used.

10.3 AUTHENTICATION PROCEDURE

The authentication procedure describes how the required security is established when a device initiates a service request to a remote device and when a device receives a service request from a remote device. The authentication procedure covers LE security mode 1. The authentication procedure shall only be initiated after a connection has been established.

LE security mode 2 pertains to the use of data signing and is covered in Section 10.4.

Authentication in LE security mode 1 is achieved by enabling encryption as defined in Section 10.6. The security of the encryption is impacted by the type of pairing performed. There are two types of pairing: authenticated pairing or unauthenticated pairing. Authenticated pairing involves performing the pairing procedure defined in [Vol 3] Part H, Section 2.1 with the authentication set to 'MITM protection'. Unauthenticated pairing involves performing the pairing procedure with authentication set to 'No MITM protection'.
Note: In this section, the terms "authenticated pairing" and "unauthenticated pairing" refer to the security method used to perform pairing and are not related to the authentication of previously bonded devices during a reconnection.

Section 10.3.1 specifies the authentication procedure when a device responds to a service request. Section 10.3.2 specifies the authentication procedure when a device initiates a service request.

10.3.1 Responding to a Service Request

In this section the local device is the device responding to a service request made by a remote device. In the L2CAP protocol the local device responds with a connection response to a remote device making a connection request. In GATT, the local device is the GATT server and the remote device is the GATT client.

When a local device receives a service request from a remote device, it shall respond with an error code if the service request is denied. The error code is dependent on whether the current connection is encrypted or not and on the type of pairing that was performed to create the LTK or STK to be used.

When a local device receives a service request from a remote device it shall behave according to the following rules:

- The local device's security database specifies the security settings required to accept a service request. If no encryption and no data signing are required, the service request shall be accepted. If encryption is required the local device must send an error code as defined in Table 10.2. If no encryption is required, but data signing is required, then the local device behavior is as defined in Section 10.4.

- If neither an LTK nor an STK is available, the service request shall be rejected with the error code “Insufficient Authentication”.

  Note: When the link is not encrypted, the error code “Insufficient Authentication” does not indicate that MITM protection is required.
- If an LTK or an STK is available and encryption is required (LE security mode 1) but encryption is not enabled, the service request shall be rejected with the error code “Insufficient Encryption”. If the encryption is enabled with insufficient key size then the service request shall be rejected with the error code “Insufficient Encryption Key Size.”
- If an authenticated pairing is required but only an unauthenticated pairing has occurred and the link is currently encrypted, the service request shall be rejected with the error code “Insufficient Authentication.”

  Note: When unauthenticated pairing has occurred and the link is currently encrypted, the error code “Insufficient Authentication” indicates that MITM protection is required.
- If LE Secure Connections pairing is required but LE legacy pairing has occurred and the link is currently encrypted, the service request shall be rejected with the error code “Insufficient Authentication”.

The local device will respond with the minimum security level required for access to its services. If the local device has no security requirement it should default to the minimum security level that the local device is capable of as defined in pairing phase 1, (see [Vol 3] Part H, Section 2.1).

A local device shall not require an authenticated pairing (MITM) if the localdevice does not support the required IO capabilities or OOB data[1].

The local device responds to a service request from a remote device are summarized in Table 10.2.

1. Note that if an OOB mechanism is used, the level of MITM protection is dependent upon the properties of the OOB communications channel. See [Vol 3] Part H, Section 2.3.5.1 for more information

Link Encryption State	Local Device's Access Requirement for Service	Local Device Pairing Status			
		No LTK No STK	**Unauthenticated LTK or Unauthenticated STK**	**Authenticated LTK or Authenticated STK**	**Authenticated LTK with Secure Connections**
Unencrypted	**None**	Request succeeds	Request succeeds	Request succeeds	Request succeeds
	Encryption, No MITM Protection	Error Resp.: Insufficient Authentication	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption
	Encryption, MITM Protection	Error Resp.: Insufficient Authentication	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption
	Encryption, MITM Protection, Secure Connections	Error Resp.: Insufficient Authentication	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption	Error Resp.: Insufficient Encryption
Encrypted	**None**	N/A (Not possible to be encrypted without LTK)	Request succeeds	Request succeeds	Request succeeds
	Encryption, No MITM Protection		Request succeeds	Request succeeds	Request succeeds
	Encryption, MITM Protection		Error Resp.: Insufficient Authentication	Request succeeds	Request succeeds
	Encryption, MITM Protection, Secure Connections		Error Resp.: Insufficient Authentication	Error Resp.: Insufficient Authentication	Request succeeds

Table 10.2: Local device responds to a service request

Figure 10.1 shows how a server handles a service request.

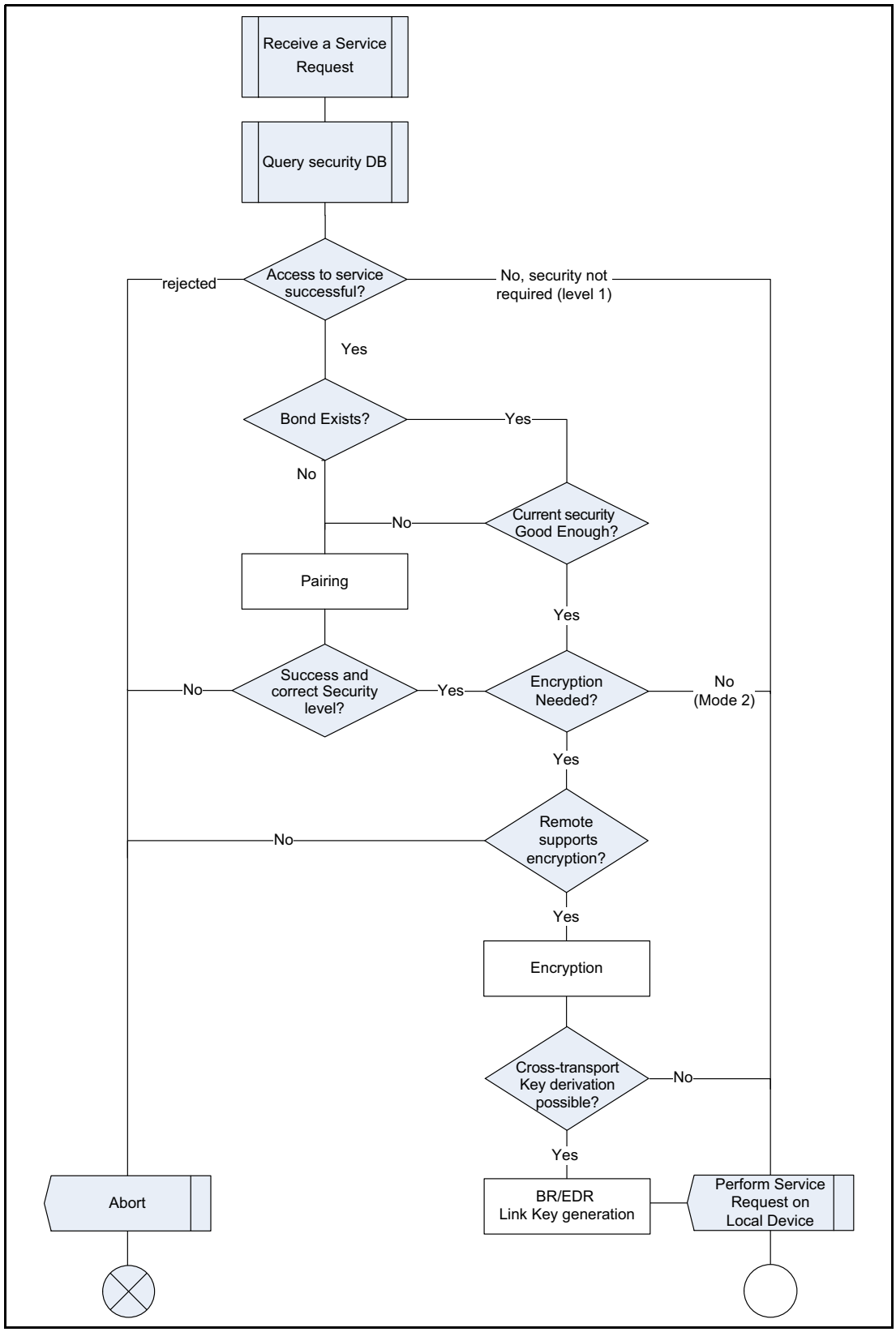

Figure 10.1: Flow chart for a local device handling a service request from a remote device

10.3.1.1 Handling of GATT Indications and Notifications

A client “requests” a server to send indications and notifications by appropriately configuring the server via a Client Characteristic Configuration Descriptor. Since the configuration is persistent across a disconnection and reconnection, security requirements must be checked upon a reconnection before sending indications or notifications. When a server reconnects to a client to send an indication or notification for which security is required, the server shall initiate or request encryption with the client prior to sending an indication or notification. If the client does not have an LTK indicating that the client has lost the bond, enabling encryption will fail.

10.3.1.2 Cross-transport Key Generation

After encryption is enabled, the correct security level has been achieved, and both devices support cross-transport key generation, the both devices may perform BR/EDR link key derivation.
Note: If the LTK has an encryption key size that is less than 16 octets (128 bits), the BR/EDR link key is derived before the LTK gets masked.

10.3.2 Initiating a Service Request

In this section the local device is the device initiating a service request to a remote device. In the L2CAP protocol the local device sends the connection request and the remote device sends the connection response. In GATT, the local device is the GATT client and the remote device is the GATT server.

When a local device initiates a service request to a remote device it shall behave according to the following rules:

- The local device’s security database specifies the security required to initiate a service request. If no encryption is required by the local device then the service request may proceed without encryption or pairing.
- If an LTK is not available but encryption is required, the pairing procedure shall be initiated with the local device’s required authentication settings. If the pairing procedure fails then the service request shall be aborted.

  Note: When encryption is not enabled, the error code “Insufficient Authentication” does not indicate to the local device that MITM protection is required.

  Note: If the local device is a Peripheral then it may send a Slave Initiated Security Request as defined in [Vol 3] Part H, Section 2.4.6.
- If pairing has occurred but the encryption key size is insufficient the pairing procedure shall be executed with the required encryption key size. If the pairing procedure fails then the service request shall be aborted.
- If an LTK is available and encryption is required (LE security mode 1) then encryption shall be enabled before the service request proceeds as defined in Section 10.6. Once encryption is enabled the service request shall

proceed. If encryption fails either the bond no longer exists on the remote device, or the wrong device has been connected. The local device must, after user interaction to confirm the remote device, re-bond, perform service discovery and re-configure the remote device. If the local device had previously determined that the remote device did not have the «Service Changed» characteristic then service discovery may be skipped.

- If an authenticated pairing is required but only an unauthenticated pairing has occurred and the link is currently encrypted, the pairing procedure should be executed with the required authentication settings. If the pairing procedure fails, or an authenticated pairing cannot be performed with the IO capabilities of the local device and remote device, then the service request shall be aborted.

  When a bond has been created between two devices, any reconnection should result in the local device enabling or requesting encryption with the remote device before initiating any service request.

  If a local device does not enable encryption before initiating a service request and relies on the error codes to determine the security requirements, the local device shall not request pairing with MITM protection in response to receiving an “Insufficient Authentication” error code from the remote device while the link is unencrypted. The local device shall only set the MITM protection required flag if the local device itself requires MITM protection.
- If encryption is not enabled at the time of the service request, the error code “Insufficient Authentication” is received, and the local device currently has an LTK, then the encryption procedure should be started (see Section 10.6). If this fails (likely indicating that the remote device has lost the bond and no longer has the LTK) or the local device does not have the correct LTK, then the pairing procedure should be started. IO capabilities are exchanged in pairing phase 1, (see [Vol 3] Part H, Section 2.1) and the security level shall be determined by the device’s IO capabilities and MITM requirements.
- If encryption is not enabled at the time of the service request, the error code “Insufficient Encryption” is received, and the local device currently has an LTK, then the encryption procedure shall be started (see Section 10.6). If starting encryption fails (likely indicating that the remote device has lost the bond and no longer has the LTK) or the local device does not have the correct LTK, then the pairing procedure should be started.
- If LE Secure Connections authenticated pairing is required but the remote device does not support LE Secure Connections, then the service request shall be aborted.

Figure 10.2 shows how a client issues a service request.

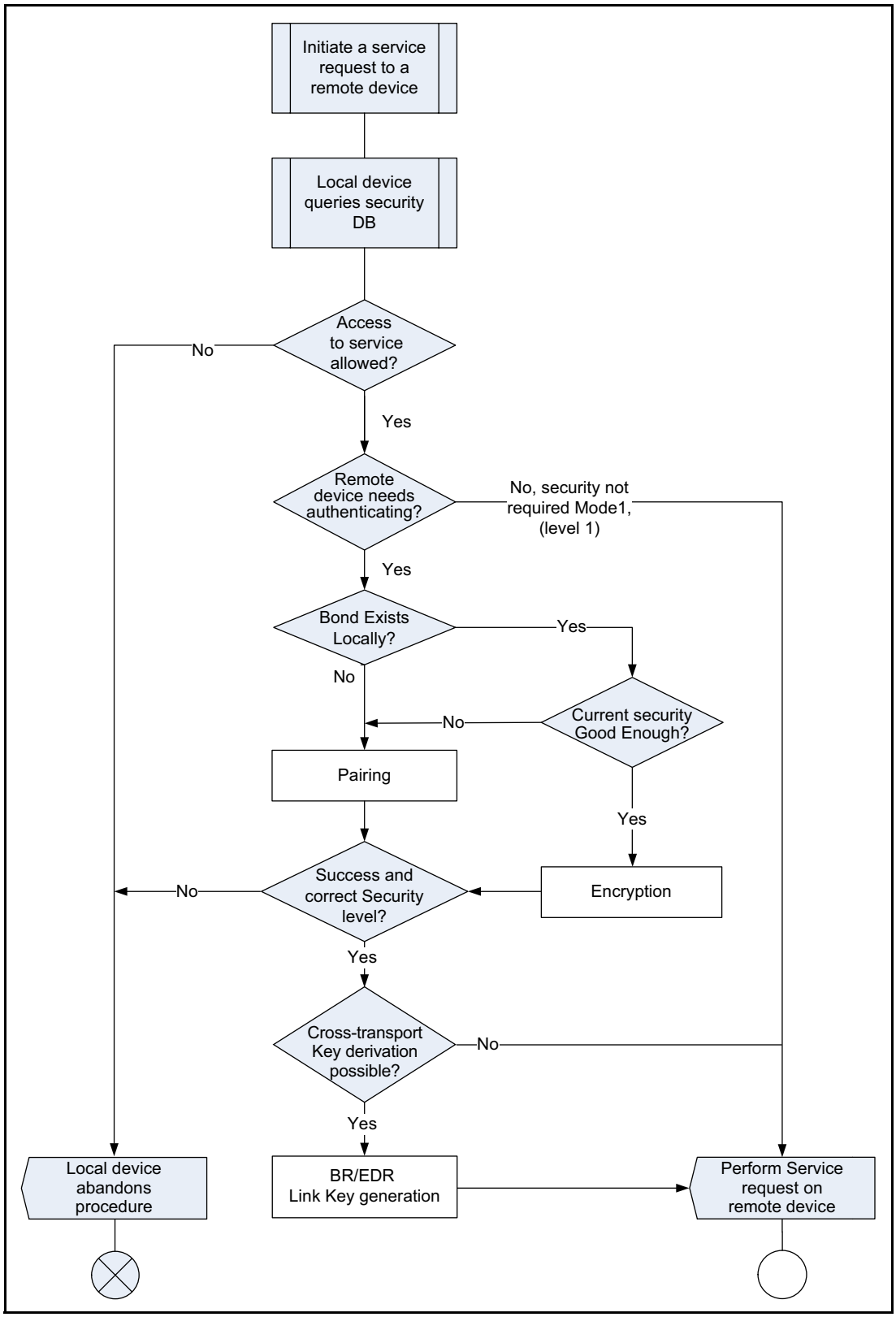

Figure 10.2: Flow chart for a local device issuing a service request to a remote device

10.3.2.1 Cross-transport Key Generation

After encryption is enabled, the correct security level has been achieved, and both devices support cross-transport key generation, the both devices may perform BR/EDR link key derivation.
Note: If the LTK has an encryption key size that is less than 16 octets (128 bits), the BR/EDR link key is derived before the LTK gets masked.

10.4 DATA SIGNING

The data signing is used for transferring authenticated data between two devices in an unencrypted connection. The data signing method is used by services that require fast connection set up and fast data transfer.

If a service request specifies LE security mode 2, the connection data signing procedure shall be used.

10.4.1 Connection Data Signing Procedure

A device shall generate a new Connection Signature Resolving Key CSRK for each set of peer device(s) to which it sends signed data in connections. CSRK is defined in [Vol 3] Part H, Section 2.4.2.2.

The data shall be formatted using the Signing Algorithm as defined in [Vol 3] Part H, Section 2.4.5 where m is the Data PDU to be signed, k is the CSRK and the SignCounter is the counter value. A Signature is composed of the counter value and the Message Authentication Code (MAC) generated by the Signing Algorithm. The counter value shall be incremented by one for each new Data PDU sent.

The format of signed data is shown in Figure 10.3.

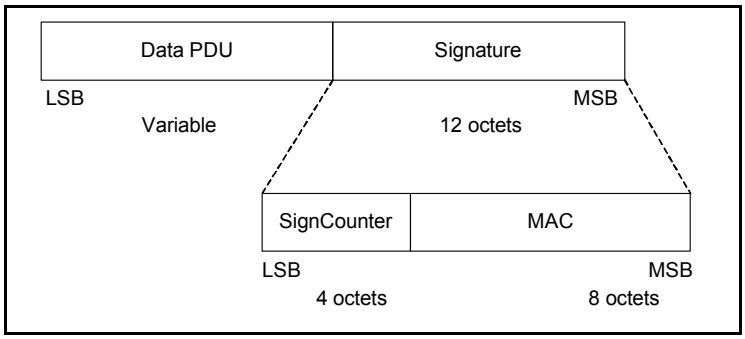

Figure 10.3: Generic format of signed data

10.4.2 Authenticate Signed Data Procedure

If encryption is not required and CSRK is available (LE security mode 2) then the data signing procedure shall be used when making a service request involving a write operation.

Note: The existence of the bond on the server can be determined by successfully enabling encryption with the server using the encryption procedure defined in Section 10.6. A higher layer profile may allow a client to not perform the authentication procedure. Alternatively, a higher layer protocol may signal the client that the signature check has failed due to a lost bond, and the client may then take action to notify the user or attempt to pair again to reestablish the bond.

A device receiving signed data shall authenticate it by performing the Signing Algorithm. The signed data shall be authenticated by performing the Signing Algorithm where m is the Data PDU to be authenticated, k is the stored CSRK and the SignCounter is the received counter value. If the MAC computed by the Signing Algorithm does not match the received MAC, the verification fails and the Host shall ignore the received Data PDU.

Note that since the server does not respond to a Signed Write Command, the higher layer application may or may not be notified of the ignored request. Hence, it is recommended that the server disconnect the link in case the client is a malicious device attempting to mount a security attack.

If the server has no stored CSRK upon receiving a signed write command, it shall ignore the received Data PDU. Note that since the server does not respond to a Signed Write Command, the higher layer application may or may not be notified of the ignored request. Although the disconnection may be an adequate indication to the user that the devices need to be paired, it is recommended that implementers consider providing a more informative indication to the user that the devices need to be paired to establish a CSRK.

If the server receives a request from a client for a write operation that requires a response (i.e. other than a Signed Write Command or Write Command), and encryption is not enabled, then the server shall respond with the error code “Insufficient Authentication”.

If the link is encrypted and the server receives a request from a client for which the server requires data signing but does not require encryption, then the server shall complete the request if it is otherwise valid as the encrypted state of the link is considered to satisfy the signing requirement.

As required by Section 10.2.2, for a given link, signed data is not used at the same time as encryption. Therefore, if the client wishes to test that the server is still bonded, and thus enables encryption, further data transfer must occur without signing, assuming the server does not disconnect the link as recommended above.

If a higher layer determines the bond no longer exists on the server, the client must, after user interaction to confirm the remote device, re-bond, perform service discovery and re-configure the server. If the client had previously determined that the server did not have the «Service Changed» characteristic then service discovery may be skipped.

The receiving device shall protect against a replay attack by comparing the received SignCounter with previously received SignCounter from the same peer device. If the SignCounter was previously used then the receiving device shall ignore the Data PDU.

10.5 AUTHORIZATION PROCEDURE

A service may require authorization before allowing access. Authorization is a confirmation by the user to continue with the procedure. Authentication does not necessarily provide authorization. Authorization may be granted by user confirmation after successful authentication.

10.6 ENCRYPTION PROCEDURE

A Central may encrypt a connection using the Encryption Session Setup as defined in [Vol 3] Part H, Section 2.4.4 to provide integrity and confidentiality.

A Peripheral may encrypt a connection using the Slave Initiated Security Request as defined in [Vol 3] Part H, Section 2.4.6 to provide integrity and confidentiality.

If the encryption procedure fails and either the Central or Peripheral used a Resolvable Private Address for the connection establishment, then the current Resolvable Private Address(es) shall be immediately discarded and new Resolvable Private Address(es) shall be generated.

10.7 PRIVACY FEATURE

The privacy feature provides a level of privacy which makes it more difficult for an attacker to track a device over a period of time. The requirements for a device to support the privacy feature are defined in Table 10.3.

Privacy Requirements	Ref.	Broadcaster	Observer	Peripheral	Central
Privacy feature	10.7	O	O	O	O
Non-resolvable private address generation procedure	10.8.2.1	C2	C4	O	O
Resolvable private address generation procedure	10.8.2.2	C3	C5	C1	C1
Resolvable private address resolution procedure	10.8.2.3	E	O	C1	C1
Bondable Mode	9.4.3	E	E	C1	C1
Bonding procedure	9.4.4	E	E	C1	C1

C1: Mandatory if privacy feature is supported, else optional

C2: Mandatory if privacy feature is supported and resolvable private address generation procedure is not supported, else optional

C3: Mandatory if privacy feature is supported and non-resolvable private address generation procedure is not supported, else optional

C4: Mandatory if privacy feature and active scanning are supported and resolvable private address generation procedure is not supported, else optional

C5: Mandatory if privacy feature and active scanning are supported and non-resolvable private address generation procedure is not supported, else optional

Table 10.3: Requirements related to privacy feature

Two modes of privacy exist:

- Device Privacy Mode: When a device is in device privacy mode, it is only concerned about its own privacy. It should accept advertising packets from peer devices that contain their identity addresses as well as their private address, even if the peer device has distributed its IRK. A device shall only use this mode when the Resolvable Private Address Only characteristic is not present in the GAP service of the peer device.
- Network Privacy Mode. When a device is in network privacy mode, it shall not accept advertising packets containing the identity address of peer devices that have distributed their IRK.

A device may use different modes for different peers.

If a device, i.e. Host and Controller, claims support for the privacy feature, the requirements in this section shall be met.

A device may support either Host-based privacy or both Host-based and Controller-based privacy. When a device supports Controller-based privacy, some of the privacy functionality is configured to be performed by the Controller by the Host.

If a device supports Controller-based privacy, the requirements in the following paragraphs shall be met.

- The Host may maintain a resolving list by adding and removing device identities. A device identity consists of the peer's identity address, and a local and peer's IRK pair. The local or peer's IRK shall be an all-zero key, if not applicable for the particular device identity.
- If a peer device provides an all-zero identity address during pairing, the Host shall choose a unique identifier to substitute the peer's device identity address. The Host shall ensure that all identities provided to the Controller are unique.
- When address resolution is enabled in the Controller, all references to peer devices that are included in the resolving list from Host to the Controller shall be done using the peer's device identity address. Likewise, all incoming events from the Controller to the Host will use the peer's device identity, if the peer's device address has been resolved.
- If the Host wants to be in device privacy mode, it shall so instruct the Controller for each peer in the resolving list.

10.7.1 Privacy Feature in a Peripheral

The privacy-enabled Peripheral shall use a resolvable private address as the advertiser's device address when in connectable mode.

A Peripheral shall use non-resolvable or resolvable private addresses when in non-connectable mode as defined in Section 9.3.2.

If a privacy-enabled Peripheral, that has a stored bond, receives a resolvable private address, the Host may resolve the resolvable private address by performing the 'resolvable private address resolution procedure' as defined in Section 10.8.2.3. If the resolution is successful, the Host may accept the connection. If the resolution procedure fails, then the Host shall disconnect with the error code "Authentication failure", or perform the pairing procedure, or perform the authentication procedure as defined in Section 10.3.

The device should not send the device name or unique data in the advertising data that can be used to recognize the device.

10.7.1.1 Privacy Feature in a Peripheral with Controller-based privacy

A privacy-enabled Peripheral shall use either the undirected connectable mode as defined in Section 9.3.4 or directed connectable mode as defined in Section

9.3.3. The directed connectable mode shall only be used if the peer device supports Address Resolution in the Controller.

The Host shall enable resolvable private address generation by enabling it in the Controller and populating the resolving list.

By default, network privacy mode is used when private addresses are resolved and generated by the Controller.

10.7.1.2 Privacy Feature in a Peripheral with Host-based privacy

A privacy-enabled Peripheral should use the undirected connectable mode as defined in Section 9.3.4, to create a connection.

The Host shall generate a resolvable private address using the 'resolvable private address generation procedure' as defined in Section 10.8.2.2 or non-resolvable private address procedure as defined in Section 10.8.2.1. The Host shall set a timer equal to T_{GAP}(private_addr_int). The Host shall generate a new resolvable private address or non-resolvable private address when the timer T_{GAP}(private_addr_int) expires.

Note: T_{GAP}(private_addr_int) timer may or may not be run if a Peripheral is not advertising.

10.7.2 Privacy Feature in a Central

The Central shall use a resolvable private address as the initiator's device address.

During active scanning, a privacy enabled Central shall use a non-resolvable or resolvable private address.

If, a privacy-enabled Central, that has a stored bond, receives a resolvable private address, the Host may resolve the resolvable private address by performing the "resolvable private address resolution procedure" as defined in Section 10.8.2.3.

10.7.2.1 Privacy Feature in a Central with Controller-based privacy

A privacy-enabled Central with Address Resolution enabled in the Controller can use any of the connection establishment procedures defined in Section 9.3.

By default, network privacy mode is used when private addresses are resolved and generated by the Controller.

10.7.2.2 Privacy Feature in a Central with Host-based privacy

A privacy-enabled Central should use the general connection establishment procedure defined in Section 9.3.6 to create a connection.

The Host shall generate a resolvable private address using the ‘resolvable private address generation procedure’ as defined in Section 10.8.2.2 or non-resolvable private address procedure as defined in Section 10.8.2.1. The Host shall set a timer equal to T_{GAP}(private_addr_int). The Host shall generate a new resolvable private address or non-resolvable private address when the timer T_{GAP}(private_addr_int) expires.

Note: T_{GAP}(private_addr_int) timer may or may not be run if a Central is not scanning or connected.

10.7.3 Privacy Feature in a Broadcaster

A privacy-enabled Broadcaster shall use the Broadcast mode defined in Section 9.1.1. The Broadcaster shall use either a resolvable private address or non-resolvable private address.

If Address Resolution is not supported or disabled in the Controller, the following applies to the Host: The Host shall generate a resolvable private address using the ‘resolvable private address generation procedure’ as defined in Section 10.8.2.2 or non-resolvable private address procedure as defined in Section 10.8.2.1. The Host shall set a timer to T_{GAP}(private_addr_int). The

Host shall generate a new resolvable private address or non-resolvable private address when the timer T_{GAP}(private_addr_int) expires.

Note: T_{GAP}(private_addr_int) timer may or may not be run if a Broadcaster is not advertising.

The device should not send the device name or unique data in the advertising data which can be used to recognize the device.

10.7.4 Privacy Feature in an Observer

A privacy-enabled Observer shall use the observation procedure defined in Section 9.1.2. During active scanning, a privacy enabled Observer shall use either a resolvable private address or non-resolvable private address.

If Address Resolution is not supported or disabled in the Controller, the following applies to the Host: The Host shall generate a resolvable private address using the 'resolvable private address generation procedure' as defined in Section 10.8.2.2 or non-resolvable private address procedure as defined in Section 10.8.2.1. The Host shall set a timer equal to T_{GAP}(private_addr_int). The Host shall generate a new resolvable private address or non-resolvable private address when the timer T_{GAP}(private_addr_int) expires.

Note: T_{GAP}(private_addr_int) timer may or may not be run if an Observer is not scanning.

10.8 RANDOM DEVICE ADDRESS

For the purposes of this profile, the random device address may be of either of the following two sub-types:

- Static address
- Private address.

The term random device address refers to both static and private address types.

The transmission of a random device address is optional. A device shall accept the reception of a random device address from a remote device.

The private address may be of either of the following two sub-types:

- Non-resolvable private address
- Resolvable private address

A bonded device shall process a resolvable private address as defined in Section 10.8.2.3 or by establishing a connection and then performing the authentication procedure as defined in Section 10.3. A device that generates a resolvable private address for its local address shall always request to

distribute its IRK value as defined in [Vol 3] Part H, Section 3.6.4 if both sides are bondable, unless keys have been pre-distributed.

After a device has distributed its IRK, it should use resolvable private addresses when establishing a connection with a peer device to which the IRK has been distributed.

10.8.1 Static Address

The Host can generate a static address using the procedure described in [Vol 6] Part B, Section 1.3.2.1.

10.8.2 Private address

The private address may be of either of the following two sub-types:

- Non-resolvable private address
- Resolvable private address

10.8.2.1 Non-Resolvable Private Address Generation Procedure

The Host can generate a non resolvable private address using the procedure described in [Vol 6] Part B, Section 1.3.2.2.

10.8.2.2 Resolvable Private Address Generation Procedure

The Host can generate a resolvable private address where the Host has its IRK using the procedure described in [Vol 6] Part B, Section 1.3.2.2.

10.8.2.3 Resolvable Private Address Resolution Procedure

The Host can resolve a resolvable private address where the Host has the peer device’s IRK or the local device's IRK, using the procedure described in [Vol 6] Part B, Section 1.3.2.3.

11 ADVERTISING AND SCAN RESPONSE DATA FORMAT

The format of Advertising data and Scan Response data is shown in Figure 11.1. The data consists of a significant part and a non-significant part. The significant part contains a sequence of AD structures. Each AD structure shall have a Length field of one octet, which contains the Length value, and a Data field of Length octets. The first octet of the Data field contains the AD type field. The content of the remaining Length - 1 octet in the Data field depends on the value of the AD type field and is called the AD data. The non-significant part extends the Advertising and Scan Response data when necessary and shall contain all-zero octets.

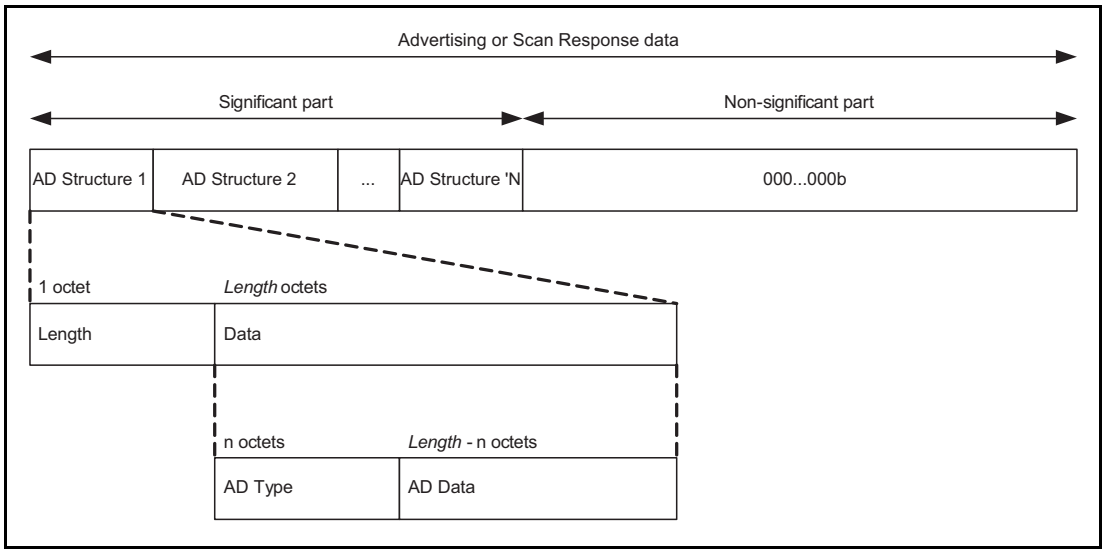

Figure 11.1: Advertising and Scan Response data format

If the Length field is set to zero, then the Data field has zero octets. This shall only occur to allow an early termination of the Advertising or Scan Response data.

Only the significant part of the Advertising or Scan Response data should be sent over the air.

The Advertising and Scan Response data is sent in advertising events. The Advertising Data is placed in the AdvData field of ADV_IND, ADV_NONCONN_IND, ADV_SCAN_IND, AUX_ADV_IND, AUX_CHAIN_IND, and AUX_SYNC_IND packets. The Scan Response data is sent in the ScanRspData field of SCAN_RSP packets or the AdvData field of the AUX_SCAN_RSP packet. If the complete Advertising or Scan Response data cannot fit in the AUX_ADV_IND or AUX_SCAN_RSP packets, AUX_CHAIN_IND packets are used to send the remaining fragments of the data.

The AD type data formats and meanings are defined in [Core Specification Supplement], Part A. The AD type identifier values are defined in the Assigned Numbers document.

12 GAP SERVICE AND CHARACTERISTICS FOR GATT SERVER

The GATT server shall contain the GAP service as defined in the GAP Service Requirements in Table 12.1. A device shall have only one instance of the GAP service in the GATT server. The GAP service is a GATT based service with the service UUID as «GAP Service» defined in the Bluetooth Assigned Numbers document.

	BR/EDR GAP Role	LE Broadcaster	LE Observer	LE Peripheral	LE Central
GAP Service	C1	E	E	M	M
C1: Mandatory for BR/EDR/LE type devices, else optional					

Table 12.1: GAP Service Requirements

The characteristics requirements for the GAP service in each of the GAP roles are shown in Table 12.2.

Characteristics	Ref.	BR/EDR GAP Role	LE Broadcaster	LE Observer	LE Peripheral	LE Central
Device Name	12.1	C1	E	E	M	M
Appearance	12.2	C1	E	E	M	M
Peripheral Preferred Connection Parameters	12.3	O	E	E	O	E
Central Address Resolution	12.4	O	E	E	C3	C2
Resolvable Private Address Only	12.5	O	E	E	C3	C3
C1: Mandatory for BR/EDR/LE type devices, else optional C2: Mandatory if Link Layer Privacy is supported, otherwise excluded C3: Optional if Link Layer Privacy is supported, otherwise excluded						

Table 12.2: Requirements related to GAP Service characteristics

A device that supports multiple GAP roles contains all the characteristics to meet the requirements for the supported roles. The device must continue to expose the characteristics when the device is operating in the role in which the characteristics are not valid.

12.1 DEVICE NAME CHARACTERISTIC

The Device Name characteristic shall contain the name of the device as an UTF-8 string as defined in Section 3.2.2. When the device is discoverable, the Device Name characteristic value shall be readable without authentication or authorization. When the device is not discoverable, the Device Name Characteristic should not be readable without authentication or authorization. The Device Name characteristic value may be writable. If writable, authentication and authorization may be defined by a higher layer specification or be implementation specific.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xMMMM	0x2A00 – UUID for «Device Name»	Device Name	Readable without authentication or authorization when discoverable. Optionally writable, authentication and authorization may be defined by a higher layer specification or be implementation specific.

Table 12.3: Device Name characteristic

The Device Name characteristic value shall be 0 to 248 octets in length.
A device shall have only one instance of the Device Name characteristic.

12.2 APPEARANCE CHARACTERISTIC

The Appearance characteristic defines the representation of the external appearance of the device. This enables the discovering device to represent the device to the user using an icon, or a string, or similar. The Appearance characteristic value shall be readable without authentication or authorization. The Appearance characteristic value may be writable. If writable, authentication and authorization may be defined by a higher layer specification or be implementation specific.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xMMMM	0x2A01 – UUID for «Appearance»	Appearance	Readable without authentication or authorization. Optionally writable, authentication and authorization may be defined by a higher layer specification or be implementation specific.

Table 12.4: Appearance characteristic

The Appearance characteristic value shall be the enumerated value as defined by Bluetooth Assigned Numbers document. The Appearance characteristic value shall be 2 octets in length. A device shall have only one instance of the Appearance characteristic.

12.3 PERIPHERAL PREFERRED CONNECTION PARAMETERS CHARACTERISTIC

The Peripheral Preferred Connection Parameters (PPCP) characteristic contains the preferred connection parameters of the Peripheral.

The Peripheral Preferred Connection Parameters characteristic value shall be readable. Authentication and authorization may be defined by a higher layer specification or be implementation specific.

The Peripheral Preferred Connection Parameters characteristic value shall not be writable.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xMMMM	0x2A04 – UUID for «Peripheral Preferred Connection Parameters»	Peripheral Preferred Connection Parameter	Readable, authentication and authorization may be defined by a higher layer specification or be implementation specific Not writable

Table 12.5: Peripheral Preferred Connection Parameters characteristic

The Peripheral Preferred Connection Parameters characteristic value shall be 8 octets in length. A device shall have only one instance of the Peripheral Preferred Connection Parameters characteristic.

The preferred connection parameters structured data is defined as follows:

Name	Size (Octet)	Description
Minimum connection interval	2	Defines minimum value for the connection interval in the following manner: $connInterval_{min}$ = Conn_Interval_Min * 1.25 ms Conn_Interval_Min range: 0x0006 to 0x0C80 Value of 0xFFFF indicates no specific minimum. Values outside the range (except 0xFFFF) are reserved for future use.

Table 12.6: Format of the preferred connection parameters structured data

Name	Size (Octet)	Description
Maximum connection interval	2	Defines maximum value for the connection interval in the following manner: $connInterval_{max}$ = Conn_Interval_Max * 1.25 ms Conn_Interval_Max range: 0x0006 to 0x0C80 Shall be equal to or greater than the Conn_Interval_Min. Value of 0xFFFF indicates no specific maximum. Values outside the range (except 0xFFFF) are reserved for future use.
Slave latency	2	Defines the slave latency for the connection in number of connection events. Slave latency range: 0x0000 to 0x01F3 Values outside the range are reserved for future use.
Connection Supervision timeout multiplier	2	Defines the connection supervisor timeout multiplier as a multiple of 10ms. Range: 0xFFFF indicates no specific value requested. Range: 0x000A to 0x0C80 Time = N * 10 ms Time Range: 100 ms to 32 seconds Values outside the range (except 0xFFFF) are reserved for future use.

Table 12.6: Format of the preferred connection parameters structured data

12.4 CENTRAL ADDRESS RESOLUTION

The Peripheral shall check if the peer device supports address resolution by reading the Central Address Resolution characteristic before using directed advertisement where the initiator address is set to a Resolvable Private Address (RPA).

The Central Address Resolution characteristic defines whether the device supports privacy with address resolution. See Table 12.7.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xMMMM	0x2AA6 - UUID of «Central Address Resolution»	Central Address Resolution Support	Readable without authentication or authorization. Not writable.

Table 12.7: Central Address Resolution Characteristic

The Central Address Resolution characteristic value shall be 1 octet in length:

0 = address resolution is not supported in this device

1 = address resolution is supported in this device

2 – 255 = Reserved for future use

A device shall have only one instance of the Central Address Resolution characteristic. If the Central Address Resolution characteristic is not present, then it shall be assumed that Central Address Resolution is not supported.

12.5 RESOLVABLE PRIVATE ADDRESS ONLY

The device shall check if the peer will only use Resolvable Private Addresses (RPAs) after bonding by reading the Resolvable Private Address Only characteristic.

The Resolvable Private Address Only characteristic defines whether the device will only use Resolvable Private Addresses (RPAs) as local addresses. See Table 12.8.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xMMMM	0x2AC9 - UUID of «Resolvable Private Address Only»	Resolvable Private Address Only	Readable without authentication or authorization. Not writable.

Table 12.8: Resolvable Private Address Only Characteristic

The Resolvable Private Address Only characteristic value shall be 1 octet in length:

0 = only Resolvable Private Addresses will be used as local addresses after bonding

1 – 255 = Reserved for future use

A device shall have only one instance of the Resolvable Private Address Only characteristic. If the Resolvable Private Address Only characteristic is not present, then it cannot be assumed that only Resolvable Private Addresses will be used over the air.

13 BR/EDR/LE OPERATION

This section describes the requirements for devices that support the BR/EDR/LE device type. The device may support any LE GAP roles allowed by the Controller over the LE physical channel.

Feature	Ref.	Broadcaster	Observer	Peripheral	Central
BR/EDR/LE modes and procedures	13.1 and 13.2	O	O	O	O

Table 13.1: Requirements for the modes of a BR/EDR/LE device type

A BR/EDR/LE device type that supports the Broadcaster role shall meet the requirements for the Broadcaster role as defined in Section 9.

A BR/EDR/LE device type that supports the Observer role shall meet the requirements for the Observer role as defined in Section 9.

A BR/EDR/LE device type that supports the Peripheral role shall meet the requirements for the Peripheral role as defined in Section 9.

A BR/EDR/LE device type that supports the Central role shall meet the requirements for the Central role as defined in Section 9.

13.1 MODES, PROCEDURES AND SECURITY ASPECTS

All modes, procedures and security aspects shall follow the requirements as specified for the physical transport over which they operate. Sections 4, 5, 6 and 7 specify the requirements for the modes, procedures and security aspects for operations performed over the BR/EDR physical transport. Sections 9 and 10 specify the requirements for the modes, procedures and security aspects performed over the LE physical transport. It is optional to support both physical transports simultaneously to the same remote device.

13.1.1 Discoverable Mode Requirements

A device shall expose the capabilities of both physical transports for both Limited and General Discoverable Mode using the advertisement Flag AD Type as follows:

a) The ‘BR/EDR Not Supported’ bit in the Flags AD type shall be set to 0 as defined in *[Core Specification Supplement]*, Part A, Section 1.3.

b) The 'Simultaneous LE and BR/EDR to Same Device Capable (Controller)' and ‘Simultaneous LE and BR/EDR to Same Device Capable (Host)’ bits in the Flags AD type shall be set to 0.

The ‘LE Supported (Controller)’ and ‘LE Supported (Host)’ bits in the LMP features shall be set as defined in [Vol 2] Part C, Section 3.2.

13.2 BONDING FOR BR/EDR/LE DEVICE TYPE

The requirements for a device supporting BR/EDR/LE device type are shown in Table 13.2.

Bonding Requirement	Ref.	Peripheral	Central
Bonding	6.5 / 9.4.4	O	O

Table 13.2: Requirements for the bonding of a BR/EDR/LE device type

If the remote device supports the BR/EDR physical transport, the bonding procedures for the BR/EDR physical transport as defined in Section 6.5 shall be used.

If the remote device supports the LE physical transport, the bonding procedures for the LE physical transport as defined in Section 9.4.4 shall be used.

13.3 RELATIONSHIP BETWEEN PHYSICAL TRANSPORTS

To determine if both the BR/EDR physical transport and the LE physical transport are established to the same peer device, the device shall use either the public address used on the LE advertising channel or the public address from the BD_ADDR field contained in the SMP Identity Address Information packet ([Vol 3] Part H, Section 3.6.5) if it has been received.

14 BR/EDR/LE SECURITY ASPECTS

The requirements for a device supporting BR/EDR/LE device type are shown in Table 14.1.

Security aspects	Ref.	Peripheral	Central
Security aspects	14	M	M

Table 14.1: Requirements for the security aspects of a BR/EDR/LE device type

If the remote device supports the BR/EDR physical transport the security procedures for the BR/EDR physical transport as defined in Section 5 shall be used.

If the remote device supports the LE physical transport the security procedures for the LE physical transport as defined in Section 10 shall be used.

If the LE transport in a BR/EDR/LE device supports Secure Connections, the security procedures in Section 14.1 may also be used.

14.1 CROSS-TRANSPORT KEY DERIVATION

If both the local and remote devices support Secure Connections over the BR/EDR and LE transports, devices may optionally generate keys of identical strength and the same MITM protection for both transports as part of a single pairing procedure.

If both the local and remote devices support Secure Connections over the LE transport but not over the BR/EDR transport, then the devices may optionally generate the BR/EDR keys of identical strength and the same MITM protection as the LE keys as part of the LE pairing procedure.

If Secure Connections pairing occurs first on the LE transport the procedures in [Vol 3] Part H, Section 2.3.5.7 may be used.

If Secure Connections pairing occurs first on the BR/EDR transport the procedures in [Vol 3] Part H, Section 2.3.5.7 may be used.

14.2 COLLISION HANDLING

If pairing has been initiated by the local device on the BR/EDR transport, and a pairing request is received from the same remote device on the LE transport, the LE pairing shall be rejected with SMP error code “BR/EDR pairing in progress” (0x0D) if both sides support LE Secure Connections.

If a BR/EDR/LE device supports LE Secure Connections, then it shall initiate pairing on only one transport at a time to the same remote device.

15 BLUETOOTH DEVICE REQUIREMENTS

15.1 BLUETOOTH DEVICE ADDRESS

All Bluetooth devices shall have a Bluetooth Device Address (BD_ADDR) that uniquely identifies the device to another Bluetooth device. The specific Bluetooth Device Address requirements depend on the type of Bluetooth device.

15.1.1 Bluetooth Device Address Types

15.1.1.1 Public Bluetooth Address

A Bluetooth public address used as the BD_ADDR for the BR/EDR physical channel is defined in [Vol 2] Part B, Section 1.2. A Bluetooth public address used as the BD_ADDR for the LE physical channel is defined in [Vol 6] Part B, Section 1.3.

15.1.1.2 Random Bluetooth Address

A random device address used as the BD_ADDR on the LE physical channel is defined in Section 10.8.

15.2 GATT PROFILE REQUIREMENTS

The requirements for supporting a GATT Client or GATT Server are specified in Table 15.1.

	BR/EDR GAP Role	LE Broadcaster	LE Observer	LE Peripheral	LE Central
GATT Client	O	E	E	O	O
GATT Server	C1	E	E	M	M
C1: Mandatory if the GATT profile is supported on the BR/EDR physical transport; otherwise excluded					

Table 15.1: Requirements based on GAP Roles Supported

15.3 SDP REQUIREMENTS

The requirements for supporting an SDP Client or SDP Server are specified in Table 15.2. There shall be no more than one active SDP server per device.

	BR/EDR and BR/EDR/LE Device Type	LE-Only Device Type
SDP Client	C1	E
SDP Server	C1 or C2	E
C1: Mandatory to support at least one; Optional to support both C2: Mandatory to support if GATT server is supported		

Table 15.2: Requirements based on GAP Roles Supported

15.4 SDP SERVICE RECORD REQUIREMENT

A BR/EDR or BR/EDR/LE device that supports a GATT server accessible over the BR/EDR physical transport shall publish the SDP record shown below in Table 15.3. The GAP Start Handle shall be set to the attribute handle of the «Generic Attribute Profile» service declaration. The GAP End Handle shall be set to the attribute handle of the last attribute within the «Generic Attribute Profile» service definition group.

Item	Definition	Type	Value	Status
Service Class ID List				M
Service Class #0		UUID	«Generic Attribute Profile»	M
ProtocolDescriptorList				M
Protocol #0		UUID	«L2CAP»	M
Parameter #0 for Protocol #0	PSM	Unit16	PSM = ATT	M
Protocol #1		UUID	«ATT»	M
Parameter #0 for Protocol #1	GAP Start Handle	Uint16		M
Parameter #1 for Protocol #1	GAP End Handle	Uint16		M
BrowseGroupList			PublicBrowseRoot	M

Table 15.3: SDP Record for the Generic Access Profile

If a BR/EDR or BR/EDR/LE device supports a GATT-based service on the BR/EDR transport, the service shall exist in the SDP server and the GATT server.

16 DEFINITIONS

In the following, terms written with capital letters refer to states.

Most definitions in this section are BR/EDR specific.

16.1 GENERAL DEFINITIONS

Mode . A set of directives that defines how a device will respond to certain events.

Idle . As seen from a remote device, a Bluetooth device is idle, or is in idle mode, when there is no link established between them.

Bond . A relation between two Bluetooth devices defined by creating, exchanging and storing a common link key. The bond is created through the bonding or LMP-pairing procedures.

16.2 CONNECTION-RELATED DEFINITIONS

Physical channel . A synchronized Bluetooth baseband-compliant RF hopping sequence.

Piconet . A set of Bluetooth devices sharing the same physical channel defined by the master parameters (clock and BD_ADDR).

Physical link . A Baseband-level connection[1] between two devices established using paging. A physical link comprises a sequence of transmission slots on a physical channel alternating between master and slave transmission slots.

ACL link . An asynchronous (packet-switched) connection[1] between two devices created on LMP level. Traffic on an ACL link uses ACL packets to be transmitted.

SCO link . A synchronous (circuit-switched) connection[1] for reserved bandwidth communications; e.g. voice between two devices, created on the LMP level by reserving slots periodically on a physical channel. Traffic on a SCO link uses SCO packets to be transmitted. SCO links can be established only after an ACL link has first been established.

Link . Shorthand for an ACL link.

PAGE . A baseband state where a device transmits page trains, and processes any eventual responses to the page trains.

1. The term ’connection’ used here is not identical to the definition below. It is used in the absence of a more concise term.

PAGE_SCAN . A baseband state where a device listens for page trains.

Page . The transmission by a device of page trains containing the Device Access Code of the device to which the physical link is requested.

Page scan . The listening by a device for page trains containing its own Device Access Code.

Channel . A logical connection on L2CAP level between two devices serving a single application or higher layer protocol.

Connection . A connection between two peer applications or higher layer protocols mapped onto a channel.

Connecting . A phase in the communication between devices when a connection between them is being established. (Connecting phase follows after the link establishment phase is completed.)

Connect (to service) . The establishment of a connection to a service. If not already done, this includes establishment of a physical link, link and channel as well.

16.3 DEVICE-RELATED DEFINITIONS

Discoverable device . A Bluetooth device in range that will respond to an inquiry (normally in addition to responding to page).

Silent device . A Bluetooth device appears as silent to a remote device if it does not respond to inquiries made by the remote device. A device may be silent due to being non-discoverable or due to baseband congestion while being discoverable.

Connectable device . A Bluetooth device in range that will respond to a page.

Trusted device . A paired device that is explicitly marked as trusted.

Paired device . A Bluetooth device with which a link key has been exchanged (either before connection establishment was requested or during connecting phase).

Pre-paired device . A Bluetooth device with which a link key was exchanged, and the link key is stored, before link establishment.

Un-paired device . A Bluetooth device for which there was no exchanged link key available before connection establishment was requested.

Known device . A Bluetooth device for which at least the BD_ADDR is stored.

Un-known device . A Bluetooth device for which no information (BD_ADDR, link key or other) is stored.

Authenticated device . A Bluetooth device whose identity has been verified during the lifetime of the current link, based on the authentication procedure.

16.4 PROCEDURE-RELATED DEFINITIONS

Paging. A procedure for establishing a physical link of ACL type on baseband level, consisting of a page action of the initiator and a page scan action of the responding device.

Link establishment . A procedure for establishing a link on LMP level. A link is established when both devices have agreed that LMP setup is completed.

Channel establishment . A procedure for establishing a channel on L2CAP level.

Connection establishment . A procedure for creating a connection mapped onto a channel.

Creation of a trusted relationship . A procedure where the remote device is marked as a trusted device. This includes storing a common link key for future authentication and pairing (if the link key is not available).

Creation of a secure connection. A procedure of establishing a connection, including authentication and encryption.

Device discovery . A procedure for retrieving the Bluetooth device address, clock, class-of-device field and used page scan mode from discoverable devices.

Name discovery . A procedure for retrieving the user-friendly name (the Bluetooth device name) of a connectable device.

Service discovery . Procedures for querying and browsing for services offered by or through another Bluetooth device.

16.5 SECURITY-RELATED DEFINITIONS

Authentication . A generic procedure based on LMP-authentication if a link key exists or on LMP-pairing if no link key exists.

LMP-authentication . An LMP level procedure for verifying the identity of a remote device. The procedure is based on a challenge-response mechanism using a random number, a secret key and the BD_ADDR of the non-initiating device. The secret key used can be a previously exchanged link key.

Authorization . A procedure where a user of a Bluetooth device grants a specific (remote) Bluetooth device access to a specific service. Authorization implies that the identity of the remote device can be verified through authentication.

Authorize . The act of granting a specific Bluetooth device access to a specific service. It may be based upon user confirmation, or given the existence of a trusted relationship.

LMP-pairing . A procedure that authenticates two devices, based on a PIN, and subsequently creates a common link key that can be used as a basis for a trusted relationship or a (single) secure connection. The procedure consists of the steps: creation of an initialization key (based on a random number and a PIN), creation and exchange of a common link key and LMP-authentication based on the common link key.

Bonding . A dedicated procedure for performing the first authentication, where a common link key is created and stored for future use.

Trusting . The marking of a paired device as trusted. Trust marking can be done by the user, or automatically by the device (e.g. when in bondable mode) after a successful pairing.

17 REFERENCES

[1] Baseband Specification

[2] Link Manager Protocol

[3] RFCOMM

[4] Telephony Control Specification

[5] Service Discovery Protocol

[6] Security Architecture (white paper)

[7] Bluetooth Assigned Numbers

APPENDIX A (NORMATIVE): TIMERS AND CONSTANTS

The following timers are required by this profile.

Timer name	Value	Description	Requirement or Recommendation
$T_{GAP}(100)$	10.24 s	Time span that a Bluetooth device performs device discovery.	Recommended value
$T_{GAP}(101)$	10.625 ms	A discoverable Bluetooth device enters INQUIRY_SCAN for at least TGAP(101) every TGAP(102).	Required value
$T_{GAP}(102)$	2.56 s	Maximum time between repeated INQUIRY_SCAN enterings.	Recommended value
$T_{GAP}(103)$	30.72 s	Minimum time span that a device is in discoverable mode.	Required value
$T_{GAP}(104)$	1 min.	Maximum time span that a device is in limited discoverable mode.	Recommended value
$T_{GAP}(105)$	100ms	Maximum time between INQUIRY_SCAN enterings	Recommended value
$T_{GAP}(106)$	100ms	Maximum time between PAGE_SCAN enterings	Recommended value
$T_{GAP}(107)$	1.28s	Maximum time between PAGE_SCAN enterings (R1 page scan)	Recommended value
$T_{GAP}(108)$	2.56s	Maximum time between PAGE_SCAN enterings (R2 page scan)	Recommended value

Table A.1: Defined GAP timers (Sheet 1 of 6)

Timer name	Value	Description	Requirement or Recommendation
T_{GAP}(adv_fast_interval1_coded)	90 ms to 180 ms	Minimum to maximum advertising interval in the following GAP Modes on the LE Coded PHY when user initiated: 1. Undirected Connectable Mode 2. Limited Discoverable Mode and sending connectable undirected advertising events 3. General Discoverable Mode and sending connectable undirected advertising events 4. Directed Connectable Mode and sending low duty cycle connectable directed advertising events	Recommended value
T_{GAP}(adv_fast_interval1)	30 ms to 60 ms	Minimum to maximum advertising interval in the following GAP Modes on the LE 1M PHY when user initiated: 1. Undirected Connectable Mode 2. Limited Discoverable Mode and sending connectable undirected advertising events 3. General Discoverable Mode and sending connectable undirected advertising events 4. Directed Connectable Mode and sending low duty cycle directed advertising events	Recommended value

Table A.1: Defined GAP timers (Sheet 2 of 6)

Timer name	Value	Description	Requirement or Recommendation
T_{GAP}(adv_fast_interval2_coded)	300 ms to 450 ms	Minimum to maximum advertising interval in the following GAP Modes on the LE Coded PHY when user initiated and sending non-connectable advertising events: 1. Non-Discoverable Mode 2. Non-Connectable Mode 3. Limited Discoverable Mode 4. General Discoverable Mode	Recommended value
T_{GAP}(adv_fast_interval2)	100 ms to 150 ms	Minimum to maximum advertising interval in the following GAP Modes on the LE 1M PHY when user initiated and sending non-connectable advertising events: 1. Non-Discoverable Mode 2. Non-Connectable Mode 3. Limited Discoverable Mode 4. General Discoverable Mode	Recommended value
T_{GAP}(adv_fast_period)	30 s	Minimum time to perform advertising when user initiated	Recommended value
T_{GAP}(adv_slow_interval_coded)	3 s to 3.6 s	Minimum to maximum advertisement interval in any discoverable or connectable mode when background advertising on the LE Coded PHY	Recommended value
T_{GAP}(adv_slow_interval)	1 s to 1.2 s	Minimum to maximum advertisement interval in any discoverable or connectable mode when background advertising on the LE 1M PHY	Recommended value

Table A.1: Defined GAP timers (Sheet 3 of 6)

Timer name	Value	Description	Requirement or Recommendation
T_{GAP}(conn_param_timeout)	30 s	Connection parameter update notification timer when performing the connection parameter update procedure	Recommended value
T_{GAP}(conn_pause_central)	1 s	Central idle timer	Recommended value
T_{GAP}(conn_pause_peripheral)	5 s	Minimum time upon connection establishment before the peripheral starts a connection update procedure	Recommended value
T_{GAP}(gen_disc_scan_min_coded)	30.72 s	Minimum time to perform scanning when performing the general discovery procedure on the LE Coded PHY	Recommended value
T_{GAP}(gen_disc_scan_min)	10.24 s	Minimum time to perform scanning when performing the general discovery procedure on the LE 1M PHY	Recommended value
T_{GAP}(initial_conn_interval_coded)	90 ms to 150 ms	Minimum to maximum connection interval upon any connection establishment on the LE Coded PHY	Recommended value
T_{GAP}(initial_conn_interval)	30 ms to 50 ms	Minimum to maximum connection interval upon any connection establishment on the LE 1M PHY	Recommended value
T_{GAP}(lim_adv_timeout)	180 s	Maximum time to remain advertising when in the limited discoverable mode	Required value
T_{GAP}(lim_disc_scan_int_coded)	33.75 ms	Scan interval used in the limited discovery procedure on the LE Coded PHY	Recommended value
T_{GAP}(lim_disc_scan_int)	11.25 ms	Scan interval used in the limited discovery procedure on the LE 1M PHY	Recommended value
T_{GAP}(lim_disc_scan_min_coded)	30.72 s	Minimum time to perform scanning when performing the limited discovery procedure on the LE Coded PHY	Recommended value

Table A.1: Defined GAP timers (Sheet 4 of 6)

Timer name	Value	Description	Requirement or Recommendation
T_{GAP}(lim_disc_scan_min)	10.24 s	Minimum time to perform scanning when performing the limited discovery procedure on the LE 1M PHY	Recommended value
T_{GAP}(private_addr_int)	15 mins	Minimum time interval between private address change	Recommended value
T_{GAP}(scan_fast_interval_coded)	90 ms to 180 ms	Scan interval in any discovery or connection establishment procedure when user initiated on the LE Coded PHY	Recommended value
T_{GAP}(scan_fast_interval)	30 ms to 60 ms	Scan interval in any discovery or connection establishment procedure when user initiated on the LE 1M PHY	Recommended value
T_{GAP}(scan_fast_period)	30.72 s	Minimum time to perform scanning when user initiated	Recommended value
T_{GAP}(scan_fast_window_coded)	90 ms	Scan window in any discovery or connection establishment procedure when user initiated on the LE Coded PHY	Recommended value
T_{GAP}(scan_fast_window)	30 ms	Scan window in any discovery or connection establishment procedure when user initiated on the LE 1M PHY	Recommended value
T_{GAP}(scan_slow_interval1_coded)	3.84 s	Scan interval in any discovery or connection establishment procedure when background scanning on the LE Coded PHY	Recommended value
T_{GAP}(scan_slow_interval1)	1.28 s	Scan interval in any discovery or connection establishment procedure when background scanning on the LE 1M PHY	Recommended value
T_{GAP}(scan_slow_interval2_coded)	7.68 s	Scan interval in any discovery or connection establishment procedure when background scanning on the LE Coded PHY	Recommended value

Table A.1: Defined GAP timers (Sheet 5 of 6)

Timer name	Value	Description	Requirement or Recommendation
T_{GAP}(scan_slow_interval2)	2.56 s	Scan interval in any discovery or connection establishment procedure when background scanning on the LE 1M PHY	Recommended value
T_{GAP}(scan_slow_window1_coded)	33.75 ms	Scan window in any discovery or connection establishment procedure when background scanning on the LE Coded PHY	Recommended value
T_{GAP}(scan_slow_window1)	11.25 ms	Scan window in any discovery or connection establishment procedure when background scanning on the LE 1M PHY	Recommended value
T_{GAP}(scan_slow_window2_coded)	67.5 ms	Scan window in any discovery or connection establishment procedure when background scanning on the LE Coded PHY	Recommended value
T_{GAP}(scan_slow_window2)	22.5 ms	Scan window in any discovery or connection establishment procedure when background scanning on the LE 1M PHY	Recommended value
T_{GAP}(Sync_Scan_Interval)	320 ms	Interval between the start of adjacent synchronization scan windows	Recommended value
T_{GAP}(Sync_Scan_Window)	91.25 ms	Duration of Synchronization scan window	Recommended value
T_{GAP}(Sync_Train_Duration)	30.72 s	Duration of synchronizability mode	Required value
T_{GAP}(Sync_Train_Interval)	80 ms	Interval between Synchronization Train events	Recommended value

Table A.1: Defined GAP timers (Sheet 6 of 6)

APPENDIX B (INFORMATIVE): INFORMATION FLOWS OF RELATED PROCEDURES

B.1 LMP – AUTHENTICATION

The specification of authentication on link level is found in [2].

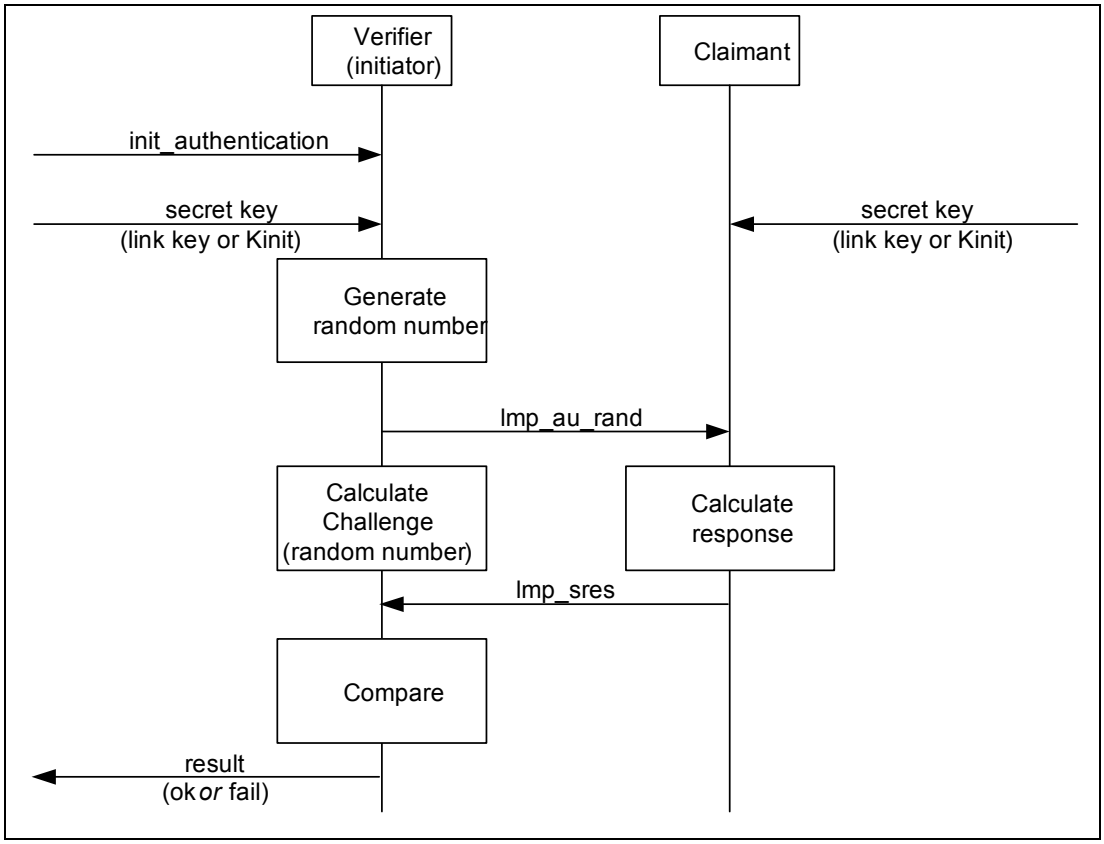

Figure B.1: LMP-authentication as defined by [2]

The secret key used here is an already exchanged link key.

B.2 LMP – PAIRING

The specification of pairing on link level is found in [2].

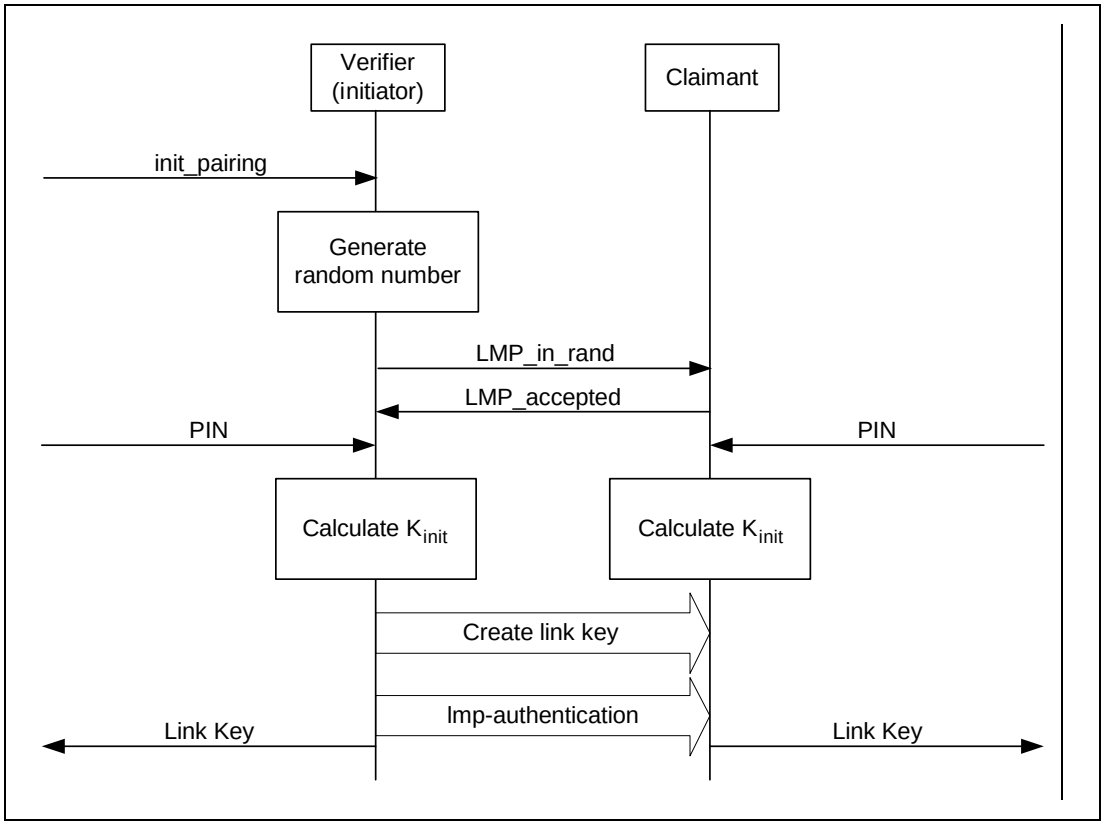

Figure B.2: LMP-pairing as defined in [2]

The PIN used here is PINBB.

The create link key procedure is described in [Vol 2] Part C, Section 4.2.2.4 and [Vol 2] Part H, Section 3.2. In case the link key is based on a combination key, a mutual authentication takes place and shall be performed irrespective of current security mode.

B.3 SERVICE DISCOVERY

The Service Discovery Protocol [5] specifies what PDUs are used over-the-air to inquire about services and service attributes. The procedures for discovery of supported services and capabilities using the Service Discovery Protocol are described in higher layer specifications. This is just an example.

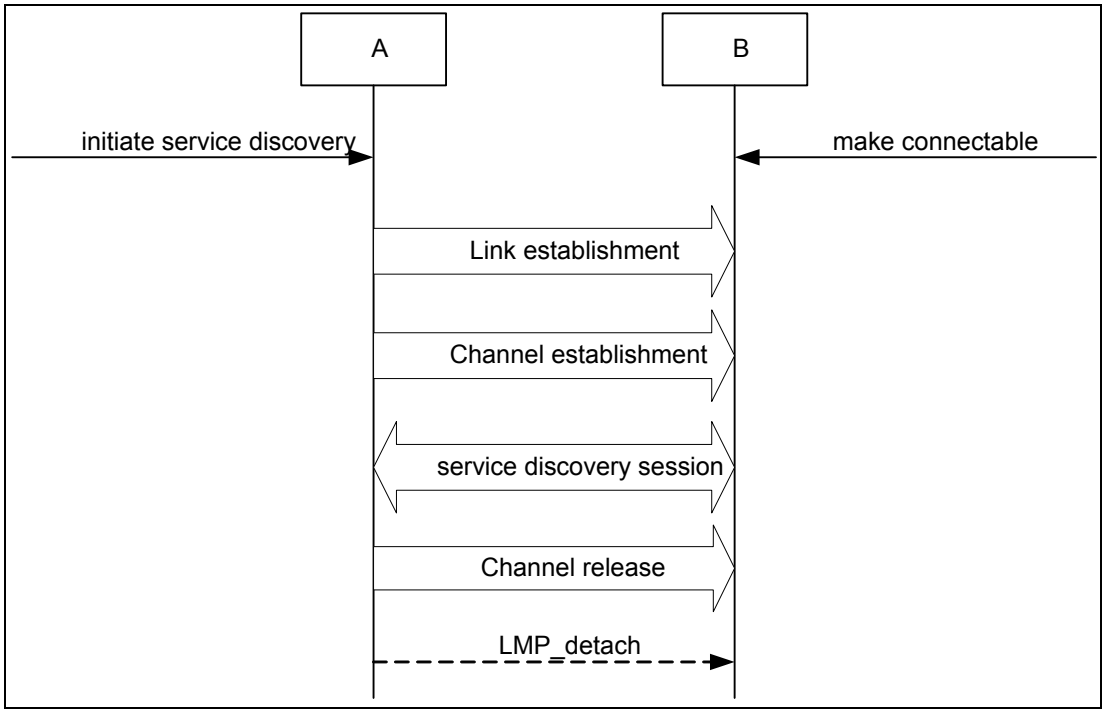

Figure B.3: Service discovery procedure

B.4 GENERATING A RESOLVABLE PRIVATE ADDRESS

Generating a resolvable private address is described in Section 10.8.2.2.

B.5 RESOLVING A RESOLVABLE PRIVATE ADDRESS

Resolving a resolvable private address is described in Section 10.8.2.3.

TEST SUPPORT

CONTENTS

1 TEST METHODOLOGY

This section describes the test modes for hardware and low-level functionality tests of Bluetooth devices.

The BR/EDR test mode supports testing of the Bluetooth transmitter and receiver including transmitter tests (packets with constant bit patterns) and loopback tests. It is intended mainly for certification/compliance testing of the radio and baseband layer, and may also be used for regulatory approval or in-production and after-sales testing.

For AMP, this section describes the AMP test mode for hardware and low-level functionality tests of Bluetooth AMP devices. The AMP test mode provides the ability to control an AMP device using HCI Commands for both MAC conformance testing and PHY transmitter and receiver tests utilising the BR/EDR connection. The AMP test mode is intended mainly for certification/compliance testing of the MAC and PHY and may also be used for regulatory approval or in production and after sales testing.

1.1 BR/EDR TEST SCENARIOS

A device in BR/EDR test mode shall not support normal operation. For security reasons the BR/EDR test mode is designed such that it offers no benefit to the user. Therefore, no data output or acceptance on a HW or SW interface shall be allowed.

1.1.1 Test Setup

The setup consists of a device under test (DUT) and a tester. Optionally, additional measurement equipment may be used.

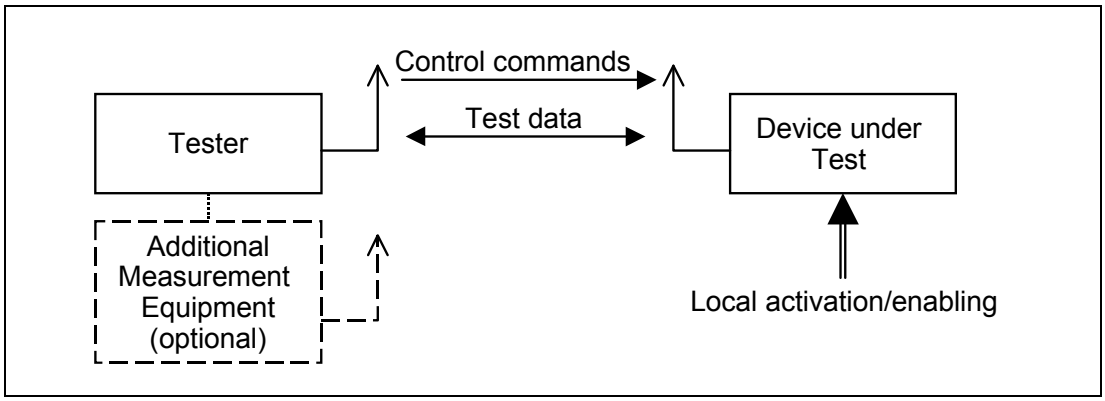

Figure 1.1: Setup for Test Mode

Tester and DUT form a piconet where the tester acts as master and has full control over the test procedure. The DUT acts as slave.

The control is done via the air interface using LMP commands (see [Vol 2] Part C, Section 4.7.3). Hardware interfaces to the DUT may exist, but are not subject to standardization.

The test mode is a special state of the Bluetooth model. For security and type approval reasons, a Bluetooth device in test mode shall not support normal operation. When the DUT leaves the test mode it enters the standby state. After power-off the Bluetooth device shall return to the standby state.

1.1.2 Transmitter Test

The Bluetooth device transmits a constant bit pattern. This pattern is transmitted periodically with packets aligned to the slave TX timing of the piconet formed by tester and DUT. The same test packet is repeated for each transmission.

The transmitter test is started when the master sends the first POLL packet. In non-hopping mode the agreed frequency is used for this POLL packet.

The tester (master) transmits control or POLL packets in the master-to-slave transmission slots. The DUT (slave) shall transmit packets in the following slave-to-master transmission slot. The tester's polling interval is fixed and defined by the LMP_test_control PDU. The device under test may transmit its burst according to the normal timing even if no packet from the tester was received. In this case, the ARQN bit is shall be set to NAK.

The burst length may exceed the length of a one slot packet. In this case the tester may take the next free master TX slot for polling. The timing is illustrated in Figure 1.2.

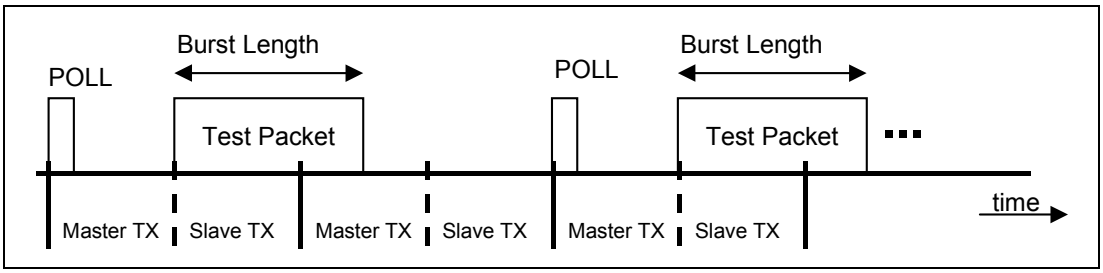

Figure 1.2: Timing for Transmitter Test

1.1.2.1 Packet Format

The test packet is a normal Bluetooth packet, see Figure 1.3. For the payload itself see below.

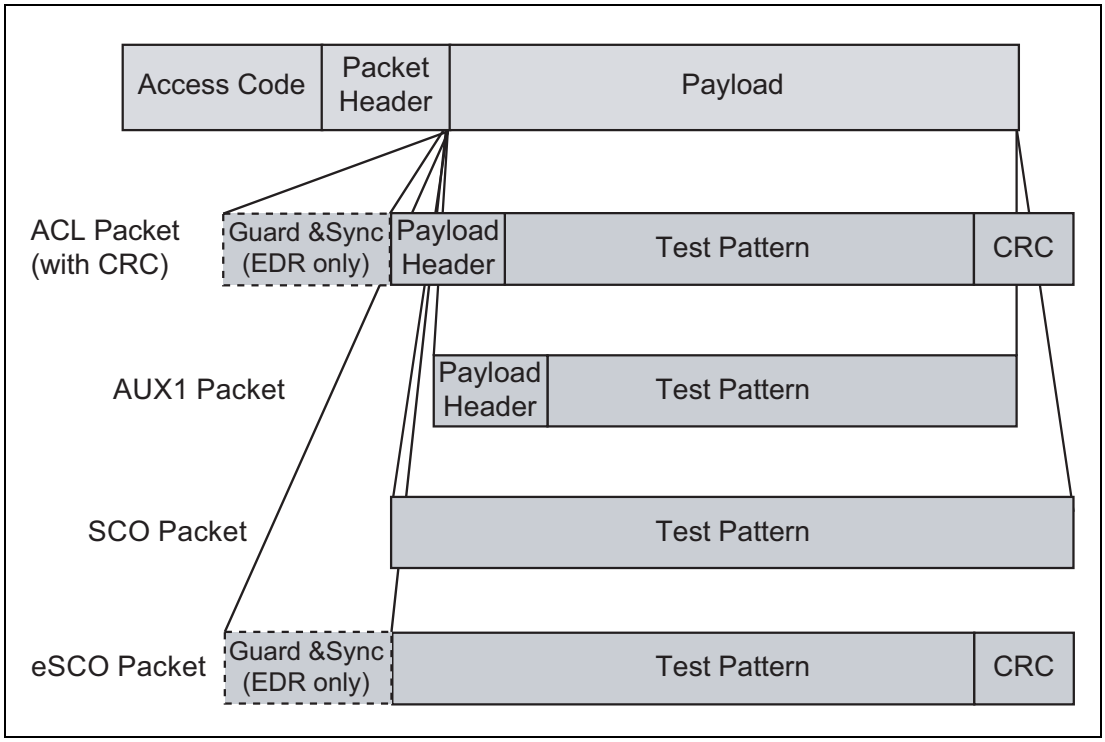

Figure 1.3: General Format of TX Packet

During configuration the tester defines:

- the packet type to be used
- payload length

For the payload length, the restrictions from the baseband specification shall apply (see Section Part B:). In case of ACL, SCO and eSCO packets the payload structure defined in the baseband specification is preserved as well, see Figure 1.3.

For the transmitter test mode, only packets without FEC should be used; i.e. HV3, EV3, EV5, DH1, DH3, DH5, 2-EV3, 2-EV5, 3-EV3, 3-EV5, 2-DH1, 2-DH3, 2-DH5, 3-DH1, 3-DH3, 3-DH5 and AUX1 packets.

In transmitter test mode, the packets exchanged between the tester and the DUT shall not be scrambled with the whitening sequence. Whitening shall be turned off when the DUT has accepted to enter the transmitter test mode, and shall be turned on when the DUT has accepted to exit the transmitter test mode, see Figure 1.4. Implementations shall ensure that retransmissions of the LMP_accepted messages use the same whitening status as used in the original LMP_accepted.

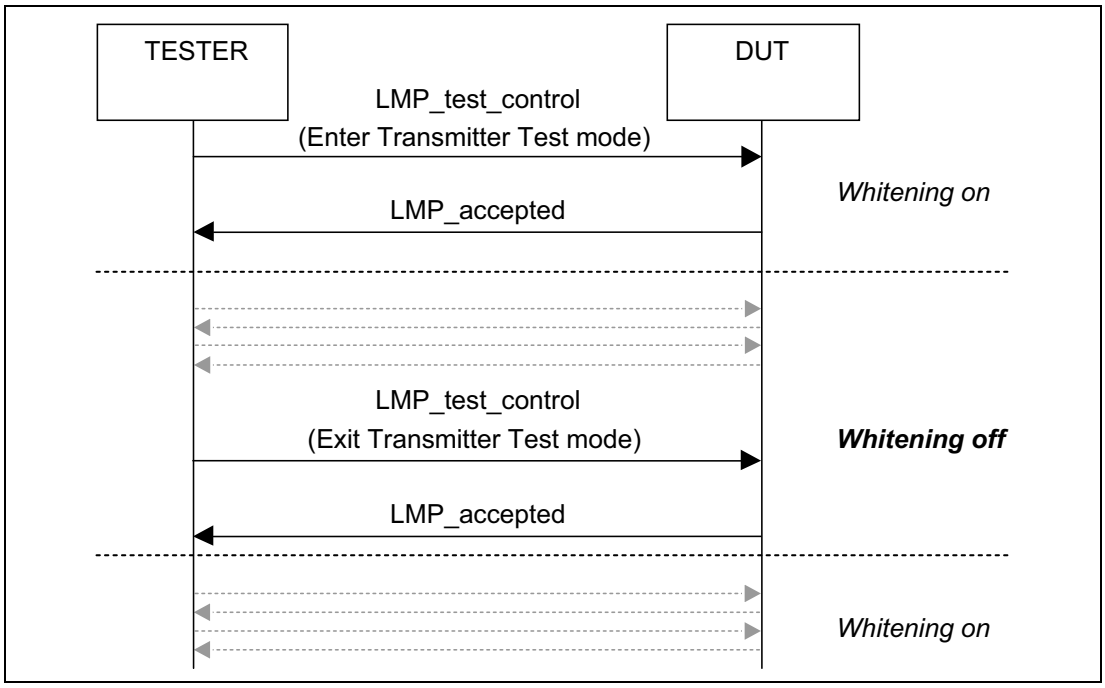

Figure 1.4: Use of whitening in Transmitter mode

1.1.2.2 Pseudorandom Sequence

The same pseudorandom sequence of bits shall be used for each transmission (i.e. the packet is repeated). A PRBS9 sequence is used, see [2] and [3].

The properties of this sequence are as follows (see [3]). The sequence may be generated in a nine-stage shift register whose 5th and 9th stage outputs are added in a modulo-two addition stage (see Figure 1.5), and the result is fed back to the input of the first stage. The sequence begins with the first ONE of 9 consecutive ONEs; i.e. the shift register is initialized with nine ones.

- Number of shift register stages: 9
- Length of pseudo-random sequence: 2^9-1 = 511 bits
- Longest sequence of zeros: 8 (non-inverted signal)

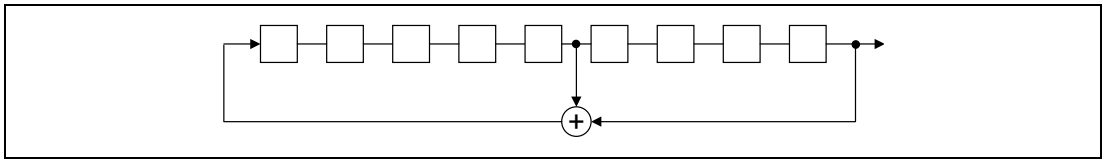

Figure 1.5: Linear Feedback Shift Register for Generation of the PRBS sequence

1.1.2.3 Control of Transmit Parameters

The following parameters can be set to configure the transmitter test:

1. Bit pattern:
   - Constant zero
   - Constant one
   - Alternating 1010...[1]
   - Alternating 1111 0000 1111 0000...[1]
   - Pseudorandom bit pattern
   - Transmission off
2. Frequency selection:
   - Single frequency
   - Normal hopping
3. TX frequency
   - k → f := (2402 + k) MHz
4. Default poll period in TDD frames (n * 1.25 ms)
5. Packet Type
6. Length of Test Sequence (user data of packet definition in Section Part B:)

1.1.2.4 Power Control

When the legacy power control mechanism is tested the DUT shall start transmitting at the maximum power and shall reduce/increase its power by one step on every LMP_incr_power_req or LMP_decr_power_req PDU received. When the enhanced power control mechanism is tested a DUT shall start transmitting at the maximum power and shall reduce/increase its power by one step or go to the maximum power level when a LMP_power_control_req PDU is received.

1.1.2.5 Switch Between Different Frequency Settings

A change in the frequency selection becomes effective when the LMP procedure is completed:

When the tester receives the LMP_accepted it shall then transmit POLL packets containing the ACK for at least 8 slots (4 transmissions). When these transmissions have been completed the tester shall change to the new frequency hop and whitening settings.

After sending LMP_accepted the DUT shall wait for the LC level ACK for the LMP_accepted. When this is received it shall change to the new frequency hop and whitening settings.

1. It is recommended that the sequence starts with a one; but, as this is irrelevant for measurements, it is also allowed to start with a zero.

There will be an implementation defined delay after sending the LMP_accepted before the TX or loopback test starts. Testers shall be able to cope with this.

Note: Loss of the LMP_accepted PDU will eventually lead to a loss of frequency synchronization that cannot be recovered. Similar problems occur in normal operation, when the hopping pattern changes.

1.1.2.6 Adaptive Frequency Hopping

Adaptive Frequency Hopping (AFH) shall only be used when the Hopping Mode is set to 79 channels (e.g. Hopping Mode = 1) in the LMP_test_control PDU. If AFH is used, the normal LMP commands and procedures shall be used. When AFH is enabled prior to entering test mode it shall continue to be used with the same parameters if Hopping Mode = 1 until the AFH parameters are changed by the LMP_set_AFH PDU.

The channel classification reporting state shall be retained upon entering or exiting Test Mode. The DUT shall change the channel classification reporting state in Test Mode based on control messages from the tester (LMP_channel_classification_req) and from the Host (HCI Write_AFH_Channel_Classification_Mode).

1.1.3 LoopBack Test

In loopback, the device under test receives normal baseband packets containing payload *Accepted* from the tester. The received packets shall be decoded in the DUT, and the payload shall be sent back using the same packet type. The return packet shall be sent back in either the slave-to-master transmission slot directly following the transmission of the tester, or it is delayed and sent back in the slave-to-master transmission slot after the next transmission of the tester (see Figure 1.7 to Figure 1.9).

There is no signaling to determine or control the mode. The device behavior shall be fixed or adjusted by other means, and shall not change randomly.

The tester can select, whether whitening is on or off. This setting holds for both uplink and downlink. For switching the whitening status, the same rules as in Section 1.1.2 (Figure 1.4) shall apply.

The following rules apply (for illustration see Figure 1.6):

- If the synch word was not detected, the DUT shall not reply.
- If the header error check (HEC) fails, the DUT shall either reply with a NULL packet with the ARQN bit set to NAK or send nothing.
- If the packet contains an LMP message relating to the control of the test mode this command shall be executed and the packet shall not be returned, though ACK or NAK shall be returned as per the usual procedure. Other LMP commands are ignored and no packet is returned.

- The payload FEC is decoded and the payload shall be encoded again for transmission. This allows testing of the FEC handling. If the pure bit error rate shall be determined the tester chooses a packet type without FEC.
- The CRC shall be evaluated. In the case of a failure, ARQN=NAK shall be returned. The payload shall be returned as received.
  A new CRC for the return packet shall be calculated for the returned payload regardless of whether the CRC was valid or not.
- If the CRC fails for a packet with a CRC and a payload header, the number of bytes as indicated in the (possibly erroneous) payload header shall be looped back.

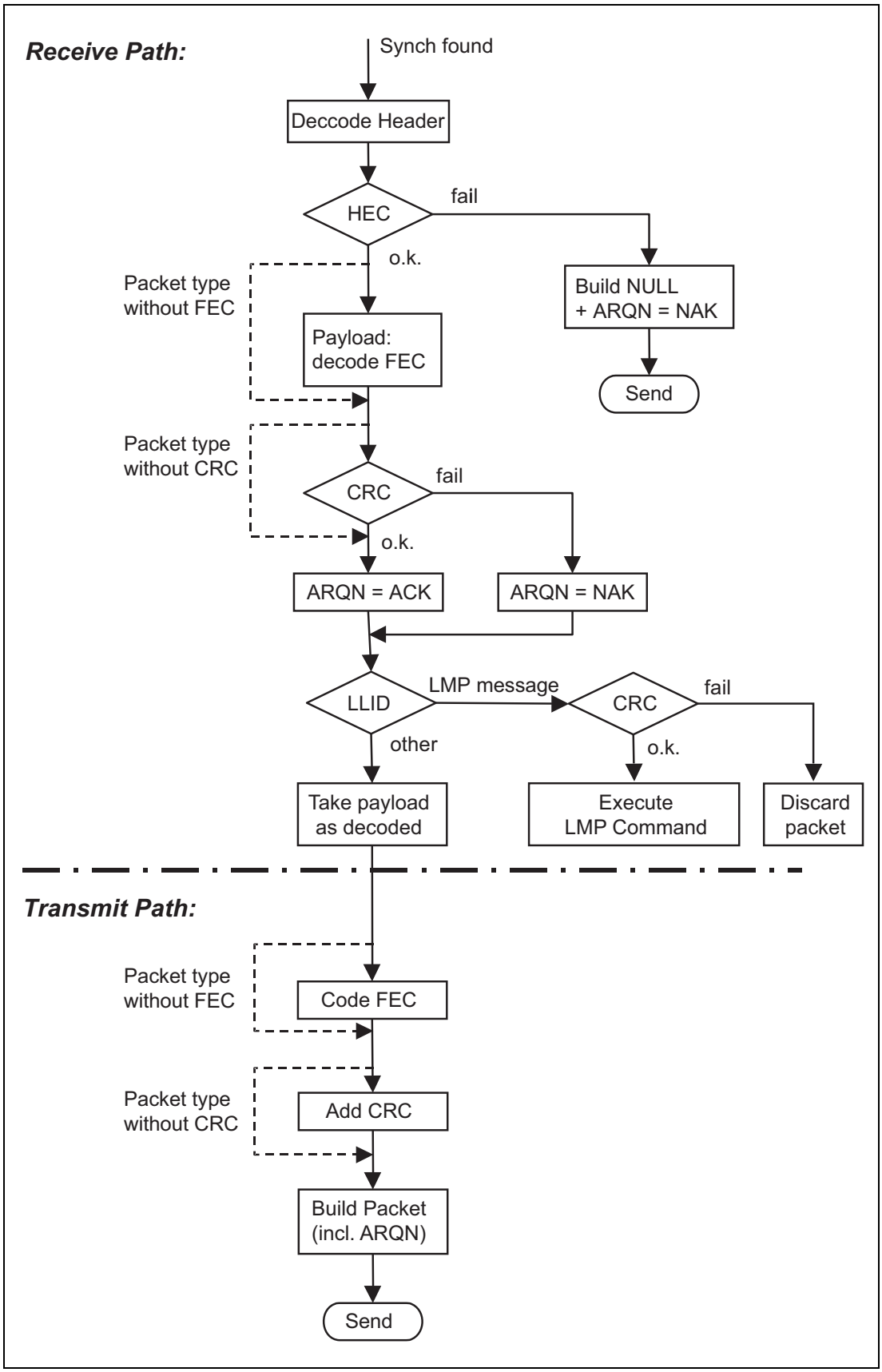

Figure 1.6: DUT Packet Handling in Loop Back Test

The timing for normal and delayed loopback is illustrated in Figure 1.7 to Figure 1.9:

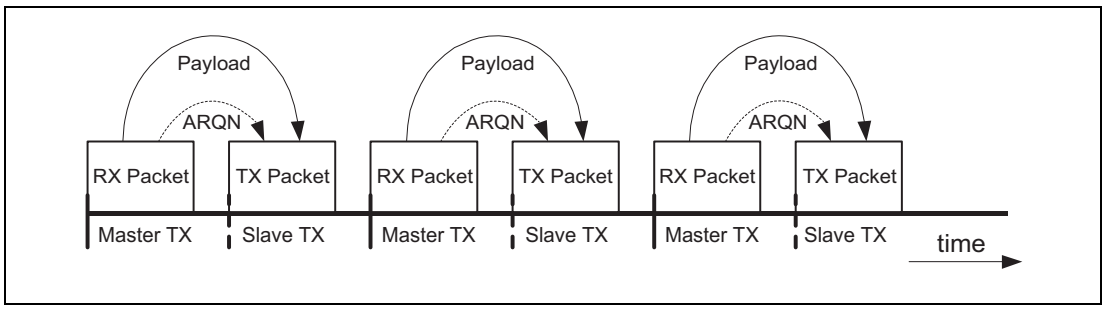

Figure 1.7: Payload & ARQN handling in normal loopback.

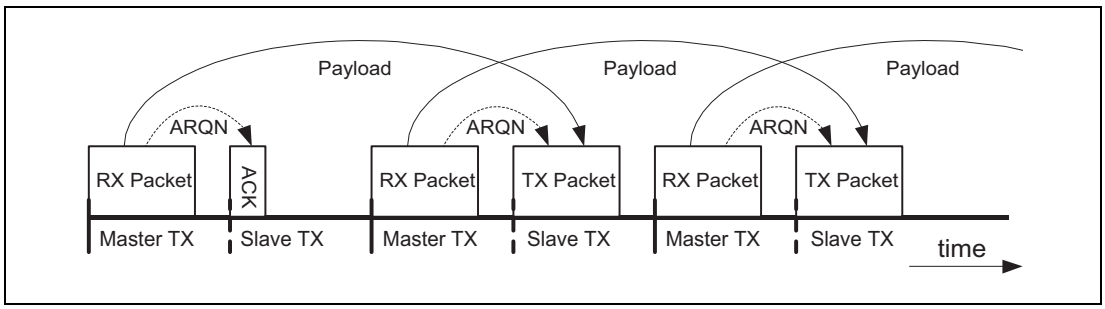

Figure 1.8: Payload & ARQN handling in delayed loopback - start.

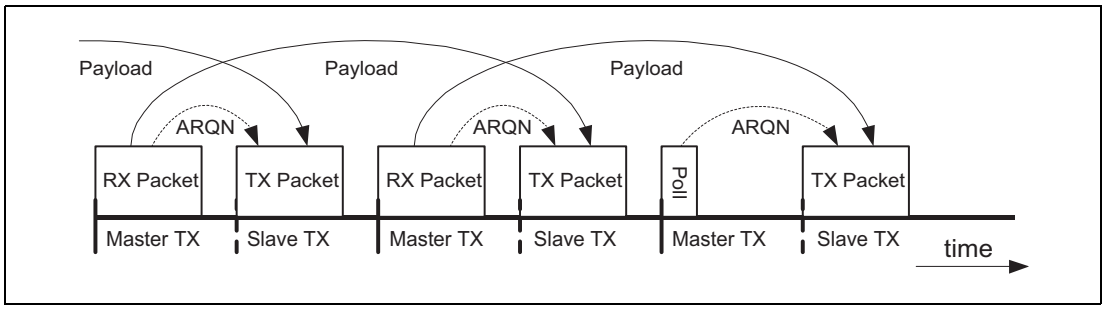

Figure 1.9: Payload & ARQN handling in delayed loopback - end.

The whitening is performed in the same way as it is used in normal active mode.

The following parameters can be set to configure the loop back test:

1. Packet Class[1]
   ACL Packets
   SCO Packets
   eSCO Packets
   ACL Packets without whitening

1. This is included because the packet type numbering is ambiguous.

SCO Packets without whitening
eSCO Packets without whitening

2. Frequency Selection
   Single frequency (independent for RX and TX)
   Normal hopping
3. Power level: (To be used according radio specification requirements)
   power control or fixed TX power

The switch of the frequency setting is done exactly as for the transmitter test (see Section 1.1.2.5).

1.1.4 Pause Test

Pause test is used by testers to put the device under test into Pause Test mode from either the loopback or transmitter test modes.

When an LMP_test_control PDU that specifies Pause Test is received the DUT shall stop the current test and enter Pause Test mode. In the case of a transmitter test this means that no more packets shall be transmitted. While in Pause Test mode the DUT shall respond normally to POLL packets (i.e. responds with a NULL packet). The DUT shall also respond normally to all the LMP packets that are allowed in test mode.

When the test scenario is set to Pause Test all the other fields in the LMP_test_control PDU shall be ignored. There shall be no change in hopping scheme or whitening as a result of a request to pause test.

1.2 AMP TEST SCENARIOS

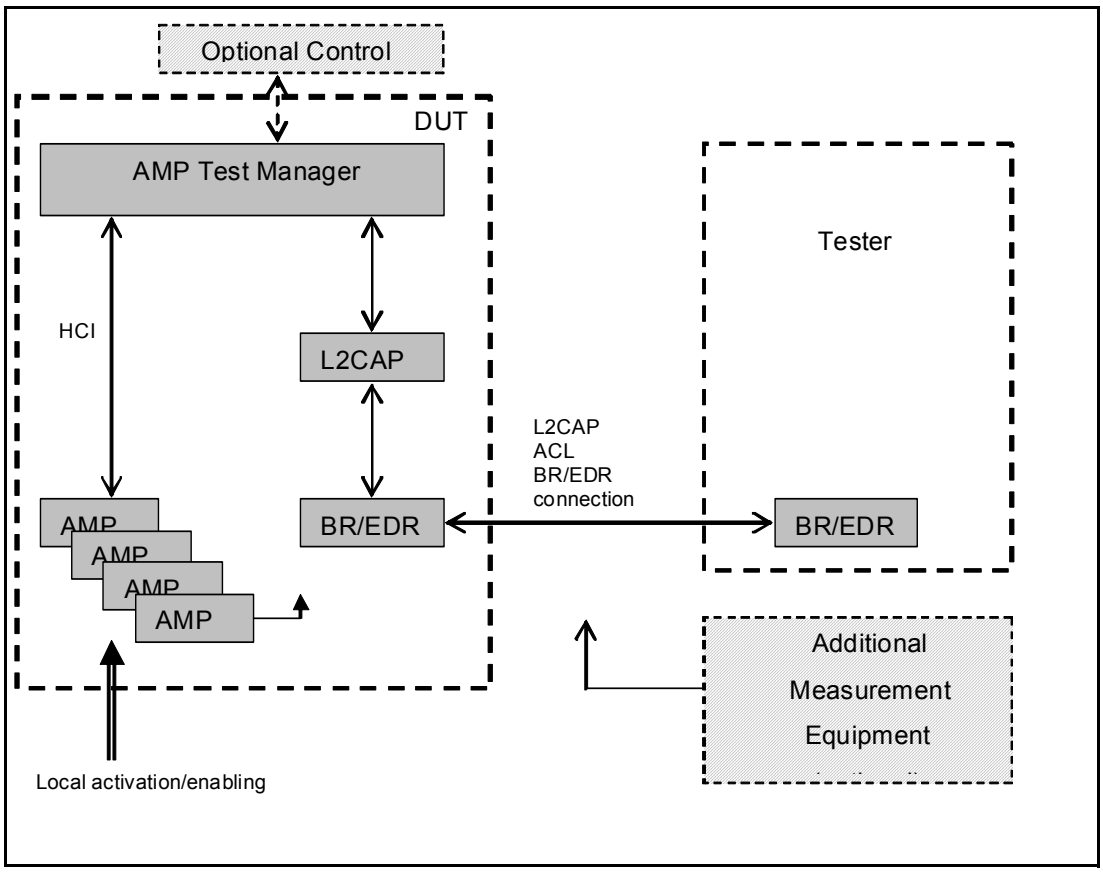

Figure 1.10: Test Architecture

1.2.1 Methodology Overview

To perform PHY tests on an AMP, the DUT shall first have AMP Test Mode enabled locally as required for a BR/EDR Controller using the HCI Enable_Device_Under_Test_Mode command. When this command is received by the AMP Controller it shall enable the AMP to accept HCI Test Commands and when received by the BR/EDR Controller it shall enable the AMP Test Manager to pass HCI commands and events between the tester and the AMP device utilizing the BR/EDR connection. A DUT AMP shall reject all AMP related HCI Test Commands, except HCI_Enable_Device_Under_Test_Mode, until the HCI_Enable_Device_Under_Test_Mode command has been issued by the local Host. Although AMP Test Mode is enabled the AMP shall not enter AMP Test Mode until the HCI_AMP_Test_Command is received.

Note: Enabling test mode with HCI_Enable_Device_Under_Test_Mode command allows the AMP to enter test mode when an HCI_AMP_Test_Command is received.

The local control of an AMP in AMP Test Mode shall be by the AMP Test Manager as shown in Figure 1.10. The AMP Test Manager will receive AMP Test Manager commands and HCI test commands via ACL data packets as

shown in Figure 1.10, using an L2CAP connectionless fixed test channel (channel 0x003F) from a Bluetooth test device. This does not exclude driving the AMP Test Manager directly from an implementation vendor specific interface as shown from the "Optional Control" in Figure 1.10.

The AMP Test Manager commands allow the tester to discover the number and type of AMPs supported and to read their PHY capability support via the AMP Test Manager.

The tester can use HCI commands and HCI Test Commands to control all of the AMPs to perform qualification, IOP testing as well as entering AMP Test Mode to perform AMP PHY tests. The HCI events and responses shall be routed back to the tester via the fixed test channel (0x003F).

If an HCI command is sent to an invalid Controller ID (a Controller not reported in the Discovery Response) the AMP Command Rejected Event shall be returned with an Invalid Controller Id as the reason.

An AMP shall be taken out of AMP Test Mode by the HCI_Reset command. This will reset only the AMP receiving the HCI_Reset.

The AMP Test Manager shall not be enabled to support HCI commands over the fixed test channel (0x003F) unless AMP Test Mode has been enabled locally with the HCI_Enable_Device_Under_Test_Mode command.

The "Optional Control" interface shown in Figure 1.10 is a vendor specific interface that allows local control of the AMP Test Manager when a BR/EDR link is not available.

1.2.1.1 Initiation Example Description

The AMP Test Manager is enabled to receive AMP test commands and HCI commands over the fixed test channel once it has been locally enabled. Using the fixed test channel, the tester shall use the AMP test commands and events to identify the number and type of AMPs available.

When the AMP Test Manager has been enabled and the AMPs identified the Tester shall use the AMP Test Manager to

- Transfer HCI commands and Events to and from the AMPs for qualification and IOP testing.
- Put the AMPs into test mode using HCI AMP test commands and events for AMP PHY testing.

1.2.2 Control and Configuration

Control and configuration of AMP tests shall be performed using two groups of commands/events over the ACL BR/EDR connection on the fixed test channel. The two groups are the AMP Test Manager commands/events which are to the AMP Test Manager and the HCI AMP test commands/events which are routed via the AMP Test Manager between the AMP indicated as part of the message structure and the tester.

AMP Test Manager commands and events	AMP Command Rejected Event
	AMP Discover Request Command
	AMP Discover Response Event
	AMP Read PHY Capability Bit Map Request
	AMP Read PHY Capability Bit Map Response Event
HCI AMP test commands and events	Read Loopback Mode Command
	Write Loopback Mode Command
	Enable AMP Receiver Reports Command
	AMP Test End Command
	AMP Test Command
	AMP Start Test Event
	AMP Test End Event
	AMP Receiver Report Event

1.2.3 AMP Test Manager

The AMP Test Manager provides the interface to the AMPs available so that qualification, IOP and PHY testing can be performed using the BR/EDR connection. The AMP Test Manager provides the following services:

1. Identification of the number and type of AMPs available
2. Enumeration of the available AMPs so that they can be communicated to individually
3. Routing of the HCI commands and events between the AMPs and the tester over the ACL BR/EDR connection on the fixed test channel, or the vendor specific interface (that is, a local interface to the AMP Test Manager other than the BR/EDR radio).

1.2.4 Test Commands/Events Format

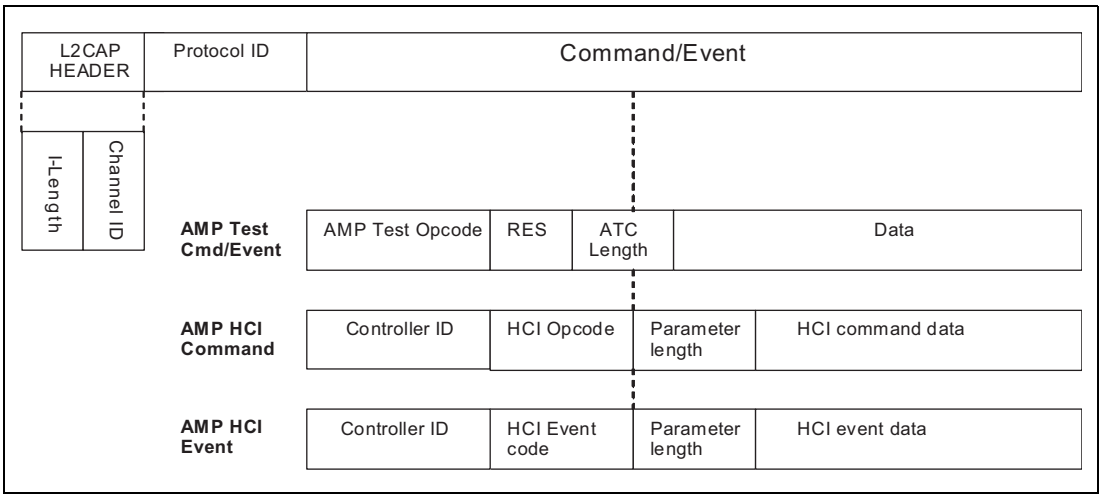

Figure 1.11: L2CAP test command/event formats

The fields shown are:

- *L2CAP header (4 octets)*

  This is the Basic L2CAP header with the Channel ID always set to test channel (0x003F). (See section [Vol 3] Part A, Section 3.1)

  Length (2 octets)

  Length of the Information payload which includes the Protocol ID and the Command/Event

  Channel ID (2 octets)

  Fixed value of (0x003F)

- *Protocol ID (1 octet)*

  This identifies the protocol in the command/event data. The IDs used are an extension of the UART transport packet types.

Protocol ID	Command/event type
0x01	HCI Command
0x02	Reserved for future use
0x03	Reserved for future use
0x04	HCI Event
0x05	AMP Test Command
0x06	AMP Test Event
Other	Reserved for future use

Table 1.1: L2CAP valid test protocol IDs

- *Controller ID (1 octet)*

  Each Controller in a device is assigned a one-octet unique identifier by the local AMP Test Manager. This field determines the destination of the HCI Command or the source of the HCI Event. The Controller ID values shall be in the range of 1 to 255. Controller ID 0 has been reserved for the primary BR/EDR Controller.

  Note: "Controller" is a generic term which covers both the primary BR/EDR Controller and any AMPs

- *ATO (AMP Test Opcode) (1 octet)*

  This is the AMP Test Manager commands or event code as described in Section 1.2.5.

- *RFU (1 octet)*

- *AMP Test Command (ATC) Length (2 octets)*

  This is the number of octets in the data portion of this message

- *AMP HCI Commands and Events*

  The format of these packets follow the standard HCI format described in [Vol 2] Part E, after the Controller ID.

Examples

	Protocol ID	**Command/Event**			
AMP Test command	0x05	AMP Test Opcode	0x00	Length	AMP Test Com-mand
AMP Test Event	0x06	AMP Test Opcode	0x00	Length	AMP Test Event
AMP HCI Command	0x01	Control-ler ID	HCI Command		
AMP HCI Event	0x04	Control-ler ID	HCI Event		

1.2.5 AMP Test Manager Commands/Events

The AMP Test Manager commands are sent to the AMP Test Manager from the tester and the events are from the AMP Test Manager to the tester.

The data fields are:

- *AMP Test Opcode (1 octet)*
  Identifies the type of AMP Test Manager command/event.
- *RFU (1 octet)*
- *Amp Test Command (ATC) length (2 octets)*
  Length of the data field of the command/event. This length does not include the AMP Test Opcode, RFU octet or the ATC length.

AMP Test Opcode	Description
0x00	Reserved for future use
0x01	AMP Command Rejected Event
0x02	AMP Discover Request
0x03	AMP Discover Response Event
0x04	AMP Read PHY Capability Bit Map Command
0x05	AMP Read PHY Capability Bit Map Response Event
Other	Reserved for future use

Table 1.2: AMP Test Opcodes

1.2.5.1 AMP Command Rejected Event

This event shall be sent by the DUT to the tester when a command cannot be accepted. The parameter returned indicates the reason.

Opcode = 0x01	RFU = 0	ATC length = 2	Reason

The data fields are:

- *AMP Test Opcode (1 octet)*
  0x01
- *RFU (1 octet)*
- *ATC length (2 octets)*
  Always set to 0x0002
- *Reason (2 octets)*
  See Table 1.3.

Reason Value	Description
0x0000	Command not recognized
0x0001	Invalid Controller ID
0x0002	Invalid Protocol ID
Other	Reserved for future use

Table 1.3: AMP Command reasons for rejection

1.2.5.2 AMP Discover Request

The tester shall send this command to the AMP Test Manager to obtain the available Controllers and their types.

Opcode = 0x02	RFU = 0	ATC length = 0

The data fields are:

- *AMP Test Opcode (1 octet)*
  Shall be set to 0x02
- *RFU (1 octet)*
- *ATC length (2 octet)*
  Shall be set to 0x0000

Events generated

On receipt of the AMP_Discover_Request command the AMP Test Manager shall return the AMP_Discover_Response event.

1.2.5.3 AMP Discover Response Event

When the AMP Test Manager receives an AMP_Discover_Request command it shall reply to the tester with an AMP_Discover_Response event indicating for each Controller the Controller ID and Controller Type. The first Controller ID and Type pair in the response shall be 0 for the BR/EDR primary Controller followed by the available additional Controllers ID and Type pairs.

Opcode = 0x03	RFU = 0	ATC length	Controller list

Controller list

Controller ID=0	Controller Type=0	Additional Controller ID and Type pairs

- *AMP Test Opcode (1 octet)*
  Shall be set to 0x03

- *RFU (1 octet)*
- *ATC length (2 octets)*

  ATClength = (Controller ID length + Controller Type length) * number of Controllers
- *Controller Types (1 octet)*

  Each type of Controller is assigned a unique one-octet value. These values are defined in Assigned Numbers. A device may have multiple AMPs of the same type.

Note: The AMP Discovery Response shall include the primary BR/EDR Controller as the first Controller ID and Controller Type pair.

1.2.5.4 AMP Read PHY Capability Bit Map Command

To perform AMP PHY tests the tester needs to know the supported PHY capabilities of the DUT. This information shall be provided in the PHY Capability Bit Map. This command shall be sent from the tester to the DUT to request the PHY Capability Bit Map from an AMP with the passed Controller ID.

Opcode = 0x04	RFU = 0	ATC length = 1	Controller ID

The data fields are:

- *AMP Test Opcode (1 octet)*

  Always set to 0x04
- *RFU (1 octet)*
- *ATC length (2 octets)*

  Always set to 0x0001
- *Controller ID (1 octet)*

  The Controller from which the PHY Capability Bit Map is being requested. This is an invalid request from a BR/EDR Controller and will be rejected with the reason of Invalid Controller ID.

1.2.5.5 AMP Read PHY Capability Bit Map Response Event

When the AMP_Read_PHY_Capability_Bit_Map Command is received by an AMP Test Manager it shall reply with the capability bit map for the AMP indicated if the Controller ID is valid.

- *AMP Test Opcode (1 octet)*

  Always set to 0x05
- *RFU (1 octet)*
- *ATC length (2 octets)*

The length of the PHY Capabilities Bit Map returned depending on the AMP type.

- *Status (1 octet)*

  See Table 1.4.

Reason Value	Description
0x00	Success
0x01	Invalid Controller ID
Other	Reserved for future use

Table 1.4: AMP Read PHY Capability Bit Map status values

Note: If the status is not Success the remaining parameters shall be zero.

- *Controller ID (1 octet)*

  This is the Controller ID from which the PHY Capability Bit Map has been sent.

- *PHY Capabilities Bit Map*

  See Volume 5 for the PHY Capabilities Bit Map.

Opcode = 0x05	RFU = 0	ATC length	Status	Controller ID	PHY Capabilities Bit Map

1.3 REFERENCES

[1] Bluetooth Link Manager Protocol.

[2] CCITT Recommendation O.153 (1992), Basic parameters for the measurement of error performance at bit rates below the primary rate.

[3] ITU-T Recommendation O.150 (1996), General requirements for instrumentation for performance measurements on digital transmission equipment.

[4] Bluetooth Baseband Specification.

2 TEST CONTROL INTERFACE (TCI)

This section describes the Bluetooth Test Control Interface (TCI). The TCI provides a uniform method of accessing the upper interface of the implementation being tested. This facilitates the use of a standardized interface on test equipment used for formal Qualification of implementations.

2.1 INTRODUCTION

2.1.1 Terms Used

Conformance testing	Testing according to the applicable procedures given in the Bluetooth Protocol Test Specifications and the Bluetooth Profile Conformance Test Specification when tested against a test system.
HCI	Host Controller Interface
IUT	Implementation Under Test: An implementation of one or more Bluetooth protocols and profiles which is to be studied by testing. This term is used when describing the test concept for products and components equipped with Bluetooth wireless technology as defined in the PRD.
PRD	Bluetooth Qualification Program Reference Document: This document is maintained by the Bluetooth Qualification Review Board and is the reference to specify the functions, organization and processes inside the Bluetooth Qualification program.
TCI	Test Control Interface: The interface and protocol used by the test equipment to send and receive messages to and from the upper interface of the IUT.

2.1.2 Usage of the Interface

For all products and components equipped with Bluetooth wireless technology, conformance testing is used to verify the implemented functionality in the lower layers. Conformance testing of the lowest layers requires an upper tester to test the implementation sufficiently well.

In order to avoid that the tester will have to adapt to each and every product and component equipped with Bluetooth wireless technology, the use of the standardized TCI is mandated. This concept puts some burden upon the manufacturer of the IUT in terms of supplying an adapter providing the necessary conversion from/to the IUT's specific interface to the TCI. The adapter can consist of hardware, firmware and software. After qualification testing has been performed the TCI may be removed from the product or component equipped with Bluetooth wireless technology. It is the

manufacturer's option to remove it from the qualified product or component equipped with Bluetooth wireless technology.

The TCI is used when qualifying the implemented functionality of the:

- Baseband layer, BB
- Link Manager layer, LM

If support of the Host Controller Interface is claimed by the manufacturer the TCI is used to qualify it.

2.2 TCI CONFIGURATIONS

This section describes the test configurations used when verifying the different Bluetooth requirements. Each layer in the Bluetooth stack is qualified using the procedures described in the layer specific test specification.

2.2.1 Bluetooth RF Requirements

For qualification of the Bluetooth Radio Frequency requirements the defined Test Mode is used, see Section 1.

Similar to TCI, the specific test mode functionality may be removed from the product or component after qualification, at the discretion of the manufacturer.

2.2.1.1 Required interfaces

For RF qualification only the air interface is required, see Figure 2.1. Depending on the physical design of the IUT it might be necessary to temporarily attach an RF connector for executing the RF tests. As stated in Section 1, the Test Mode shall be locally enabled on the IUT for security reasons. The implementation of this local enabling is not subject to standardization.

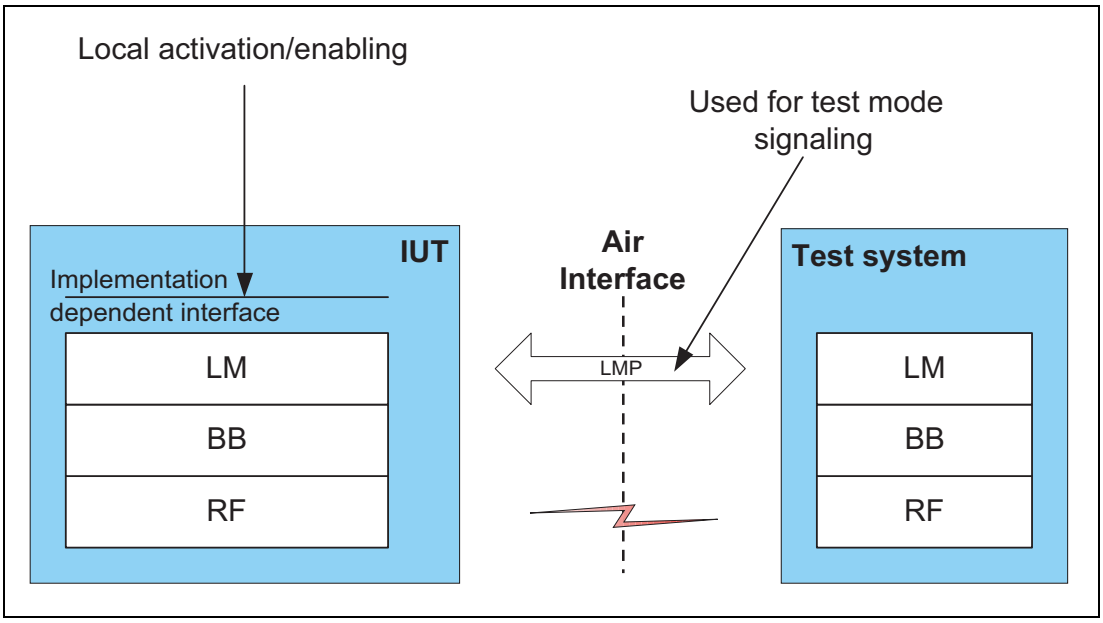

Figure 2.1: General test set-up for RF qualification

2.2.2 Bluetooth Protocol Requirements

Depending on which of the Bluetooth layers BB, LM or HCI are implemented in the product subject to qualification, the amount of testing needed to verify the Bluetooth protocol requirements differs. Also, the TCI used during the qualification is slightly different. The commands and events necessary for qualification are detailed in the test specifications and only those commands indicated in the test cases to be executed need be implemented.

For other protocols in the Bluetooth stack the TCI is not used. An implementation specific user interface is used to interact with the IUT's upper interface.

2.2.2.1 Required interfaces

For BB, LM and HCI qualification both the air interface of the IUT and the TCI are required. For other protocols both the air interface and the user interface are used as described in the test specification.

2.2.3 Bluetooth Profile Requirements

For each Bluetooth profile for which conformance is claimed, profile qualification testing is performed to verify the Bluetooth profile requirements. With higher layer protocols the TCI is not used during testing. A user interface specific to the implementation is used to interact with the IUT's upper interface.

2.2.3.1 Required interfaces

For this type of qualification both the air interface and the user interface of the IUT are used as described in the test specification.

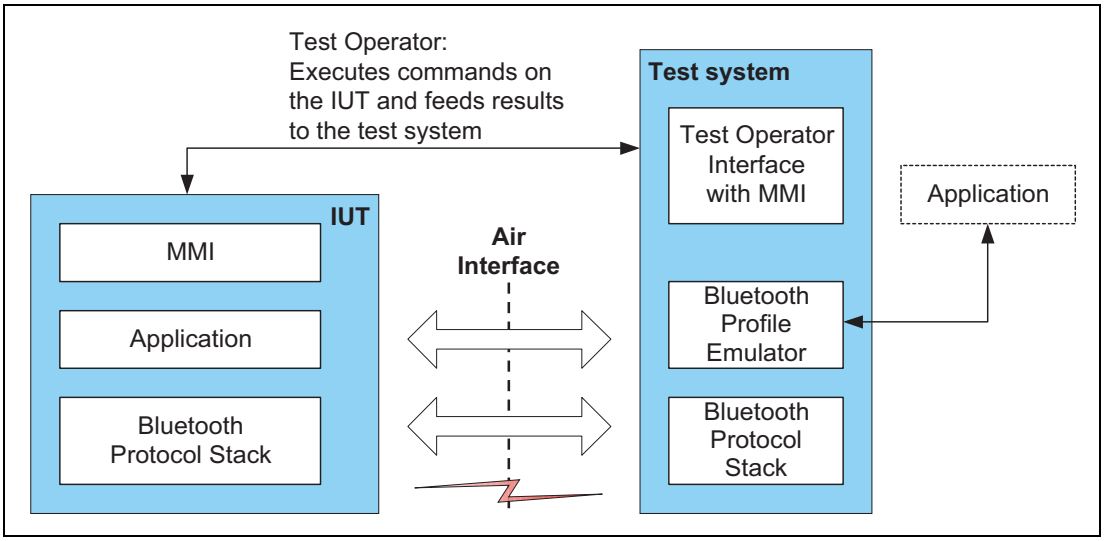

Figure 2.2: General test set-up for profile qualification

2.3 TCI CONFIGURATION AND USAGE

This interface is semantically and syntactically identical to the HCI interface described in Section Part E:. The complete HCI interface is not required in the TCI, but the subset of HCI commands and events necessary for verifying the functionality of the IUT. The exact set of commands and events is specified in the test specifications for the layers subject to testing.

It is worth emphasizing again the TCI is an adapter, logically attached to the upper interface of the IUT. As such the TCI adapts the standardized signaling described here to the implementation specific interface of the IUT.

2.3.1 Transport Layers

The method used to convey commands and events between the tester and the IUT's upper interface can be either physical bearer or "software bearer".

2.3.1.1 Physical bearer

It is recommended to use one of the transport layers specified for the HCI in Volume 4, Host Controller Interface [Transport Layer]. However, other physical bearers are not excluded and may be provided on test equipment. The use of a physical bearer is required for test cases active in category A. Please see the PRD for the definitions of test case categories. Please see the current active Test Case Reference List for the categorization of specific test cases.

2.3.1.2 Software bearer

There is no physical connection between the tester and the IUT's upper interface. In this case, the manufacturer of the IUT shall supply test software and hardware that can be operated by a test operator. The operator will receive instructions from the tester and will execute them on the IUT. The "software bearer" shall support the same functionality as if using the TCI with a physical bearer. Use of the "software bearer" shall be agreed upon between the manufacturer of the IUT and the test facility that performs the qualification tests. The test facilities can themselves specify requirements placed on such a "software bearer". Furthermore, the use of a "software bearer" is restricted to test cases active in one of the three lower categories B, C and D.

2.3.2 Baseband and Link Manager Qualification

For the qualification of the link control part of the Baseband layer and for the Link Manager layer, the TCI is used as the interface between the test system and the upper interface of the IUT. The test system accesses the upper interface of the IUT by sending HCI commands and receiving HCI events from the IUT as described in the HCI specification. The required functionality on the TCI depends on the IUT's implemented functionality of the BB and LM layers, and therefore which test cases are executed.

A schematic example in Figure 2.3 shows the test configuration for BB and LM qualification of Bluetooth products which do not support HCI, and use a physical bearer for the TCI. In this example the Test Control (TC) Software represents what the manufacturer has to supply with the IUT when using an external test facility for qualification. The function of the TC Software is to adapt the implementation dependent interface to the TCI.

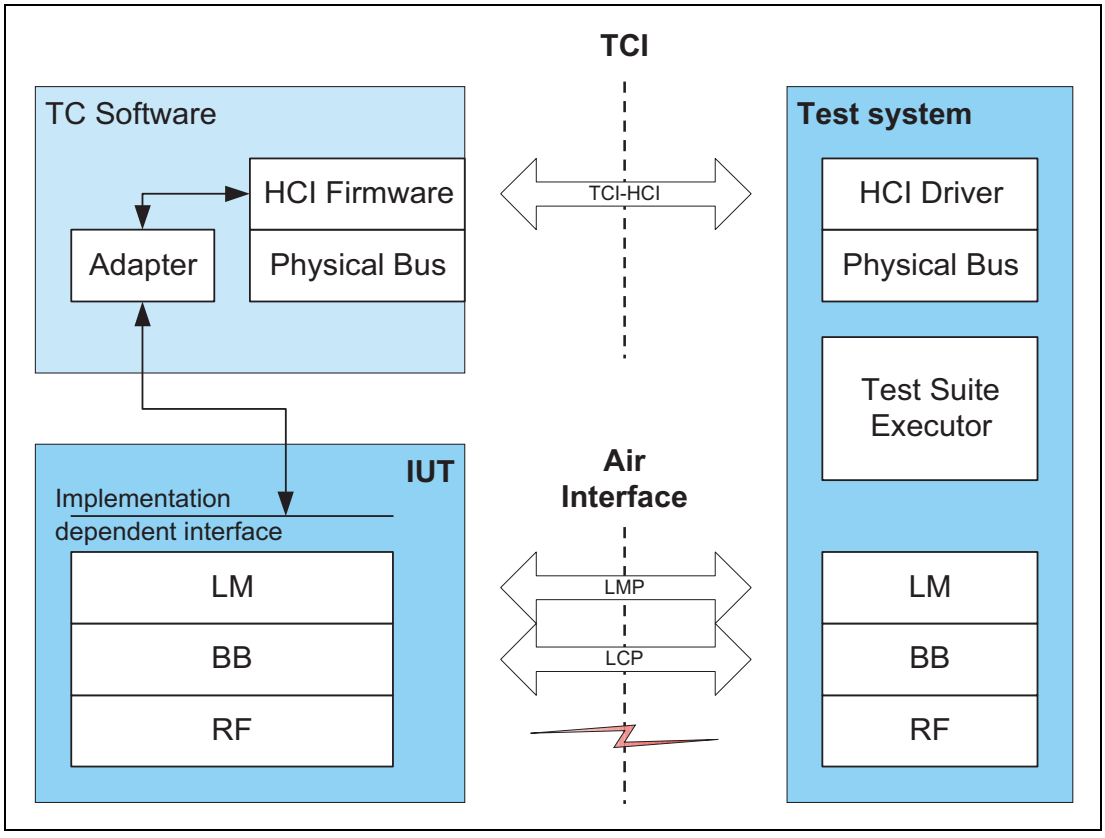

Figure 2.3: BB and LM qualification with TCI physical bearer

Figure 2.4 shows a schematic example of the test configuration for the same Bluetooth product using a "software bearer" for the TCI. Here the function of the Test Control Software is to represent the application that can be controlled by the test operator.

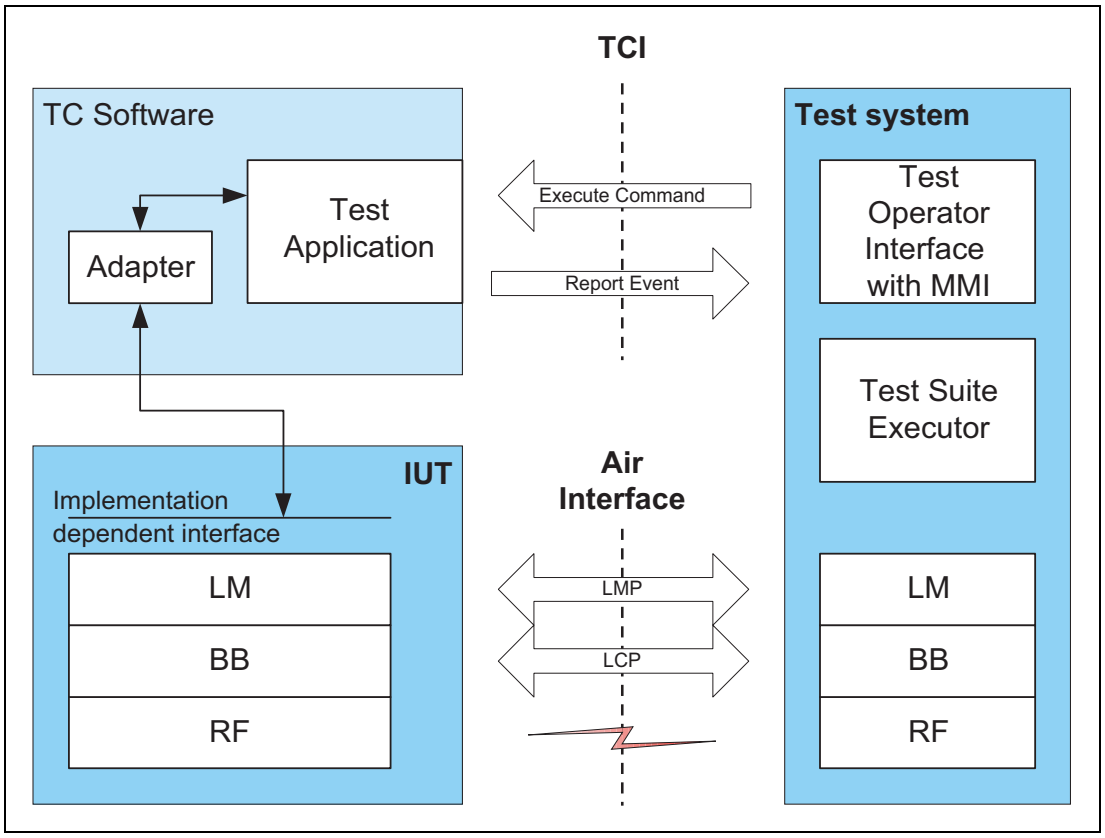

Figure 2.4: BB and LM qualification with "software bearer"

2.3.3 HCI Qualification

The TCI may also be used for HCI signaling verification and qualification. The HCI signaling is only verified if support of the HCI functionality is claimed by the manufacturer.

A schematic example in Figure 2.5 shows the test configuration for HCI qualification of Bluetooth products. As can be seen in the figure the implemented HCI is used as the interface to the tester.

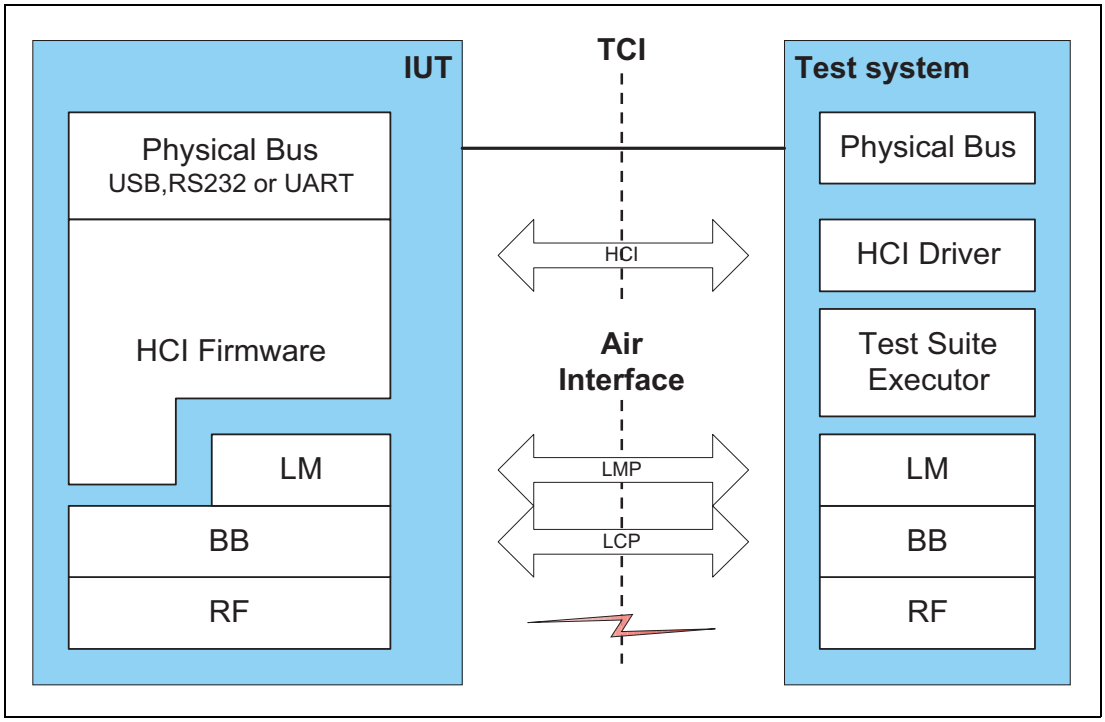

Figure 2.5: General test set-up for HCI qualification

AMP MANAGER PROTOCOL SPECIFICATION

This document specifies the changes to the Core specification required to incorporate the AMP Manager Protocol (A2MP) for the Alternate MAC/PHY feature.

CONTENTS

1 INTRODUCTION

1.1 GENERAL DESCRIPTION

The AMP Manager Protocol (A2MP) provides a means for one device to solicit information regarding AMP capabilities from another device. Each device contains an abstract entity called an AMP Manager which uses the AMP Manager Protocol to communicate with a peer AMP Manager on another device.

2 GENERAL OPERATION

2.1 BASIC CAPABILITIES

The AMP Manager entity has the following responsibilities and capabilities:

1. Ability to discover remote AMP Managers
2. Ability to discover available Controllers
3. Ability to query remote AMP Controller information
4. Ability to manage AMP physical links
5. Responsible for the creation of dedicated AMP keys

The AMP Manager communicates with the local AMP PAL and communicates with remote AMP Managers using the AMP Manager Protocol over a fixed L2CAP channel. The AMP Manager entity exists within the Bluetooth stack as depicted in Figure 2.1.

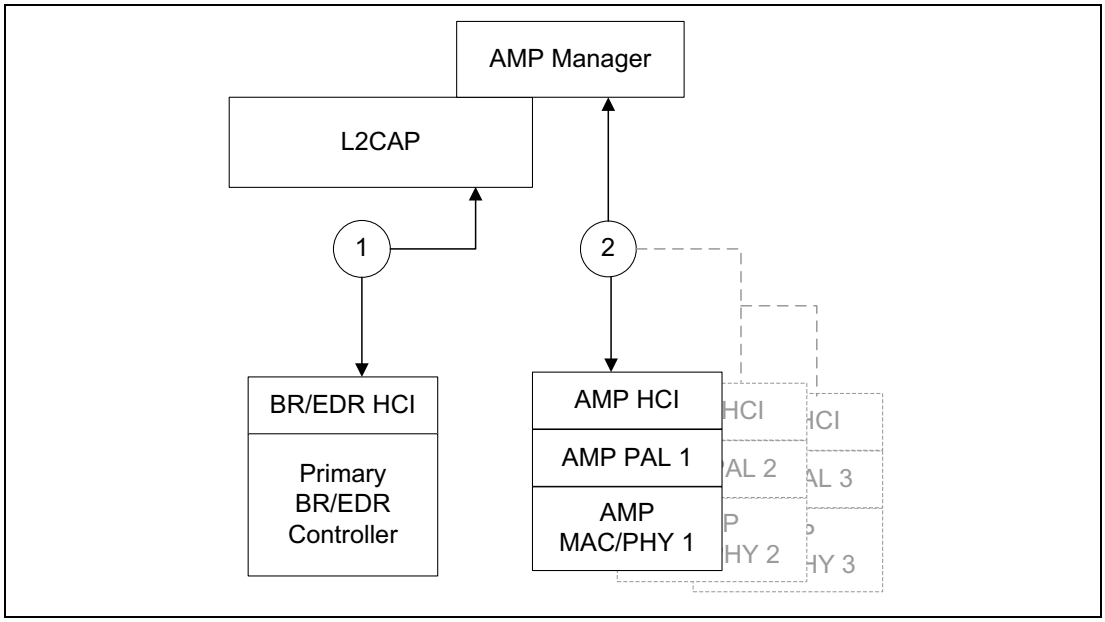

Figure 2.1: Overview of the Lower Software Layers

Figure 2.1 shows the two basic communication paths for the AMP Manager. The AMP Manager uses path 1 via L2CAP and the Primary BR/EDR Controller to first discover remote AMP Managers. The AMP Manager can query for the possibility of available remote AMPs and their capabilities as well as other information. The AMP Managers communicate over the AMP Manager Protocol Channel (A2MP Channel). See Section 2.2 for more information on the A2MP Channel.

After discovering the AMPs supported by the remote device, the AMP Manager uses communication path 2 to manage the physical links between its local AMP(s) and AMPs on remote devices. Note that there can be more than one local AMP and there also may be more than one AMP located on the remote device.

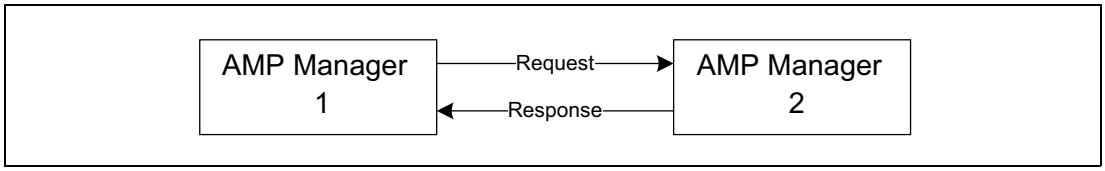

Figure 2.2: AMP Manager Peers

The AMP Manager Protocol is a request / response protocol between two AMP Managers. Requests and responses go in both directions. Either peer can request the same category of information from its corresponding peer.

2.2 AMP MANAGER CHANNEL OVER L2CAP

Peer AMP Managers communicate over the A2MP Channel which is an L2CAP fixed channel. The configuration parameters for the AMP Manager channel shall be as shown below. The MTU value shall be any valid value greater than or equal to 670 bytes.

Parameter	Value
MTU	≥ 670
Flush Timeout	0xFFFF (Infinite)
QoS	Best Effort
Mode	Enhanced Retransmission Mode
FCS Option	16-bit FCS

Table 2.1: AMP Manager Channel configuration parameters

The parameters for the Enhanced Retransmission Mode used on the fixed channel shall be as shown below. The Retransmission Time-out, Monitor Time-out and MPS shall be any valid value that is greater than or equal to the values stated in the following tables.

Parameter	Value
TxWindow size	1
Max Transmit	0xff
Retransmission time-out	≥ 2 seconds
Monitor time-out	≥ 12 seconds

Table 2.2: AMP Manager Channel Enhanced Retransmission Mode parameters

Parameter	Value
Maximum PDU size (MPS)	≥ 670
16-bit FCS	Enabled

Table 2.2: AMP Manager Channel Enhanced Retransmission Mode parameters

The minimum value for both MTU and MPS is 670 bytes. A larger MTU and MPS size can be communicated using the AMP Discover request (see section 3.3) and AMP Discover response (see Section 3.4) packets. The MTU parameter and the Enhanced Retransmission mode MPS parameter are numerically equal to allow an AMP manager to send any A2MP packet using a single L2CAP PDU. A device may segment any A2MP packet into multiple L2CAP PDUs.

2.3 USING THE AMP MANAGER PROTOCOL

The following text describes how the AMP Manager Protocol is used to establish an AMP physical link between two devices.

2.3.1 Discovering a Remote AMP Manager

Once an ACL connection is established over the Primary BR/EDR Controller, the local AMP Manager shall examine the L2CAP extended features bits of the remote device to determine if L2CAP fixed channels are supported (see [Vol 3] Part A, Section 4.12). If so, a query for the existence of its peer (AMP Manager) may be made by issuing an Information Request for all available fixed channels.

2.3.2 Discovering Available Controllers on a Remote Device

The next step is to discover the existence and capabilities of the AMP Controllers of the peer. An AMP Discover Request packet can be issued over the AMP Manager Protocol channel for this purpose.

In an AMP Discover Response packet, the peer AMP Manager will return information about its local AMP capabilities in the form of a Controller List. A Controller List is a sequence of Controller ID/Controller Type/Controller Status triples identifying the Controllers that are available for communication.

The Controller List contains a basic top level description of the available peer Controllers and their status. The AMP Manager parses this list for physical radio compatibility. If more information is required about a remote AMP Controller, the local AMP Manager can subsequently issue an AMP Get Info Request packet using the Controller ID retrieved via the AMP Discover exchange. An AMP Get Info Response packet is returned from the peer with AMP Controller Info for the specified AMP Controller. The AMP Controller Info contains information about the AMP Controller that can be used by the Host to determine whether or not to create a physical link to the AMP Controller.

2.3.3 Creation of AMP Physical Links

Once it has been determined that a Bluetooth connection over an AMP is desired, the AMP Manager retrieves the remote AMP Controller's AMP_Assoc structure by issuing an AMP Get AMP Assoc Request packet. It then passes the AMP_Assoc structure received from the remote device to its local AMP PAL and signals it to begin the physical discovery and connection process. In devices that support HCI this is done via the HCI_Create_Physical_Link command followed by the HCI_Write_Remote_AMP_ASSOC command.

Note that the AMP Manager only holds the contents of the AMP_Assoc structure for use in AMP Manager operations. The AMP Manager does not directly attempt to interpret the contents of the AMP_Assoc structure.

The AMP manager is responsible for generating the Physical Link Handle used in the HCI_Create_Physical_Link and HCI_Accept_Physical_Link commands. See section [Vol 2] Part E, Section 5.3.2 for details. When the AMP PAL is ready it will generate an HCI_Channel_Selected event which is a signal to read the local AMP_Assoc structure using the HCI_Read_Local_AMP_ASSOC command.

The AMP Manager shall not create or accept a physical link over an AMP if mutual authentication was not performed or encryption was not enabled over BR/EDR.

When the AMP Manager does not have a dedicated AMP key for the selected Controller type between the two devices and the BR/EDR link key type is not "Debug", the AMP Manager shall call the Secure Simple Pairing h2 function (see [Vol 2] Part H, Section 7.7.5.2) to generate a dedicated AMP key. This dedicated AMP key shall be used during subsequent connections.

If the Bluetooth device supports more than one AMP type, the AMP Manager shall call the h2 function a second time to regenerate Key_GAMP as defined in [Vol 2] Part H, Section 7.7.5.3 before generating a Dedicated AMP link key for a different AMP type.

When the BR/EDR link key type is set to "Debug", the AMP Manager shall use Key_GAMP directly as the key for the AMP regardless of the AMP Type. The key length, key type and the link key itself are passed to the AMP Controller in the HCI_Create_Physical_Link command.

After receiving the HCI_Channel_Selected event and reading the local AMP_Assoc structure the AMP Manager then issues an AMP Create Physical Link Request packet to send the local AMP_Assoc structure to the peer device in order to engage the peer device in the AMP physical link creation.

If the peer accepts the request it issues an HCI_Accept_Physical_Link command to its local AMP and passes the AMP_Assoc structure received in the AMP Create Physical Link Request packet to its local AMP Controller. The

peer responds with an AMP Create Physical Link Response packet to either accept or reject the request to create a physical link.

Both Hosts will receive an HCI_Physical_Link_Complete event indicating the completion of the physical link creation.

On success, the procedure for creation of a logical connection can then commence.

2.4 CONTROLLER IDS

Each Controller in a device is assigned a one-octet unique identifier by the local AMP Manager. From the perspective of a remote device, Controller IDs are only valid during the life time of the AMP Manager Protocol channel. The Controller IDs on a remote device become invalid when the A2MP Channel is disconnected. If a local Controller becomes unavailable during the life time of the A2MP channel, the Controller ID may be reclaimed after receiving the AMP Change Response to the AMP Change Notify packets sent to all affected remote AMP Managers. It can then be assigned to any new AMP that is added. The value 0 is reserved for the Primary BR/EDR Controller. Other Controllers in the device shall be assigned values from 1 to 255.

If an AMP Controller becomes unavailable and later becomes available again during the life time of the A2MP Channel, remote AMP Managers shall not assume that the AMP Controller will be assigned the Controller ID that it was previously assigned.

2.5 CONTROLLER TYPES

Each type of Controller is assigned a unique one-octet value. These values are defined in Assigned Numbers. A device may have multiple AMPs of the same type.

3 PROTOCOL DESCRIPTION

The AMP Manager Protocol defines the procedures and format of the packets used to exchange information between two peer AMP Managers.

3.1 PACKET FORMATS

This section describes the packets used in the AMP Manager Protocol. Unless otherwise stated an implementation shall include all specified fields in a packet.

Figure 3.1 displays the general format of all AMP Manager Protocol packets.

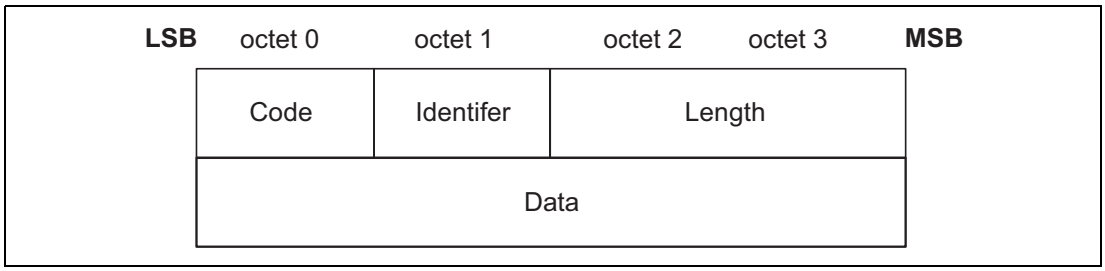

Figure 3.1: AMP Manager Protocol Packet Format

The fields shown are:

- *Code (1 octet)*

  The code identifies the type of packet. When an AMP manager receives a packet with an unknown Code field it shall send a Command Reject packet in response. Table 3.1 lists the codes defined by this document. All codes are specified with the most significant bit in the left most position.

Code	Description
0x00	Reserved for future use
0x01	AMP Command Reject
0x02	AMP Discover request
0x03	AMP Discover response
0x04	AMP Change notify
0x05	AMP Change response
0x06	AMP Get Info request
0x07	AMP Get Info response
0x08	AMP Get AMP Assoc request
0x09	AMP Get AMP Assoc response

Table 3.1: Codes

Code	Description
0x0A	AMP Create Physical Link request
0x0B	AMP Create Physical Link response
0x0C	AMP Disconnect Physical Link request
0x0D	AMP Disconnect Physical Link response
0x0E - 0xFF	Reserved for future use

Table 3.1: Codes

- *Identifier (1 octet)*

  The Identifier field matches responses with requests. The requesting device sets this field and the responding devices uses the same value in the response. For each A2MP channel an AMP manger shall use different identifiers for each request sent (this includes the AMP Change Notify command). Following the original transmission of an identifier in a request, the identifier may be recycled if all other identifiers have subsequently been used.

  A response packet with an invalid identifier is discarded. Identifier 0x00 is an illegal identifier and shall never be used in any packet. Table 3.2 shows the valid values for the Identifier field,

Value	Description
0x00	Invalid
0x01 - 0xFF	Valid

Table 3.2: Identifier

- *Length (2 octets)*

  The Length field indicates the size in octets of the data field of the packet only, i.e. it does not cover the Code, Identifier and Length fields.

- *Data (0 or more octets)*

  The Data field is variable in length. The Code field determines the format of the Data field. The Length field determines the length of the Data field.

3.2 AMP COMMAND REJECT (CODE 0x01)

An AMP Manager shall send an AMP Command Reject packet in response to a request packet with an unknown code or when sending the corresponding response is inappropriate. The identifier shall match the identifier of the request packet being rejected. AMP Command Reject packets shall not be sent in response to an unknown response packet.

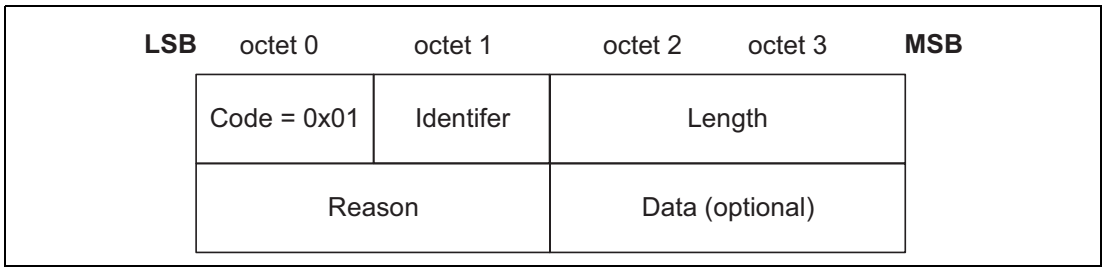

Figure 3.2: AMP Command Reject Packet

The data fields are

- *Reason (2 octets)*

  The Reason field describes why the request packet was rejected, and is set to one of the following Reason codes.

Reason value	Description
0x0000	Command not recognized
Other	Reserved for future use

Table 3.3: AMP Command Reject reasons

- *Data (0 or more octets)*

  The length and content of the Data field depends on the Reason code. If the reason code is 0x0000 "Command not recognized" no Data field is used.

3.3 AMP DISCOVER REQUEST (CODE 0x02)

An AMP Manager sends an AMP Discover Request packet to a peer AMP Manager to obtain the list of the available Controllers supported by the peer device.

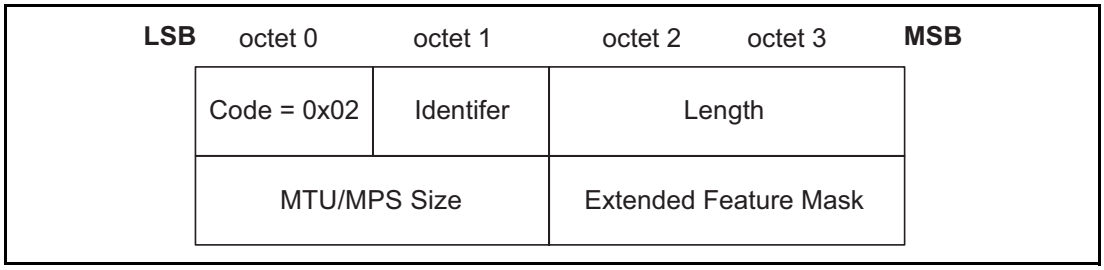

Figure 3.3: AMP Discover Request Packet

The data fields are

- *MTU/MPS size (2 octets)*

  The MTU/MPS Size field in the AMP Discover Request packet indicates the MTU/MPS that the sender of the request can receive on the AMP Manager Protocol Channel. The minimum value is 670 (see Section 2.2). An AMP manager shall send the same value for the AMP Manager Protocol Channel MTU/MPS in both AMP Discover Request and AMP Discover Response packets.

- *Extended Feature Mask (2 octets)*

  The extended features supported by the AMP Manager are represented by a bit mask. Each feature is represented by a single bit which shall be set to 1 if the feature is supported and set to 0 otherwise.

  The feature mask is defined in Table 3.4.

Supported Feature	Octet	Bit
Reserved for future use	0	0-7
Reserved for future use	1	0-6
Extension Bit	1	7

Table 3.4: A2MP Extended Feature Mask

  Bit 7 of Octet 1 of this field is used to extend the A2MP Extended Feature Mask. If the Extension Bit is set then the Extended Feature Mask field is extended by two octets. Each two octet extension includes an Extension Bit that allows a further two octets to be added to the field. Figure 3.4 shows how the Extension Bit (E) can be used to extend the A2MP Extended Feature Mask.

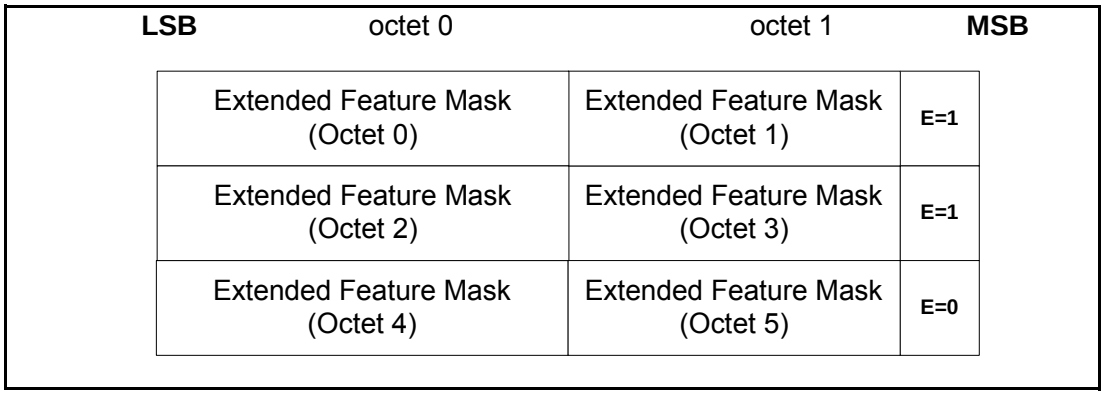

Figure 3.4: Example A2MP Extended Feature Mask

3.4 AMP DISCOVER RESPONSE (CODE 0x03)

When an AMP Manager receives an AMP Discover Request packet it shall reply with an AMP Discover Response packet indicating the IDs, types and status of the Controllers that are currently available on the local device. If there is a change in the number or status of supported Controllers after sending an AMP Discover Response packet and before the A2MP Channel is disconnected, the AMP Manager shall send an AMP Change Notify packet to the peer AMP Manager.

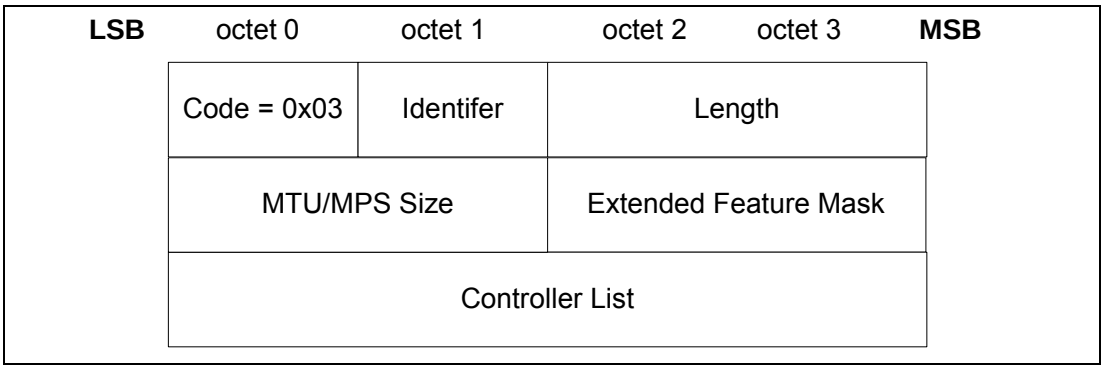

Figure 3.5: AMP Discover Response Packet

The data fields are

- *MTU/MPS size (2 octets)*

  The MTU/MPS Size field in the AMP Discover Response packet indicates the MTU/MPS that the sender of the response can receive on the AMP Manager Protocol Channel. The minimum value is 670 (see Section 2.2). An AMP Manager shall send the same value for the AMP Manager Protocol Channel MTU/MPS supported in both AMP Discover Request and AMP Discover Response packets.

- *Extended Feature Mask (2 octets)*

  The extended features supported by the AMP Manager are represented by a bit mask. Each feature is represented by a single bit which shall be set to 1

if the feature is supported and set to 0 otherwise. All unknown or unassigned feature bits are reserved for future use.

The feature mask is defined in Table 3.4 and Figure 3.4.

- *Controller List (3 or more octets)*

  Controller List is variable in length. It consists of 1 or more entries. Each entry is comprised of a Controller ID, a Controller Type and a Controller status.

  An entry for Controller ID 0x00 (Primary BR/EDR Controller) shall always be sent and shall be the first entry in the Controller List. The Controller Type for this entry shall be set to 0x00 (Primary BR/EDR Controller). The Controller status for this entry shall be set to 0x01 (The AMP Controller can only be used by Bluetooth technology). If the Primary BR/EDR Controller's Link Manager does not support Secure Simple Pairing, it shall be the only Controller in the Controller List.

  Figure 3.6 displays the format of the Controller list.

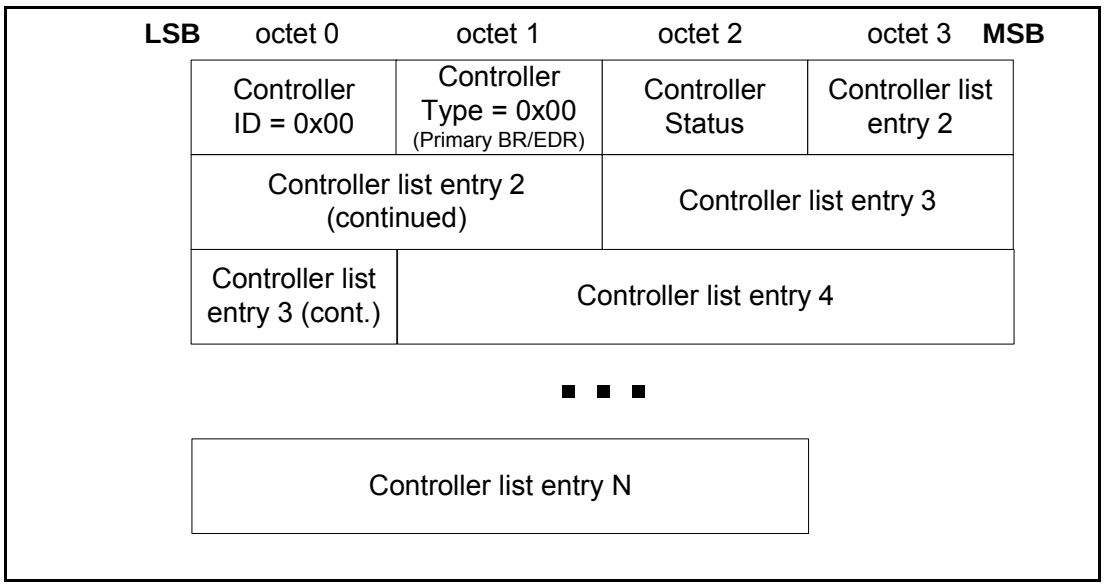

Figure 3.6: Controller list format

- *Controller ID (1 octet)*

  The Controller ID uniquely identifies a Controller (see Section 2.4 for more information about Controller IDs).

- *Controller Type (1 octet)*

  The Controller Type specifies the type of the Controller. The Controller type values are defined in Assigned Numbers.

- *Controller Status (1 octet)*

  The Controller Status field indicates the current status of the AMP. The status information can be used by the receiving device to help decide if it should use the AMP. If multiple AMPs are available the status can also be used by an implementation to determine which would be the optimal AMP to

use. None of the AMP status values indicate that a Physical Link shall not be created to the AMP. If an implementation wishes to ensure it does not receive Create Physical Link Requests for a given AMP then it should remove the associated entry from the Controller list it sends.

Table 3.5 contains the different values of the Controller Status field.

Value	Parameter Description
0x00	The Controller radio is available but is currently physically powered down. This value should be used if the AMP Controller is present and can be powered up by the AMP Manager. A Controller List entry shall not exist for an AMP that is not present or cannot be powered up by the AMP manager. This value indicates that there may be a cost of time and power to use this AMP Controller (i.e., the time taken and power required to power up the AMP Controller). These costs are AMP type and AMP implementation dependent.
0x01	This value indicates that the AMP Controller is only used by the Bluetooth technology and will not be shared with other non-Bluetooth technologies. This value shall only be used if the AMP Controller is powered up. This value does not indicate how much bandwidth is currently free on the AMP Controller.
0x02	The AMP Controller has no capacity available for Bluetooth operation. This value indicates that all of the AMP Controller's bandwidth is currently allocated to servicing a non Bluetooth technology. A device may create a Physical Link to an AMP Controller that has this status. This value shall only be used if the AMP Controller is powered up.
0x03	The AMP Controller has low capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controller's bandwidth is currently allocated to servicing a non Bluetooth technology. An AMP Controller with capacity in the approximate range of 0 < capacity < 30% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently being used. This value shall only be used if the AMP Controller is powered up.
0x04	The AMP Controller has medium capacity available for Bluetooth operation. An AMP Controller with capacity in the approximate range of 30% < capacity < 70% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently being used. This value shall only be used if the AMP Controller is powered up.

Table 3.5: Controller Status

Value	Parameter Description
0x05	The AMP Controller has high capacity available for Bluetooth operation. This value indicates that the majority of the AMP Controller's bandwidth is currently allocated to servicing the Bluetooth technology. An AMP Controller with capacity in the approximate range of 70% < capacity < 100% should indicate this value. This value does not indicate how much of the capacity available for Bluetooth operation is currently being used. This value shall only be used if the AMP Controller is powered up.
0x06	The AMP Controller has full capacity available for Bluetooth operation. This value indicates that while currently the AMP is only being used by Bluetooth the device allows a different technology to share the radio. This value shall be used as the default Controller Status value for devices that are not capable of determining the available capacity for Bluetooth operation for an AMP Controller. This value does not indicate how much of the capacity available for Bluetooth operation is currently being used. This value shall only be used if the AMP Controller is powered up.
Other	Reserved for future use

Table 3.5: Controller Status

The available capacity ranges given for values 0x03, 0x04, and 0x05 are only approximate and permit an implementation to not send an AMP Change Notify packet if the current availability is moving frequently from one range to another (e.g., if the current availability is moving between 68% (corresponding to Controller status 0x04) and 72% (corresponding to Controller status 0x05) frequently an implementation is not mandated to send an AMP Change Notify packet every time the value crosses the approximate 70% threshold between the two Controller Status values).

3.5 AMP CHANGE NOTIFY (CODE 0x04)

The AMP Change Notify packet indicates to the peer device that something has changed in the list of supported Controllers. An AMP Change Notify packet shall only be sent to a remote AMP Manager if it has previously requested a Controller List via an AMP Discover Request. Examples of when an AMP Change Notify packet is sent is when a new Controller becomes available or one or several Controllers advertised in the previous AMP Discover Response or AMP Change Notify packet become unavailable or if the status of a previously advertised Controller changes. The AMP Change Notify carries the new list of the available Controllers. Based on the changes from the previous Change Notify or Discovery Response, the AMP Manager can identify added or deleted Controllers or Controllers that have changed status.

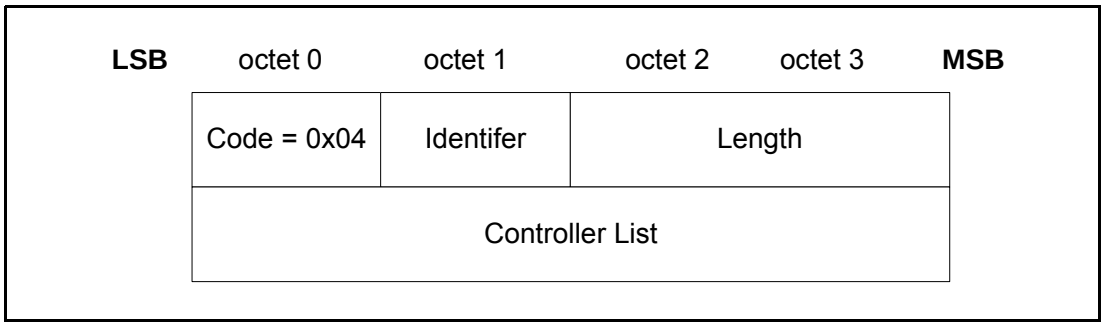

Figure 3.7: AMP Change Notify Packet

- *Controller List (3 or more octets)*

  Controller List is variable in length. It consists of 1 or more entries. Each entry is comprised of a Controller ID, a Controller Type and a Controller status (see Section 3.4 for a description of Controller List).

3.6 AMP CHANGE RESPONSE (CODE 0x05)

The AMP Change Response packet shall be sent to acknowledge receipt of the AMP Change Notify packet.

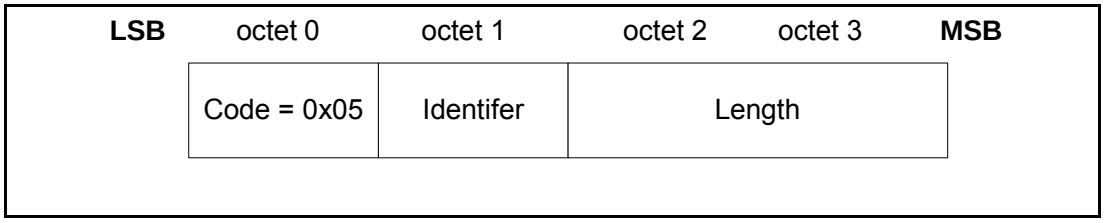

Figure 3.8: AMP Change Response Packet

3.7 AMP GET INFO REQUEST (CODE 0x06)

To determine if a physical link should be established to a particular AMP Controller, an AMP Manager may need to obtain further information for a remote AMP Controller. For each Controller ID reported in the AMP Discover Response or AMP Change Notify packet the AMP Manager can query this information by issuing an AMP Get Info Request packet. The exception is Controller ID 0. Information for the Primary BR/EDR radio shall not be obtained with an AMP Get Info Request packet.

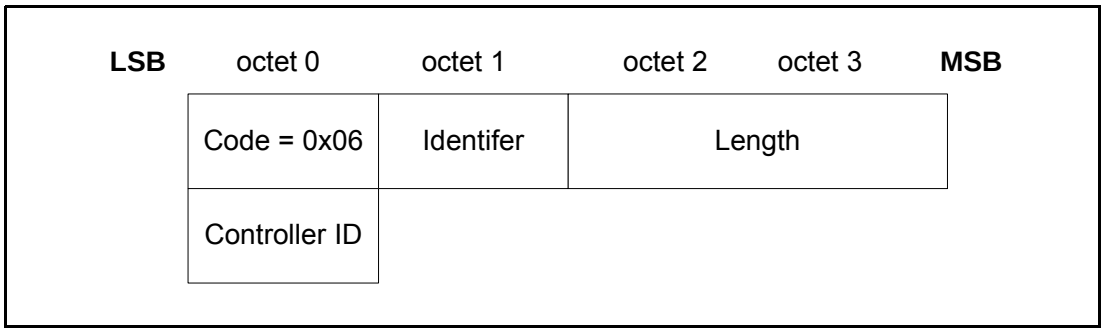

Figure 3.9: AMP Get Info Request Packet

The data fields are

- *Controller ID (1 octet)*

  Controller ID is one of the IDs reported in the latest AMP Discover Response, or AMP Change Notify packet received from the peer AMP Manager.

3.8 AMP GET INFO RESPONSE (CODE 0x07)

When an AMP Manager receives an AMP Get Info Request packet it shall reply with the AMP Get Info Response packet. This packet carries Controller Information including bandwidth and latency capabilities. The receiver of the AMP Get Info Response packet can assume that the value of all fields shall remain constant while the remote AMP remains active.

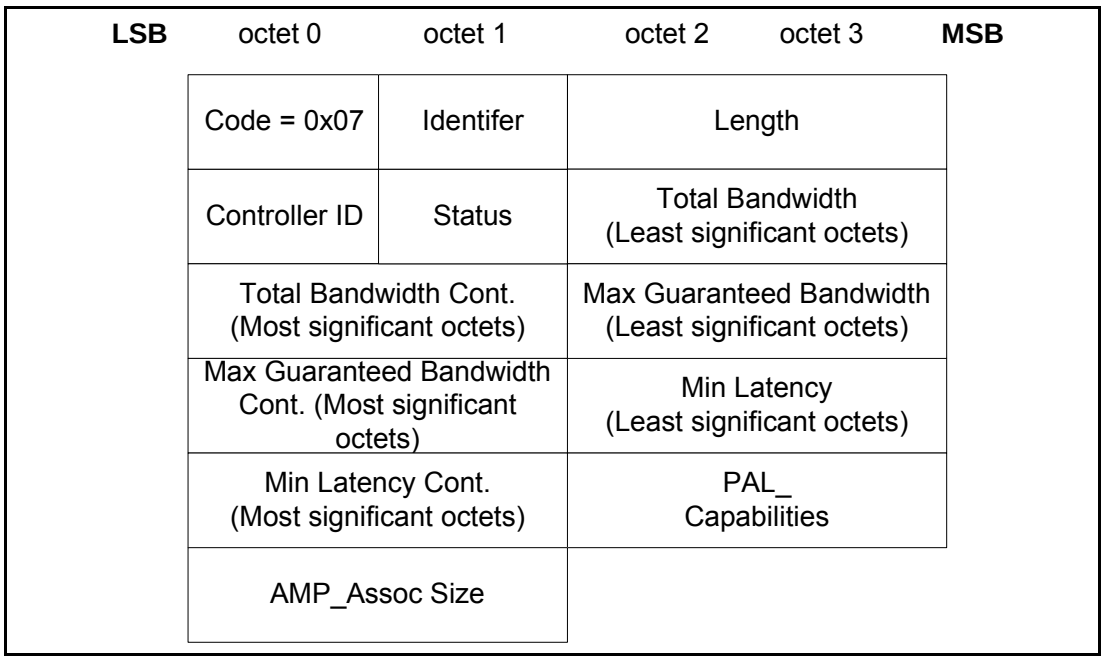

Figure 3.10: AMP Get Info Response Packet

- *Controller ID (1 octet)*

  Controller ID is the identifier requested in the AMP Get Info Request.

- *Status (1 octet)*

  The Status field indicates the status of the request

Status Code	Description
0x00	Success
0x01	Invalid Controller ID
Other	Reserved for future use

Table 3.6: AMP Get Info Response Status values

An AMP Get Info Response with status of Invalid Controller ID shall be sent by an AMP manager that has received an AMP Get Info Request containing either:

a) A Controller ID that has not been allocated by the AMP manager

b) A Controller ID of 0

If the Status field is set to Invalid Controller ID all subsequent fields in the AMP Get Info Response shall be ignored by the receiver.

- *Total Bandwidth (4 octets)*

  The Total Bandwidth field indicates the total data rate in kilobits per second (1000 b/s) that can be achieved by the Controller for applications. This value shall account for any bandwidth limitations of the Host and the HCI transport if present. The Host is responsible for determining these bandwidth limitations.

- *Max Guaranteed Bandwidth (4 octets)*

  The Maximum Guaranteed Bandwidth field indicates the maximum data rate in kilobits per second that the AMP can guarantee for a logical channel. Any request made by an application above this level will be rejected. This value shall account for any bandwidth limitations of the Host and the HCI transport if present. The Host is responsible for determining these bandwidth limitations.

- *Min Latency (4 octets)*

  The Min Latency field indicates the minimum latency in microseconds that the AMP can guarantee for a logical channel. This value shall account for any latency limitations of the Host and the HCI transport if present. The Host is responsible for determining these latency limitations.

- *PAL_Capabilities (2 octets)*

  The PAL_Capabilities field contains the PAL capabilities returned via HCI Read Local AMP Info Command (see [Vol 2] Part E, Section 7.5.8 for more information).

- AMP_Assoc Structure Size (2 octets)

  The maximum size in octets of the requested AMP's AMP_Assoc structure. The value of the AMP_Assoc Structure Size for a given AMP is determined by the Controller. If an HCI is being used this value can be retrieved by the Host sending the HCI_Read_Local_AMP_Info command to the Controller.

3.9 AMP GET AMP ASSOC REQUEST (CODE 0x08)

To establish a physical link to a particular Controller, an AMP Manager needs to obtain the AMP_Assoc structure for the remote Controller. The remote AMP is identified by its Controller ID as reported in the AMP Discover Response or AMP Change Notify packet. AMP Get AMP Assoc Request packet shall not be used to obtain an AMP_Assoc structure for the Primary BR/EDR Controller.

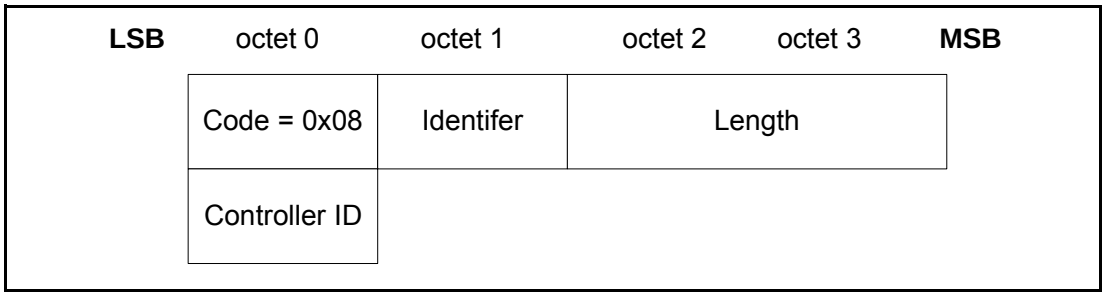

Figure 3.11: AMP Get AMP Assoc Request Packet

The data fields are:

- *Controller ID (1 octet)*

  Controller ID is one of the IDs reported in the latest AMP Discover Response or AMP Change Notify packet received from the peer AMP Manager.

3.10 AMP GET AMP ASSOC RESPONSE (CODE 0x09)

When an AMP Manager receives an AMP Get AMP Assoc Request packet it shall reply with the AMP Get AMP Assoc Response packet. This packet carries the AMP_Assoc structure. The AMP_Assoc structure is used in creating the physical AMP link. The exact length and format of the AMP_Assoc structure shall be defined in each AMP PAL specification.

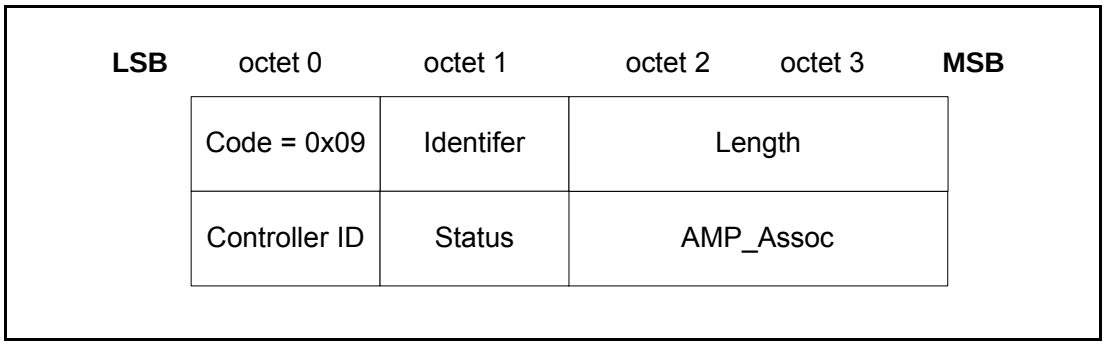

Figure 3.12: AMP Get AMP Assoc Response Packet

The data fields are

- *Controller ID (1 octet)*

  Controller ID is the identifier requested in the AMP Get AMP Assoc Request packet.

- *Status (1 octet)*

  The Status field indicates the status of the request.

Status Code	Description
0x00	Success
0x01	Invalid Controller ID
Other	Reserved for future use

Table 3.7: AMP Get AMP Assoc Response Status values

An AMP Get AMP Assoc Response packet with status of Invalid Controller ID shall be sent by an AMP manager that has received an AMP Get AMP Assoc Request packet containing either

a) A Controller ID that has not been allocated by the AMP manager

b) A Controller ID of 0

If the Status field is set to Invalid Controller ID (0x01) then the AMP_Assoc structure shall not be included in the Get AMPAssoc Response packet.

- *AMP_Assoc structure (from 0 to (A2MP MTU - 6) octets)*

  AMP_Assoc structure is variable in length. The Controller Type of the Controller ID referenced in the AMP Get AMP Assoc Request packet determines the format and the length of the AMP_Assoc structure. The length of the AMP_Assoc structure can be determined by subtracting two from the Length field.

  The length of the AMP_Assoc structure shall not exceed any previously communicated AMP_Assoc length (the AMP_Assoc length is included in the AMP Get Info Response packet. See Section 3.8).

3.11 AMP CREATE PHYSICAL LINK REQUEST (CODE 0x0A)

Establishing an AMP physical link requires signaling between the AMP Managers in order to turn the AMP Controller on, if it is not already turned on, and to provide information to set the required state of the AMP Controller, setup addressing, security, etc. When an AMP Manager receives an AMP Create Physical Link request packet it shall initiate its part of the AMP physical link creation and send the AMP Create Physical Link Response packet. AMP Create Physical Link request shall not be used to establish a physical link to the Primary BR/EDR Controller.

For some AMP Controllers it may be required to send additional information to the peer AMP Manager. This information is packaged in a variable size

AMP_Assoc structure. The exact length and format of the AMP_Assoc structure shall be defined in each AMP PAL specification.

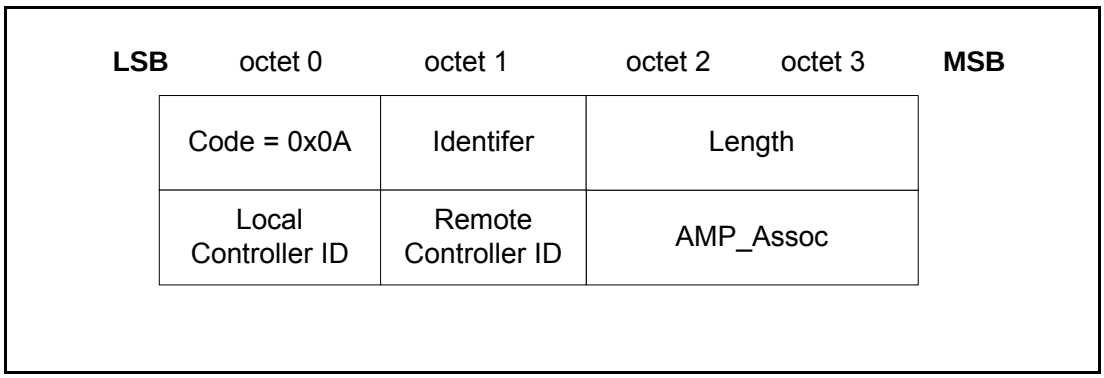

Figure 3.13: AMP Create Physical Link Request Packet

- *Local Controller ID (1 octet)*

  Local Controller ID is the ID of the Controller to be used on the device sending the AMP Create Physical Request packet.

- *Remote Controller ID (1 octet)*

  The ID of the AMP Controller to use on the device that receives the AMP Create Physical Link Request packet. The sender of the AMP Create Physical Link Request packet obtains the Remote Controller ID from the latest Discover Response, or the Change Notify packet received from the peer AMP Manager.

- *AMP_Assoc structure (from 0 to (A2MP MTU - 6) octets)*

  AMP_Assoc structure is variable in length. See section 3.10 for a description of AMP_Assoc structure.

3.12 AMP CREATE PHYSICAL LINK RESPONSE (CODE 0x0B)

For each AMP Create Physical Link Request the AMP Manager shall reply with an AMP Create Physical Link Response packet. If the device has sent its own AMP Create Physical Link Request to create a physical link with the same AMP Controller a collision has occurred and one of the requests shall be rejected while the other request shall proceed. The algorithm described in Section 3.15 shall be used to determine which request to reject.

When the AMP Manager receives an AMP Create Physical Link Request packet it shall try to perform the requested actions and send a response identifying the status of the operation.

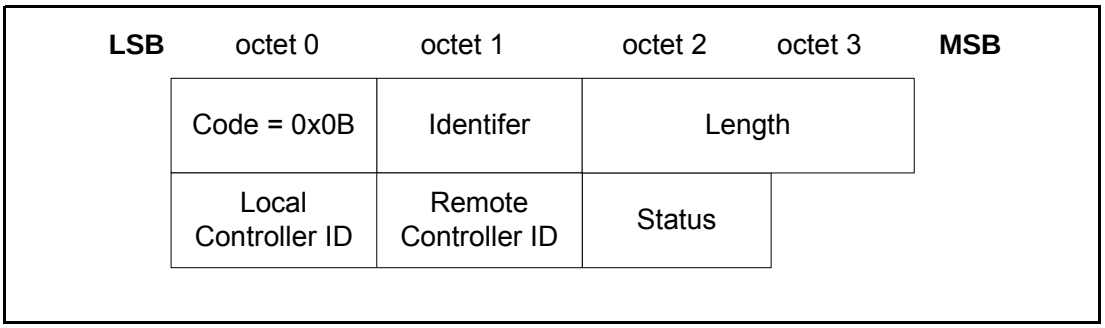

Figure 3.14: AMP Create Physical Link Response Packet

The data fields are

- *Local Controller ID (1 octet)*

  This field contains the Controller ID local to the sender of the AMP Create Physical Link Response packet. The ID value is the same as the Remote Controller ID that was in the associated AMP Create Physical Link Request packet.

- *Responder Controller ID (1 octet)*

  This field contains the Controller ID used by the receiver of the AMP Create Physical Link Response packet. The ID value is the same as the Local Controller ID that was in the associated AMP Create Physical Link Request packet.

- *Status (1 octet)*

  The Status field indicates the result of the request.

Status Code	Description
0x00	Success - Link creation is started
0x01	Invalid Controller ID
0x02	Failed - Unable to start link creation
0x03	Failed - Collision Occurred
0x04	Failed - AMP Disconnected Physical Link Request packet received
0x05	Failed - Physical Link Already Exists
0x06	Failed - Security violation
Other	Reserved for future use

Table 3.8: AMP Create Physical Link Response Status values

An AMP Create Physical Link Response with status of Invalid Controller ID shall be sent by an AMP manager that has received an AMP Create Physical Link Request containing either

a) A Controller ID that has not been allocated by the AMP manager

b) A Controller ID of 0

An AMP Create Physical Link Response with status of Failed - Security Violation shall be sent by an AMP manager that has received an AMP Create Physical Link Request without mutual authentication being performed over the BR/EDR Controller and without encryption being enabled on the BR/EDR Controller.

3.13 AMP DISCONNECT PHYSICAL LINK REQUEST (CODE 0x0C)

AMP Disconnect Physical Link request is an optional request that can be used by either initiator or responder to either abort the creation of an AMP physical link or disconnect an existing Physical Link.

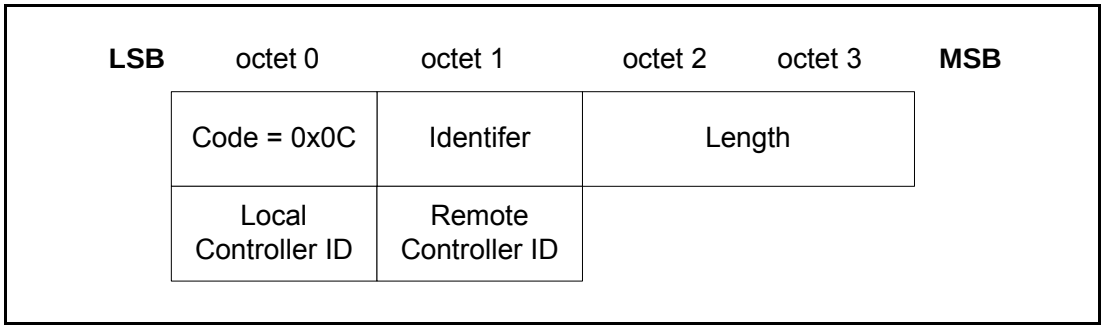

Figure 3.15: AMP Disconnect Physical Link Request Packet

The data fields are:

- *Local Controller ID (1 octet)*

  Local Controller ID is the ID of the Controller on the device sending the AMP Disconnect Physical Link Request packet.

- *Remote Controller ID (1 octet)*

  The ID of the AMP Controller on the device that receives the AMP Disconnect Physical Link Request packet.

3.14 AMP DISCONNECT PHYSICAL LINK RESPONSE (CODE 0x0D)

If an AMP Manager receives an AMP Disconnect Physical Link request packet while creation of a physical link is outstanding, it shall abort the operation. In devices that support HCI the Host may send an HCI_Disconnect_Physical_Link command to cause the Controller to abort the creation of a Physical Link.

If an AMP Disconnect Physical Link request packet is received from a device that has an AMP Create Physical Link request packet outstanding, the receiver shall send both an AMP Create Physical Link Response packet with a status of 'Failed - AMP Disconnected Physical Link Request packet received' and an AMP Disconnect Physical Link response packet with a status of 'Success'.

If an AMP manager receives an AMP Disconnect Physical Link request packet when creation of a physical link is not outstanding and a Physical Link does not exist for the given local and remote AMP IDs it shall send an AMP Disconnect Physical Link Response with a status of 'Failed - No Physical Link exists and no Physical Link creation is in progress'.

The status of 'Invalid Controller ID' shall only be used if the receiver of the AMP Disconnect Request packet does not have an AMP with an ID that matches the Remote Controller ID in the received AMP Disconnect Request packet.

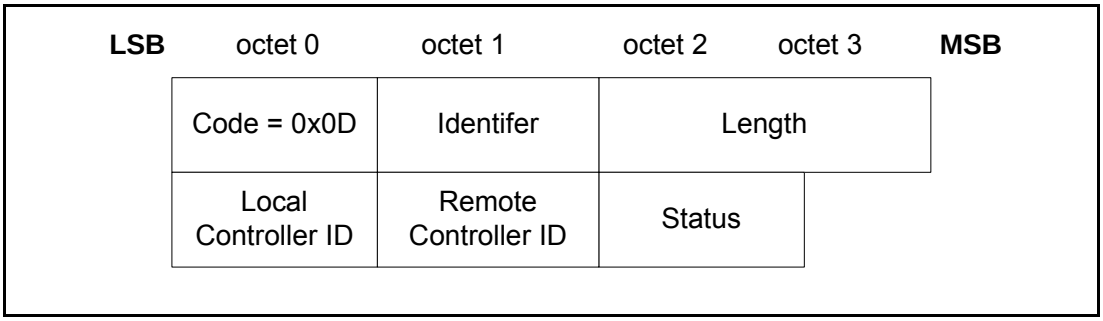

Figure 3.16: AMP Disconnect Physical Link Response Packet

The data fields are:

- *Local Controller ID (1 octet)*

  This field contains the Controller ID local to the sender of the AMP Disconnect Physical Link Response packet. The ID value is the same as the Remote Controller ID that was in the associated AMP Disconnect Physical Link Request packet.

- *Remote Controller ID (1 octet)*

  This field contains the Controller ID used by the receiver of the AMP Disconnect Physical Link Response packet. The ID value is the same as the Local Controller ID that was in the associated AMP Disconnect Physical Link Request packet.

- *Status (1 octet)*

  The Status field indicates the result of the request.

Status Code	Description
0x00	Success
0x01	Invalid Controller ID
0x02	Failed - No Physical Link exists and no Physical Link creation is in progress
Other	Reserved for future use

Table 3.9: AMP Disconnect Physical Link Response Status values

3.15 CREATE PHYSICAL LINK COLLISION RESOLUTION

If two devices simultaneously attempt to create a physical link a collision will occur. In this situation one of the requests shall be cancelled while the other request shall proceed. Both devices must know which request will be rejected. The following algorithm shall be used by both devices to determine which request to reject.

1. Set i=0 (representing the least significant octet of the BD_ADDR).
2. Compare the least significant octet, octet[i] of the BD_ADDR, of both devices. If the octets are not equal go to step 4.
3. Increment i by 1. Go to step 2.
4. The device with the larger BD_ADDR octet shall send an AMP Create Physical Link Response with the Status field set to "Failed - Collision Occurred."

3.16 RESPONSE TIMEOUT

The Response Timeout is used to monitor the response to request packets. The exact timeout value is implementation dependent and may be chosen within the range of 15 - 60 seconds. The recommended value is 20 seconds. If a response to a request packet is not received within the Response Timeout then the ACL link shall be disconnected.

3.17 UNEXPECTED BR/EDR PHYSICAL LINK DISCONNECT

It is possible that the BR/EDR link between two devices might unexpectedly disconnect (Link Supervision Timeout) while AMP links between the same two devices remain active. This situation is problematic since the BR/EDR link is used for L2CAP and AMP Manager signaling between the two devices.

When the BR/EDR link with a remote device unexpectedly disconnects due to Link Supervision Timeout the AMP manager shall disconnect all AMP physical links to the same remote device.

ATTRIBUTE PROTOCOL (ATT)

This specification defines the Attribute Protocol; a protocol for discovering, reading, and writing attributes on a peer device

CONTENTS

1 INTRODUCTION

1.1 SCOPE

The attribute protocol allows a device referred to as the server to expose a set of attributes and their associated values to a peer device referred to as the client. These attributes exposed by the server can be discovered, read, and written by a client, and can be indicated and notified by the server.

1.2 CONFORMANCE

If conformance to this protocol is claimed, all capabilities indicated as mandatory for this protocol shall be supported in the specified manner (process-mandatory). This also applies to all optional and conditional capabilities for which support is indicated. All mandatory capabilities, and optional and conditional capabilities for which support is indicated, are subject to verification as part of the Bluetooth qualification program.

1.3 CONVENTIONS

In this specification PDU names appear in italics. Error codes defined in Table 3.3 (see Section 3.4.1.1) appear in « » (e.g. «Attribute Not Found»). Other names such as parameters appear in Roman text.

2 PROTOCOL OVERVIEW

The attribute protocol defines two roles; a server role and a client role. It allows a server to expose a set of attributes to a client that are accessible using the attribute protocol.

An attribute is a discrete value that has the following three properties associated with it:

a) attribute type, defined by a UUID

b) attribute handle

c) a set of permissions that are defined by each higher layer specification that utilizes the attribute; these permissions cannot be accessed using the Attribute Protocol.

The attribute type specifies what the attribute represents. Bluetooth SIG defined attribute types are defined in the Bluetooth SIG Assigned Numbers page, and used by an associated higher layer specification. Non-Bluetooth SIG attribute types may also be defined.

The attribute handle uniquely identifies an attribute on a server, allowing a client to reference the attribute in read or write requests; see Section 3.4.4, Section 3.4.5, and Section 3.4.6. It allows a client to uniquely identify the attribute being notified or indicated, see Section 3.4.7. Clients are able to discover the handles of the server's attributes; see Section 3.4.3. Permissions may be applied to an attribute to prevent applications from obtaining or altering an attribute's value. An attribute may be defined by a higher layer specification to be readable or writable or both, and may have additional security requirements. For more information, see Section 3.2.5.

A client may send attribute protocol requests to a server, and the server shall respond to all requests that it receives. A device can implement both client and server roles, and both roles can function concurrently in the same device and between the same devices. There shall be only one instance of a server on each Bluetooth device; this implies that the attribute handles shall be identical for all supported bearers. For a given client, the server shall have one set of attributes. The server can support multiple clients. Note: Multiple services may be exposed on a single server by allocating separate ranges of handles for each service. The discovery of these handle ranges is defined by a higher layer specification.

The attribute protocol has notification and indication capabilities that provide an efficient way of sending attribute values to a client without the need for them to be read; see Section 3.3.

3 PROTOCOL REQUIREMENTS

3.1 INTRODUCTION

Each attribute has an attribute type that identifies, by means of a UUID (Universally Unique IDentifier), what the attribute represents so that a client can understand the attributes exposed by a server. Each attribute has an attribute handle that is used for accessing the attribute on a server, as well as an attribute value.

An attribute value is accessed using its attribute handle. The attribute handles are discovered by a client using attribute protocol PDUs (Protocol Data Unit). Attributes that have the same attribute type may exist more than once in a server. Attributes also have a set of permissions that controls whether they can be read or written, or whether the attribute value shall be sent over an encrypted link. Security aspects of the attribute protocol are defined in Section 4.

3.2 BASIC CONCEPTS

3.2.1 Attribute Type

A universally unique identifier (UUID) is used to identify every attribute type. A UUID is considered unique over all space and time. A UUID can be independently created by anybody and distributed or published as required. There is no central registry for UUIDs, as they are based off a unique identifier that is not duplicated. The attribute protocol allows devices to identify attribute types using UUIDs regardless of the local handle used to identify them in a read or write request.

Universal unique identifiers are defined in SDP [Vol 3] Part B, Section 2.5.1.

All 32-bit Attribute UUIDs shall be converted to 128-bit UUIDs when the Attribute UUID is contained in an ATT PDU.

3.2.2 Attribute Handle

An attribute handle is a 16-bit value that is assigned by each server to its own attributes to allow a client to reference those attributes. An attribute handle shall not be reused while an ATT Bearer exists between a client and its server.

Attribute handles on any given server shall have unique, non-zero values. Attributes are ordered by attribute handle.

An attribute handle of value 0x0000 is reserved for future use. An attribute handle of value 0xFFFF is known as the maximum attribute handle.

Note: Attributes can be added or removed while an ATT Bearer is active, however, an attribute that has been removed cannot be replaced by another attribute with the same handle while an ATT Bearer is active.

3.2.3 Attribute Handle Grouping

Grouping is defined by a specific attribute placed at the beginning of a range of other attributes that are grouped with that attribute, as defined by a higher layer specification. Clients can request the first and last handles associated with a group of attributes.

3.2.4 Attribute Value

An attribute value is an octet array that may be either fixed or variable length. For example, it can be a one octet value, or a four octet integer, or a variable length string. An attribute may contain a value that is too large to transmit in a single PDU and can be sent using multiple PDUs. The values that are transmitted are opaque to the attribute protocol. The encoding of these octet arrays is defined by the attribute type.

When transmitting attribute values in a request, a response, a notification or an indication, the attribute value length is not sent in any field of the PDU. The length of a variable length field in the PDU is implicitly given by the length of the packet that carries this PDU. This implies that:

a) only one attribute value can be placed in a single request, response, notification or indication unless the attribute values have lengths known by both the server and client, as defined by the attribute type.

b) This attribute value will always be the only variable length field of a request, response, notification or indication.

c) The bearer protocol (e.g. L2CAP) preserves datagram boundaries.

Note: Some responses include multiple attribute values, for example when client requests multiple attribute reads. For the client to determine the attribute value boundaries, the attribute values must have a fixed size defined by the attribute type.

3.2.5 Attribute Permissions

An attribute has a set of permission values associated with it. The permissions associated with an attribute specifies that it may be read and/or written. The permissions associated with the attribute specifies the security level required for read and/or write access, as well as notification and/or indication. The permissions of a given attribute are defined by a higher layer specification, and are not discoverable using the attribute protocol.

If access to a secure attribute requires an authenticated link, and the client is not already authenticated with the server with sufficient security, then an error response shall be sent with the error code «Insufficient Authentication». When a client receives this error code it may try to authenticate the link, and if the authentication is successful, it can then access the secure attribute.

If access to a secure attribute requires an encrypted link, and the link is not encrypted, then an error response shall be sent with the error code «Insufficient Encryption». When a client receives this error code it may try to encrypt the link and if the encryption is successful, it can then access the secure attribute.

If access to a secure attribute requires an encrypted link, and the link is encrypted but with an encryption key size that is too short for the level of security required, then an error response shall be sent with the error code «Insufficient Encryption Key Size». When a client receives this error code it may try to encrypt the link with a larger key size, and if the encryption is successful, it can then access the secure attribute.

Attribute permissions are a combination of access permissions, encryption permissions, authentication permissions and authorization permissions.

The following access permissions are possible:

- Readable
- Writeable
- Readable and writable

The following encryption permissions are possible:

- Encryption required
- No encryption required

The following authentication permissions are possible:

- Authentication Required
- No Authentication Required

The following authorization permissions are possible:

- Authorization Required
- No Authorization Required

Encryption, authentication, and authorization permissions can have different possibilities; for example, a specific attribute could require a particular kind of authentication or a certain minimum encryption key length. An attribute can have several combinations of permissions that apply; for example, a specific attribute could allow any of the following:

- Read if encrypted (authentication not required)

- Write if authenticated and encrypted
- Read or write if authenticated and authorized (irrespective of encryption)

Access permissions are used by a server to determine if a client can read and/or write an attribute value.

Authentication permissions are used by a server to determine if an authenticated physical link is required when a client attempts to access an attribute. Authentication permissions are also used by a server to determine if an authenticated physical link is required before sending a notification or indication to a client.

Authorization permissions determine if a client needs to be authorized before accessing an attribute value.

3.2.6 Control-Point Attributes

Attributes that cannot be read, but can only be written, notified or indicated are called control-point attributes. These control-point attributes can be used by higher layers to enable device specific procedures, for example the writing of a command or the indication when a given procedure on a device has completed.

3.2.7 Protocol Methods

The attribute protocol uses methods defined in Section 3.4 to find, read, write, notify, and indicate attributes. A method is categorized as either a command, a request, a response, a notification, an indication, or a confirmation method; see Section 3.3. Some attribute protocol PDUs can also include an Authentication Signature, to allow authentication of the originator of this PDU without requiring encryption. The method and signed bit are known as the opcode.

3.2.8 Exchanging MTU Size

ATT_MTU is defined as the maximum size of any packet sent between a client and a server. A higher layer specification defines the default ATT_MTU value.

The client and server may optionally exchange the maximum size of a packet that can be received using the Exchange MTU Request and Response PDUs. Both devices then use the minimum of these exchanged values for all further communication (see Section 3.4.2).

A device that is acting as a server and client at the same time shall use the same value for Client Rx MTU and Server Rx MTU.

The ATT_MTU value is a per ATT Bearer value. Note: A device with multiple ATT Bearers may have a different ATT_MTU value for each ATT Bearer.

3.2.9 Long Attribute Values

The longest attribute that can be sent in a single packet is (ATT_MTU-1) octets in size. At a minimum, the Attribute Opcode is included in an Attribute PDU.

An attribute value may be defined to be larger than (ATT_MTU-1) octets in size. These attributes are called long attributes.

To read the entire value of an attributes larger than (ATT_MTU-1) octets, the read blob request is used. It is possible to read the first (ATT_MTU-1) octets of a long attribute value using the read request.

To write the entire value of an attribute larger than (ATT_MTU-3) octets, the prepare write request and execute write request is used. It is possible to write the first (ATT_MTU-3) octets of a long attribute value using the write request.

It is not possible to determine if an attribute value is longer than (ATT_MTU-3) octets using this protocol. A higher layer specification will state that a given attribute can have a maximum length larger than (ATT_MTU-3) octets.

The maximum length of an attribute value shall be 512 octets.

Note: The protection of an attribute value changing when reading the value using multiple attribute protocol PDUs is the responsibility of the higher layer.

3.2.10 Atomic Operations

The server shall treat each request or command as an atomic operation that cannot be affected by another client sending a request or command at the same time. If a physical link is disconnected for any reason (user action or loss of the radio link), the value of any modified attribute is the responsibility of the higher layer specification.

Long attributes cannot be read or written in a single atomic operation.

3.3 ATTRIBUTE PDU

Attribute PDUs have one of six types:

- Commands—PDUs sent to a server by a client that do not invoke a response.
- Requests—PDUs sent to a server by a client that invoke a response.
- Responses—PDUs sent to a client by a server in response to a request.
- Notifications—Unsolicited PDUs sent to a client by a server that do not invoke a confirmation.
- Indications—Unsolicited PDUs sent to a client by a server that invoke a confirmation.

- Confirmations—PDUs sent to a server by a client to confirm receipt of an indication.

A server shall be able to receive and properly respond to the following requests:

- *Find Information Request*
- *Read Request*

Support for all other PDU types in a server can be specified in a higher layer specification, see Section 3.4.8.

If a client sends a request, then the client shall support all possible responses PDUs for that request.

If a server receives a request that it does not support, then the server shall respond with the *Error Response* with the Error Code «Request Not Supported», with the Attribute Handle In Error set to 0x0000.

If a server receives a command that it does not support, indicated by the Command Flag of the PDU set to one, then the server shall ignore the Command.

If the server receives an invalid request – for example, the PDU is the wrong length – then the server shall respond with the *Error Response* with the Error Code «Invalid PDU», with the Attribute Handle In Error set to 0x0000.

If a server does not have sufficient resources to process a request, then the server shall respond with the *Error Response* with the Error Code «Insufficient Resources», with the Attribute Handle In Error set to 0x0000.

If a server cannot process a request because an error was encountered during the processing of this request, then the server shall respond with the *Error Response* with the Error Code «Unlikely Error», with the Attribute Handle In Error set to 0x0000.

3.3.1 Attribute PDU Format

Attribute PDUs has the following format:

Name	Size (octets)	Description
Attribute Opcode	1	The attribute PDU operation code bit7: Authentication Signature Flag bit6: Command Flag bit5-0: Method

Table 3.1: Format of Attribute PDU

Name	Size (octets)	Description
Attribute Parameters	0 to (ATT_MTU - X)	The attribute PDU parameters X = 1 if Authentication Signature Flag of the Attribute Opcode is 0 X = 13 if Authentication Signature Flag of the Attribute Opcode is 1
Authentication Signature	0 or 12	Optional authentication signature for the Attribute Opcode and Attribute Parameters

Table 3.1: Format of Attribute PDU

Multi-octet fields within the attribute protocol shall be sent least significant octet first (little endian) with the exception of the Attribute Value field. The endianness of the Attribute Value field is defined by a higher layer specification.

The Attribute Opcode is composed of three fields, the Authentication Signature Flag, the Command Flag, and the Method. The Method is a 6-bit value that determines the format and meaning of the Attribute Parameters.

If the Authentication Signature Flag of the Attribute Opcode is set to one, the Authentication Signature value shall be appended to the end of the attribute PDU, and X is 13. If the Authentication Signature Flag of the Attribute Opcode is set to zero, the Authentication Signature value shall not be appended, and X is 1.

The Authentication Signature field is calculated as defined in Security Manager (see [Vol 3] Part H, Section 2.4.5). This value provides an Authentication Signature for the variable length message (m) consisting of the following values in this order: Attribute Opcode, Attribute Parameters.

An Attribute PDU that includes an Authentication Signature should not be sent on an encrypted link. Note: An encrypted link already includes authentication data on every packet and therefore adding more authentication data is not required.

If the Command Flag of the Attribute Opcode is set to one, the PDU shall be considered to be a Command.

Only the Write Command may include an Authentication Signature.

3.3.2 Sequential Protocol

Many attribute protocol PDUs use a sequential request-response protocol.

Once a client sends a request to a server, that client shall send no other request to the same server until a response PDU has been received.

Indications sent from a server also use a sequential indication-confirmation protocol. No other indications shall be sent to the same client from this server until a confirmation PDU has been received. The client, however, is free to send commands and requests prior to sending a confirmation.

For notifications, which do not have a response PDU, there is no flow control and a notification can be sent at any time.

Commands that do not require a response do not have any flow control. Note: A server can be flooded with commands, and a higher layer specification can define how to prevent this from occurring.

Commands and notifications that are received but cannot be processed, due to buffer overflows or other reasons, shall be discarded. Therefore, those PDUs must be considered to be unreliable.

Note: Flow control for each client and a server is independent.

Note: It is possible for a server to receive a request, send one or more notifications, and then the response to the original request. The flow control of requests is not affected by the transmission of the notifications.

Note: It is possible for a server to receive a request and then a command before responding to the original request. The flow control of requests is not affected by the transmission of commands.

Note: It is possible for a notification from a server to be sent after an indication has been sent but the confirmation has not been received. The flow control of indications is not affected by the transmission of notifications.

Note: It is possible for a client to receive an indication from a server and then send a request or command to that server before sending the confirmation of the original indication.

3.3.3 Transaction

An attribute protocol request and response or indication-confirmation pair is considered a single transaction. A transaction shall always be performed on one ATT Bearer, and shall not be split over multiple ATT Bearers.

On the client, a transaction shall start when the request is sent by the client. A transaction shall complete when the response is received by the client.

On a server, a transaction shall start when a request is received by the server. A transaction shall complete when the response is sent by the server.

On a server, a transaction shall start when an indication is sent by the server. A transaction shall complete when the confirmation is received by the server.

On a client, a transaction shall start when an indication is received by the client. A transaction shall complete when the confirmation is sent by the client.

A transaction not completed within 30 seconds shall time out. Such a transaction shall be considered to have failed and the local higher layers shall

be informed of this failure. No more attribute protocol requests, commands, indications or notifications shall be sent to the target device on this ATT Bearer.

Note: To send another attribute protocol PDU, a new ATT Bearer must be established between these devices. The existing ATT Bearer may need to be disconnected or the bearer terminated before the new ATT Bearer is established.

If the ATT Bearer is disconnected during a transaction, then the transaction shall be considered to be closed, and any values that were being modified on the server will be in an undetermined state, and any queue that was prepared by the client using this ATT Bearer shall be cleared.

Note: Each Prepare Write Request is a separate request and is therefore a separate transaction.

Note: Each Read Blob Request is a separate request and is therefore a separate transaction.

3.4 ATTRIBUTE PROTOCOL PDUS

3.4.1 Error Handling

3.4.1.1 Error Response

The *Error Response* is used to state that a given request cannot be performed, and to provide the reason.

Note: The Write Command does not generate an Error Response.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x01 = Error Response
Request Opcode In Error	1	The request that generated this error response
Attribute Handle In Error	2	The attribute handle that generated this error response
Error Code	1	The reason why the request has generated an error response

Table 3.2: Format of Error Response

The Request Opcode In Error parameter shall be set to the Attribute Opcode of the request that generated this error.

The Attribute Handle In Error parameter shall be set to the attribute handle in the original request that generated this error. If there was no attribute handle in

the original request or if the request is not supported, then the value 0x0000 shall be used for this field.

The Error Code parameter shall be set to one of the following values:

Name	Error Code	Description
Invalid Handle	0x01	The attribute handle given was not valid on this server.
Read Not Permitted	0x02	The attribute cannot be read.
Write Not Permitted	0x03	The attribute cannot be written.
Invalid PDU	0x04	The attribute PDU was invalid.
Insufficient Authentication	0x05	The attribute requires authentication before it can be read or written.
Request Not Supported	0x06	Attribute server does not support the request received from the client.
Invalid Offset	0x07	Offset specified was past the end of the attribute.
Insufficient Authorization	0x08	The attribute requires authorization before it can be read or written.
Prepare Queue Full	0x09	Too many prepare writes have been queued.
Attribute Not Found	0x0A	No attribute found within the given attribute handle range.
Attribute Not Long	0x0B	The attribute cannot be read using the Read Blob Request.
Insufficient Encryption Key Size	0x0C	The Encryption Key Size used for encrypting this link is insufficient.
Invalid Attribute Value Length	0x0D	The attribute value length is invalid for the operation.
Unlikely Error	0x0E	The attribute request that was requested has encountered an error that was unlikely, and therefore could not be completed as requested.
Insufficient Encryption	0x0F	The attribute requires encryption before it can be read or written.
Unsupported Group Type	0x10	The attribute type is not a supported grouping attribute as defined by a higher layer specification.
Insufficient Resources	0x11	Insufficient Resources to complete the request.
Reserved for future use	0x012 – 0x7F	Reserved for future use.

Table 3.3: Error Codes

Name	Error Code	Description
Application Error	0x80-0x9F	Application error code defined by a higher layer specification.
Reserved for future use	0xA0 – 0xDF	Reserved for future use
Common Profile and Service Error Codes	0xE0 – 0xFF	Common profile and service error codes defined in [Core Specification Supplement], Part B.

Table 3.3: Error Codes

If an error code is received in the *Error Response* that is not understood by the client, for example an error code that was reserved for future use that is now being used in a future version of this specification, then the *Error Response* shall still be considered to state that the given request cannot be performed for an unknown reason.

3.4.2 MTU Exchange

3.4.2.1 Exchange MTU Request

The *Exchange MTU Request* is used by the client to inform the server of the client's maximum receive MTU size and request the server to respond with its maximum receive MTU size.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x02 = Exchange MTU Request
Client Rx MTU	2	Client receive MTU size

Table 3.4: Format of Exchange MTU Request

The Client Rx MTU shall be greater than or equal to the default ATT_MTU.

This request shall only be sent once during a connection by the client. The Client Rx MTU parameter shall be set to the maximum size of the attribute protocol PDU that the client can receive.

3.4.2.2 Exchange MTU Response

The *Exchange MTU Response* is sent in reply to a received *Exchange MTU Request*.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x03 = Exchange MTU Response
Server Rx MTU	2	Attribute server receive MTU size

Table 3.5: Format of Exchange MTU Response

The Server Rx MTU shall be greater than or equal to the default ATT_MTU.

The Server Rx MTU parameter shall be set to the maximum size of the attribute protocol PDU that the server can receive.

The server and client shall set ATT_MTU to the minimum of the Client Rx MTU and the Server Rx MTU. The size is the same to ensure that a client can correctly detect the final packet of a long attribute read.

This ATT_MTU value shall be applied in the server after this response has been sent and before any other attribute protocol PDU is sent.

This ATT_MTU value shall be applied in the client after this response has been received and before any other attribute protocol PDU is sent.

If either Client Rx MTU or Service Rx MTU are incorrectly less than the default ATT_MTU, then the ATT_MTU shall not be changed and the ATT_MTU shall be the default ATT_MTU.

If a device is both a client and a server, the following rules shall apply:

1. A device's *Exchange MTU Request* shall contain the same MTU as the device's *Exchange MTU Response* (i.e. the MTU shall be symmetric).
2. If MTU is exchanged in one direction, that is sufficient for both directions.
3. It is permitted, (but not necessary - see 2.) to exchange MTU in both directions, but the MTUs shall be the same in each direction (see 1.)
4. If an Attribute Protocol Request is received after the MTU Exchange Request is sent and before the MTU Exchange Response is received, the associated Attribute Protocol Response shall use the default MTU. Figure 3.1 shows an example that is covered by this rule. In this case device A and device B both use the default MTU for the Attribute Protocol Response.
5. Once the MTU Exchange Request has been sent, the initiating device shall not send an Attribute Protocol Indication or Notification until after the MTU Exchange Response has been received. Note: This stops the risk of a cross-over condition where the MTU size is unknown for the Indication or Notification.

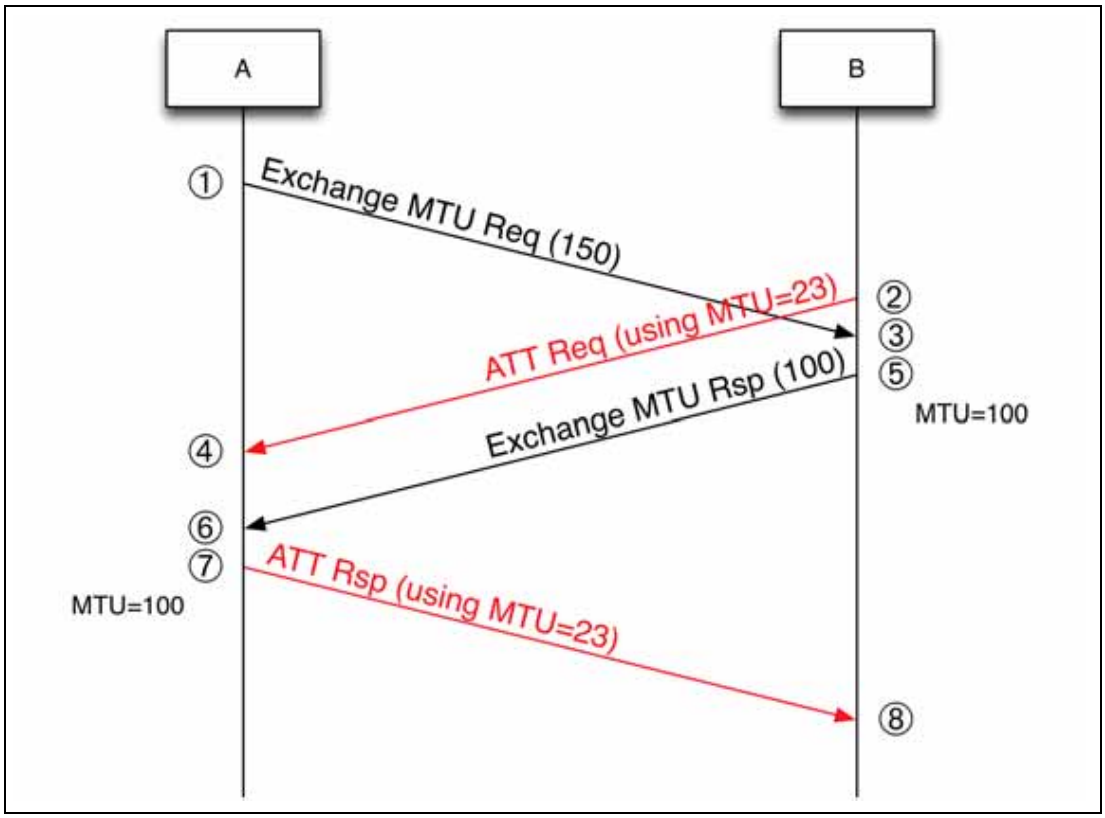

Figure 3.1: MTU request and response exchange

3.4.3 Find Information

3.4.3.1 Find Information Request

The *Find Information Request* is used to obtain the mapping of attribute handles with their associated types. This allows a client to discover the list of attributes and their types on a server.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x04 = Find Information Request
Starting Handle	2	First requested handle number
Ending Handle	2	Last requested handle number

Table 3.6: Format of Find Information Request

Only attributes with attribute handles between and including the Starting Handle parameter and the Ending Handle parameter will be returned. To read all attributes, the Starting Handle parameter shall be set to 0x0001, and the Ending Handle parameter shall be set to 0xFFFF. The Starting Handle parameter shall be less than or equal to the Ending Handle parameter.

If one or more attributes will be returned, a *Find Information Response* PDU shall be sent.

If a server receives a *Find Information Request* with the Starting Handle parameter greater than the Ending Handle parameter or the Starting Handle parameter is 0x0000, an *Error Response* shall be sent with the «Invalid Handle» error code; the Attribute Handle In Error parameter shall be set to the Starting Handle parameter.

If no attributes will be returned, an *Error Response* shall be sent with the «Attribute Not Found» error code; the Attribute Handle In Error parameter shall be set to the Starting Handle parameter.

The server shall not respond to the *Find Information Request* with an *Error Response* with the «Insufficient Authentication», «Insufficient Authorization», «Insufficient Encryption Key Size» or «Application Error» error code.

3.4.3.2 Find Information Response

The *Find Information Response* is sent in reply to a received *Find Information Request* and contains information about this server.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x05 = Find Information Response
Format	1	The format of the information data.
Information Data	4 to (ATT_MTU-2)	The information data whose format is determined by the Format field

Table 3.7: Format of Find Information Response

The *Find Information Response* shall have complete handle-UUID pairs. Such pairs shall not be split across response packets; this also implies that a handle-UUID pair shall fit into a single response packet. The handle-UUID pairs shall be returned in ascending order of attribute handles.

The Format parameter can contain one of two possible values.

Name	Format	Description
Handle(s) and 16-bit Bluetooth UUID(s)	0x01	A list of 1 or more handles with their 16-bit Bluetooth UUIDs
Handle(s) and 128-bit UUID(s)	0x02	A list of 1 or more handles with their 128-bit UUIDs

Table 3.8: Format field values

The information data field is comprised of a list of data defined in the tables below depending on the value chosen for the format.

Handle	16-bit Bluetooth UUID
2 octets	2 octets

Table 3.9: Format 0x01 - handle and 16-bit Bluetooth UUIDs

Handle	128-bit UUID
2 octets	16 octets

Table 3.10: Format 0x02 - handle and 128-bit UUIDs

Note: If sequential attributes have differing UUID sizes, it may happen that a *Find Information Response* is not filled with the maximum possible amount of (handle, UUID) pairs. This is because it is not possible to include attributes with differing UUID sizes into a single response packet. In that case, the following attribute would have to be read using another *Find Information Request* with its starting handle updated.

3.4.3.3 Find By Type Value Request

The *Find By Type Value Request* is used to obtain the handles of attributes that have a 16-bit UUID attribute type and attribute value.This allows the range of handles associated with a given attribute to be discovered when the attribute type determines the grouping of a set of attributes. Note: Generic Attribute Profile defines grouping of attributes by attribute type.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x06 = Find By Type Value Request
Starting Handle	2	First requested handle number
Ending Handle	2	Last requested handle number
Attribute Type	2	2 octet UUID to find
Attribute Value	0 to (ATT_MTU-7)	Attribute value to find

Table 3.11: Format of Find By Type Value Request

Only attributes with attribute handles between and including the Starting Handle parameter and the Ending Handle parameter that match the requested attribute type and the attribute value that have sufficient permissions to allow reading will be returned. To read all attributes, the Starting Handle parameter shall be set to 0x0001, and the Ending Handle parameter shall be set to 0xFFFF.

If one or more handles will be returned, a *Find By Type Value Response* PDU shall be sent.

Note: Attribute values will be compared in terms of length and binary representation.

Note: It is not possible to use this request on an attribute that has a value longer than (ATT_MTU-7).

If a server receives a *Find By Type Value Request* with the Starting Handle parameter greater than the Ending Handle parameter or the Starting Handle parameter is 0x0000, an *Error Response* shall be sent with the «Invalid Handle» error code. The Attribute Handle In Error parameter shall be set to the Starting Handle parameter.

If no attributes will be returned, an *Error Response* shall be sent by the server with the error code «Attribute Not Found». The Attribute Handle In Error parameter shall be set to the starting handle.

The server shall not respond to the *Find By Type Value Request* with an *Error Response* with the «Insufficient Authentication», «Insufficient Authorization», «Insufficient Encryption Key Size», «Insufficient Encryption» or «Application Error» error code.

3.4.3.4 Find By Type Value Response

The *Find By Type Value Response* is sent in reply to a received *Find By Type Value Request* and contains information about this server.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x07 = Find By Type Value Response
Handles Information List	4 to (ATT_MTU-1)	A list of 1 or more Handle Informations

Table 3.12: Format of Find By Type Value Response

The Handles Information List field is a list of one or more Handle Informations. The Handles Information field is an attribute handle range as defined in Table 3.13.

Found Attribute Handle	Group End Handle
2 octets	2 octets

Table 3.13: Format of the Handles Information

The *Find By Type Value Response* shall contain one or more complete Handles Information. Such Handles Information shall not be split across response packets. The Handles Information List is ordered sequentially based on the found attribute handles.

For each handle that matches the attribute type and attribute value in the *Find By Type Value Request* a Handles Information shall be returned. The Found Attribute Handle shall be set to the handle of the attribute that has the exact attribute type and attribute value from the *Find By Type Value Request*. If the attribute type in the *Find By Type Value Request* is a grouping attribute as defined by a higher layer specification, the Group End Handle shall be defined by that higher layer specification. If the attribute type in the *Find By Type Value Request* is not a grouping attribute as defined by a higher layer specification, the Group End Handle shall be equal to the Found Attribute Handle.

Note: The Group End Handle may be greater than the Ending Handle in the *Find By Type Value Request*.

If a server receives a *Find By Type Value Request*, the server shall respond with the *Find By Type Value Response* containing as many handles for attributes that match the requested attribute type and attribute value that exist in the server that will fit into the maximum PDU size of (ATT_MTU-1).

3.4.4 Reading Attributes

3.4.4.1 Read By Type Request

The *Read By Type Request* is used to obtain the values of attributes where the attribute type is known but the handle is not known.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x08 = Read By Type Request
Starting Handle	2	First requested handle number
Ending Handle	2	Last requested handle number
Attribute Type	2 or 16	2 or 16 octet UUID

Table 3.14: Format of Read By Type Request

Only the attributes with attribute handles between and including the Starting Handle and the Ending Handle with the attribute type that is the same as the Attribute Type given will be returned. To search through all attributes, the starting handle shall be set to 0x0001 and the ending handle shall be set to 0xFFFF.

Note: All attribute types are effectively compared as 128-bit UUIDs, even if a 16-bit UUID is provided in this request or defined for an attribute. See [Vol 3] Part B, Section 2.5.1.

The starting handle shall be less than or equal to the ending handle. If a server receives a *Read By Type Request* with the Starting Handle parameter greater than the Ending Handle parameter or the Starting Handle parameter is 0x0000, an *Error Response* shall be sent with the «Invalid Handle» error code; The Attribute Handle In Error parameter shall be set to the Starting Handle parameter.

If no attribute with the given type exists within the handle range, then no attribute handle and value will be returned, and an *Error Response* shall be sent with the error code «Attribute Not Found». The Attribute Handle In Error parameter shall be set to the starting handle.

The attributes returned shall be the attributes with the lowest handles within the handle range. These are known as the requested attributes.

If the attributes with the requested type within the handle range have attribute values that have the same length, then these attributes can all be read in a single request.

The attribute server shall include as many attributes as possible in the response in order to minimize the number of PDUs required to read attributes of the same type.

Note: If the attributes with the requested type within the handle range have attribute values with different lengths, then multiple *Read By Type Request*s must be made.

When multiple attributes match, then the rules below shall be applied to each in turn.

- Only attributes that can be read shall be returned in a *Read By Type Response*.
- If an attribute in the set of requested attributes would cause an *Error Response* then this attribute cannot be included in a *Read By Type Response* and the attributes before this attribute shall be returned.
- If the first attribute in the set of requested attributes would cause an *Error Response* then no other attributes in the requested attributes can be considered.

The server shall respond with a *Read By Type Response* if the requested attributes have sufficient permissions to allow reading.

If the client has insufficient authorization to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has insufficient security to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has an insufficient encryption key size to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has not enabled encryption, and encryption is required to read the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the requested attribute's value cannot be read due to permissions then an *Error Response* shall be sent with the error code «Read Not Permitted». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

Note: If there are multiple attributes with the requested type within the handle range, and the client would like to get the next attribute with the requested type, it would have to issue another *Read By Type Request* with its starting handle updated. The client can be sure there are no more such attributes remaining once it gets an *Error Response* with the error code «Attribute Not Found».

3.4.4.2 Read By Type Response

The *Read By Type Response* is sent in reply to a received *Read By Type Request* and contains the handles and values of the attributes that have been read.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x09 = Read By Type Response
Length	1	The size of each attribute handle-value pair
Attribute Data List	2 to (ATT_MTU- 2)	A list of Attribute Data

Table 3.15: Format of Read By Type Response

The *Read By Type Response* shall contain complete handle-value pairs. Such pairs shall not be split across response packets. The handle-value pairs shall be returned sequentially based on the attribute handle.

The Length parameter shall be set to the size of one attribute handle-value pair.

The maximum length of an attribute handle-value pair is 255 octets, bounded by the Length parameter that is one octet. Therefore, the maximum length of an attribute value returned in this response is (Length – 2) = 253 octets.

The attribute handle-value pairs shall be set to the value of the attributes identified by the attribute type within the handle range within the request. If the attribute value is longer than (ATT_MTU - 4) or 253 octets, whichever is smaller, then the first (ATT_MTU - 4) or 253 octets shall be included in this response.

Note: The *Read Blob Request* would be used to read the remaining octets of a long attribute value.

The Attribute Data field is comprised of a list of attribute handle and value pairs as defined in Table 3.16.

Attribute Handle	Attribute Value
2 octets	(Length – 2) octets

Table 3.16: Format of the Attribute Data

3.4.4.3 Read Request

The *Read Request* is used to request the server to read the value of an attribute and return its value in a *Read Response*.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0A = Read Request
Attribute Handle	2	The handle of the attribute to be read

Table 3.17: Format of Read Request

The attribute handle parameter shall be set to a valid handle.

The server shall respond with a *Read Response* if the handle is valid and the attribute has sufficient permissions to allow reading.

If the client has insufficient authorization to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization».

If the client has insufficient security to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication».

If the client has an insufficient encryption key size to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size».

If the client has not enabled encryption, and encryption is required to read the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption».

If the handle is invalid, then an *Error Response* shall be sent with the error code «Invalid Handle».

If the attribute value cannot be read due to permissions then an *Error Response* shall be sent with the error code «Read Not Permitted».

3.4.4.4 Read Response

The read response is sent in reply to a received *Read Request* and contains the value of the attribute that has been read.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0B = Read Response
Attribute Value	0 to (ATT_MTU-1)	The value of the attribute with the handle given

Table 3.18: Format of Read Response

The attribute value shall be set to the value of the attribute identified by the attribute handle in the request. If the attribute value is longer than (ATT_MTU-1) then the first (ATT_MTU-1) octets shall be included in this response.

Note: The *Read Blob Request* would be used to read the remaining octets of a long attribute value.

3.4.4.5 Read Blob Request

The *Read Blob Request* is used to request the server to read part of the value of an attribute at a given offset and return a specific part of the value in a *Read Blob Response*.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0C = Read Blob Request
Attribute Handle	2	The handle of the attribute to be read
Value Offset	2	The offset of the first octet to be read

Table 3.19: Format of Read Blob Request

The attribute handle parameter shall be set to a valid handle.

The value offset parameter is based from zero; the first value octet has an offset of zero, the second octet has a value offset of one, etc.

The server shall respond with a *Read Blob Response* if the handle is valid and the attribute and value offset is not greater than the length of the attribute value and has sufficient permissions to allow reading.

If the client has insufficient authorization to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization».

If the client has insufficient security to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication».

If the client has an insufficient encryption key size to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size».

If the client has not enabled encryption, and encryption is required to read the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption».

If the handle is invalid, then an *Error Response* shall be sent with the error code «Invalid Handle».

If the attribute value cannot be read due to permissions then an *Error Response* shall be sent with the error code «Read Not Permitted».

If the value offset of the *Read Blob Request* is greater than the length of the attribute value, an *Error Response* shall be sent with the error code «Invalid Offset».

If the attribute value has a fixed length that is less than or equal to (ATT_MTU - 1) octets in length, then an *Error Response* may be sent with the error code «Attribute Not Long».

If the value offset of the *Read Blob Request* is equal to the length of the attribute value, then the length of the part attribute value in the response shall be zero.

Note: If the attribute is longer than (ATT_MTU-1) octets, the Read Blob Request is the only way to read the additional octets of a long attribute. The first (ATT_MTU-1) octets may be read using a *Read Request*, an *Handle Value Notification* or an *Handle Value Indication*.

Note: Long attributes may or may not have their length specified by a higher layer specification. If the long attribute has a variable length, the only way to get to the end of it is to read it part by part until the value in the *Read Blob Response* has a length shorter than (ATT_MTU-1) or an *Error Response* with the error code «Invalid Offset».

Note: The value of a Long Attribute may change between one Read Blob Request and the next Read Blob Request. A higher layer specification should be aware of this and define appropriate behavior.

3.4.4.6 Read Blob Response

The *Read Blob Response* is sent in reply to a received *Read Blob Request* and contains part of the value of the attribute that has been read.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0D = Read Blob Response
Part Attribute Value	0 to (ATT_MTU-1)	Part of the value of the attribute with the handle given

Table 3.20: Format of Read Blob Response

The part attribute value shall be set to part of the value of the attribute identified by the attribute handle and the value offset in the request. If the value offset is equal to the length of the attribute value, then the length of the part attribute value shall be zero. If the attribute value is longer than (Value Offset + ATT_MTU-1) then (ATT_MTU-1) octets from Value Offset shall be included in this response.

3.4.4.7 Read Multiple Request

The *Read Multiple Request* is used to request the server to read two or more values of a set of attributes and return their values in a *Read Multiple Response*. Only values that have a known fixed size can be read, with the exception of the last value that can have a variable length. The knowledge of whether attributes have a known fixed size is defined in a higher layer specification.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0E = Read Multiple Request
Set Of Handles	4 to (ATT_MTU - 1)	A set of two or more attribute handles.

Table 3.21: Format of Read Multiple Request

The attribute handles in the Set Of Handles parameter shall be valid handles.

The server shall respond with a *Read Multiple Response* if all the handles are valid and all attributes have sufficient permissions to allow reading.

Note: The attribute values for the attributes in the Set Of Handles parameters do not have to all be the same size.

Note: The attribute handles in the Set Of Handles parameter do not have to be in attribute handle order; they are in the order that the values are required in the response.

If the client has insufficient authorization to read any of the attributes then an *Error Response* shall be sent with the error code «Insufficient Authorization».

If the client has insufficient security to read any of the attributes then an *Error Response* shall be sent with the error code «Insufficient Authentication».

If the client has an insufficient encryption key size to read any of the attributes then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size».

If the client has not enabled encryption, and encryption is required to read the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption».

If any of the handles are invalid, then an *Error Response* shall be sent with the error code «Invalid Handle».

If any of the attribute values cannot be read due to permissions then an *Error Response* shall be sent with the error code «Read Not Permitted».

If an *Error Response* is sent, the Attribute Handle In Error parameter shall be set to the handle of the first attribute causing the error.

3.4.4.8 Read Multiple Response

The read response is sent in reply to a received *Read Multiple Request* and contains the values of the attributes that have been read.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x0F = Read Multiple Response
Set Of Values	0 to (ATT_MTU-1)	A set of two or more values

Table 3.22: Format of Read Multiple Response

The Set Of Values parameter shall be a concatenation of attribute values for each of the attribute handles in the request in the order that they were requested. If the Set Of Values parameter is longer than (ATT_MTU-1) then only the first (ATT_MTU-1) octets shall be included in this response.

Note: A client should not use this request for attributes when the Set Of Values parameter could be (ATT_MTU-1) as it will not be possible to determine if the last attribute value is complete, or if it overflowed.

3.4.4.9 Read by Group Type Request

The *Read By Group Type Request* is used to obtain the values of attributes where the attribute type is known, the type of a grouping attribute as defined by a higher layer specification, but the handle is not known.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x10 = Read By Group Type Request
Starting Handle	2	First requested handle number
Ending Handle	2	Last requested handle number
Attribute Group Type	2 or 16	2 or 16 octet UUID

Table 3.23: Format of Read By Group Type Request

Only the attributes with attribute handles between and including the Starting Handle and the Ending Handle with the attribute type that is the same as the Attribute Group Type given will be returned. To search through all attributes, the starting handle shall be set to 0x0001 and the ending handle shall be set to 0xFFFF.

Note: All attribute types are effectively compared as 128-bit UUIDs, even if a 16-bit UUID is provided in this request or defined for an attribute. See [Vol 3] Part B, Section 2.5.1.

The starting handle shall be less than or equal to the ending handle. If a server receives a *Read By Group Type Request* with the Starting Handle parameter greater than the Ending Handle parameter or the Starting Handle parameter is

0x0000, an *Error Response* shall be sent with the «Invalid Handle» error code; The Attribute Handle In Error parameter shall be set to the Starting Handle parameter.

If the Attribute Group Type is not a supported grouping attribute as defined by a higher layer specification then an *Error Response* shall be sent with the error code «Unsupported Group Type». The Attribute Handle In Error parameter shall be set to the Starting Handle.

If no attribute with the given type exists within the handle range, then no attribute handle and value will be returned, and an *Error Response* shall be sent with the error code «Attribute Not Found». The Attribute Handle In Error parameter shall be set to the starting handle.

The attributes returned shall be the attributes with the lowest handles within the handle range. These are known as the requested attributes.

If the attributes with the requested type within the handle range have attribute values that have the same length, then these attributes can all be read in a single request.

The attribute server shall include as many attributes as possible in the response in order to minimize the number of PDUs required to read attributes of the same type.

Note: If the attributes with the requested type within the handle range have attribute values with different lengths, then multiple *Read By Group Type Request*s must be made.

When multiple attributes match, then the rules below shall be applied to each in turn.

- Only attributes that can be read shall be returned in a *Read By Group Type Response*.
- If an attribute in the set of requested attributes would cause an *Error Response* then this attribute cannot be included in a *Read By Group Type Response* and the attributes before this attribute shall be returned.
- If the first attribute in the set of requested attributes would cause an *Error Response* then no other attributes in the requested attributes can be considered.

The server shall respond with a *Read By Group Type Response* if the requested attributes have sufficient permissions to allow reading.

If the client has insufficient authorization to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has insufficient security to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has an insufficient encryption key size to read the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the client has not enabled encryption, and encryption is required to read the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

If the requested attribute's value cannot be read due to permissions then an *Error Response* shall be sent with the error code «Read Not Permitted». The Attribute Handle In Error parameter shall be set to the handle of the attribute causing the error.

Note: If there are multiple attributes with the requested type within the handle range, and the client would like to get the next attribute with the requested type, it would have to issue another *Read By Group Type Request* with its starting handle updated. The client can be sure there are no more such attributes remaining once it gets an *Error Response* with the error code «Attribute Not Found».

3.4.4.10 Read by Group Type Response

The *Read By Group Type Response* is sent in reply to a received *Read By Group Type Request* and contains the handles and values of the attributes that have been read.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x11 = Read By Group Type Response
Length	1	The size of each Attribute Data
Attribute Data List	4 to (ATT_MTU- 2)	A list of Attribute Data

Table 3.24: Format of Read By Group Type Response

The *Read By Group Type Response* shall contain complete Attribute Data. An Attribute Data shall not be split across response packets. The Attribute Data List is ordered sequentially based on the attribute handles

The Length parameter shall be set to the size of the one Attribute Data.

The maximum length of an Attribute Data is 255 octets, bounded by the Length parameter that is one octet. Therefore, the maximum length of an attribute value returned in this response is (Length – 4) = 251 octets.

The Attribute Data List shall be set to the value of the attributes identified by the attribute type within the handle range within the request. If the attribute value is longer than (ATT_MTU - 6) or 251 octets, whichever is smaller, then the first (ATT_MTU - 6) or 251 octets shall be included in this response.

Note: The *Read Blob Request* would be used to read the remaining octets of a long attribute value.

The Attribute Data List is comprised of a list of Attribute Data as defined in Table 3.25.

Attribute Handle	End Group Handle	Attribute Value
2 octets	2 octets	(Length - 4) octets

Table 3.25: Format of the Attribute Data

3.4.5 Writing Attributes

3.4.5.1 Write Request

The *Write Request* is used to request the server to write the value of an attribute and acknowledge that this has been achieved in a *Write Response*.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x12 = Write Request
Attribute Handle	2	The handle of the attribute to be written
Attribute Value	0 to (ATT_MTU-3)	The value to be written to the attribute

Table 3.26: Format of Write Request

The Attribute Handle shall be set to a valid handle.

The Attribute Value shall be set to the new value of the attribute.

If the attribute value has a variable length, then the attribute value shall be truncated or lengthened to match the length of the Attribute Value parameter.

Note: If an attribute value has a variable length and if the Attribute Value parameter is of zero length, the attribute value will be fully truncated.

If the attribute value has a fixed length and the Attribute Value parameter length is less than or equal to the length of the attribute value, the octets of the attribute value parameter length shall be written; all other octets in this attribute value shall be unchanged.

The server shall respond with a *Write Response* if the handle is valid, the attribute has sufficient permissions to allow writing, and the attribute value has a valid size and format, and it is successful in writing the attribute.

If the attribute value has a variable length and the Attribute Value parameter length exceeds the maximum valid length of the attribute value then the server shall respond with an *Error Response* with the error code «Invalid Attribute Value Length».

If the attribute value has a fixed length and the requested attribute value parameter length is greater than the length of the attribute value then the server shall respond with an *Error Response* with the error code «Invalid Attribute Value Length».

If the client has insufficient authorization to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization».

If the client has insufficient security to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication».

If the client has an insufficient encryption key size to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size».

If the client has not enabled encryption, and encryption is required to write the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption».

If the handle is invalid, then an *Error Response* shall be sent with the error code «Invalid Handle».

If the attribute value cannot be written due to permissions then an *Error Response* shall be sent with the error code «Write Not Permitted».

If the attribute value cannot be written due to an application error then an *Error Response* shall be sent with an error code defined by a higher layer specification.

3.4.5.2 Write Response

The *Write Response* is sent in reply to a valid *Write Request* and acknowledges that the attribute has been successfully written.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x13 = Write Response

Table 3.27: Format of Write Response

The *Write Response* shall be sent after the attribute value is written.

3.4.5.3 Write Command

The *Write Command* is used to request the server to write the value of an attribute, typically into a control-point attribute.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x52 = Write Command
Attribute Handle	2	The handle of the attribute to be set
Attribute Value	0 to (ATT_MTU-3)	The value of be written to the attribute

Table 3.28: Format of Write Command

The attribute handle parameter shall be set to a valid handle.

The attribute value parameter shall be set to the new value of the attribute.

If the attribute value has a variable length, then the attribute value shall be truncated or lengthened to match the length of the attribute value parameter.

Note: If an attribute value has a variable length and if the attribute value parameter is of zero length, the attribute value will be fully truncated.

If the attribute value has a fixed length and the attribute value parameter length is less than or equal to the length of the attribute value, the octets up to the attribute value parameter length shall be written; all other octets in this attribute value shall be unchanged.

If the attribute value has a variable length and the attribute value parameter length exceeds the maximum valid length of the attribute value then the server shall ignore the command.

If the attribute value has a fixed length and the requested attribute value parameter length is greater than the length of the attribute value then the server shall ignore the command.

No *Error Response* or *Write Response* shall be sent in response to this command. If the server cannot write this attribute for any reason the command shall be ignored.

3.4.5.4 Signed Write Command

The *Signed Write Command* is used to request the server to write the value of an attribute with an authentication signature, typically into a control-point attribute.

Parameter	Size (Octets)	Description
Attribute Opcode	1	0xD2 = Signed Write Command
Attribute Handle	2	The handle of the attribute to be set
Attribute Value	0 to (ATT_MTU - 15)	The value to be written to the attribute
Authentication Signature	12	Authentication signature for the Attribute Opcode, Attribute Handle and Attribute Value Parameters

Table 3.29: Format of Signed Write Command

The attribute handle parameter shall be set to a valid handle.

The attribute value parameter shall be set to the new value of the attribute.

The attribute signature shall be calculated as defined in Section 3.3.1.
For example, if the variable length message m to be signed is ‘D212001337’, SignCounter is 0x00000001 and key is 0x611B64EBFBCD1FD372EC9196DF425E50, then message to be signed (M) by the CMAC function is the octet sequence ‘D21200133701000000’.
The padding(M) is 0x0000000137130012D280000000000000, resultant CMAC is 0xF20F903C931E87F159B64F012574B4D0 and Authentication Signature is the octet sequence ‘01000000F1871E933C900FF2’.
The final signed message is ‘D21200133701000000F1871E933C900FF2’.

If the attribute value has a variable length, then the attribute value shall be truncated or lengthened to match the length of the attribute value parameter.

Note: If an attribute value has a variable length and if the attribute value parameter is of zero length, the attribute value will be fully truncated.

If the attribute value has a fixed length and the attribute value parameter length is less than or equal to the length of the attribute value, the octets up to the attribute value parameter length shall be written; all other octets in this attribute value shall be unchanged.

If the attribute value has a variable length and the attribute value parameter length exceeds the maximum valid length of the attribute value then the server shall ignore the command.

If the attribute value has a fixed length and the requested attribute value parameter length is greater than the length of the attribute value then the server shall ignore the command.

If the authentication signature verification fails, then the server shall ignore the command.

No *Error Response* or *Write Response* shall be sent in response to this command. If the server cannot write this attribute for any reason the command shall be ignored.

3.4.6 Queued Writes

The purpose of queued writes is to queue up writes of values of multiple attributes in a first-in first-out queue and then execute the write on all of them in a single atomic operation.

3.4.6.1 Prepare Write Request

The *Prepare Write Request* is used to request the server to prepare to write the value of an attribute. The server will respond to this request with a *Prepare Write Response*, so that the client can verify that the value was received correctly.

A client may send more than one *Prepare Write Request* to a server, which will queue and send a response for each handle value pair.

A server may limit the number of prepare write requests that it can accept. A higher layer specification should define this limit.

After a *Prepare Write Request* has been issued, and the response received, any other attribute command or request can be issued from the same client to the same server.

Each client's queued values are separate; the execution of one queue shall not affect the preparation or execution of any other client's queued values.

Any actions on attributes that exist in the prepare queue shall proceed as if the prepare queue did not exist, and the prepare queue shall be unaffected by these actions. A subsequent execute write will write the values in the prepare queue even if the value of the attribute has changed since the prepare writes were started.

The attribute protocol makes no determination on the validity of the Part Attribute Value or the Value Offset. A higher layer specification determines the meaning of the data.

Each *Prepare Write Request* will be queued even if the attribute handle is the same as a previous *Prepare Write Request*. These will then be executed in the order received, causing multiple writes for this attribute to occur.

If the link is lost while a number of prepared write requests have been queued, the queue will be cleared and no writes will be executed.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x16 = Prepare Write Request
Attribute Handle	2	The handle of the attribute to be written
Value Offset	2	The offset of the first octet to be written
Part Attribute Value	0 to (ATT_MTU-5)	The value of the attribute to be written

Table 3.30: Format of Prepare Write Request

The Attribute Handle parameter shall be set to a valid handle.

The Value Offset parameter shall be set to the offset of the first octet where the Part Attribute Value parameter is to be written within the attribute value. The Value Offset parameter is based from zero; the first octet has an offset of zero, the second octet has an offset of one, etc.

The server shall respond with a *Prepare Write Response* if the handle is valid, the attribute has sufficient permissions to allow writing at this time, and the prepare queue has sufficient space.

Note: The Attribute Value validation is done when an Execute Write Request is received. Hence, any Invalid Offset or Invalid Attribute Value Length errors are generated when an Execute Write Request is received.

If the client has insufficient authorization to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authorization».

If the client has insufficient security to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Authentication».

If the client has an insufficient encryption key size to write the requested attribute then an *Error Response* shall be sent with the error code «Insufficient Encryption Key Size».

If the client has not enabled encryption, and encryption is required to write the requested attribute, then an *Error Response* shall be sent with the error code «Insufficient Encryption».

If the server does not have sufficient space to queue this request then an *Error Response* shall be sent with the error code «Prepare Queue Full».

If the handle is invalid, then an *Error Response* shall be sent with the error code «Invalid Handle».

If the attribute value cannot be written then an *Error Response* shall be sent with the error code «Write Not Permitted».

The server shall not change the value of the attribute until an *Execute Write Request* is received.

If a *Prepare Write Request* was invalid, and therefore an *Error Response* has been issued, then this prepared write will be considered to have not been received. All existing prepared writes in the prepare queue shall not be affected by this invalid request.

3.4.6.2 Prepare Write Response

The *Prepare Write Response* is sent in response to a received *Prepare Write Request* and acknowledges that the value has been successfully received and placed in the prepare write queue.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x17 = Prepare Write Response
Attribute Handle	2	The handle of the attribute to be written
Value Offset	2	The offset of the first octet to be written
Part Attribute Value	0 to (ATT_MTU-5)	The value of the attribute to be written

Table 3.31: Format of Prepare Write Response

The attribute handle shall be set to the same value as in the corresponding *Prepare Write Request*.

The value offset and part attribute value shall be set to the same values as in the corresponding *Prepare Write Request*.

3.4.6.3 Execute Write Request

The *Execute Write Request* is used to request the server to write or cancel the write of all the prepared values currently held in the prepare queue from this client. This request shall be handled by the server as an atomic operation.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x18 = Execute Write Request

Table 3.32: Format of Execute Write Request

Parameter	Size (octets)	Description
Flags	1	0x00 – Cancel all prepared writes 0x01 – Immediately write all pending prepared values

Table 3.32: Format of Execute Write Request

When the flags parameter is set to 0x01, values that were queued by the previous prepare write requests shall be written in the order they were received in the corresponding *Prepare Write Request*. The queue shall then be cleared, and an *Execute Write Response* shall be sent.

When the flags parameter is set to 0x00 all pending prepare write values shall be discarded for this client. The queue shall then be cleared, and an *Execute Write Response* shall be sent.

If there are no pending prepared write values, then no values are written, and an *Execute Write Response* shall be sent.

If the prepared Attribute Value exceeds the maximum valid length of the attribute value then all pending prepare write values shall be discarded for this client, the queue shall then be cleared, and an *Error Response* shall be sent with the error code «Invalid Attribute Value Length».

If the prepare Value Offset is greater than the current length of the attribute value then all pending prepare write values shall be discarded for this client, the queue shall be cleared and then an *Error Response* shall be sent with the «Invalid Offset».

If the prepare write requests cannot be written, due to an application error, the queue shall be cleared and then an *Error Response* shall be sent with a higher layer specification defined error code. The Attribute Handle In Error parameter shall be set to the attribute handle of the attribute from the prepare queue that caused this application error. The state of the attributes that were to be written from the prepare queue is not defined in this case.

3.4.6.4 Execute Write Response

The *Execute Write Response* is sent in response to a received *Execute Write Request*.

Parameter	Size	Description
Attribute Opcode	1	0x19 - Execute Write Response

Table 3.33: Format of Execute Write Response

The *Execute Write Response* shall be sent after the attributes are written. In case an action is taken in response to the write, an indication may be used once the action is complete.

3.4.7 Server Initiated

3.4.7.1 Handle Value Notification

A server can send a notification of an attribute's value at any time.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x1B = Handle Value Notification
Attribute Handle	2	The handle of the attribute
Attribute Value	0 to (ATT_MTU-3)	The current value of the attribute

Table 3.34: Format of Handle Value Notification

The attribute handle shall be set to a valid handle.

The attribute value shall be set to the current value of attribute identified by the attribute handle.

If the attribute value is longer than (ATT_MTU-3) octets, then only the first (ATT_MTU-3) octets of this attributes value can be sent in a notification.

Note: For a client to get a long attribute, it would have to use the *Read Blob Request* following the receipt of this notification.

If the attribute handle or the attribute value is invalid, then this notification shall be ignored upon reception.

3.4.7.2 Handle Value Indication

A server can send an indication of an attribute's value.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x1D = Handle Value Indication
Attribute Handle	2	The handle of the attribute
Attribute Value	0 to (ATT_MTU-3)	The current value of the attribute

Table 3.35: Format of Handle Value Indication

The attribute handle shall be set to a valid handle.

The attribute value shall be set to the current value of attribute identified by the attribute handle.

If the attribute value is longer than (ATT_MTU-3) octets, then only the first (ATT_MTU - 3) octets of this attributes value can be sent in an indication.

Note: For a client to get a long attribute, it would have to use the *Read Blob Request* following the receipt of this indication.

The client shall send a *Handle Value Confirmation* in response to a *Handle Value Indication*. No further indications to this client shall occur until the confirmation has been received by the server.

If the attribute handle or the attribute value is invalid, the client shall send a handle value confirmation in response and shall discard the handle and value from the received indication.

3.4.7.3 Handle Value Confirmation

The *Handle Value Confirmation* is sent in response to a received *Handle Value Indication* and confirms that the client has received an indication of the given attribute.

Parameter	Size (octets)	Description
Attribute Opcode	1	0x1E = Handle Value Confirmation

Table 3.36: Format of Handle Value Confirmation

3.4.8 Attribute Opcode Summary

Table 3.37 gives a summary of the attribute protocol PDUs. .

Attribute PDU Name	Attribute Opcode	Parameters
Error Response	0x01	Request Opcode in Error, Attribute Handle In Error, Error Code
Exchange MTU Request	0x02	Client Rx MTU
Exchange MTU Response	0x03	Server Rx MTU
Find Information Request	0x04	Starting Handle, Ending Handle
Find Information Response	0x05	Format, Information Data
Find By Type Value Request	0x06	Starting Handle, Ending Handle, Attribute Type, Attribute Value
Find By Type Value Response	0x07	Handles Information List
Read By Type Request	0x08	Starting Handle, Ending Handle, UUID
Read By Type Response	0x09	Length, Attribute Data List
Read Request	0x0A	Attribute Handle
Read Response	0x0B	Attribute Value
Read Blob Request	0x0C	Attribute Handle, Value Offset
Read Blob Response	0x0D	Part Attribute Value
Read Multiple Request	0x0E	Handle Set
Read Multiple Response	0x0F	Value Set
Read by Group Type Request	0x10	Start Handle, Ending Handle, UUID
Read by Group Type Response	0x11	Length, Attribute Data List
Write Request	0x12	Attribute Handle, Attribute Value
Write Response	0x13	-

Table 3.37: Attribute Protocol Summary

Attribute PDU Name	Attribute Opcode	Parameters
Write Command	0x52	Attribute Handle, Attribute Value
Prepare Write Request	0x16	Attribute Handle, Value Offset, Part Attribute Value
Prepare Write Response	0x17	Attribute Handle, Value Offset, Part Attribute Value
Execute Write Request	0x18	Flags
Execute Write Response	0x19	-
Handle Value Notification	0x1B	Attribute Handle, Attribute Value
Handle Value Indication	0x1D	Attribute Handle, Attribute Value
Handle Value Confirmation	0x1E	
Signed Write Command	0xD2	Attribute Handle, Attribute Value, Authentication Signature

Table 3.37: Attribute Protocol Summary

3.4.9 Attribute PDU Response Summary

Table 3.38 gives a summary of the Attribute PDU Method responses that are allowed. Each method indicates the method that should be sent as a successful response, and whether an Error Response can be sent in response instead. If an Error Response can be sent, then the table also indicates the Error Codes that are valid within this Error Response for the given method.

Attribute PDU Method	Successful Response	Error Response Allowed	Error Response Error Codes
Exchange MTU Request	Exchange MTU Response	Yes	Request Not Supported
Find Information Request	Find Information Response	Yes	Invalid Handle, Attribute Not Found
Find By Type Value Request	Find By Type Value Response	Yes	Invalid Handle, Request Not Supported, Attribute Not Found
Read By Type Request	Read By Type Response	Yes	Invalid Handle, Request Not Supported, Attribute Not Found, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size, Read Not Permitted, Application Error
Read Request	Read Response	Yes	Invalid Handle, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size, Read Not Permitted, Application Error

Table 3.38: Attribute Request and Response Summary

Attribute PDU Method	Successful Response	Error Response Allowed	Error Response Error Codes
Read Blob Request	Read Blob Response	Yes	Invalid Handle, Request Not Supported, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size, Read Not Permitted, Invalid Offset, Attribute Not Long, Application Error
Read Multiple Request	Read Multiple Response	Yes	Invalid Handle, Request Not Supported, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size, Read Not Permitted, Application Error
Read by Group Type Request	Read by Group Type Response	Yes	Invalid Handle, Request Not Supported, Attribute Not Found, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size Read Not Permitted, Unsupported Group Type, Application Error
Write Request	Write Response	Yes	Invalid Handle, Request Not Supported, Insufficient Authorization, Insufficient Authentication, Insufficient Encryption, Insufficient Encryption Key Size, Write Not Permitted, Invalid Attribute Value Length, Application Error

Table 3.38: Attribute Request and Response Summary

Attribute PDU Method	Successful Response	Error Response Allowed	Error Response Error Codes
Write Command	N/A	No	
Signed Write Command	N/A	No	
Prepare Write Request	Prepare Write Response	Yes	Invalid Handle, Request Not Supported, Insufficient Authorization, Insufficient Authentication, Write Not Permitted, Prepare Queue Full, Insufficient Encryption, Insufficient Encryption Key Size, Application Error
Execute Write Request	Execute Write Response	Yes	Application Error, Invalid Offset, Invalid Attribute Value Length
Handle Value Notification	N/A	No	
Handle Value Indication	Handle Value Confirmation	No	

Table 3.38: Attribute Request and Response Summary

4 SECURITY CONSIDERATIONS

The attribute protocol can be used to access information that may require both authorization and an authenticated and encrypted physical link before an attribute can be read or written.

If such a request is issued when the client has not been authorized to access this information, the server shall send an *Error Response* with the error code set to «Insufficient Authorization». The authorization requirements for access to a given attribute are not defined in this specification. Each device implementation will determine how authorization occurs. Authorization procedures are defined in GAP, and may be further refined in a higher layer specification.

If such a request is issued when the physical link is unauthenticated, the server shall send an *Error Response* with the error code set to «Insufficient Authentication». A client wanting to read or write this attribute can then request that the physical link be authenticated, and once this has been completed, send the request again.

The attribute protocol can be used to notify or indicate the value of an attribute that may require an authenticated and encrypted physical link before an attribute notification or indication is performed. A server wanting to notify or indicate this attribute can then request that the physical link be authenticated, and once this has been completed, send the notification or indication.

The list of attributes that a device supports is not considered private or confidential information, and therefore the *Find Information Request* shall always be permitted. This implies that an «Insufficient Authorization» or «Insufficient Authentication» error code shall not be used in an *Error Response* for a *Find Information Request*.

For example, an attribute value may be allowed to be read by any device, but only written by an authenticated device. An implementation should take this into account, and not assume that just because it can read an attribute’s value, it will also be able to write the value. Similarly, just because an attribute value can be written, does not mean that an attribute value can also be read. Each individual attribute could have different security requirements.

When a client accesses an attribute, the order of checks that are performed on the server will have security implications. A server shall check authentication and authorization requirements before any other check is performed.

Note: For example, if the authentication and authorization requirement checks are not performed first then the size of an attribute could be determined by performing repeated read blob requests on an attribute that a client does not have access to, because either an «Invalid Offset» error code or «Insufficient Authentication» error codes would be returned.

GENERIC ATTRIBUTE PROFILE (GATT)

This specification defines the Generic Attribute Profile that describes a service framework using the Attribute Protocol for discovering services, and for reading and writing characteristic values on a peer device.

CONTENTS

1 INTRODUCTION

1.1 SCOPE

The Generic Attribute Profile (GATT) defines a service framework using the Attribute Protocol. This framework defines procedures and formats of services and their characteristics. The procedures defined include discovering, reading, writing, notifying and indicating characteristics, as well as configuring the broadcast of characteristics.

1.2 PROFILE DEPENDENCY

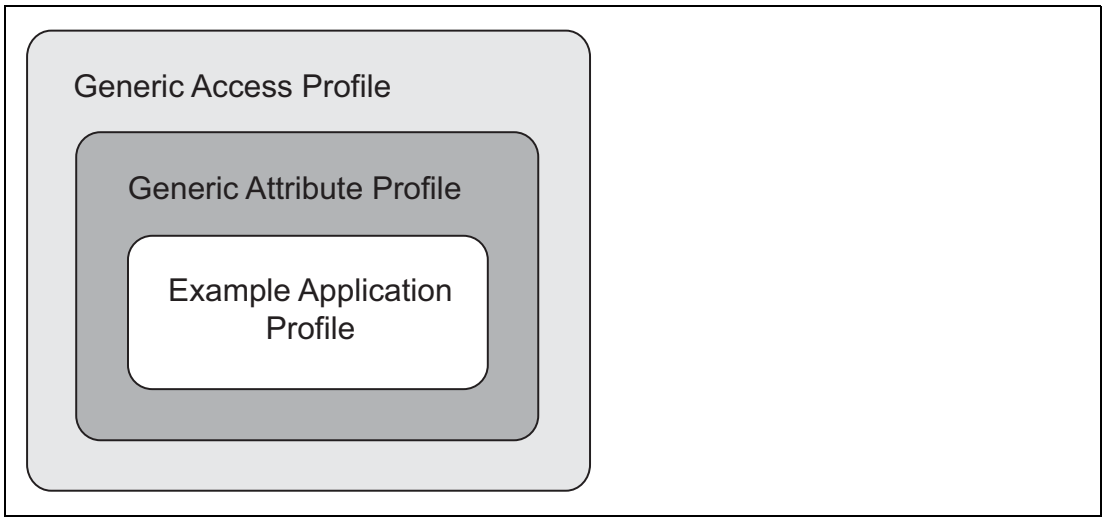

Figure 1.1: Profile dependencies

Figure 1.1 depicts the structure and the dependencies of the profiles. A profile is dependent upon another profile if it re-uses parts of that profile by implicitly or explicitly referencing it.

1.3 CONFORMANCE

If conformance to this profile is claimed, all capabilities indicated as mandatory for this profile shall be supported in the specified manner (process-mandatory). This also applies for all optional and conditional capabilities for which support is indicated. All mandatory capabilities, and optional and conditional capabilities for which support is indicated, are subject to verification as part of the Bluetooth qualification program.

1.4 BLUETOOTH SPECIFICATION RELEASE COMPATIBILITY

This specification can be used with Bluetooth Core Specification Version 1.2 or later when using the profile on the BR/EDR physical link and Bluetooth Core Specification Version 4.0 or later when using the profile on the LE physical link.

1.5 CONVENTIONS

In this specification the use of literal terms such as procedure, PDUs, opcodes or function names appear in italics. Specific names of fields in structures, packets, etc. also appear in italics. The use of « » (e.g. «Primary Service») indicates a UUID or an Attribute Protocol error code (see [Vol 3] Part F, Table 3.3).

2 PROFILE OVERVIEW

The GATT profile is designed to be used by an application or another profile, so that a client can communicate with a server. The server contains a number of attributes, and the GATT Profile defines how to use the Attribute Protocol to discover, read, write and obtain indications of these attributes, as well as configuring broadcast of attributes.

2.1 PROTOCOL STACK

Figure 2.1 shows the peer protocols used by this profile.

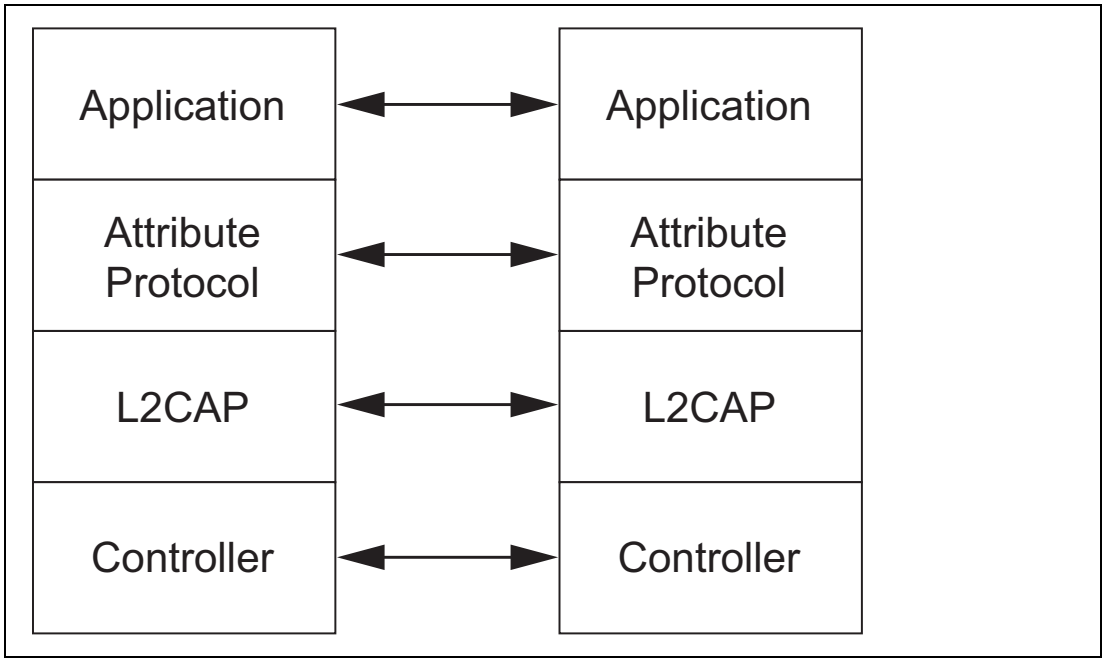

Figure 2.1: Protocol model

2.2 CONFIGURATIONS AND ROLES

The following roles are defined for devices that implement this profile:

Client—This is the device that initiates commands and requests towards the server and can receive responses, indications and notifications sent by the server.

Server—This is the device that accepts incoming commands and requests from the client and sends responses, indications and notifications to a client.

Note: The roles are not fixed to the device. The roles are determined when a device initiates a defined procedure, and they are released when the procedure ends.

A device can act in both roles at the same time.

An example of configurations illustrating the roles for this profile is depicted in Figure 2.2.

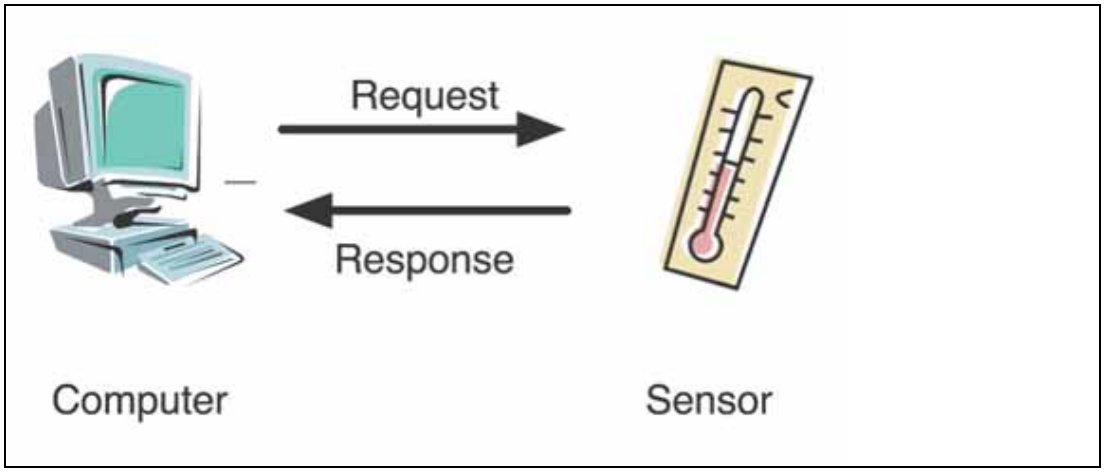

Figure 2.2: Examples of configuration

In Figure 2.2, the computer is the temperature service client and the sensor is the temperature service server. The computer initiates procedures to configure the sensor or to read the sensor values. In this example the sensor provides information about the characteristics the sensor device exposes as part of the temperature service and may permit some characteristics to be written. Also, the sensor responds to read requests with the appropriate values.

2.3 USER REQUIREMENTS AND SCENARIOS

The following scenarios are covered by this profile:

- Exchanging configuration
- Discovery of services and characteristics on a device
- Reading a characteristic value
- Writing a characteristic value
- Notification of a characteristic value
- Indication of a characteristic value

2.4 PROFILE FUNDAMENTALS

This profile can be used over any physical link, using the Attribute Protocol L2CAP channel, known as the ATT Bearer. Here is a brief summary of lower layer requirements communication between the client and the server.

- An ATT Bearer is established using “Channel Establishment” as defined in Section 6.

- The profile roles are not tied to the Controller master/slave roles.
- On an LE Physical link, use of security features such as authorization, authentication and encryption are optional. On a BR/EDR physical link encryption is mandatory.
- Multi-octet fields within the GATT Profile shall be sent least significant octet first (little endian).

2.5 ATTRIBUTE PROTOCOL

The GATT Profile requires the implementation of the Attribute Protocol (ATT) and the required Attribute opcodes indicated in Section 4.2 and Section 4.13.

2.5.1 Overview

The GATT Profile uses the Attribute Protocol to transport data in the form of commands, requests, responses, indications, notifications and confirmations between devices. This data is contained in Attribute Protocol PDUs.

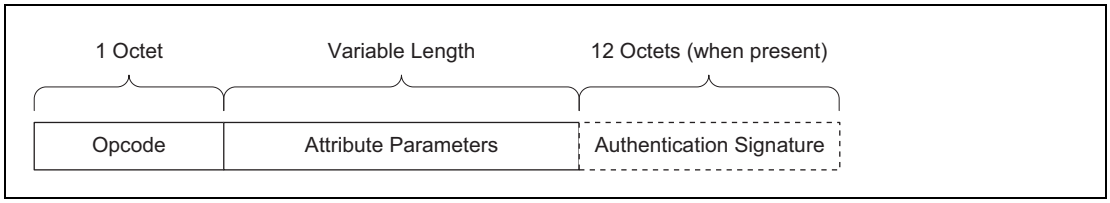

Figure 2.3: Attribute Protocol PDU

The *Opcode* contains the specific command, request, response, indication, notification or confirmation opcode and a flag for authentication. The *Attribute Parameters* contain data for the specific command or request or the data returned in a response, indication or notification. The *Authentication Signature* is optional and is described in [Vol 3] Part H, Section 2.4.5.

Attribute Protocol commands and requests act on values stored in Attributes on the server device. An Attribute is composed of four parts: *Attribute Handle*, *Attribute Type*, *Attribute Value,* and *Attribute Permissions*. Figure 2.4 shows a logical representation of an Attribute. The actual representation for a given implementation is specific to that implementation.

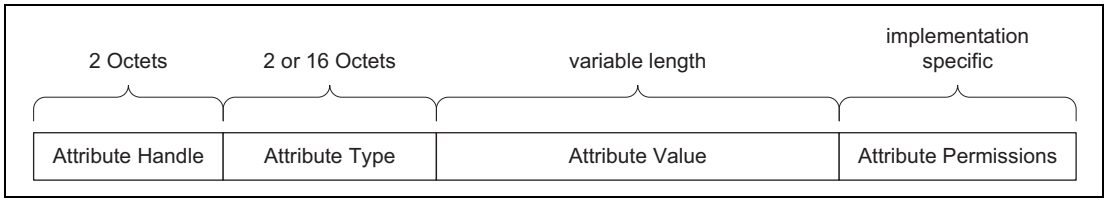

Figure 2.4: Logical Attribute Representation

The *Attribute Handle* is an index corresponding to a specific Attribute. The *Attribute Type* is a UUID that describes the *Attribute Value*. The *Attribute Value* is the data described by the *Attribute Type* and indexed by the *Attribute Handle*. The Attributes are ordered by increasing *Attribute Handle* values. *Attribute Handle* values may begin at any value between 0x0001 and 0xFFFF. Although the *Attribute Handle* values are in increasing order, following *Attribute Handle* values may differ by more than one. That is to say there may be gaps between successive *Attribute Handles*. When this specification requires two attribute handles to be adjacent or for one to immediately follow one the other, such gaps are still permitted and shall be ignored.

Attribute Permissions is part of the Attribute that cannot be read from or written to using the Attribute Protocol. It is used by the server to determine whether read or write access is permitted for a given attribute. *Attribute Permissions* are established by the GATT profile, a higher layer profile or are implementation specific if not specified.

2.5.2 Attribute Caching

Attribute caching is an optimization that allows the client to discover the Attribute information such as *Attribute Handles* used by the server once and use the same Attribute information across reconnections without rediscovery. Without caching the Attribute information, the client shall rediscover the *Attribute* information at each reconnection. With caching, time is saved and a significant amount of packets exchanged between the client and server is not required. The Attribute information that shall be cached by a client is the *Attribute Handle*s of all server attributes and the GATT service characteristics values.

Attribute Handles used by the server should not change over time. This means that once an *Attribute Handle* is discovered by a client the *Attribute Handle* for that Attribute should not be changed.

Some circumstances may cause servers to change the *Attribute Handles* used for services, perhaps due to a factory reset or a firmware upgrade procedure being performed. The following is only required on the server if the services on the server can be added, modified or removed. If GATT based services on the server cannot be changed during the usable lifetime of the device, the *Service Changed* characteristic shall not exist on the server and the client does not need to ever perform service discovery after the initial service discovery for that server.

To support caching when a server supports changes in GATT based services, an indication is sent by the server to clients when a service is added, removed, or modified on the server. A GATT based service is considered modified if the binding of the *Attribute Handles* to the associated Attributes grouped within a service definition are changed. Any change to the GATT service definition characteristic values other than the *Service Changed* characteristic value itself shall also be considered a modification.

For clients that have a trusted relationship (i.e. bond) with the server, the attribute cache is valid across connections. For clients with a trusted relationship and not in a connection when a service change occurs, the server shall send an indication when the client reconnects to the server (see Section 7.1). For clients that do not have a trusted relationship with the server, the attribute cache is valid only during the connection. Clients without a trusted relationship shall receive an indication when the service change occurs only during the current connection.

Note: Clients without a trusted relationship must perform service discovery on each connection if the server supports the *Service Changed* characteristic.

The server shall send a *Handle Value Indication* containing the range of affected *Attribute Handles* that shall be considered invalid in the client's attribute cache. The start *Attribute Handle* shall be the start *Attribute Handle* of the service definition containing the change and the end *Attribute Handle* shall be the last *Attribute Handle* of the service definition containing the change. The value in the indication is composed of two 16-bit *Attribute Handle*s concatenated to indicate the affected *Attribute Handle* range.

Note: A server may set the affected *Attribute Handle* range to 0x0001 to 0xFFFF to indicate to the client to rediscover the entire set of *Attribute Handles* on the server.

The client, upon receiving a Handle Value Indication containing the range of affected Attribute Handles, shall consider the attribute cache invalid over the affected Attribute Handle range. Any outstanding request transaction shall be considered invalid if the Attribute Handle is contained within the affected Attribute Handle range. The client must perform service discovery before the client uses any service that has an attribute within the affected Attribute Handle range.

Once the server has received the Handle Value Confirmation, the server can consider the client to be aware of the updated Attribute Handles.

The client shall consider the affected *Attribute Handle* range to be invalid in its attribute cache and perform the discovery procedures to restore the attribute cache. The server shall store service changed information for all bonded devices.

2.5.3 Attribute Grouping

Generic attribute profile defines grouping of attributes for three attribute types: «Primary Service», «Secondary Service» and «Characteristic». A group begins with a declaration, and ends as defined in Section 3.1 for services and Section 3.3 for characteristics. Not all of the grouping attributes can be used in the ATT Read By Group Type Request. The «Primary Service» and «Secondary Service» grouping types may be used in the Read By Group Type Request.

The «Characteristic» grouping type shall not be used in the ATT Read By Group Type Request.

2.5.4 UUIDs

All 16-bit UUIDs shall be contained in exactly 2 octets. All 128-bit UUIDs shall be contained in exactly 16 octets.

All 32-bit UUIDs shall be converted to 128-bit UUIDs when the UUID is contained in an ATT PDU. See [Vol 3] Part B, Section 2.5.1 for the method of conversion.

2.6 GATT PROFILE HIERARCHY

2.6.1 Overview

The GATT Profile specifies the structure in which profile data is exchanged. This structure defines basic elements such as services and characteristics, used in a profile. All of the elements are contained by Attributes. Attributes used in the Attribute Protocol are containers that carry this profile data.

The top level of the hierarchy is a profile. A profile is composed of one or more services necessary to fulfill a use case. A service is composed of characteristics or references to other services. Each characteristic contains a value and may contain optional information about the value. The service and characteristic and the components of the characteristic (i.e. value and descriptors) contain the profile data and are all stored in Attributes on the server.

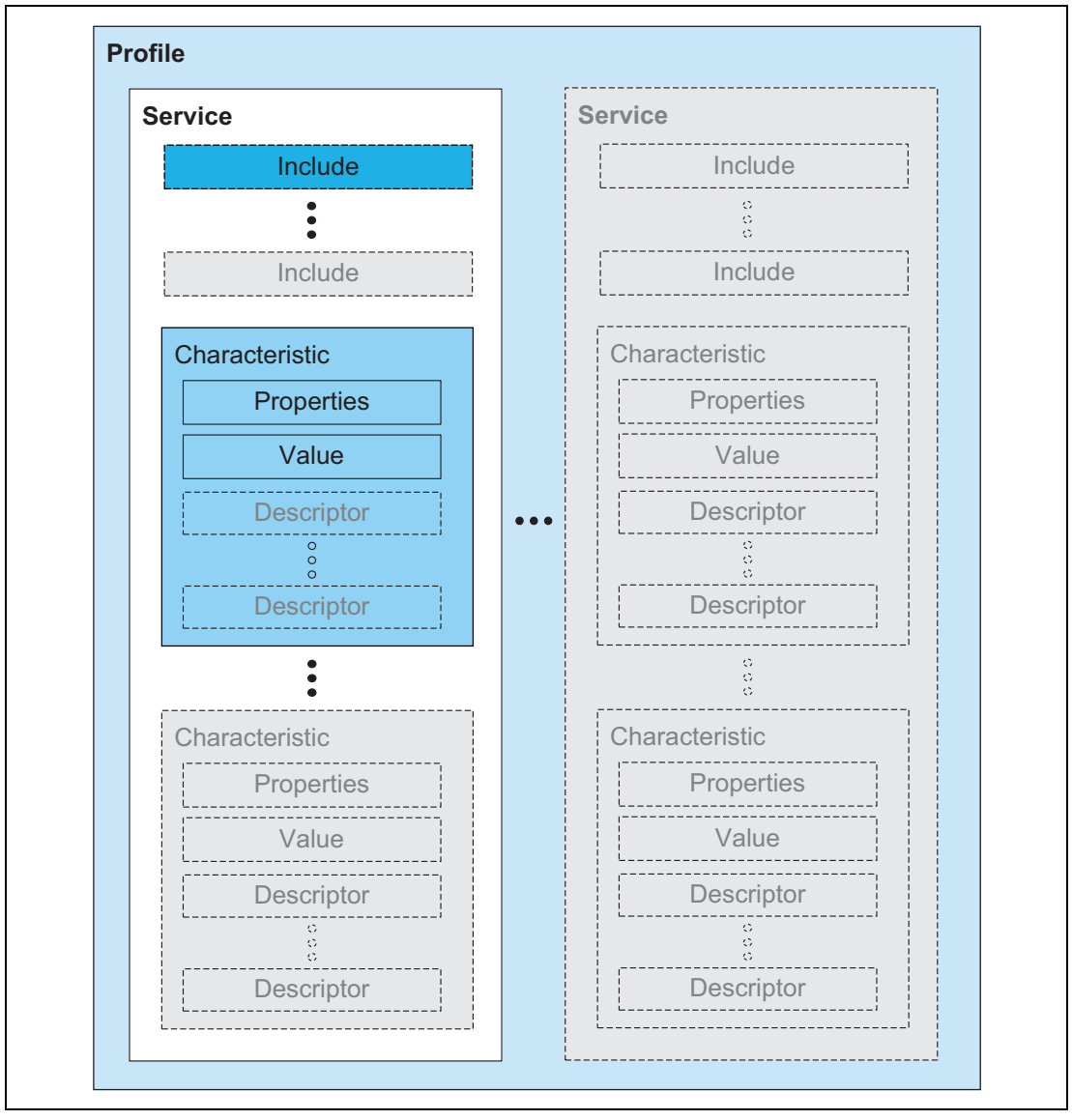

Figure 2.5: GATT Profile hierarchy

2.6.2 Service

A service is a collection of data and associated behaviors to accomplish a particular function or feature. In GATT, a service is defined by its service definition. A service definition may contain referenced services, mandatory characteristics and optional characteristics.

To maintain backward compatibility with earlier clients, later versions of a service definition can only add new referenced services or optional characteristics. Later versions of a service definition are forbidden from changing behaviors from previous versions of the service definition.

There are two types of services: primary service and secondary service. A primary service is a service that exposes the primary usable functionality of this device. A primary service can be included by another service. Primary services can be discovered using Primary Service Discovery procedures. A secondary service is a service that is only intended to be referenced from a primary service or another secondary service or other higher layer specification. A secondary service is only relevant in the context of the entity that references it.

The determination of whether a service is either a primary or secondary service can be mandated by a higher layer specification.

Services may be used in one or more higher layer specifications to fulfill a particular use case.

The service definition is described in Section 3.1.

2.6.3 Included Services

An included service is a method to reference another service definition existing on the server into the service being defined. To include another service, an include definition is used at the beginning of the service definition. When a service definition uses an include definition to reference the included service, the entire included service definition becomes part of the new service definition. This includes all the included services and characteristics of the included service. The included service still exists as an independent service. A service that is included by another service shall not be changed by the act of inclusion or by the including service. There are no limits to the number of include definitions or the depth of nested includes in a service definition.

The include definition is described in Section 3.2.

2.6.4 Characteristic

A characteristic is a value used in a service along with properties and configuration information about how the value is accessed and information about how the value is displayed or represented. In GATT, a characteristic is defined by its characteristic definition. A characteristic definition contains a characteristic declaration, characteristic properties, and a value and may contain descriptors that describe the value or permit configuration of the server with respect to the characteristic.

The characteristic definition is described in Section 3.3.

2.7 CONFIGURED BROADCAST

For LE physical links, Configured Broadcast is a method for a client to indicate to a server which *Characteristic Value* shall be broadcast in the advertising data when the server is executing the broadcast mode procedure. For BR/EDR physical links, Configured Broadcast is not supported.

To configure a *Characteristic Value* to be broadcast by the server when in broadcast mode, the client sets the broadcast configuration bit described in Section 3.3.3.4. The frequency of the broadcast is part of the service behavior definition.

3 SERVICE INTEROPERABILITY REQUIREMENTS

3.1 SERVICE DEFINITION

A service definition shall contain a service declaration and may contain include definitions and characteristic definitions. The service definition ends before the next service declaration or after the maximum *Attribute Handle* is reached. Service definitions appear on the server in an order based on *Attribute Handle*.

All include definitions and characteristic definitions contained within the service definition are considered to be part of the service. All include definitions shall immediately follow the service declaration and precede any characteristic definitions. A service definition may have zero or more include definitions. All characteristic definitions shall be immediately following the last include definition or in the event of no include definitions, immediately following the service declaration. A service definition may have zero or more characteristic definitions. There is no upper limit for include or characteristic definitions.

A service declaration is an Attribute with the *Attribute Type* set to the UUID for «Primary Service» or «Secondary Service». The *Attribute Value* shall be the 16-bit Bluetooth UUID or 128-bit UUID for the service, known as the service UUID. A client shall support the use of both 16-bit and 128-bit UUIDs. A client may ignore any service definition with an unknown service UUID. An unknown service UUID is a UUID for an unsupported service. The *Attribute Permissions* shall be read-only and shall not require authentication or authorization.

When multiple services exist, services definitions with service declarations using 16-bit Bluetooth UUID should be grouped together (i.e. listed sequentially) and services definitions with service declarations using 128-bit UUID should be grouped together.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permission
0xNNNN	0x2800 – UUID for «Primary Service» OR 0x2801 for «Secondary Service»	16-bit Bluetooth UUID or 128-bit UUID for Service	Read Only, No Authentication, No Authorization

Table 3.1: Service Declaration

A device or higher level specification may have multiple service definitions and may have multiple service definitions with the same service UUID.

All Attributes on a Server shall either contain a service declaration or exist within a service definition.

Service definitions contained in a server may appear in any order; a client shall not assume the order of service definitions on a server.

3.2 INCLUDE DEFINITION

An include definition shall contain only one include declaration.

The include declaration is an Attribute with the *Attribute Type* set to the UUID for «Include». The *Attribute Value* shall be set to the included service *Attribute Handle,* the End Group Handle, and the *service UUID*. The Service UUID shall only be present when the UUID is a 16-bit Bluetooth UUID.The *Attribute Permissions* shall be read only and not require authentication or authorization.

Attribute Handle	Attribute Type	Attribute Value			Attribute Permission
0xNNNN	0x2802 – UUID for «Include»	Included Service Attribute Handle	End Group Handle	Service UUID	Read Only, No Authentication, No Authorization

Table 3.2: Include Declaration

A server shall not contain a service definition with an include definition to another service that references the original service. This applies to each of the services the included definition references. This is referred to as a circular reference.

If the client detects a circular reference or detects nested include declarations to a greater level than it expects, it should terminate the ATT Bearer.

3.3 CHARACTERISTIC DEFINITION

A characteristic definition shall contain a characteristic declaration, a Characteristic Value declaration and may contain characteristic descriptor declarations. A characteristic definition ends at the start of the next characteristic declaration or service declaration or after the maximum *Attribute Handle*. Characteristic definitions appear on the server within a service definition in an order based on *Attribute Handle*.

Each declaration above is contained in a separate Attribute. The two required declarations are the characteristic declaration and the Characteristic Value declaration. The Characteristic Value declaration shall exist immediately following the characteristic declaration. Any optional characteristic descriptor declarations are placed after the Characteristic Value declaration. The order of the optional characteristic descriptor declarations is not significant.

A characteristic definition may be defined to concatenate several Characteristic Values into a single aggregated Characteristic Value. This may be used to optimize read and writes of multiple Characteristic Values through the reading and writing of a single aggregated Characteristic Value. This type of characteristic definition is the same as a normal characteristic definition. The characteristic declaration shall use a characteristic UUID that is unique to the

aggregated characteristic definition. The aggregated characteristic definition may also contain a characteristic aggregate format descriptor that describes the display format of the aggregated Characteristic Value.

3.3.1 Characteristic Declaration

A characteristic declaration is an Attribute with the Attribute Type set to the UUID for «Characteristic» and *Attribute Value* set to the Characteristic Properties, Characteristic Value *Attribute Handle* and Characteristic UUID. The Attribute Permissions shall be readable and not require authentication or authorization.

The characteristic declaration *Attribute Value* shall not change while the server has a trusted relationship with any client.

Attribute Handle	**Attribute Types**	**Attribute Value**			**Attribute Permissions**
0xNNNN	0x2803–UUID for «Characteristic»	Charac-teristic Properties	Character-istic Value Attribute Handle	Character-istic UUID	Read Only, No Authentication, No Authorization

Table 3.3: Characteristic declaration

The *Attribute Value* of a characteristic declaration is read only.

Attribute Value	**Size**	**Description**
Characteristic Properties	1 octets	Bit field of characteristic properties
Characteristic Value Handle	2 octets	Handle of the Attribute containing the value of this characteristic
Characteristic UUID	2 or 16 octets	16-bit Bluetooth UUID or 128-bit UUID for Char-acteristic Value

Table 3.4: Attribute Value Field in characteristic declaration

A service may have multiple characteristic definitions with the same Characteristic UUID.

Within a service definition, some characteristics may be mandatory and those characteristics shall be located after the include declarations and before any optional characteristics within the service definition. A client shall not assume any order of those characteristics that are mandatory or any order of those characteristics that are optional within a service definition. Whenever possible and within the requirements stated earlier, characteristics definitions with characteristic declarations using 16-bit Bluetooth UUIDs should be grouped together (i.e. listed sequentially) and characteristics definitions with characteristic declarations using 128-bit UUIDs should be grouped together.

3.3.1.1 Characteristic Properties

The Characteristic Properties bit field determines how the Characteristic Value can be used, or how the characteristic descriptors (see Section 3.3.3) can be accessed. If the bits defined in Table 3 5 are set, the action described is permitted. Multiple Characteristic Properties can be set.

These bits shall be set according to the procedures allowed for this characteristic, as defined by higher layer specifications, without regard to security requirements.

Properties	Value	Description
Broadcast	0x01	If set, permits broadcasts of the Characteristic Value using Server Characteristic Configuration Descriptor. If set, the Server Characteristic Configuration Descriptor shall exist.
Read	0x02	If set, permits reads of the Characteristic Value using procedures defined in Section 4.8
Write Without Response	0x04	If set, permit writes of the Characteristic Value without response using procedures defined in Section 4.9.1.
Write	0x08	If set, permits writes of the Characteristic Value with response using procedures defined in Section 4.9.3 or Section 4.9.4.
Notify	0x10	If set, permits notifications of a Characteristic Value without acknowledgment using the procedure defined in Section 4.10. If set, the Client Characteristic Configuration Descriptor shall exist.
Indicate	0x20	If set, permits indications of a Characteristic Value with acknowledgment using the procedure defined in Section 4.11. If set, the Client Characteristic Configuration Descriptor shall exist.
Authenticated Signed Writes	0x40	If set, permits signed writes to the Characteristic Value using the procedure defined in Section 4.9.2.
Extended Properties	0x80	If set, additional characteristic properties are defined in the Characteristic Extended Properties Descriptor defined in Section 3.3.3.1. If set, the Characteristic Extended Properties Descriptor shall exist.

Table 3.5: Characteristic Properties bit field

3.3.1.2 Characteristic Value Attribute Handle

The Characteristic Value *Attribute Handle* field is the *Attribute Handle* of the Attribute that contains the *Characteristic Value*.

3.3.1.3 Characteristic UUID

The *Characteristic UUID* field is a 16-bit Bluetooth UUID or 128-bit UUID that describes the type of *Characteristic Value*. A client shall support the use of both 16-bit and 128-bit *Characteristic UUIDs*. A client may ignore any characteristic

definition with an unknown *Characteristic UUID*. An unknown characteristic UUID is a UUID for an unsupported characteristic.

3.3.2 Characteristic Value Declaration

The *Characteristic Value* declaration contains the value of the characteristic. It is the first Attribute after the characteristic declaration. All characteristic definitions shall have a *Characteristic Value* declaration.

A Characteristic Value declaration is an Attribute with the Attribute Type set to the 16-bit Bluetooth or 128-bit UUID for the Characteristic Value used in the characteristic declaration. The *Attribute Value* is set to the *Characteristic Value*. The *Attribute Permissions* are specified by the service or may be implementation specific if not specified otherwise.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0xuuuu – 16-bit Bluetooth UUID or 128-bit UUID for Characteristic UUID	Characteristic Value	Higher layer profile or implementation specific

Table 3.6: Characteristic Value declaration

3.3.3 Characteristic Descriptor Declarations

Characteristic descriptors are used to contain related information about the *Characteristic Value*. The GATT profile defines a standard set of characteristic descriptors that can be used by higher layer profiles. Higher layer profiles may define additional characteristic descriptors that are profile specific. Each characteristic descriptor is identified by the characteristic descriptor UUID. A client shall support the use of both 16-bit and 128-bit characteristic descriptor UUIDs. A client may ignore any characteristic descriptor declaration with an unknown characteristic descriptor UUID. An unknown characteristic descriptor UUID is a UUID for an unsupported characteristic descriptor.

Characteristic descriptors if present within a characteristic definition shall follow the *Characteristic Value* declaration. The characteristic descriptor declaration may appear in any order within the characteristic definition. The client shall not assume the order in which a characteristic descriptor declaration appears in a characteristic definition following the *Characteristic Value* declaration.

Characteristic descriptor declaration permissions are defined by a higher layer profile or are implementation specific. A client shall not assume all characteristic descriptor declarations are readable.

3.3.3.1 Characteristic Extended Properties

The *Characteristic Extended Properties* declaration is a descriptor that defines additional *Characteristic Properties*. If the *Extended Properties* bit of the *Characteristic Properties* is set then this characteristic descriptor shall exist. The characteristic descriptor may occur in any position within the characteristic definition after the Characteristic Value. Only one *Characteristic Extended Properties* declaration shall exist in a characteristic definition.

The characteristic descriptor is contained in an Attribute and the *Attribute Type* shall be set to the UUID for «Characteristic Extended Properties» and the *Attribute Value* shall be the *Characteristic Extended Properties Bit Field*. The *Attribute Permissions* shall be readable without authentication and authorization being required.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0x2900 – UUID for «Characteristic Extended Properties»	Characteristic Extended Properties Bit Field	Read Only, No Authentication, No Authorization

Table 3.7: Characteristic Extended Properties declaration

The *Characteristic Extended Properties* bit field describes additional properties on how the Characteristic Value can be used, or how the characteristic descriptors (see Section 3.3.3.3) can be accessed. If the bits defined in Table 3 8 are set, the action described is permitted. *Multiple Characteristic Properties* can be set.

Properties	Value	Description
Reliable Write	0x0001	If set, permits reliable writes of the Characteristic Value using the procedure defined in Section 4.9.5
Writable Auxiliaries	0x0002	If set, permits writes to the characteristic descriptor defined in Section 3.3.3.2
Reserved for Future Use	0xFFFC	Reserved for Future Use

Table 3.8: Characteristic Extended Properties bit field

3.3.3.2 Characteristic User Description

The *Characteristic User Description* declaration is an optional characteristic descriptor that defines a UTF-8 string of variable size that is a user textual description of the *Characteristic Value*. If the *Writable Auxiliary* bit of the *Characteristic Properties* is set then this characteristic descriptor can be written. The characteristic descriptor may occur in any position within the characteristic definition after the *Characteristic Value*. Only one *Characteristic User Description* declaration shall exist in a characteristic definition.

The characteristic descriptor is contained in an Attribute and the *Attribute Type* shall be set to the UUID for «Characteristic User Description» and the *Attribute Value* shall be set to the characteristic user description UTF-8 string. The *Attribute Permissions* are specified by the profile or may be implementation specific if not specified otherwise.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0x2901 – UUID for «Characteristic User Description»	Characteristic User Description UTF-8 String	Higher layer profile or implementation specific

Table 3.9: Characteristic User Description declaration

3.3.3.3 Client Characteristic Configuration

The *Client Characteristic Configuration* declaration is an optional characteristic descriptor that defines how the characteristic may be configured by a specific client. The Client Characteristic Configuration descriptor value shall be persistent across connections for bonded devices. The Client Characteristic Configuration descriptor value shall be set to the default value at each connection with non-bonded devices.The characteristic descriptor value is a bit field. When a bit is set, that action shall be enabled, otherwise it will not be used. The *Client Characteristic Configuration* descriptor may occur in any position within the characteristic definition after the Characteristic Value. Only one *Client Characteristic Configuration* declaration shall exist in a characteristic definition.

A client may write this configuration descriptor to control the configuration of this characteristic on the server for the client. Each client has its own instantiation of the *Client Characteristic Configuration*. Reads of the *Client Characteristic Configuration* only shows the configuration for that client and writes only affect the configuration of that client. Authentication and authorization may be required by the server to write the configuration descriptor. The *Client Characteristic Configuration* declaration shall be readable and writable.

The characteristic descriptor is contained in an Attribute. The *Attribute Type* shall be set to the UUID for «Client Characteristic Configuration». The *Attribute Value* shall be set to the characteristic descriptor value. The *Attribute Permissions* are specified by the profile or may be implementation specific if not specified otherwise.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0x2902 – UUID for «Client Characteristic Configuration»	Characteristic Configuration Bits	Readable with no authentication or authorization. Writable with authentication and authorization defined by a higher layer specification or is implementation specific.

Table 3.10: Client Characteristic Configuration declaration

The following Client Characteristic Configuration bits are defined:

Configuration	Value	Description
Notification	0x0001	The Characteristic Value shall be notified.This value can only be set if the characteristic's property has the notify bit set.
Indication	0x0002	The Characteristic Value shall be indicated. This value can only be set if the characteristic's property has the indicate bit set.
Reserved for Future Use	0xFFFC	Reserved for future use.

Table 3.11: Client Characteristic Configuration bit field definition

The default value for the *Client Characteristic Configuration* descriptor value shall be 0x0000.

In the case where multiple ATT bearers from the same device are supported by the GATT server, each ATT bearer shall be considered to have a separate GATT client instance. Therefore each GATT client shall have a separate Client Characteristic Configuration.

3.3.3.4 Server Characteristic Configuration

The *Server Characteristic Configuration* declaration is an optional characteristic descriptor that defines how the characteristic may be configured for the server. The characteristic descriptor value is a bit field. When a bit is set, that action shall be enabled, otherwise it will not be used. The *Server Characteristic Configuration* descriptor may occur in any position within the characteristic definition after the *Characteristic Value*. Only one *Server Characteristic Configuration* declaration shall exist in a characteristic definition. The *Server Characteristic Configuration* declaration shall be readable and writable.

A client may write this configuration descriptor to control the configuration of this characteristic on the server for all clients. There is a single instantiation of the *Server Characteristic Configuration* for all clients. Reads of the *Server Characteristic Configuration* shows the configuration all clients and writes affect the configuration for all clients. Authentication and authorization may be required by the server to write the configuration descriptor.

The characteristic descriptor is contained in an Attribute. The *Attribute Type* shall be set to the UUID for «Server Characteristic Configuration». The *Attribute Value* shall be set to the characteristic descriptor value. The *Attribute Permissions* are specified by the profile or may be implementation specific if not specified otherwise.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0x2903 – UUID for «Server Characteristic Configuration»	Characteristic Configuration Bits	Readable with no authentication or authorization. Writable with authentication and authorization defined by a higher layer specification or is implementation specific.

Table 3.12: Server Characteristic Configuration declaration

The following *Server Characteristic Configuration* bits are defined:

Configuration	Value	Description
Broadcast	0x0001	The Characteristic Value shall be broadcast when the server is in the broadcast procedure if advertising data resources are available. This value can only be set if the characteristic's property has the broadcast bit set.
Reserved for Future Use	0xFFFE	Reserved for future use.

Table 3.13: Server Characteristic Configuration bit field definition

3.3.3.5 Characteristic Presentation Format

The *Characteristic Presentation Format* declaration is an optional characteristic descriptor that defines the format of the *Characteristic Value*. The characteristic descriptor may occur in any position within the characteristic definition after the *Characteristic Value*. If more than one *Characteristic Presentation Format* declarations exist, in a characteristic definition, then a *Characteristic Aggregate Format* declaration shall exist as part of the characteristic definition.

The characteristic format value is composed of five parts: format, exponent, unit, name space, and description.

The characteristic descriptor is contained in an Attribute. The *Attribute Type* shall be set to the UUID for «Characteristic Format». The *Attribute Value* shall be set to the characteristic descriptor value. The *Attribute Permissions* shall be read only and not require authentication or authorization.

Attribute Handle	Attribute Type	Attribute Value					Attribute Permissions
0xNNNN	0x2904 – UUID for «Characteristic Format»	Format	Exponent	Unit	Name Space	Description	Read only No Authentication, NO authorization

Table 3.14: Characteristic Format declaration

The definition of the Characteristic Presentation Format descriptor Attribute Value field is the following.

Field Name	Value Size	Description
Format	1 octet	Format of the value of this characteristic.
Exponent	1 octet	Exponent field to determine how the value of this characteristic is further formatted.
Unit	2 octets	The unit of this characteristic as defined in [1]
Name Space	1 octet	The name space of the description as defined in [1]
Description	2 octets	The description of this characteristic as defined in a higher layer profile.

Table 3.15: Characteristic Format Value definition

3.3.3.5.1 Bit Ordering

The bit ordering used for the Characteristic Format descriptor shall be little-endian.

3.3.3.5.2 Format

The format field determines how a single value contained in the *Characteristic Value* is formatted. If a format is not a whole number of octets, then the data shall be stored in the smallest number of octets that can contain the value. The data shall occupy the whole of each octet except the most significant bits of the last octet; all other bits in the last octet shall be reserved for future use.

Signed integers shall use two's-complement representation.

The following format values are defined:

Format	Short Name	Description	Exponent Value
0x00	rfu	Reserved for Future Use	No
0x01	boolean	unsigned 1-bit; 0 = false, 1 = true	No
0x02	2bit	unsigned 2-bit integer	No
0x03	nibble	unsigned 4-bit integer	No
0x04	uint8	unsigned 8-bit integer	Yes
0x05	uint12	unsigned 12-bit integer	Yes
0x06	uint16	unsigned 16-bit integer	Yes
0x07	uint24	unsigned 24-bit integer	Yes
0x08	uint32	unsigned 32-bit integer	Yes
0x09	uint48	unsigned 48-bit integer	Yes
0x0A	uint64	unsigned 64-bit integer	Yes
0x0B	uint128	unsigned 128-bit integer	Yes
0x0C	sint8	signed 8-bit integer	Yes
0x0D	sint12	signed 12-bit integer	Yes
0x0E	sint16	signed 16-bit integer	Yes
0x0F	sint24	signed 24-bit integer	Yes
0x10	sint32	signed 32-bit integer	Yes
0x11	sint48	signed 48-bit integer	Yes
0x12	sint64	signed 64-bit integer	Yes
0x13	sint128	signed 128-bit integer	Yes
0x14	float32	IEEE-754 32-bit floating point	No
0x15	float64	IEEE-754 64-bit floating point	No
0x16	SFLOAT	IEEE-11073 16-bit SFLOAT	No
0x17	FLOAT	IEEE-11073 32-bit FLOAT	No

Table 3.16: Characteristic Format types

Format	Short Name	Description	Exponent Value
0x18	duint16	IEEE-20601 format	No
0x19	utf8s	UTF-8 string	No
0x1A	utf16s	UTF-16 string	No
0x1B	struct	Opaque structure	No
0x1C – 0xFF	rfu	Reserved for Future Use	No

Table 3.16: Characteristic Format types

When encoding an IPv4 address, the uint32 Format type shall be used.

When encoding an IPv6 address, the uint128 Format type shall be used.

When encoding a Bluetooth BD_ADDR, the uint48 Format type shall be used.

A duint16 is two uint16 values concatenated together.

3.3.3.5.3 Exponent

The exponent field is used with integer data types to determine how the value is further formatted. The exponent field is only used on integer format types as indicated in the format field in Table 3.16. The exponent field is a two's-complement signed integer.

$$\text{actual value} = \textit{Characteristic Value} * 10^{\text{Exponent}}$$

As can be seen in the above equation, the actual value is a combination of the Characteristic Value and the value 10 to the power Exponent. This is sometimes known as a fixed point number.

For example, if the Exponent is 2 and the *Characteristic Value* is 23, the actual value would be 2300.

For example, if the Exponent is -3 and the *Characteristic Value* is 3892, the actual value would be 3.892.

3.3.3.5.4 Unit

The Unit is a UUID as defined in the Assigned Numbers document [1].

3.3.3.5.5 Name Space

The Name Space field is used to identify the organization as defined in the Assigned Numbers document [1], that is responsible for defining the enumerations for the description field.

3.3.3.5.6 Description

The Description is an enumerated value as defined in the Assigned Numbers document [1] from the organization identified by the Name Space field.

3.3.3.6 Characteristic Aggregate Format

The *Characteristic Aggregate Format* declaration is an optional characteristic descriptor that defines the format of an aggregated *Characteristic Value*.

The characteristic descriptor may occur in any position within the characteristic definition after the *Characteristic Value*. Only one *Characteristic Aggregate Format* declaration shall exist in a characteristic definition.

The Characteristic Aggregate Format value is composed of a list of Attribute Handles of *Characteristic Presentation Format* declarations, where each *Attribute Handle* points to a *Characteristic Presentation Format* declaration.

The *Attribute Permissions* shall be read only and not require authentication or authorization.

Attribute Handle	Attribute Type	Attribute Value	Attribute Permissions
0xNNNN	0x2905 – UUID for «Characteristic Aggregate Format»	List of *Attribute Handles* for the Characteristic Presentation Format Declarations	Read only No authentication No authorization

Table 3.17: Characteristic Aggregate Format declaration

The *List of Attribute Handles* is the concatenation of multiple 16-bit *Attribute Handle* values into a single *Attribute Value*. The list shall contain at least two *Attribute Handle for Characteristic Presentation Format declarations*. The Characteristic Value shall be decomposed by each of the *Characteristic Presentation Format* declarations pointed to by the *Attribute Handles*. The order of the *Attribute Handles* in the list is significant.

If more than one *Characteristic Presentation Format* declarations exist in a characteristic definition, there shall also be one Characteristic Aggregate Format declaration. The *Characteristic Aggregate Format* declaration shall include each *Characteristic Presentation Format* declaration in the characteristic definition in the list of *Attribute Handles*. Characteristic Presentation Format declarations from other characteristic definitions may also be used.

A *Characteristic Aggregate Format* declaration may exist without a *Characteristic Presentation Format* declaration existing in the characteristic definition. The *Characteristic Aggregate Format* declaration may use *Characteristic Presentation Format* declarations from other characteristic definitions.

3.4 SUMMARY OF GATT PROFILE ATTRIBUTE TYPES

The following table summarizes the Attribute Types defined by the GATT Profile.

Attribute Type	UUID	Description
«Primary Service»	0x2800	Primary Service Declaration
«Secondary Service»	0x2801	Secondary Service Declaration
«Include»	0x2802	Include Declaration
«Characteristic»	0x2803	Characteristic Declaration
«Characteristic Extended Properties»	0x2900	Characteristic Extended Properties
«Characteristic User Description»	0x2901	Characteristic User Description Descriptor
«Client Characteristic Configuration»	0x2902	Client Characteristic Configuration Descriptor
«Server Characteristic Configuration»	0x2903	Server Characteristic Configuration Descriptor
«Characteristic Format»	0x2904	Characteristic Format Descriptor
«Characteristic Aggregate Format»	0x2905	Characteristic Aggregate Format Descriptor

Table 3.18: Summary of GATT Profile Attribute types

4 GATT FEATURE REQUIREMENTS

4.1 OVERVIEW

There are 11 features defined in the GATT Profile:

1. Server Configuration
2. Primary Service Discovery
3. Relationship Discovery
4. Characteristic Discovery
5. Characteristic Descriptor Discovery
6. Reading a Characteristic Value
7. Writing a Characteristic Value
8. Notification of a Characteristic Value
9. Indication of a Characteristic Value
10. Reading a Characteristic Descriptor
11. Writing a Characteristic Descriptor

Each of the features is mapped to procedures and sub-procedures. These procedures and sub-procedures describe how the Attribute Protocol is used to accomplish the corresponding feature.

4.2 FEATURE SUPPORT AND PROCEDURE MAPPING

The table below maps each feature to the procedures used for that feature, and indicates whether the procedure is optional or mandatory for that feature. The procedures are described in the referenced section.

Item No.	Feature	Sub-Procedure	Ref.	Support in Client	Support in Server
1	Server Configuration	Exchange MTU	4.3.1	O	O
2	Primary Service Discovery	Discover All Primary Services	4.4.1	O	M
		Discover Primary Services By Service UUID	4.4.2	O	M
3	Relationship Discovery	Find Included Services	4.5.1	O	M
4	Characteristic Discovery	Discover All Characteristic of a Service	4.6.1	O	M
		Discover Characteristic by UUID	4.6.2	O	M

Table 4.1: GATT feature mapping to procedures

Item No.	Feature	Sub-Procedure	Ref.	Support in Client	Support in Server
5	Characteristic Descriptor Discovery	Discover All Characteristic Descriptors	4.7.1	O	M
6	Characteristic Value Read	Read Characteristic Value	4.8.1	O	M
		Read Using Characteristic UUID	4.8.2~~4.8.1~~	O	M
		Read Long Characteristic Values	4.8.3~~4.8.2~~	O	O
		Read Multiple Characteristic Values	4.8.4~~4.8.3~~	O	O
7	Characteristic Value Write	Write Without Response	4.9.1	O	C.1
		Signed Write Without Response	4.9.2	O	O
		Write Characteristic Value	4.9.3	O	C.2
		Write Long Characteristic Values	4.9.4	O	O
		Characteristic Value Reliable Writes	4.9.5	O	O
8	Characteristic Value Notification	Notifications	4.10.1	O	O
9	Characteristic Value Indication	Indications	4.11.1	M	C3
10	Characteristic Descriptor Value Read	Read Characteristic Descriptors	4.12.1	O	O
		Read Long Characteristic Descriptors	4.12.2	O	O
11	Characteristic Descriptor Value Write	Write Characteristic Descriptors	4.12.3	O	O
		Write Long Characteristic Descriptors	4.12.4	O	O

C1: Write Without Response is mandatory if Signed Write Without Response is supported otherwise optional

C2: Write Characteristic Value is mandatory if Write Long Characteristic Values is supported otherwise optional

C3: If *Service Changed Characteristic* is present, this feature is mandatory, otherwise optional.

Table 4.1: GATT feature mapping to procedures

4.3 SERVER CONFIGURATION

This procedure is used by the client to configure the Attribute Protocol. This procedure has only one sub-procedure used to set the MTU sizes.

4.3.1 Exchange MTU

This sub-procedure is used by the client to set the ATT_MTU to the maximum possible value that can be supported by both devices when the client supports a value greater than the default ATT_MTU for the Attribute Protocol. This sub-procedure shall only be initiated once during a connection.

This sub-procedure shall not be used on a BR/EDR physical link since the MTU size is negotiated using L2CAP channel configuration procedures.

The Attribute Protocol *Exchange MTU Request* is used by this sub-procedure. The Client Rx MTU parameter shall be set to the maximum MTU that this client can receive.

Two possible responses can be sent from the server for the *Exchange MTU Request: Exchange MTU Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

The server shall respond to this message with an *Exchange MTU Response* with the Server Rx MTU parameter set to the maximum MTU that this server can receive.

If the *Error Response* is sent by the server with the *Error Code* set to *Request Not Supported*, the *Attribute Opcode* is not supported and the default MTU shall be used.

Once the messages have been exchanged, the ATT_MTU shall be set to the minimum of the Client Rx MTU and Server Rx MTU values.

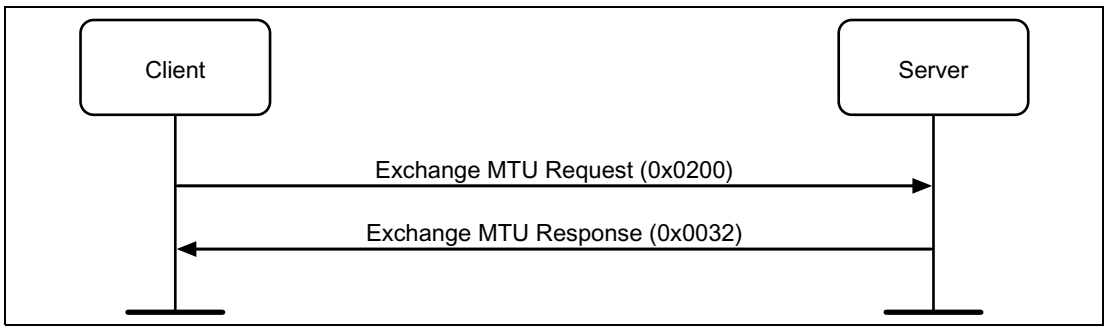

Figure 4.1: Exchange MTU

For example, in Figure 4.1, based on the exchanged ATT_MTU value in the ATT_MTU would be 0x0032.

4.4 PRIMARY SERVICE DISCOVERY

This procedure is used by a client to discover primary services on a server. Once the primary services are discovered, additional information about the primary services can be accessed using other procedures, including characteristic discovery and relationship discovery to find other related primary and secondary services.

There are two sub-procedures that can be used for primary service discovery: Discover All Primary Services and Discover Primary Services by Service UUID.

4.4.1 Discover All Primary Services

This sub-procedure is used by a client to discover all the primary services on a server.

The Attribute Protocol *Read By Group Type Request* shall be used with the Attribute Type parameter set to the UUID for «Primary Service». The *Starting Handle* shall be set to 0x0001 and the *Ending Handle* shall be set to 0xFFFF.

Two possible responses can be sent from the server for the *Read By Group Type Request: Read By Group Type Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Read By Group Type Response returns a list of *Attribute Handle*, *End Group Handle,* and *Attribute Value* tuples corresponding to the services supported by the server. Each *Attribute Value* contained in the response is the Service UUID of a service supported by the server. The *Attribute Handle* is the handle for the service declaration. The *End Group Handle* is the handle of the last attribute within the service definition. The *End Group Handle* of the last service in a device can be 0xFFFF. The *Read By Group Type Request* shall be called again with the *Starting Handle* set to one greater than the last *End Group Handle* in the *Read By Group Type Response*.

This sub-procedure is complete when the *Error Response* is received and the *Error Code* is set to «Attribute Not Found» or when the *End Group Handle* in the *Read by Type Group Response* is 0xFFFF.

It is permitted to end the sub-procedure early if a desired primary service is found prior to discovering all the primary services on the server.

Note: The service declaration described in Section 3.1 specifies that the service declaration is readable and requires no authentication or authorization, therefore insufficient authentication or read not permitted errors shall not occur.

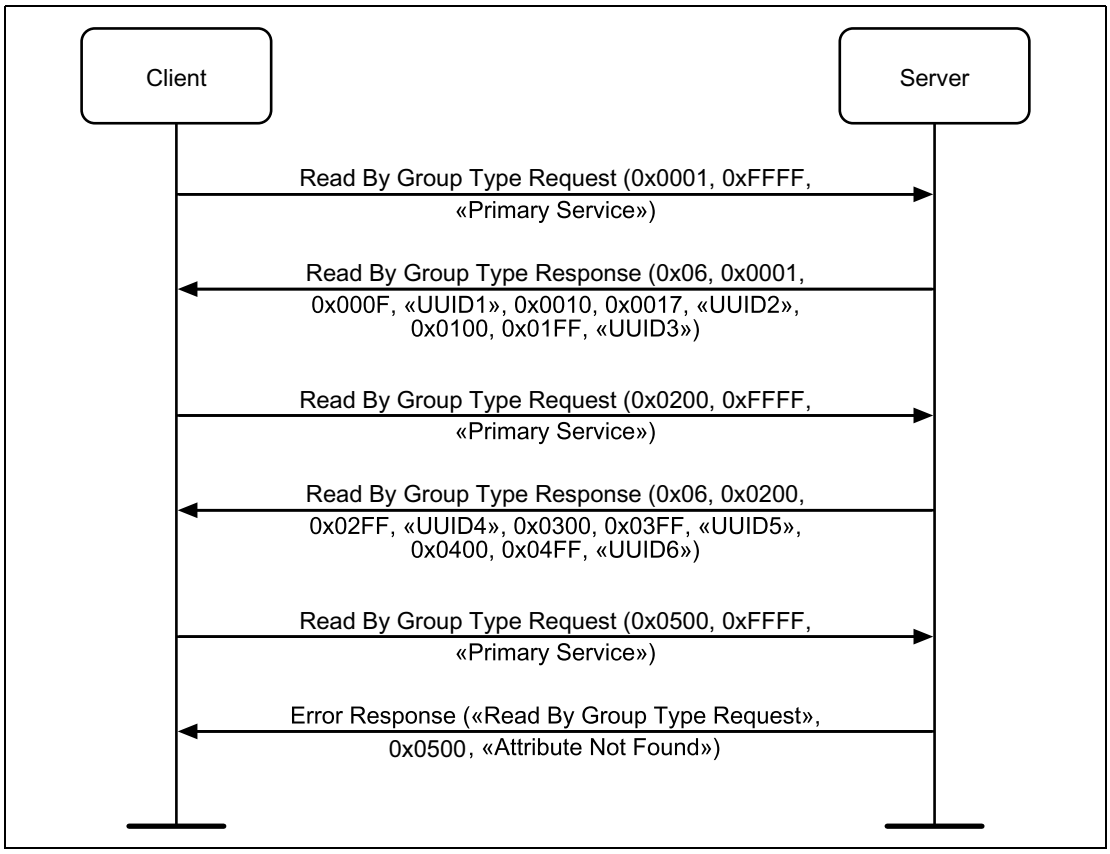

Figure 4.2: Discover All Primary Services example

4.4.2 Discover Primary Service by Service UUID

This sub-procedure is used by a client to discover a specific primary service on a server when only the Service UUID is known. The specific primary service may exist multiple times on a server. The primary service being discovered is identified by the service UUID.

The Attribute Protocol *Find By Type Value Request* shall be used with the Attribute Type parameter set to the UUID for «Primary Service» and the *Attribute Value* set to the 16-bit Bluetooth UUID or 128-bit UUID for the specific primary service. The *Starting Handle* shall be set to 0x0001 and the *Ending Handle* shall be set to 0xFFFF.

Two possible responses can be sent from the server for the *Find By Type Value Request: Find By Type Value Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Find By Type Value Response returns a list of *Attribute Handle* ranges. The *Attribute Handle* range is the starting handle and the ending handle of the service definition. The *End Group Handle* of the last service in a device can be 0xFFFF. If the *Attribute Handle* range for the Service UUID being searched is returned and the End Found Handle is not 0xFFFF, the *Find By Type Value*

Request may be called again with the *Starting Handle* set to one greater than the last *Attribute Handle* range in the Find By Type Value Response.

This sub-procedure is complete when the *Error Response* is received and the *Error Code* is set to «Attribute Not Found» or when the *End Group Handle* in the *Find By Type Value Response* is 0xFFFF.

It is permitted to end the sub-procedure early if a desired primary service is found prior to discovering all the primary services of the specified service UUID supported on the server.

Note: The service declaration described in Section 3.1 specifies that the service declaration is readable and requires no authentication or authorization, therefore insufficient authentication or read not permitted errors shall not occur.

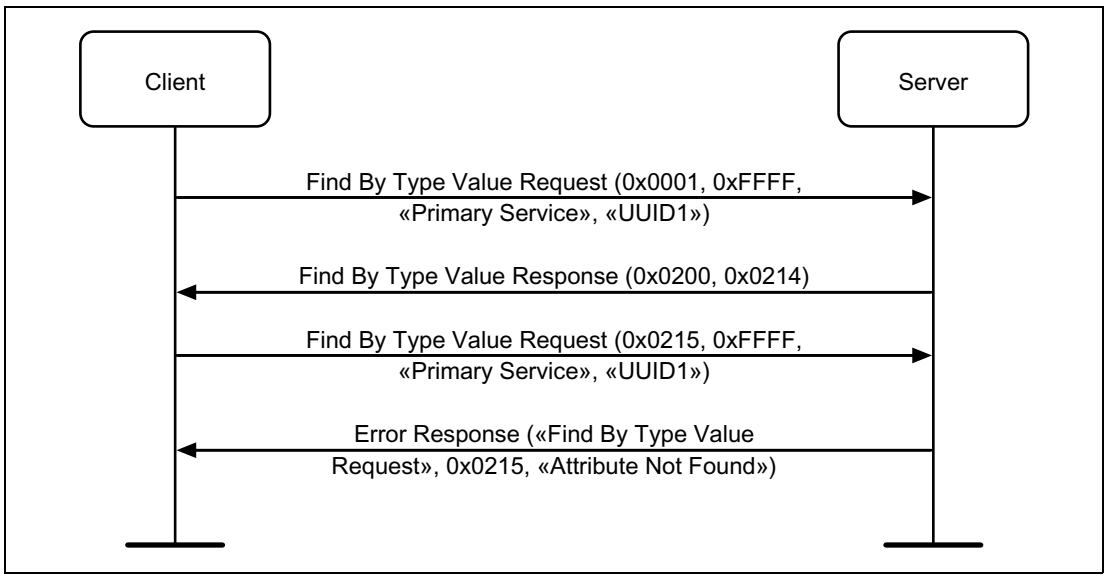

Figure 4.3: Discover Primary Service by Service UUID example

4.5 RELATIONSHIP DISCOVERY

This procedure is used by a client to discover service relationships to other services.

There is one sub-procedure that can be used for relationship discovery: Find Included Services.

4.5.1 Find Included Services

This sub-procedure is used by a client to find include service declarations within a service definition on a server. The service specified is identified by the service handle range.

The Attribute Protocol *Read By Type Request* shall be used with the *Attribute Type* parameter set to the UUID for «Include» The *Starting Handle* shall be set to starting handle of the specified service and the *Ending Handle* shall be set to the ending handle of the specified service. It is permitted to end the sub-procedure early if a desired included service is found prior to discovering all the included services of the specified service supported on the server.

Two possible responses can be sent from the server for the *Read By Type Request: Read By Type Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Read By Type Response returns a set of *Attribute Handle* and *Attribute Value* pairs corresponding to the included services in the service definition. Each *Attribute Value* contained in the response is composed of the *Attribute Handle* of the included service declaration and the *End Group Handle*. If the service UUID is a 16-bit Bluetooth UUID it is also returned in the response. The *Read By Type Request* shall be called again with the *Starting Handle* set to one greater than the last *Attribute Handle* in the *Read By Type Response*.

The sub-procedure is complete when either the *Error Response* is received with the *Error Code* set to *Attribute Not Found* or the *Read By Type Response* has an *Attribute Handle* of the included service declaration that is equal to the *Ending Handle* of the request.

To get the included service UUID when the included service uses a 128-bit UUID, the *Read Request* is used. The *Attribute Handle* for the *Read Request* is the *Attribute Handle* of the included service.

Note: The include declaration described in Section 3.2 specifies that the include declaration is readable and requires no authentication or authorization, therefore insufficient authentication or read not permitted errors shall not occur.

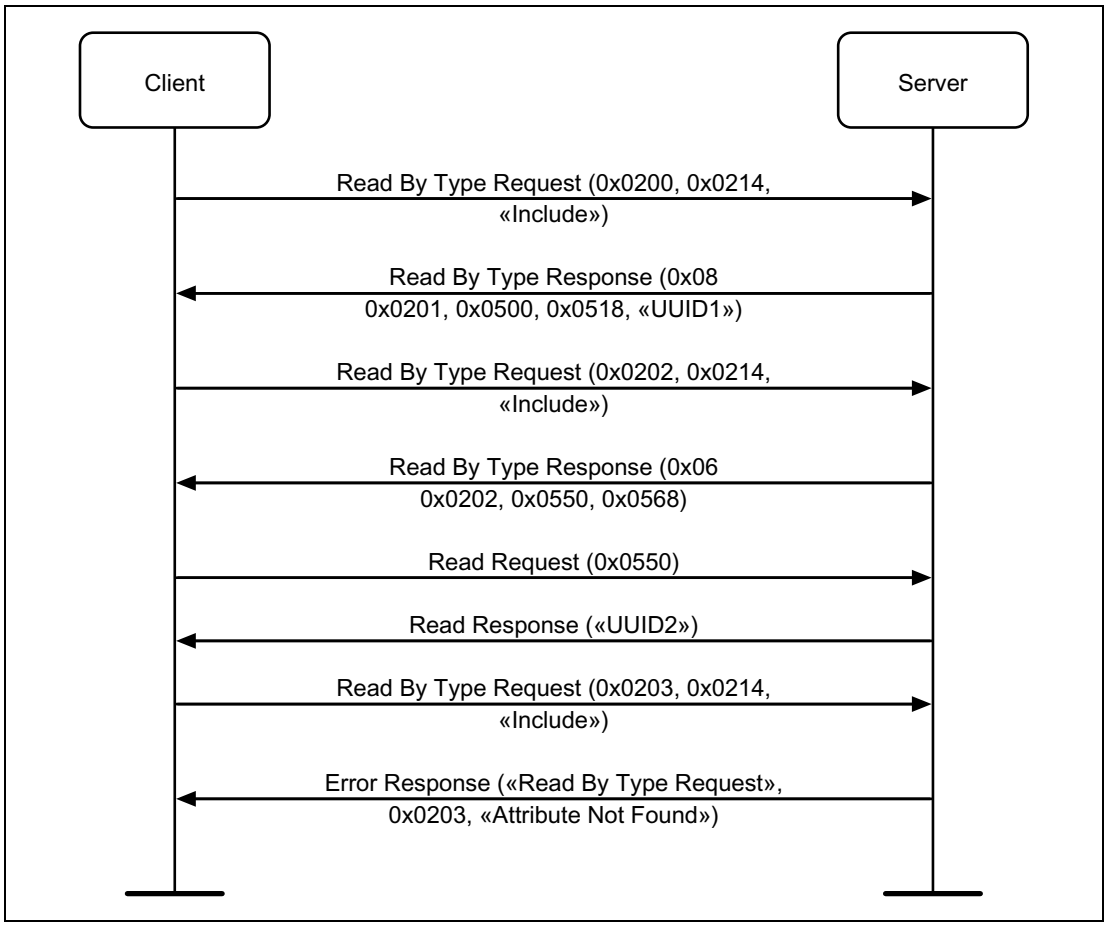

Figure 4.4: Find Included Services example

4.6 CHARACTERISTIC DISCOVERY

This procedure is used by a client to discover service characteristics on a server. Once the characteristics are discovered additional information about the characteristics can be discovered or accessed using other procedures.

There are two sub-procedures that can be used for characteristic discovery: Discover All Characteristics of a Service and Discover Characteristics by UUID.

4.6.1 Discover All Characteristics of a Service

This sub-procedure is used by a client to find all the characteristic declarations within a service definition on a server when only the service handle range is known. The service specified is identified by the service handle range.

The Attribute Protocol *Read By Type Request* shall be used with the *Attribute Type* parameter set to the UUID for «Characteristic» The *Starting Handle* shall be set to starting handle of the specified service and the *Ending Handle* shall be set to the ending handle of the specified service.

Two possible responses can be sent from the server for the *Read By Type Request: Read By Type Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Read By Type Response returns a list of *Attribute Handle* and *Attribute Value* pairs corresponding to the characteristics in the service definition. The *Attribute Handle* is the handle for the characteristic declaration. The *Attribute Value* is the Characteristic Properties, Characteristic Value Handle and Characteristic UUID. The Read By Type Request shall be called again with the *Starting Handle* set to one greater than the last *Attribute Handle* in the *Read By Type Response*.

The sub-procedure is complete when the *Error Response* is received and the *Error Code* is set to *Attribute Not Found* or the *Read By Type Response* has an *Attribute Handle* that is equal to the *Ending Handle* of the request.

It is permitted to end the sub-procedure early if a desired characteristic is found prior to discovering all the characteristics of the specified service supported on the server.

Note: The characteristic declaration described in Section 3.3 specifies that the characteristic declaration is readable and requires no authentication or authorization, therefore insufficient authentication or read not permitted errors should not occur.

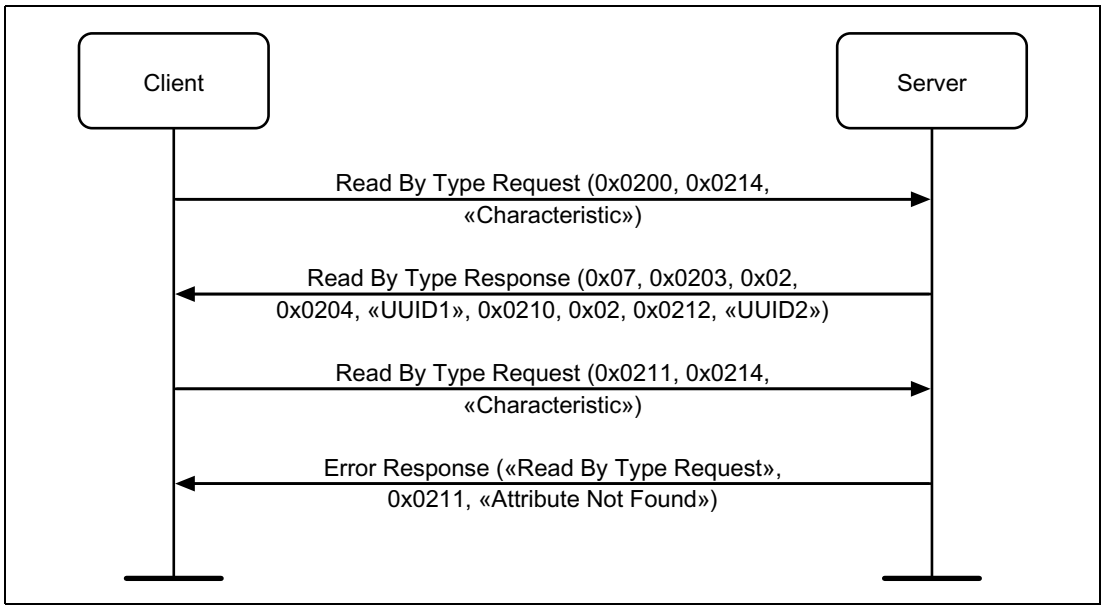

Figure 4.5: Discover All Characteristics of a Service example

Note: In this example «UUID1» and «UUID2» are 16 bits (2 octets).
If they were 128 bits (16 octets) then the *Read By Type Response* data would instead be:
0x15, 0x0203, 0x02, 0x0204, «UUID1», 0x0210, 0x02, 0x0212, «UUID2»

4.6.2 Discover Characteristics by UUID

This sub-procedure is used by a client to discover service characteristics on a server when only the service handle ranges are known and the characteristic UUID is known. The specific service may exist multiple times on a server. The characteristic being discovered is identified by the characteristic UUID.

The Attribute Protocol *Read By Type Request* is used to perform the beginning of the sub-procedure. The *Attribute Type* is set to the UUID for «Characteristic» and the *Starting Handle* and *Ending Handle* parameters shall be set to the service handle range.

Two possible responses can be sent from the server for the *Read By Type Request: Read By Type Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Read By Type Response returns a list of *Attribute Handle* and *Attribute Value* pairs corresponding to the characteristics contained in the handle range provided. Each *Attribute Value* in the list is the *Attribute Value* for the characteristic declaration. The *Attribute Value* contains the characteristic properties, Characteristic *Value Handle* and characteristic UUID. The *Attribute Value* for each *Attribute Handle* and *Attribute Value* pairs are checked for a matching characteristic UUID. Once found, the sub-procedure continues until the end of the service handle range is exhausted. The *Read By Type Request* is called again with the *Starting Handle* set to one greater than the last *Attribute Handle* in the *Read By Type Response*.

If the *Error Response* is sent by the server with the *Error Code* set to *Attribute Not Found*, the characteristic does not exist on the server within the handle range provided.

It is permitted to end the sub-procedure early if a desired characteristic is found prior to discovering all the characteristics for the specified service supported on the server.

Note: The characteristic declaration described in Section 3.3 specifies that the characteristic declaration is readable and requires no authentication or authorization, therefore insufficient authentication or read not permitted errors shall not occur.

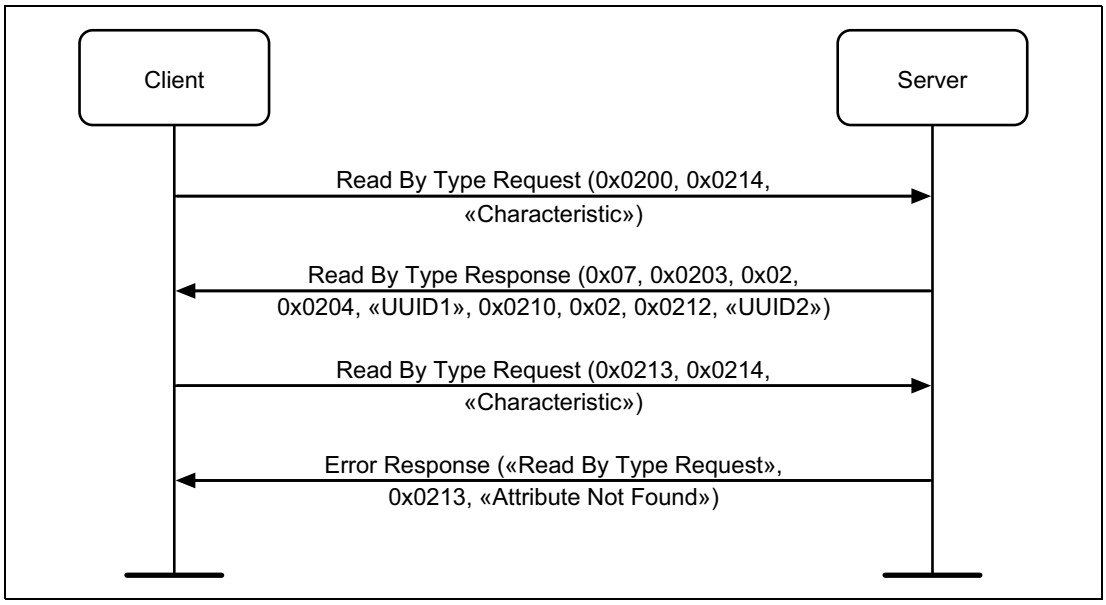

Figure 4.6: Discover Characteristics by UUID example

4.7 CHARACTERISTIC DESCRIPTOR DISCOVERY

This procedure is used by a client to discover characteristic descriptors of a characteristic. Once the characteristic descriptors are discovered additional information about the characteristic descriptors can be accessed using other procedures.

There is one sub-procedure that can be used for characteristic descriptor discovery: Discover All Characteristic Descriptors.

4.7.1 Discover All Characteristic Descriptors

This sub-procedure is used by a client to find all the characteristic descriptor's Attribute Handles and Attribute Types within a characteristic definition when only the characteristic handle range is known. The characteristic specified is identified by the characteristic handle range.

The Attribute Protocol *Find Information Request* shall be used with the Starting Handle set to the handle of the specified characteristic value + 1 and the *Ending Handle* set to the ending handle of the specified characteristic.

Two possible responses can be sent from the server for the *Find Information Request: Find Information Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Find Information Response returns a list of *Attribute Handle* and *Attribute Value* pairs corresponding to the characteristic descriptors in the characteristic definition. The *Attribute Handle* is the handle for the characteristic descriptor declaration. The *Attribute Value* is the Characteristic Descriptor UUID. The

Find Information Request shall be called again with the *Starting Handle* set to one greater than the last *Attribute Handle* in the Find Information Response.

The sub-procedure is complete when the *Error Response* is received and the *Error Code* is set to *Attribute Not Found* or the *Find Information* Response has an *Attribute Handle* that is equal to the *Ending Handle* of the request.

It is permitted to end the sub-procedure early if a desired Characteristic Descriptor is found prior to discovering all the characteristic descriptors of the specified characteristic.

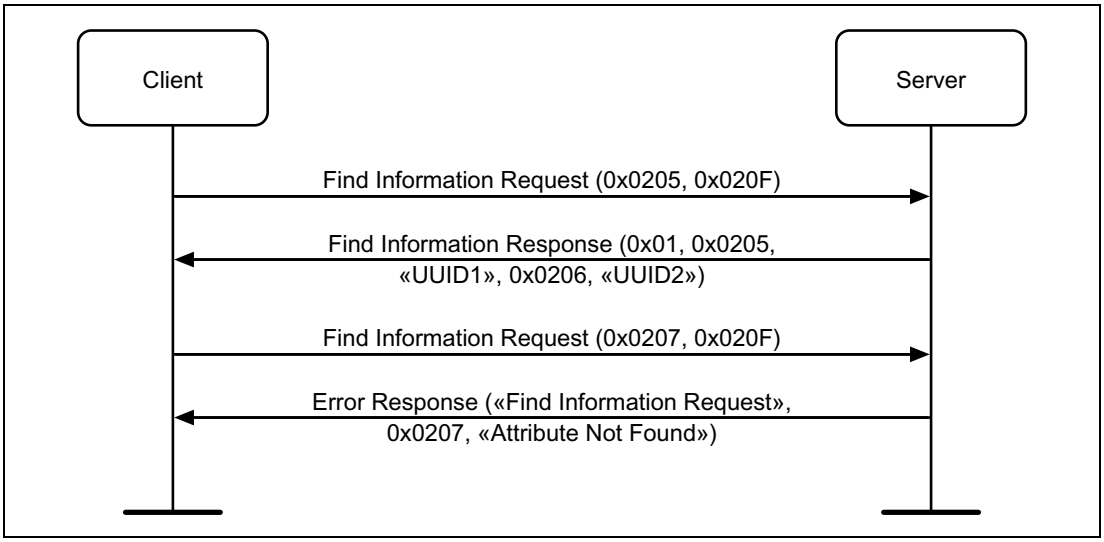

Figure 4.7: Discover All Characteristic Descriptors example

4.8 CHARACTERISTIC VALUE READ

This procedure is used to read a *Characteristic Value* from a server. There are four sub-procedures that can be used to read a *Characteristic Value*: Read Characteristic Value, Read Using Characteristic UUID, Read Long Characteristic Values, and Read Multiple Characteristic Values.

4.8.1 Read Characteristic Value

This sub-procedure is used to read a *Characteristic Value* from a server when the client knows the *Characteristic Value Handle*. The Attribute Protocol *Read Request* is used with the *Attribute Handle* parameter set to the *Characteristic Value Handle*. The *Read Response* returns the *Characteristic Value* in the *Attribute Value* parameter.

The *Read Response* only contains the complete *Characteristic Value* if that is less than or equal to (ATT_MTU – 1) octets in length. If the *Characteristic Value* is greater than (ATT_MTU – 1) octets in length, the *Read Response* only contains the first portion of the *Characteristic Value* and the *Read Long Characteristic Value* procedure may be used if the rest is required.

An *Error Response* shall be sent by the server in response to the *Read Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a read operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set as specified in the Attribute Protocol.

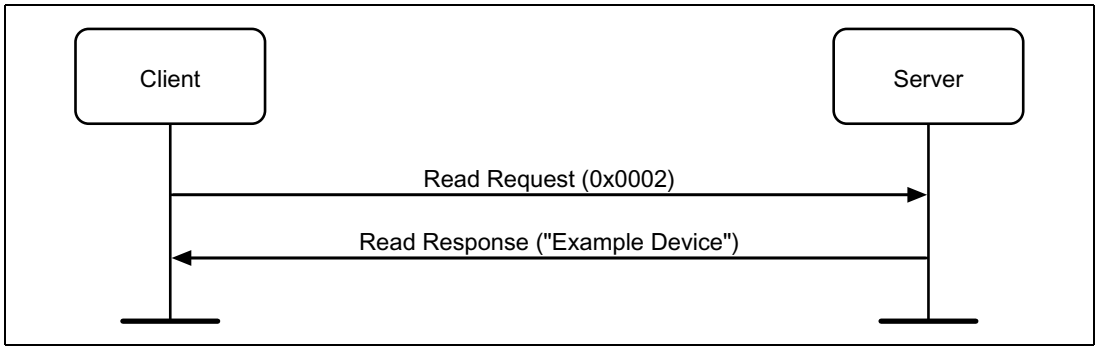

Figure 4.8: Read Characteristic Value example

4.8.2 Read Using Characteristic UUID

This sub-procedure is used to read a *Characteristic Value* from a server when the client only knows the characteristic UUID and does not know the handle of the characteristic.

The Attribute Protocol *Read By Type Request* is used to perform the sub-procedure. The Attribute Type is set to the known characteristic UUID and the Starting Handle and Ending Handle parameters shall be set to the range over

which this read is to be performed. This is typically the handle range for the service in which the characteristic belongs.

Two possible responses can be sent from the server for the *Read By Type Request: Read By Type Response* and *Error Response*.

Error Response is returned if an error occurred on the server.

Read By Type Response returns a list of *Attribute Handle* and *Attribute Value* pairs corresponding to the first characteristics contained in the handle range that will fit into the *Read By Type Response* PDU. This procedure does not return the complete list of all characteristics with the given characteristic UUID within the range of values. If such an operation is required, then the *Discover All Characteristics by UUID* sub procedure shall be used.

If the Error Response is sent by the server with the *Error Code* set to *Attribute Not Found*, the characteristic does not exist on the server within the handle range provided.

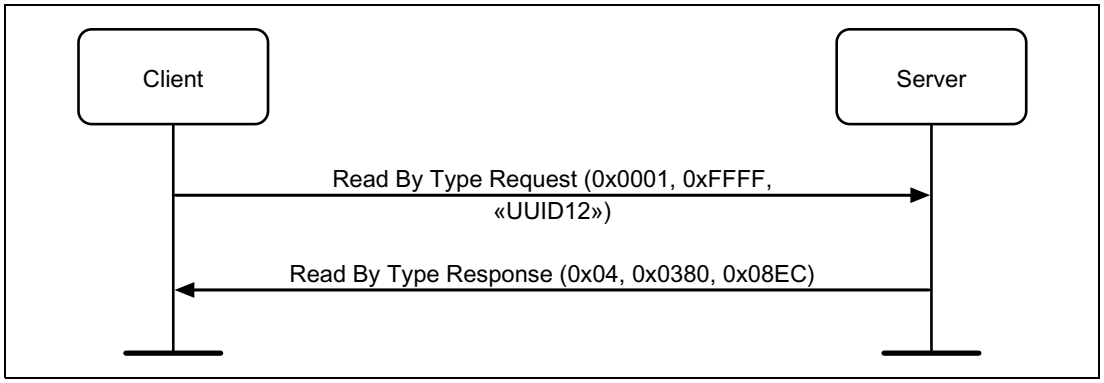

Figure 4.9: Read Using Characteristic UUID example

4.8.3 Read Long Characteristic Values

This sub-procedure is used to read a *Characteristic Value* from a server when the client knows the *Characteristic Value Handle* and the length of the *Characteristic Value* is longer than can be sent in a single *Read Response* Attribute Protocol message.

The Attribute Protocol *Read Blob Request* is used to perform this sub-procedure. The *Attribute Handle* shall be set to the *Characteristic Value Handle* of the *Characteristic Value* to be read. The Value Offset parameter shall be the offset within the *Characteristic Value* to be read. To read the complete *Characteristic Value* the offset should be set to 0x00 for the first *Read Blob Request*. The offset for subsequent *Read Blob Requests* is the next octet that has yet to be read. The *Read Blob Request* is repeated until the *Read Blob Response's Part Attribute Value* parameter is shorter than (ATT_MTU – 1).

For each *Read Blob Request* a *Read Blob Response* is received with a portion of the Characteristic Value contained in the *Part Attribute Value* parameter.

An *Error Response* shall be sent by the server in response to the *Read Blob Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a read operation is not permitted on the *Characteristic Value*. The Error Code parameter is set as specified in the Attribute Protocol. If the *Characteristic Value* is not longer than (ATT_MTU – 1) an *Error Response* with the *Error Code* set to Attribute Not Long shall be received on the first *Read Blob Request*.

Note: The *Read Blob Request* may be used to read the remainder of an Attribute where the first part was read using a simple *Read Request*.

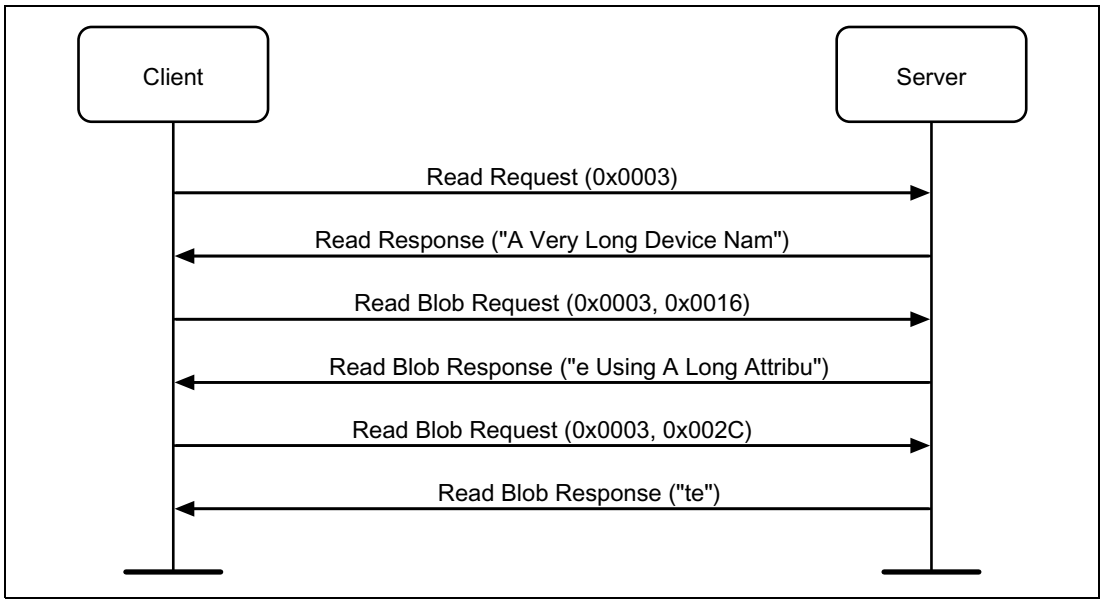

Figure 4.10: Read Long Characteristic Values example

4.8.4 Read Multiple Characteristic Values

This sub-procedure is used to read multiple *Characteristic Values* from a server when the client knows the *Characteristic Value Handles*. The Attribute Protocol *Read Multiple Requests* is used with the *Set Of Handles* parameter set to the *Characteristic Value Handles*. The *Read Multiple Response* returns the *Characteristic Values* in the *Set Of Values* parameter.

The *Read Multiple Response* only contains a set of *Characteristic Values* that is less than or equal to (ATT_MTU – 1) octets in length. If the *Set Of Values* is greater than (ATT_MTU – 1) octets in length, only the first (ATT_MTU – 1) octets are included in the response.

Note: A client should not request multiple *Characteristic Values* when the response's *Set Of Values* parameter is equal to (ATT_MTU – 1) octets in length

since it is not possible to determine if the last *Characteristic Value* was read or additional *Characteristic Values* exist but were truncated.

An *Error Response* shall be sent by the server in response to the *Read Multiple Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a read operation is not permitted on any of the *Characteristic Values*. The *Error Code* parameter is set as specified in the Attribute Protocol.

Refer to the Attribute Protocol specification for the format of the *Set Of Handles* and *Set Of Values* parameter.

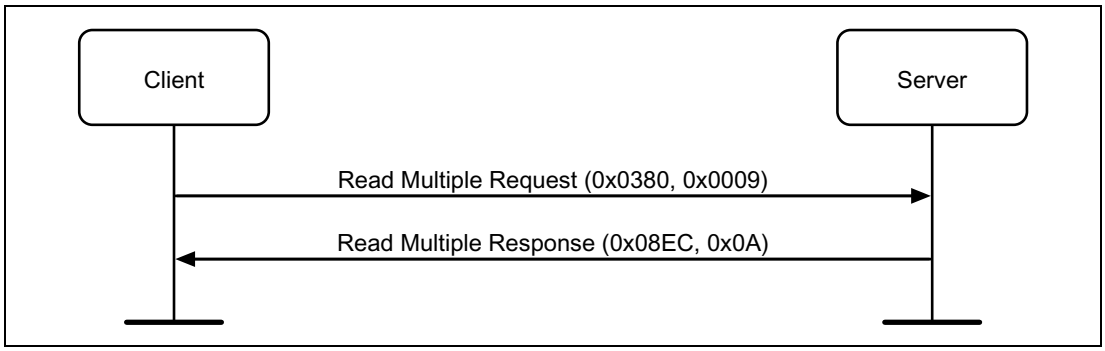

Figure 4.11: Read Multiple Characteristic Values example

4.9 CHARACTERISTIC VALUE WRITE

This procedure is used to write a *Characteristic Value* to a server.

There are five sub-procedures that can be used to write a *Characteristic Value*: Write Without Response, Signed Write Without Response, Write Characteristic Value, Write Long Characteristic Values and Reliable Writes.

4.9.1 Write Without Response

This sub-procedure is used to write a *Characteristic Value* to a server when the client knows the *Characteristic Value Handle* and the client does not need an acknowledgment that the write was successfully performed. This sub-procedure only writes the first (ATT_MTU – 3) octets of a *Characteristic Value*. This sub-procedure cannot be used to write a long characteristic; instead the *Write Long Characteristic Values* sub-procedure should be used.

The Attribute Protocol *Write Command* is used for this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle*. The *Attribute Value* parameter shall be set to the new *Characteristic Value*.

If the *Characteristic Value* write request is the wrong size, or has an invalid value as defined by the profile, then the write shall not succeed and no error shall be generated by the server.

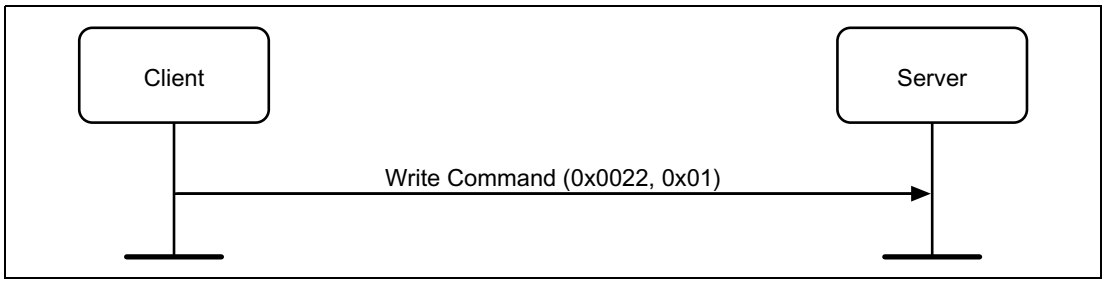

Figure 4.12: Write Without Response example

4.9.2 Signed Write Without Response

This sub-procedure is used to write a *Characteristic Value* to a server when the client knows the *Characteristic Value Handle* and the ATT Bearer is not encrypted. This sub-procedure shall only be used if the *Characteristic Properties* authenticated bit is enabled and the client and server device share a bond as defined in [Vol 3] Part C, Generic Access Profile.

This sub-procedure only writes the first (ATT_MTU – 15) octets of an *Attribute Value.* This sub-procedure cannot be used to write a long Attribute.

The Attribute Protocol *Signed Write Command* is used for this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle*. The *Attribute Value* parameter shall be set to the new *Characteristic Value* authenticated by signing the value, as defined in the Security Manager [Vol 3] Part H, Section 2.4.5.

If the authenticated *Characteristic Value* that is written is the wrong size, has an invalid value as defined by the profile, or the signed value does not authenticate the client, then the write shall not succeed and no error shall be generated by the server.

If a connection is already encrypted with LE security mode 1, level 2 or level 3 as defined in [Vol 3] Part C, Section 10.2 then, a Write Without Response as defined in Section 4.9.1 shall be used instead of a Signed Write Without Response.

Note: On BR/EDR, the ATT Bearer is always encrypted, due to the use of Security Mode 4, therefore this sub-procedure shall not be used.

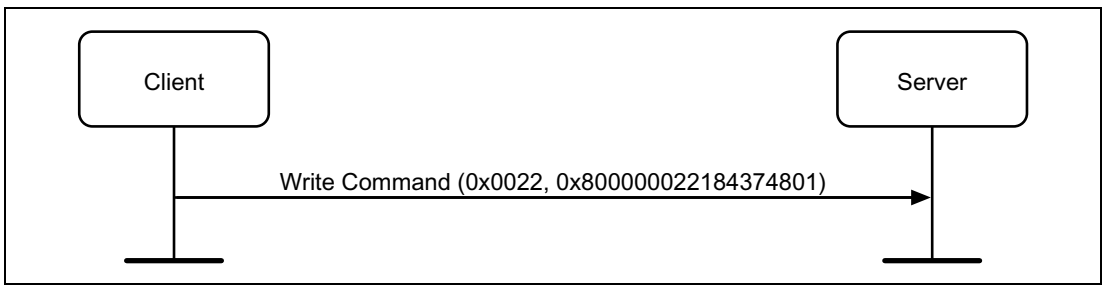

Figure 4.13: Signed Write Without Response example

4.9.3 Write Characteristic Value

This sub-procedure is used to write a *Characteristic Value* to a server when the client knows the *Characteristic Value Handle*. This sub-procedure only writes the first (ATT_MTU – 3) octets of a *Characteristic Value*. This sub-procedure cannot be used to write a long Attribute; instead the *Write Long Characteristic Values* sub-procedure should be used.

The Attribute Protocol *Write Request* is used to for this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle*. The *Attribute Value* parameter shall be set to the new characteristic.

A *Write Response* shall be sent by the server if the write of the *Characteristic Value* succeeded.

An *Error Response* shall be sent by the server in response to the *Write Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a write operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set as specified in the Attribute Protocol. If the *Characteristic Value* that is written is the wrong size, or has an invalid value as defined by the profile, then the value shall not be written and an *Error Response* shall be sent with the *Error Code* set to *Application Error* by the server.

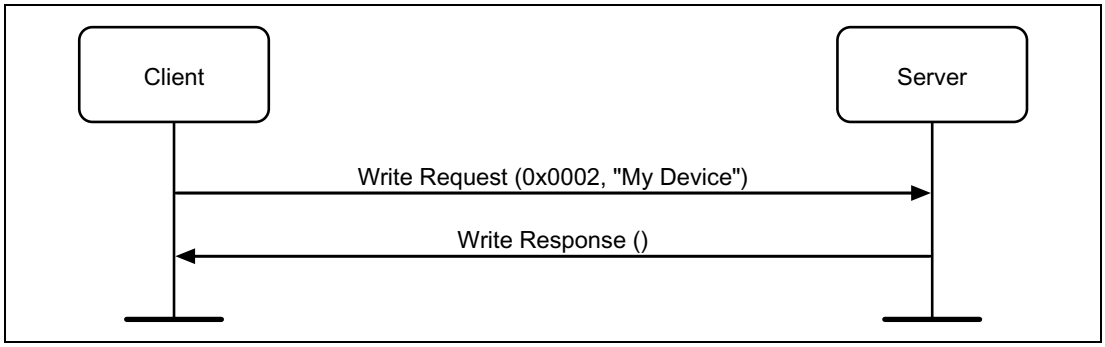

Figure 4.14: Write Characteristic Value example

4.9.4 Write Long Characteristic Values

This sub-procedure is used to write a *Characteristic Value* to a server when the client knows the *Characteristic Value Handle* but the length of the *Characteristic Value* is longer than can be sent in a single *Write Request* Attribute Protocol message.

The Attribute Protocol *Prepare Write Request* and *Execute Write Request* are used to perform this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle* of the *Characteristic Value* to be written. The *Part Attribute Value* parameter shall be set to the part of the *Attribute Value* that is being written. The *Value Offset* parameter shall be the offset within the *Characteristic Value* to be written. To write the complete

Characteristic Value the offset should be set to 0x0000 for the first *Prepare Write Request*. The offset for subsequent *Prepare Write Requests* is the next octet that has yet to be written. The *Prepare Write Request* is repeated until the complete *Characteristic Value* has been transferred, after which an Executive Write Request is used to write the complete value.

Note: The values in the Prepare Write Response do not need to be verified in this sub-procedure.

An *Error Response* shall be sent by the server in response to the *Prepare Write Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a write operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set as specified in the Attribute Protocol. If the *Attribute Value* that is written is the wrong size, or has an invalid value as defined by the profile, then the write shall not succeed and an *Error Response* shall be sent with the *Error Code* set to *Application Error* by the server.

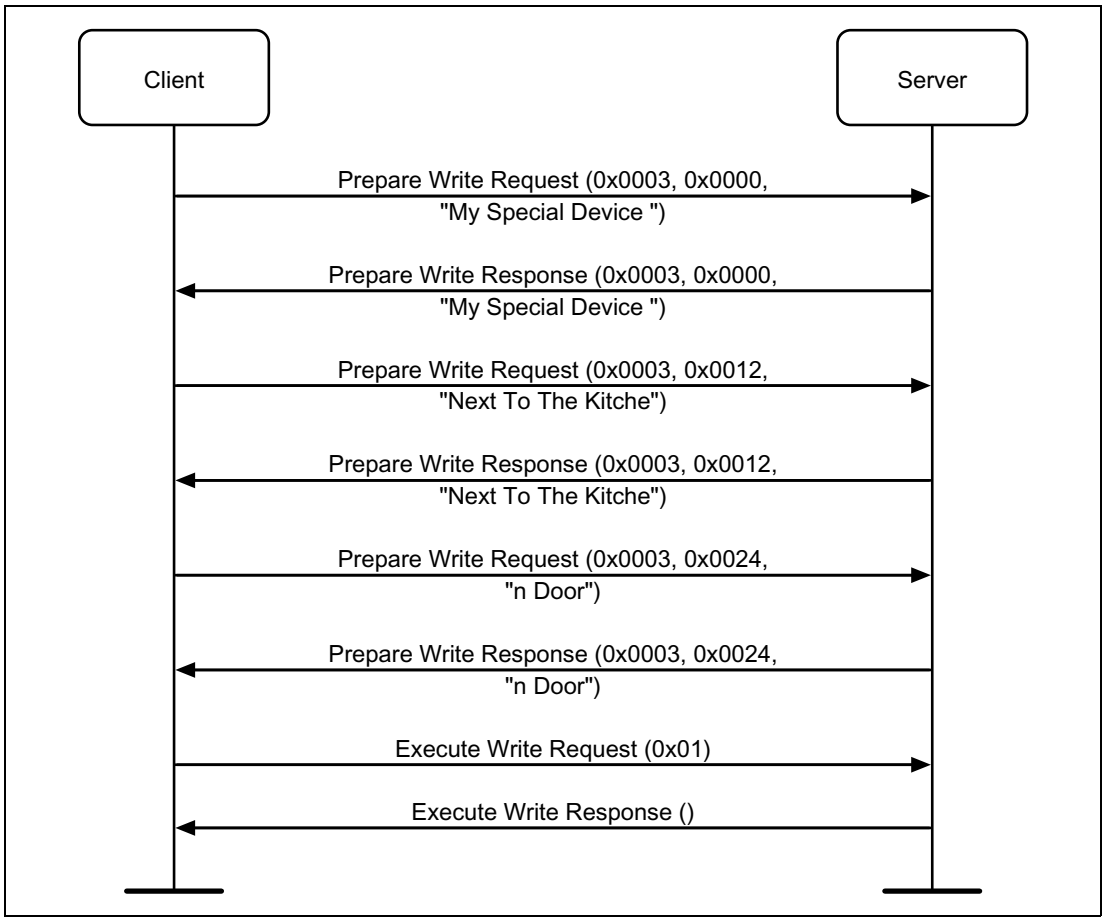

Figure 4.15: Write Long Characteristic Values example

4.9.5 Reliable Writes

This sub-procedure is used to write a *Characteristic Value* to a server when the client knows the *Characteristic Value Handle*, and assurance is required that the correct *Characteristic Value* is going to be written by transferring the *Characteristic Value* to be written in both directions before the write is performed. This sub-procedure can also be used when multiple values must be written, in order, in a single operation.

The sub-procedure has two phases; the first phase prepares the *Characteristic Values* to be written. To do this, the client transfers the *Characteristic Values* to the server. The server checks the validity of the *Characteristic Values*. The client also checks each *Characteristic Value* to verify it was correctly received by the server using the server responses. Once this is complete, the second phase performs the execution of all of the prepared Characteristic Value writes on the server from this client.

In the first phase, the Attribute Protocol *Prepare Write Request* is used. The *Attribute Handle* shall be set to the *Characteristic Value Handle* that is to be prepared to write. The *Value Offset* and *Part Attribute Value* parameter shall be set to the new *Characteristic Value*.

There are two possible responses; *Prepare Write Response* or *Error Response*.

If the number of prepared write requests exceeds the number of prepared writes supported, then an *Error Response* with the *Error Code* set to *Prepare Queue Full* shall be sent by the server.

An *Error Response* shall be sent by the server in response to the *Prepare Write Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a write operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set as specified in the Attribute Protocol.

If a *Characteristic Value* is prepared two or more times during this sub-procedure, then all prepared values are written to the same *Characteristic Value* in the order that they were prepared.

If a *Prepare Write Response* is returned, then the *Value Offset* and *Part Attribute Value* parameter in the response shall be checked with the *Value Offset* and *Part Attribute Value* parameter that was sent in the *Prepare Write Request;* if they are different, then the value has been corrupted during transmission, and the sub-procedure shall be aborted by sending an *Execute Write Request* with the Flags parameter set to 0x00 to cancel all prepared writes. The complete sub-procedure may be restarted.

Multiple Prepare Write Requests can be sent by a client, each of which will be queued by the server.

In the second phase, the Attribute Protocol *Execute Write Request* is used. The Attribute Flags parameter shall be set to 0x01 to immediately write all pending prepared values in the order that they were prepared. The server shall write the prepared writes once it receives this request and shall only send the *Execute Write Response* once all the prepared values have been successfully written. If the *Characteristic Value* that is written is the wrong size, or has an invalid value as defined by the profile, then the write shall not succeed, and an *Error Response* with the *Error Code* set to *Application Error* shall be send by the server. The state of the Characteristic Values that were prepared is undefined.

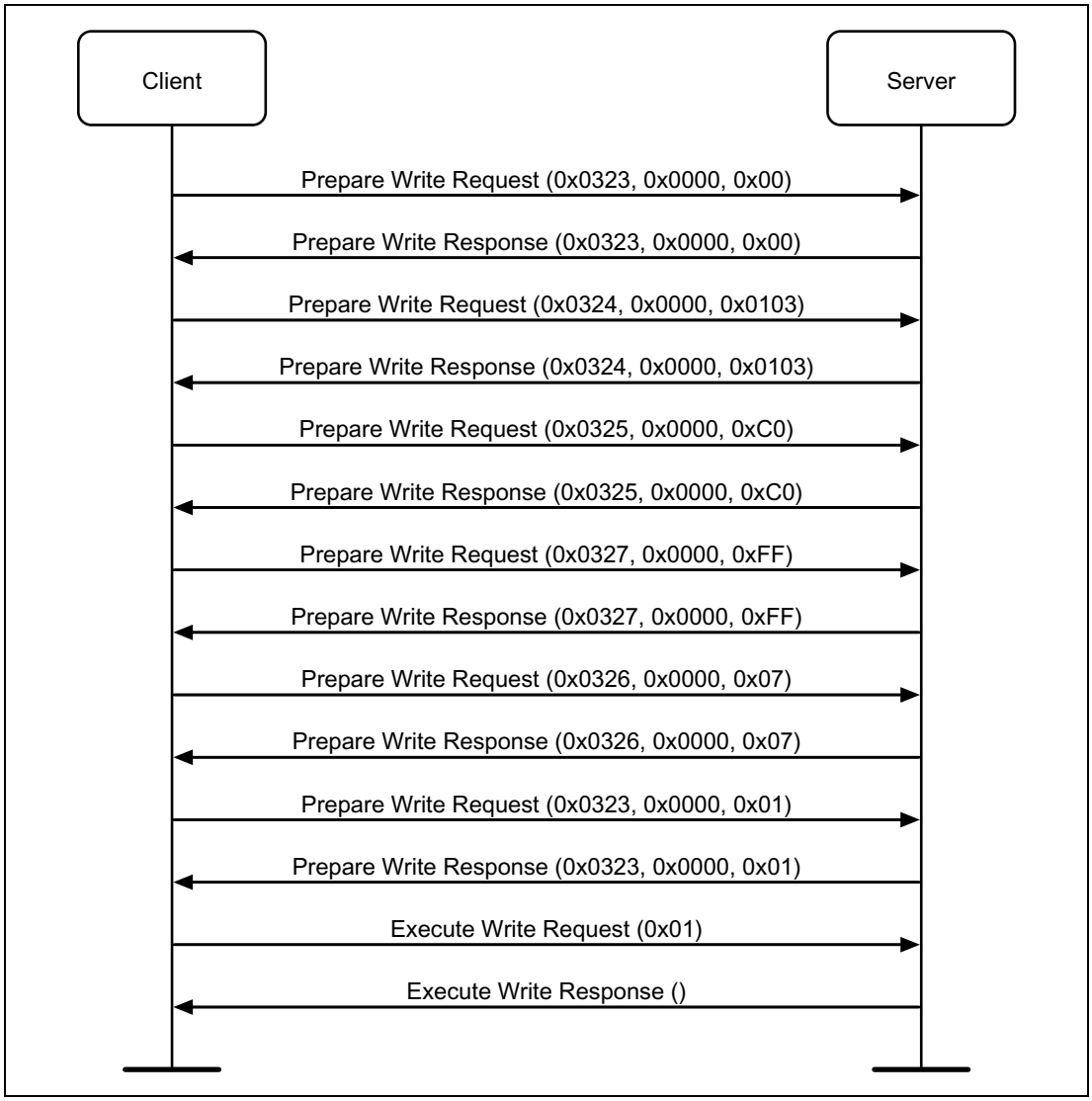

Figure 4.16: Reliable Writes example

4.10 CHARACTERISTIC VALUE NOTIFICATION

This procedure is used to notify a client of the value of a *Characteristic Value* from a server. There is one sub-procedure that can be used to notify a value:

Notifications. Notifications can be configured using the Client Characteristic Configuration descriptor (See Section 3.3.3.3).

A profile defines when to use Notifications.

4.10.1 Notifications

This sub-procedure is used when a server is configured to notify a *Characteristic Value* to a client without expecting any Attribute Protocol layer acknowledgment that the notification was successfully received.

The Attribute Protocol *Handle Value Notification* is used to perform this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle* being notified, and the *Attribute Value* parameter shall be set to the *Characteristic Value*.

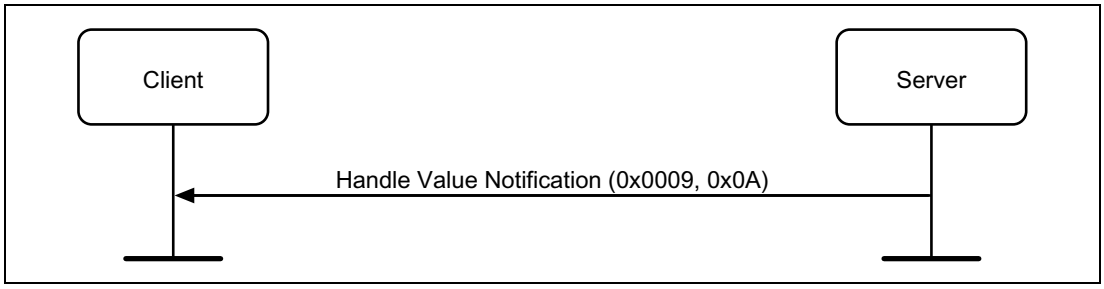

Figure 4.17: Notifications example

4.11 CHARACTERISTIC VALUE INDICATIONS

This procedure is used to indicate the *Characteristic Value* from a server to a client. There is one sub-procedure that can be used to indicate a value: Indications. Indications can be configured using the Client Characteristic Configuration descriptor (See Section 3.3.3.3).

A profile defines when to use Indications.

4.11.1 Indications

This sub-procedure is used when a server is configured to indicate a *Characteristic Value* to a client and expects an Attribute Protocol layer acknowledgment that the indication was successfully received.

The Attribute Protocol *Handle Value Indication* is used to perform this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Value Handle* being indicated, and the *Attribute Value* parameter shall be set to the *Characteristic Value*. Once the *Handle Value Indication* is received by the client, the client shall respond with a *Handle Value Confirmation*.

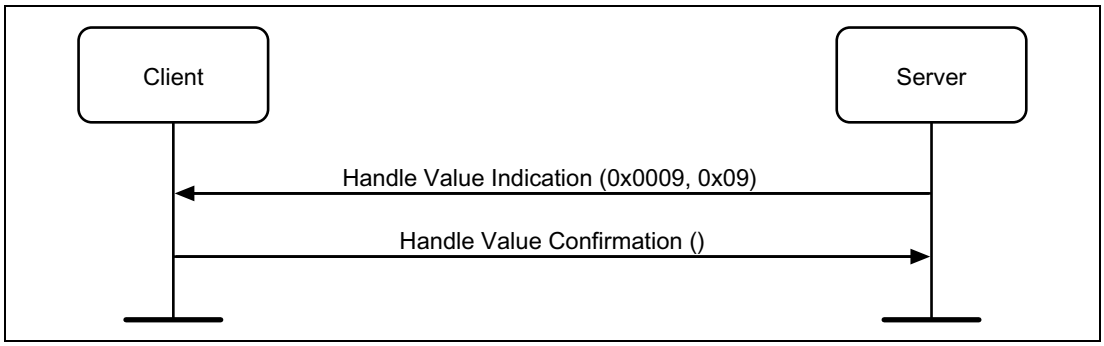

Figure 4.18: Indications example

4.12 CHARACTERISTIC DESCRIPTORS

This procedure is used to read and write characteristic descriptors on a server. There are two sub-procedures that can be used to read and write characteristic descriptors: Read Characteristic Descriptors and Write Characteristic Descriptors.

4.12.1 Read Characteristic Descriptors

This sub-procedure is used to read a characteristic descriptor from a server when the client knows the characteristic descriptor declaration's Attribute handle.

The Attribute Protocol *Read Request* is used for this sub-procedure. The *Read Request* is used with the *Attribute Handle* parameter set to the characteristic descriptor handle. The *Read Response* returns the characteristic descriptor value in the *Attribute Value* parameter.

An *Error Response* shall be sent by the server in response to the *Read Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a read operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set accordingly.

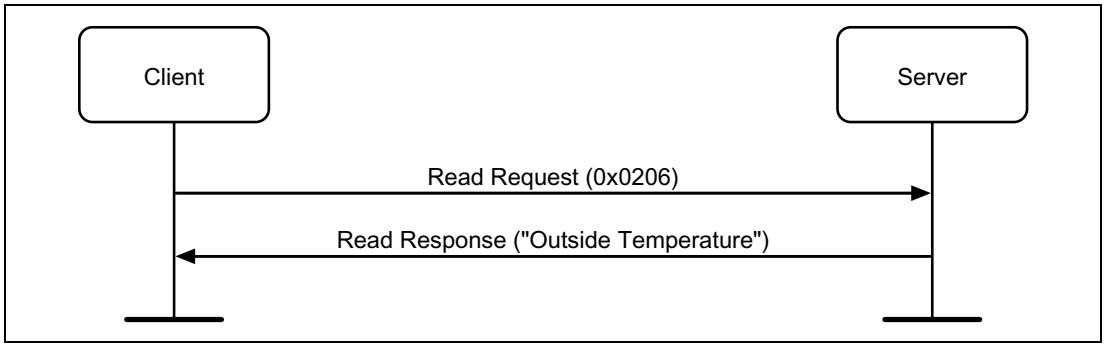

Figure 4.19: Read Characteristic Descriptors example

4.12.2 Read Long Characteristic Descriptors

This sub-procedure is used to read a characteristic descriptor from a server when the client knows the characteristic descriptor declaration's Attribute handle and the length of the characteristic descriptor declaration is longer than can be sent in a single Read Response Attribute Protocol message.

The Attribute Protocol Read Blob Request is used to perform this sub-procedure. The Attribute Handle parameter shall be set to the characteristic descriptor handle. The Value Offset parameter shall be the offset within the characteristic descriptor to be read. To read the complete characteristic descriptor the offset should be set to 0x00 for the first Read Blob Request. The offset for subsequent Read Blob Requests is the next octet that has yet to be read. The Read Blob Request is repeated until the Read Blob Response's Part

Attribute Value parameter is zero or an Error Response is sent by the server with the Error Code set to Invalid Offset.

For each Read Blob Request a Read Blob Response is received with a portion of the characteristic descriptor value contained in the Part Attribute Value parameter.

An Error Response shall be sent by the server in response to the Read Blob Request if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a read operation is not permitted on the characteristic descriptor. The Error Code parameter is set accordingly.

Note: The Read Blob Request may be used to read the remainder of an characteristic descriptor value where the first part was read using a simple Read Request.

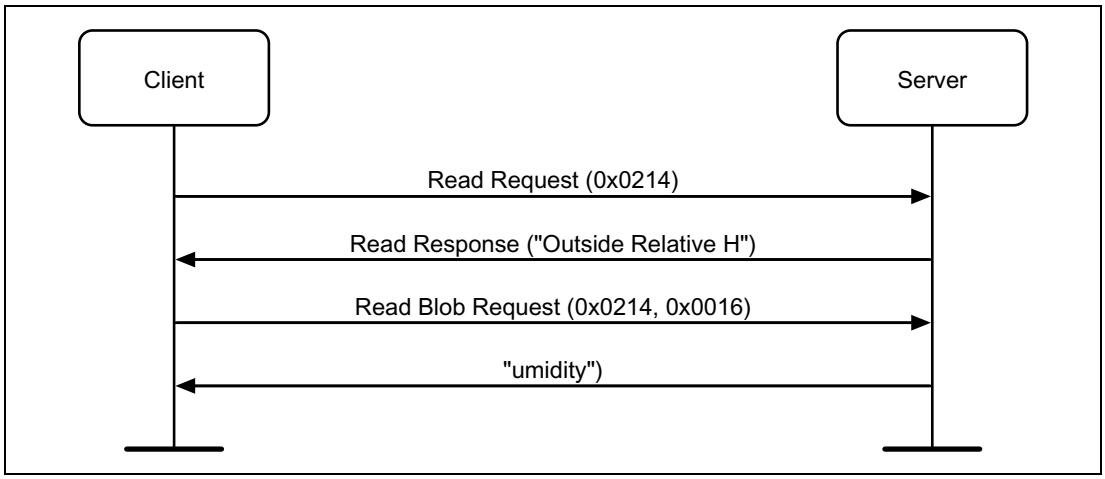

Figure 4.20: Read Long Characteristic Descriptors example

4.12.3 Write Characteristic Descriptors

This sub-procedure is used to write a characteristic descriptor value to a server when the client knows the characteristic descriptor handle.

The Attribute Protocol *Write Request* is used for this sub-procedure. The *Attribute Handle* parameter shall be set to the characteristic descriptor handle. The *Attribute Value* parameter shall be set to the new characteristic descriptor value.

A *Write Response* shall be sent by the server if the write of the characteristic descriptor value succeeded.

An *Error Response* shall be sent by the server in response to the *Write Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a write operation is not permitted on the *Characteristic Value*. The *Error Code* parameter shall be set as specified in the Attribute Protocol. If the characteristic descriptor value that is

written is the wrong size, or has an invalid value as defined by the profile, or the operation is not permitted at this time then the value shall not be written and an *Error Response* shall be sent with the *Error Code* set to *Application Error* by the server.

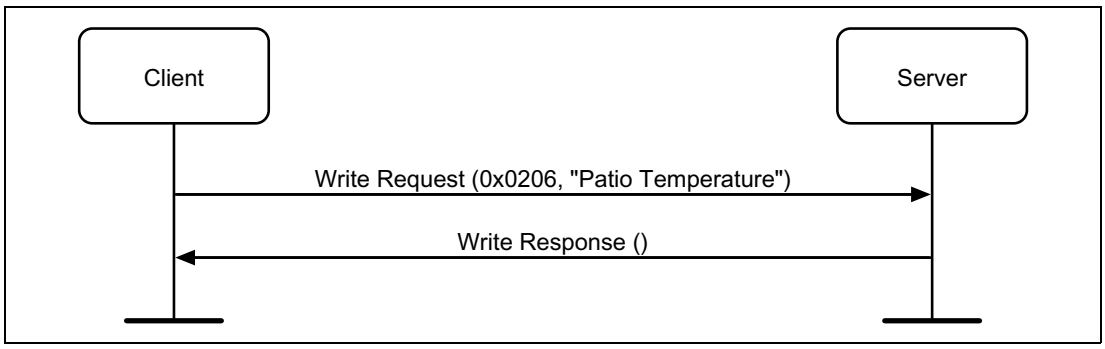

Figure 4.21: Write Characteristic Descriptors example

4.12.4 Write Long Characteristic Descriptors

This sub-procedure is used to write a characteristic descriptor value to a server when the client knows the characteristic descriptor handle but the length of the characteristic descriptor value is longer than can be sent in a single Write Request Attribute Protocol message.

The Attribute Protocol *Prepare Write Request* and *Execute Write Request* are used to perform this sub-procedure. The *Attribute Handle* parameter shall be set to the *Characteristic Descriptor Handle* of the *Characteristic Value* to be written. The *Part Attribute Value* parameter shall be set to the part of the *Attribute Value* that is being written. The *Value Offset* parameter shall be the offset within the *Characteristic Value* to be written. To write the complete *Characteristic Value* the offset should be set to 0x0000 for the first *Prepare Write Request*. The offset for subsequent *Prepare Write Requests* is the next octet that has yet to be written. The *Prepare Write Request* is repeated until the complete *Characteristic Value* has been transferred, after which an *Executive Write Request* is used to write the complete value.

Note: The values in the Prepare Write Response do not need to be verified in this sub-procedure.

An *Error Response* shall be sent by the server in response to the *Prepare Write Request* or *Executive Write Request* if insufficient authentication, insufficient authorization, insufficient encryption key size is used by the client, or if a write operation is not permitted on the *Characteristic Value*. The *Error Code* parameter is set as specified in the Attribute Protocol. If the *Attribute Value* that is written is the wrong size, or has an invalid value as defined by the profile, then the write shall not succeed and an *Error Response* shall be sent with the *Error Code* set to *Application Error* by the server.

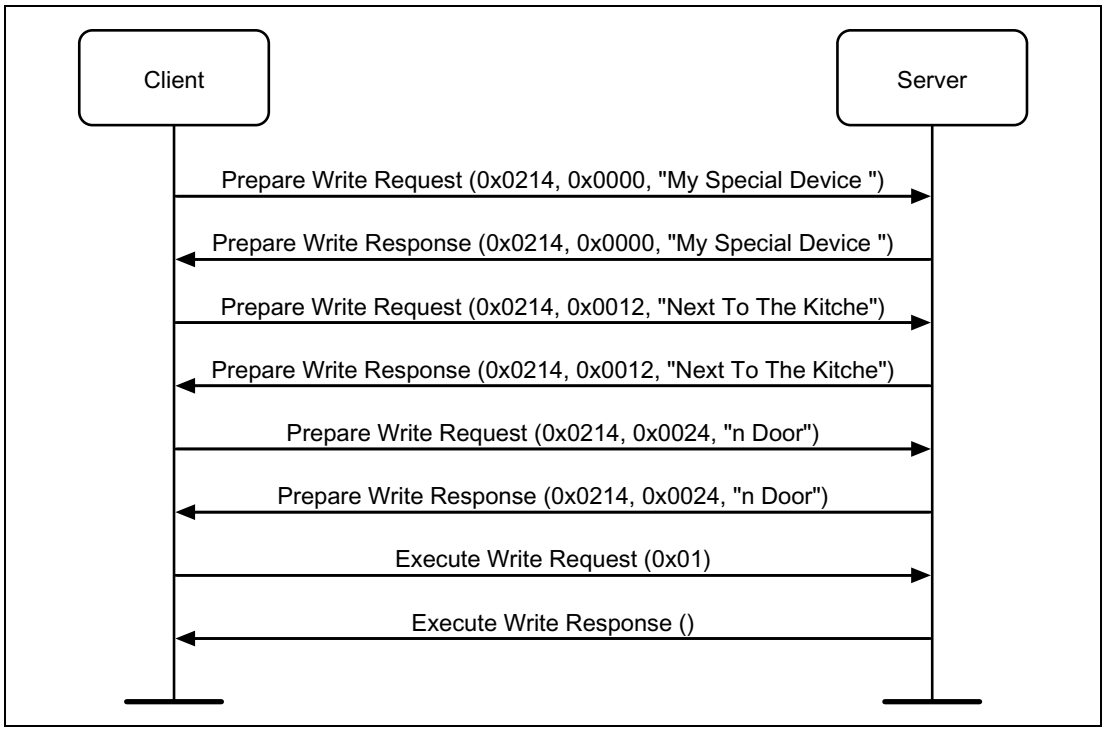

Figure 4.22: Write Long Characteristic Descriptors example

4.13 GATT PROCEDURE MAPPING TO ATT PROTOCOL OPCODES

The following table describes the mapping of the ATT protocol opcodes to the GATT procedures and sub-procedures. Only those portions of the ATT protocol requests, responses, notifications or indications necessary to implement the mandatory or supported optional sub-procedures is required.

Feature	Sub-Procedure	ATT Protocol Opcodes
Server Configuration	Exchange MTU	Exchange MTU Request Exchange MTU Response Error Response
Primary Service Discovery	Discover All Primary Services	Read By Group Type Request Read By Group Type Response Error Response
	Discover Primary Services By Service UUID	Find By Type Value Request Find By Type Value Response Error Response
Relationship Discovery	Find Included Services	Read By Type Request Read By Type Response Error Response

Table 4.2: GATT Procedure mapping to ATT protocol opcodes

Feature	Sub-Procedure	ATT Protocol Opcodes
Characteristic Discovery	Discover All Characteristic of a Service	Read By Type Request Read By Type Response Error Response
	Discover Characteristic by UUID	Read By Type Request Read By Type Response Error Response
Characteristic Descriptor Discovery	Discover All Characteristic Descriptors	Find Information Request Find Information Response Error Response
Characteristic Value Read	Read Characteristic Value	Read Request Read Response Error Response
	Read Using Characteristic UUID	Read By Type Request Read By Type Response Error Response
	Read Long Characteristic Values	Read Blob Request Read Blob Response Error Response
	Read Multiple Characteristic Values	Read Multiple Request Read Multiple Response Error Response
Characteristic Value Write	Write Without Response	Write Command
	Signed Write Without Response	Write Command
	Write Characteristic Value	Write Request Write Response Error Response
	Write Long Characteristic Values	Prepare Write Request Prepare Write Response Execute Write Request Execute Write Response Error Response
	Characteristic Value Reliable Writes	Prepare Write Request Prepare Write Response Execute Write Request Execute Write Response Error Response

Table 4.2: GATT Procedure mapping to ATT protocol opcodes

Feature	Sub-Procedure	ATT Protocol Opcodes
Characteristic Value Notification	Notifications	Handle Value Notification
Characteristic Value Indication	Indications	Handle Value Indication Handle Value Confirmation
Characteristic Descriptor Value Read	Read Characteristic Descriptors	Read Request Read Response Error Response
	Read Long Characteristic Descriptors	Read Blob Request Read Blob Response Error Response
Characteristic Descriptor Value Write	Write Characteristic Descriptors	Write Request Write Response Error Response
	Write Long Characteristic Descriptors	Prepare Write Request Prepare Write Response Prepare Write Request Prepare Write Response Error Response

Table 4.2: GATT Procedure mapping to ATT protocol opcodes

4.14 PROCEDURE TIMEOUTS

GATT procedures are protected from failure with an Attribute Protocol transaction timeout.

If the Attribute Protocol transaction times out, the procedure shall be considered to have failed, and the local higher layer shall be notified. No further GATT procedures shall be performed. A new GATT procedure shall only be performed when a new ATT Bearer has been established.

5 L2CAP INTEROPERABILITY REQUIREMENTS

The following default values shall be used by an implementation of this profile. The default values used may be different depending on the physical channel that the Attribute Protocol is being sent over.

5.1 BR/EDR L2CAP INTEROPERABILITY REQUIREMENTS

Over BR/EDR, L2CAP connection oriented channels are used to transmit Attribute Protocol PDUs. These channels use the channel establishment procedure from L2CAP using the fixed PSM (see [1]) including the configuration procedure to determine the ATT_MTU. Therefore, the ATT Bearer (or the logical link as referred to in the Attribute Protocol) is, in this case, an established L2CAP connection-oriented channel.

5.1.1 ATT_MTU

At the end of the L2CAP configuration phase, upon transition to the OPEN state, the ATT_MTU for this ATT Bearer shall be set to the minimum of the negotiated Maximum Transmission Unit configuration options.

Note: The minimum ATT_MTU for BR/EDR is 48 octets, as defined by L2CAP in [Vol 3] Part A, Section 5.1.

5.1.2 BR/EDR Channel Requirements

All Attribute Protocol messages sent by GATT over an L2CAP channel are sent using a dynamic channel ID derived by connecting using a fixed PSM. The use of a fixed PSM allows rapid reconnection of the L2CAP channel for Attribute Protocol as a preliminary SDP query is not required.

All packets sent on this L2CAP channel shall be Attribute PDUs.

PDUs shall be reliably sent.

The flow specification for the Attribute Protocol shall be best effort.

If operating in Basic L2CAP mode, the information payload of the L2CAP B-frame shall be a single Attribute PDU.

The channel shall be encrypted. The Key_Type shall be either an Unauthenticated Combination Key or an Authenticated Combination Key.

5.1.3 BR/EDR Channel Establishment Collisions

The L2CAP connection can be initiated by the client or by the server.

Only one BR/EDR L2CAP connection shall be established between a client and a server. If the L2CAP connection already exists, the client or server shall not initiate the connection request.

If both devices open an L2CAP connection simultaneously both channels shall be closed and each device shall wait a random time (not more than 1 second and not less than 100 ms) and then try to open the L2CAP connection again. If it is known which device is the master, that device can re-try at once.

5.2 LE L2CAP INTEROPERABILITY REQUIREMENTS

Over LE, the ATT Bearer (or logical link as referred to in the Attribute Protocol) is the Attribute L2CAP fixed channel.

Note: To remove the ATT Bearer, the physical channel has to be disconnected.

5.2.1 ATT_MTU

Both a GATT client and server implementations shall support an ATT_MTU not less than the default value.

Default Value	Value for LE
ATT_MTU	23

Table 5.1: LE L2CAP ATT_MTU

5.2.2 LE Channel Requirements

All Attribute Protocol messages sent by GATT over an L2CAP logical link are sent using a fixed channel ID. This enables very fast transmission of the Attribute Protocol messages once a Host connection setup is complete. The use of a fixed channel ID also enables the default channel properties to be defined.

L2CAP fixed CID 0x0004 shall be used for the Attribute Protocol. All packets sent on this fixed channel shall be Attribute Protocol PDUs.

The flow specification for the Attribute Protocol shall be best effort.

PDUs shall be reliably sent, and not flushed.

The retransmission and flow control mode for this channel shall be Basic L2CAP mode

The default parameters for the payload of the L2CAP B-frame shall be a single Attribute PDU.

Parameter	Value
MTU	23
Flush Timeout	0xFFFF (Infinite)
QoS	Best Effort
Mode	Basic Mode

Table 5.2: Attribute Protocol Fixed channel configuration parameters

6 GAP INTEROPERABILITY REQUIREMENTS

6.1 BR/EDR GAP INTEROPERABILITY REQUIREMENTS

6.1.1 Connection Establishment

To establish an ATT Bearer, the Channel Establishment procedure (as defined in [Vol 3] Part C, Section 7.2) shall be used.

Either device may terminate a link at any time.

No idle mode procedures or modes are defined by this profile.

6.2 LE GAP INTEROPERABILITY REQUIREMENTS

6.2.1 Connection Establishment

To establish a link, the Connection Establishment procedure (as defined in [Vol 3] Part C, Section 9.3.5 through Section 9.3.8) shall be used.

Either device may terminate a link at any time.

No idle mode procedures or modes are defined by this profile.

6.2.2 Profile Roles

This profile can be used in the following profile roles (as defined in [Vol 3] Part G):

- Central
- Peripheral

6.3 DISCONNECTED EVENTS

6.3.1 Notifications and Indications While Disconnected

If a client has configured the server to send a notification or indication to the client, it shall be configured to allow re-establishment of the connection when it is disconnected.

If the client is disconnected, but intends to become a Central in the connection it shall perform a GAP connection establishment procedure. If the client is disconnected, but intends to become a Peripheral in the connection it shall go into a GAP connectable mode.

A server shall re-establish a connection with a client when an event or trigger operation causes a notification or indication to a client.

If the server is disconnected, but intends to become a Peripheral in the connection it shall go into a GAP connectable mode. If the server is disconnected, but intends to become a Central in the connection it shall perform a GAP connection establishment procedure.

If the server cannot re-establish a connection, then the notification or indication for this event shall be discarded and no further connection re-establishment shall occur, until another event occurs.

7 DEFINED GENERIC ATTRIBUTE PROFILE SERVICE

All characteristics defined within this section shall be contained in a primary service with the service UUID set to «GATT Service» as defined in Section 3.1. Only one instance of the GATT service shall be exposed on a GATT server.

Table 7.1 lists characteristics that may be present in the server and the characteristics that may be supported by the client.

Item No.	Characteristic	Ref.	Support in Client	Support in Server
1	Service Changed	7.1	M	C1

Table 7.1: GATT Profile service characteristic support

C1: Mandatory if service definitions on the server can be added, changed or removed; otherwise optional

The assigned UUIDs for these characteristics are defined in [1].

7.1 SERVICE CHANGED

The «Service Changed» characteristic is a control-point attribute (as defined in [Vol 3] Part F, Section 3.2.6) that shall be used to indicate to connected devices that services have changed (i.e., added, removed or modified). The characteristic shall be used to indicate to clients that have a trusted relationship (i.e. bond) with the server when GATT based services have changed when they re-connect to the server. See Section 2.5.2.

This *Characteristic Value* shall be configured to be indicated, using the Client Characteristic Configuration descriptor by a client. Indications caused by changes to the Service Changed Characteristic Value shall be considered lost if the client has not enabled indications in the Client Configuration Characteristic Descriptor.

Attribute Handle	Attribute Type	Attribute Value			Attribute Permission
0xNNNN	0x2803 – UUID for «Charac-teristic»	Characteristic Properties = 0x20	0xMMMM = Handle of Characteristic Value	0x2A05 – UUID for «Service Changed»	No Authentication, No Authorization

Table 7.2: Service Changed Characteristic declaration

The *Service Changed Characteristic Value* is two 16-bit *Attribute Handles* concatenated together indicating the beginning and ending *Attribute Handles* affected by an addition, removal, or modification to a GATT-based service on the server. A change to a characteristic value is not considered a modification

of the service. If a change has been made to any of the GATT service definition characteristic values other than the *Service Changed* characteristic value, the range shall also include the beginning and ending *Attribute Handle* for the GATT service definition.

Attribute Handle	Attribute Type	Attribute Value		Attribute Permission
0xM-MMM	0x2A05 – UUID for «Service Changed»	0xuuuu – Start of Affected Attribute Handle Range	0xuuuu – End of Affected Attribute Handle Range	No Authentication, No Authorization, Not Readable, Not Writable

Table 7.3: Service Changed Characteristic Value declaration

There is only one instance of the *Service Changed* characteristic within the GATT service definition. A *Service Changed* characteristic value shall exist for each client with a trusted relationship.

If the list of GATT based services and the service definitions cannot change for the lifetime of the device then this characteristic shall not exist, otherwise this characteristic shall exist.

If the *Service Changed* characteristic exists on the server, the *Characteristic Value Indication* support on the server is mandatory.

The client shall support *Characteristic Value Indication* of the *Service Changed* characteristic.

The *Service Changed* characteristic *Attribute Handle* on the server shall not change if the server has a trusted relationship with any client.

8 SECURITY CONSIDERATIONS

8.1 AUTHENTICATION REQUIREMENTS

Authentication in the GATT Profile is applied to each characteristic independently. Authentication requirements are specified in this profile, related higher layer specifications or are implementation specific if not specified otherwise.

The GATT Profile procedures are used to access information that may require the client to be authenticated and have an encrypted connection before a characteristic can be read or written.

If such a request is issued when the physical link is unauthenticated or unencrypted, the server shall send an Error Response. The client wanting to read or write this characteristic can then request that the physical link be authenticated using the GAP authentication procedure, and once this has been completed, send the request again.

The list of services and characteristics that a device supports is not considered private or confidential information, and therefore the Service and Characteristic Discovery procedures shall always be permitted. This implies that an *Insufficient Authentication* status code shall not be used in an *Error Response* for a *Find Information Request*.

Note: A characteristic may be allowed to be read by any device, but only written by an authenticated device. An implementation should take this into account, and not assume that if it can read a *Characteristic Value*, it will also be able to write the *Characteristic Value*. Similarly, if a characteristic can be written, it does not mean the characteristic can also be read. Each individual characteristic could have different security properties.

Once sufficient authentication of the client has been established to allow access to one characteristic within a service definition, a server may also allow access to other characteristics within the service definition depending on the higher level or implementation specific requirements.

A server may allow access to most characteristics within a service definition once sufficient authentication has been performed, but restrict access to other characteristics within the same service definition. This may result due to some characteristics requiring stronger authentication requirements than currently enabled.

Once a server has authenticated a client for access to characteristics in one service definition, it may automatically allow access to characteristics in other service definitions.

8.2 AUTHORIZATION REQUIREMENTS

Authorization in the GATT Profile is applied to each characteristic independently. Authorization requirements may be specified in this profile, related higher layer specifications or are implementation specific if not specified otherwise.

The GATT Profile can be used to access information that may require authorization before a characteristic can be read or written.

If such a request is issued to a characteristic contained in a service definition that is not authorized, the responder shall send an *Error Response* with the status code set to *Insufficient Authorizatio*n.

Once a server has authorized a client for access to characteristics in one group or service definition, it may automatically allow access to characteristics in other service definitions.

9 SDP INTEROPERABILITY REQUIREMENTS

A device that supports GATT over BR/EDR shall publish the following SDP record. The GATT Start Handle shall be set to the attribute handle of the «Generic Attribute Profile» service declaration. The GATT End Handle shall be set to the attribute handle of the last attribute within the «Generic Attribute Profile» service definition group.

Item	Definition	Type	Value	Status
Service Class ID List				M
Service Class #0		UUID	GATT Service	M
Protocol Descriptor List				M
Protocol #0		UUID	L2CAP	M
Parameter #0 for Protocol #0	PSM	Uint16	PSM = ATT	M
Protocol #1		UUID	ATT	M
Parameter #0 for Protocol #1	GATT Start Handle	Uint16		M
Parameter #1 for Protocol #1	GATT End Handle	Uint16		M
BrowseGroupList			PublicBrowseRoot	M

Table 9.1: SDP Record for the Generic Attribute Profile

10 REFERENCES

[1] Assigned Numbers Specification:
https://www.bluetooth.org/en-us/specification/assigned-numbers

APPENDIX A EXAMPLE ATTRIBUTE SERVER ATTRIBUTES

The following table shows an example Server and the Attributes contained on the server.

Note: This example does not necessarily use UUIDs or services defined by the Bluetooth SIG or in adopted profiles.

Handle	Attribute Type	Attribute Value
0x0001	«Primary Service»	«GAP Service»
0x0004	«Characteristic»	{0x02, 0x0006, «Device Name»}
0x0006	«Device Name»	“Example Device”
0x0010	«Primary Service»	«GATT Service»
0x0011	«Characteristic»	{0x26, 0x0012, «Service Changed»}
0x0012	«Service Changed»	0x0000, 0x0000
0x0100	«Primary Service»	«Battery State Service»
0x0106	«Characteristic»	{0x02, 0x0110, «Battery State»}
0x0110	«Battery State»	0x04
0x0200	«Primary Service»	«Thermometer Humidity Service»
0x0201	«Include»	{0x0500, 0x0504, «Manufacturer Service»}
0x0202	«Include»	{0x0550,0x0568}
0x0203	«Characteristic»	{0x02, 0x0204, «Temperature»}
0x0204	«Temperature»	0x028A
0x0205	«Characteristic Format»	{0x0E, 0xFE, «degrees Celsius», 0x01, «Outside»}
0x0206	«Characteristic User Description»	“Outside Temperature”
0x0210	«Characteristic»	{0x02, 0x0212, «Relative Humidity»}
0x0212	«Relative Humidity»	0x27
0x0213	«Characteristic Format»	{0x04, 0x00, «Percent», «Bluetooth SIG», «Outside»}
0x0214	«Characteristic User Description»	“Outside Relative Humidity”
0x0280	«Primary Service»	«Weight Service»

Table A.1: Example Attribute Server Attributes

Handle	Attribute Type	Attribute Value
0x0281	«Include»	0x0505, 0x0509, «Manufacturer Service»}
0x0282	«Characteristic»	{0x02, 0x0283, «Weight kg»}
0x0283	«Weight kg»	0x00005582
0x0284	«Characteristic Format»	{0x08, 0xFD, «kilogram», «Bluetooth SIG», «Hanging»}
0x0285	«Characteristic User Description»	“Rucksack Weight”
0x0300	«Primary Service»	«Position Service»
0x0301	«Characteristic»	{0x02, 0x0302, «Latitude Longitude»}
0x0302	«Latitude Longitude»	0x28BEAFA40B320FCE
0x0304	«Characteristic»	{0x02, 0x0305, «Latitude Longitude Elevation»}
0x0305	«Latitude Longitude Elevation»	0x28BEAFA40B320FCE0176
0x0400	«Primary Service»	«Alert Service»
0x0401	«Characteristic»	{0x0E, 0x0402, «Alert Enumeration»}
0x0402	«Alert Enumeration»	0x00
0x0500	«Secondary Service»	«Manufacturer Service»
0x0501	«Characteristic»	{0x02, 0x0502, «Manufacturer Name»}
0x0502	«Manufacturer Name»	“ACME Temperature Sensor”
0x0503	«Characteristic»	{0x02, 0x0504, «Serial Number»}
0x0504	«Serial Number»	“237495-3282-A”
0x0505	«Secondary Service»	«Manufacturer Service»
0x0506	«Characteristic»	{0x02, 0x0507, «Manufacturer Name»}
0x0507	«Manufacturer Name»	“ACME Weighing Scales”
0x0508	«Characteristic»	{0x02, 0x0509, «Serial Number»}
0x0509	«Serial Number»	“11267-2327A00239”
0x0550	«Secondary Service»	«Vendor Specific Service»
0x0560	«Characteristic»	{0x02, 0x0568, «Vendor Specific Type»}
0x0568	«Vendor Specific Type»	0x56656E646F72

Table A.1: Example Attribute Server Attributes

As can be seen, the attribute server indicates support for ten services: GAP Service, GATT Service, Battery State Service, Thermometer Humidity Service, Weight Service, Position Service, Alert Service, two Manufacturer Services, and a Vendor Specific Service.

The server contains the following information about each of the services:

- The characteristic containing the name of the device is “Example Device”.
- The characteristic indicating the server supports all the attribute opcodes, and supports two prepared write values.
- The characteristic containing the battery state with a value of 0x04, meaning it is discharging.
- The characteristic containing the outside temperature with a value of 6.5 °C.
- The characteristic containing the outside relative humidity with a value of 39%.
- The characteristic containing the weight hanging off the device with a value of 21.89 kg.
- The characteristic containing the position of this device with the value of 68.3585444 degrees north, 18.7830222 degrees east, with an elevation of 374 meters.
- The characteristic containing the temperature sensor manufacturer with the value of ACME Temperature Sensor.
- The characteristic containing the serial number for the temperature sensor with a value of 237495-3282-A.
- The characteristic containing the weighing sensor is manufacturer with a value of ACME Weight Scales.
- The characteristic containing the serial number for the weighing sensor with a value of 11267-2327A00239.

The device is therefore on the side of the Abisko Turiststation, Norrbottens Län, Sweden, with a battery in good state, measuring a relatively warm day, with low humidity, and a heavy rucksack.

SECURITY MANAGER SPECIFICATION

The Security Manager (SM) defines the protocol and behavior to manage pairing, authentication and encryption between LE-only or BR/EDR/LE devices.

CONTENTS

1 INTRODUCTION

1.1 SCOPE

The Security Manager defines methods of pairing and key distribution, a protocol for those methods and a security toolbox to be used by those methods and other parts of an LE-only or BR/EDR/LE device.

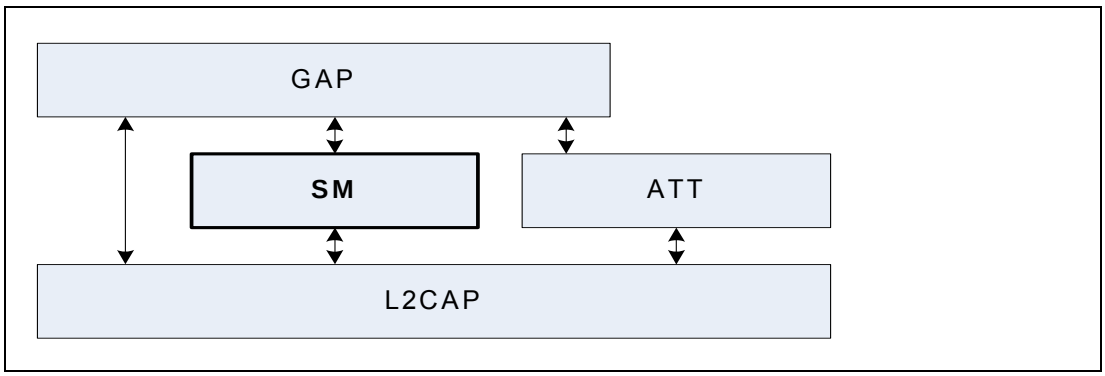

Figure 1.1: Relationship of the Security Manager to the rest of the LE Bluetooth architecture

The document describes master and slave roles in terms of protocol and requirements; these have the same meaning and are mapped to the LE device roles described in [Vol 1] Part A, Section 1.2 or BR/EDR device roles (see [Vol 1] Part A, Section 1.1).

1.2 CONVENTIONS

1.2.1 Bit and Byte Ordering Conventions

When multiple bit fields are contained in a single octet and represented in a drawing in this specification, the least significant (low-order) bits are shown toward the left and most significant (high-order) bits toward the right.

Multiple-octet fields are drawn with the least significant octets toward the left and the most significant octets toward the right. Multiple-octet fields shall be transmitted with the least significant octet first.

Multiple-octet values written in hexadecimal notation have the most significant octet towards the left and the least significant octet towards the right, for example if ‘12’ is the most significant octet and ‘34’ is the least significant octet it would be written as 0x1234.

2 SECURITY MANAGER

2.1 INTRODUCTION

The Security Manager (SM) uses a key distribution approach to perform identity and encryption functionalities in radio communication. This means that each device generates and controls the keys it distributes and no other device affects the generation of these keys. The strength of a key is as strong as the algorithms implemented inside the distributing device.

The security architecture is designed such that memory and processing requirements for a responding device are lower than the memory and processing requirement for an initiating device.

Pairing is performed to establish keys which can then be used to encrypt a link. A transport specific key distribution is then performed to share the keys which can be used to encrypt a link in future reconnections, verify signed data and random address resolution.

Pairing is a three-phase process. The first two phases are always used and may be followed by an optional transport specific key distribution phase (see Figure 2.1):

- Phase 1: Pairing Feature Exchange
- Phase 2 (LE legacy pairing): Short Term Key (STK) Generation
- Phase 2 (LE Secure Connections): Long Term Key (LTK) Generation
- Phase 3: Transport Specific Key Distribution

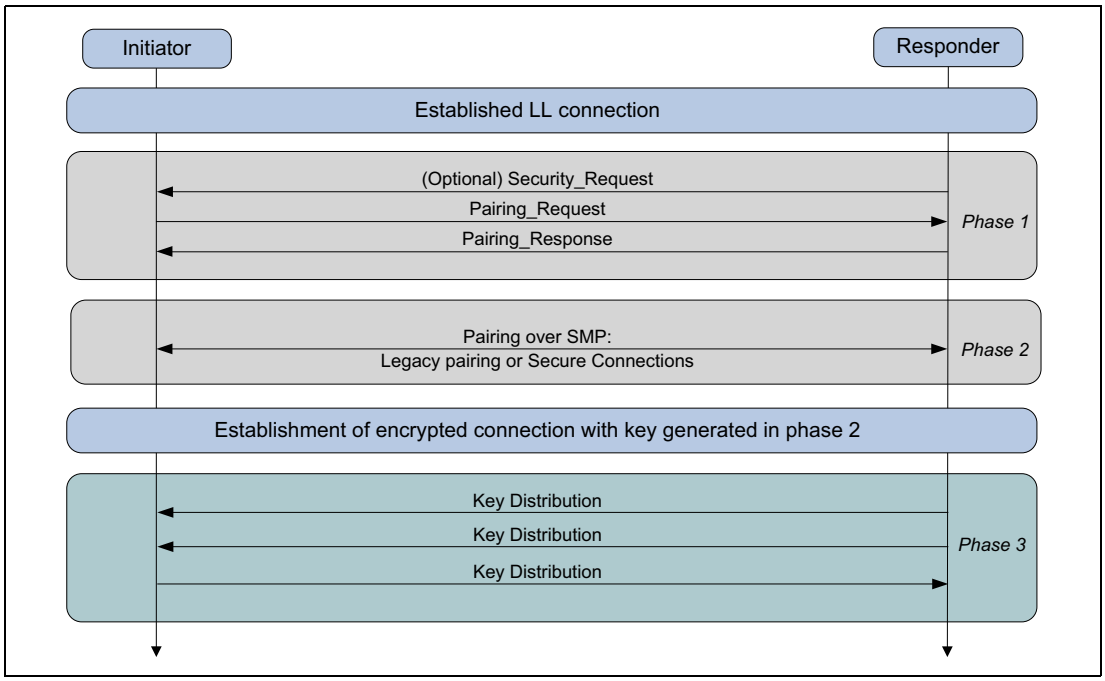

Figure 2.1: LE Pairing Phases

The devices shall first exchange authentication requirements and IO capabilities in the Pairing Feature Exchange to determine which of the following methods shall be used in Phase 2:

- Just Works
- Numeric Comparison (Only for LE Secure Connections)
- Passkey Entry
- Out Of Band (OOB)

Authentication requirements retrieved from the Pairing Feature Exchange also determine whether LE Secure Connections or LE legacy pairing is used.

Optionally, Phase 3 may then be performed to distribute transport specific keys, for example the Identity Resolving Key (IRK) value and Identity Address information. Phase 1 and Phase 3 are identical regardless of the method used in Phase 2.

Phase 3 shall only be performed on a link which is encrypted using:

- The STK generated in Phase 2 when using LE legacy pairing or
- The LTK generated in Phase 2 when using LE Secure Connections or
- The shared Link Key generated using BR/EDR pairing (see Section 2.3.5.7).

Phase 1 and Phase 2 may be performed on a link which is either encrypted or not encrypted.

2.2 CRYPTOGRAPHIC TOOLBOX

In order to support random addressing, pairing and other operations SM provides a toolbox of cryptographic functions. The following cryptographic functions are defined:

- *ah* is used to create a 24-bit hash used in random address creation and resolution.

The following cryptographic functions are defined to support the LE legacy pairing process:

- *c1* is used to generate confirm values used during the pairing process.
- *s1* is used to generate the STK during the pairing process.

The following cryptographic functions are defined to support the LE Secure Connections pairing process:

- *f4* is used to generate confirm values during the pairing process.
- *f5* is used to generate the LTK and the MacKey during the pairing process.
- *f6* is used to generate the check values during authentication stage 2 in the pairing process.
- *g2* is used to generate the 6-digit numeric comparison values during authentication stage 1 in the pairing process.
- *h6* is used to generate the LE LTK from a BR/EDR link key derived from Secure Connections and is used to generate the BR/EDR link key from an LE LTK derived from Secure Connections.
- *h7* is used to generate intermediate keys while generating the LE LTK from a BR/EDR link key derived from Secure Connections and the BR/EDR link key from an LE LTK derived from Secure Connections.

The building block for the cryptographic functions *ah*, *c1* and *s1* is the security function *e*.

The building block for the cryptographic functions *f4, f5, f6, g2, h6,* and *h7* is the security function AES-CMAC.

Inside the *f4, f5, f6, g2, h6,* and *h7* functions when a multi-octet integer parameter is used as input to AES-CMAC the most significant octet of the integer shall be the first octet of the stream and the least significant octet of the integer shall be the last octet of the stream. The output of AES-CMAC inside these functions is a multi-octet integer where the first octet is MSB and the last octet is LSB of this integer.

2.2.1 Security function *e*

Security function *e* generates 128-bit *encryptedData* from a 128-bit key and 128-bit *plaintextData* using the AES-128-bit block cypher as defined in FIPS-197[1]:

encryptedData = *e*(*key*, *plaintextData*)

The most significant octet of *key* corresponds to key[0], the most significant octet of *plaintextData* corresponds to in[0] and the most significant octet of *encryptedData* corresponds to out[0] using the notation specified in FIPS-197[1].

Note: The security function *e* can be implemented in a Host or be implemented using the HCI_LE_Encrypt command (see [Vol 2] Part E, Section 7.8.22).

2.2.2 Random Address Hash function *ah*

The random address hash function *ah* is used to generate a hash value that is used in resolvable private addresses, see [Vol 3] Part C, Section 10.8.2.

The following are inputs to the random address hash function *ah*:

k is 128 bits

r is 24 bits

padding is 104 bits

r is concatenated with *padding* to generate *r'* which is used as the 128-bit input parameter *plaintextData* to security function *e*:

r' = padding || r

The least significant octet of *r* becomes the least significant octet of *r'* and the most significant octet of *padding* becomes the most significant octet of *r'*.

For example, if the 24-bit value *r* is 0x423456 then *r'* is 0x000000000000000000000000423456.

The output of the random address function *ah* is:

$ah(k, r) = e(k, r') \bmod 2^{24}$

The output of the security function *e* is then truncated to 24 bits by taking the least significant 24 bits of the output of *e* as the result of *ah*.

1. NIST Publication FIPS-197 (http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf)

2.2.3 Confirm value generation function *c1* for LE Legacy Pairing

During the LE legacy pairing process confirm values are exchanged. This confirm value generation function *c1* is used to generate the confirm values.

The following are inputs to the confirm value generation function *c1*:

k is 128 bits
r is 128 bits
pres is 56 bits
preq is 56 bits
iat is 1 bit
ia is 48 bits
rat is 1 bit
ra is 48 bits
padding is 32 bits or 0

iat is concatenated with 7-bits of 0 to create *iat'* which is 8 bits in length. *iat* is the least significant bit of *iat'*.

rat is concatenated 7-bits of 0 to create *rat'* which is 8 bits in length. *rat* is the least significant bit of *rat'*.

pres, *preq*, *rat'* and *iat'* are concatenated to generate *p1* which is XORed with *r* and used as 128-bit input parameter *plaintextData* to security function *e*:

p1 = pres || preq || rat' || iat'

The octet of *iat'* becomes the least significant octet of *p1* and the most significant octet of *pres* becomes the most significant octet of *p1*.

For example, if the 8-bit *iat'* is 0x01, the 8-bit *rat'* is 0x00, the 56-bit *preq* is 0x07071000000101 and the 56 bit *pres* is 0x05000800000302 then *p1* is 0x05000800000302070710000001010001.

ra is concatenated with *ia* and *padding* to generate *p2* which is XORed with the result of the security function *e* using *p1* as the input parameter *plaintextData* and is then used as the 128-bit input parameter *plaintextData* to security function *e*:

p2 = padding || ia || ra

The least significant octet of *ra* becomes the least significant octet of *p2* and the most significant octet of *padding* becomes the most significant octet of *p2*.

For example, if 48-bit *ia* is 0xA1A2A3A4A5A6 and the 48-bit *ra* is 0xB1B2B3B4B5B6 then *p2* is 0x00000000A1A2A3A4A5A6B1B2B3B4B5B6.

The output of the confirm value generation function *c1* is:

c1 (k, r, preq, pres, iat, rat, ia, ra) = e(k, e(k, r XOR p1) XOR p2)

The 128-bit output of the security function *e* is used as the result of confirm value generation function *c1*.

For example, if the 128-bit *k* is 0x00000000000000000000000000000000, the 128-bit value *r* is 0x5783D52156AD6F0E6388274EC6702EE0, the 128-bit value *p1* is 0x05000800000302070710000001010001 and the 128-bit value *p2* is 0x00000000A1A2A3A4A5A6B1B2B3B4B5B6 then the 128-bit output from the *c1* function is 0x1e1e3fef878988ead2a74dc5bef13b86.

2.2.4 Key generation function *s1* for LE Legacy Pairing

The key generation function *s1* is used to generate the STK during the LE legacy pairing process.

The following are inputs to the key generation function *s1* :

k is 128 bits

r1 is 128 bits

r2 is 128 bits

The most significant 64-bits of r1 are discarded to generate r1' and the most significant 64-bits of r2 are discarded to generate r2'.

For example if the 128-bit value r1 is 0x000F0E0D0C0B0A091122334455667788 then r1' is 0x1122334455667788. If the 128-bit value r2 is 0x010203040506070899AABBCCDDEEFF00 then r2' is 0x99AABBCCDDEEFF00.

r1' is concatenated with *r2'* to generate *r*' which is used as the 128-bit input parameter *plaintextData* to security function *e*:

r' = *r1'* || *r2*'

The least significant octet of *r2'* becomes the least significant octet of r' and the most significant octet of *r1'* becomes the most significant octet of *r'*.

For example, if the 64-bit value *r1'* is 0x1122334455667788 and *r2'* is 0x99AABBCCDDEEFF00 then *r'* is 0x11223344556778899AABBCCDDEEFF00.

The output of the key generation function *s1* is:

s1(k, *r1*, *r2*) = e(k, r')

The 128-bit output of the security function e is used as the result of key generation function *s1*.

For example if the 128-bit value *k* is

0x00000000000000000000000000000000

and the 128-bit value *r'* is

0x11223344556778899AABBCCDDEEFF00

then the output from the key generation function *s1* is

0x9a1fe1f0e8b0f49b5b4216ae796da062.

2.2.5 Function AES-CMAC

RFC-4493[1] defines the Cipher-based Message Authentication Code (CMAC) that uses AES-128 as the block cipher function, also known as AES-CMAC.

The inputs to AES-CMAC are:

m is the variable length data to be authenticated

k is the 128-bit key

The 128-bit message authentication code (MAC) is generated as follows:[2]

$MAC = AES\text{-}CMAC_k(m)$

A device can implement AES functions in the Host or can use the HCI_LE_Encrypt command (see [Vol 2] Part E, Section 7.8.22) in order to use the AES function in the Controller.

2.2.6 LE Secure Connections Confirm Value Generation Function *f4*

During the LE Secure Connections pairing process, confirm values are exchanged. These confirm values are computed using the confirm value generation function *f4*.

This confirm value generation function makes use of the MAC function $AES\text{-}CMAC_X$, with a 128-bit key X.

The inputs to function f4 are:

U is 256 bits

V is 256 bits

X is 128 bits

Z is 8 bits

Z is zero (i.e. 8 bits of zeros) for Numeric Comparison and OOB protocol. In the Passkey Entry protocol, the most significant bit of Z is set equal to one and the least significant bit is made up from one bit of the passkey e.g. if the passkey bit is 1, then Z = 0x81 and if the passkey bit is 0, then Z = 0x80.

U, V and Z are concatenated and used as input *m* to the function AES-CMAC and X is used as the key *k*.

1. http://www.ietf.org/rfc/rfc4493.txt
2. RFC4493 uses the notation MAC = AES-CMAC(k,m) where k is the key. This is functionally the same as the notation used in this specification $MAC = AES\text{-}CMAC_k(m)$

The inputs to *f4* are different depending on different association models:

Numeric Comparison/ Just Works	**Out-Of-Band**	**Passkey Entry**
Ca = *f4*(PKax, PKbx, Na, 0) Cb = *f4*(PKbx, PKax, Nb, 0)	Ca = *f4*(PKax, PKax, ra, 0) Cb = *f4*(PKbx, PKbx, rb, 0)	Cai = *f4*(PKax, PKbx, Nai, rai) Cbi = *f4*(PKbx, PKax, Nbi, rbi)

Table 2.1: Inputs to f4 for the different protocols

PKax denotes the x-coordinate of the public key PKa of A.
Similarly, PKbx denotes the x-coordinate of the public key PKb of B.
Nai is the nonce value of i^{th} round. For each round Nai value is a new 128-bit number. Similarly, rai is a one bit value of the passkey expanded to 8 bits (either 0x80 or 0x81).

Na and Nb are nonces from Devices A and B. ra and rb are random values generated by devices A and B.

The output of the confirm value generation function *f4* is as follows:

$$f4(U, V, X, Z) = \text{AES-CMAC}_X (U \,||\, V \,||\, Z)$$

The least significant octet of Z becomes the least significant octet of the AES-CMAC input message *m* and the most significant octet of U becomes the most significant octet of the AES-CMAC input message *m*.

2.2.7 LE Secure Connections Key Generation Function *f5*

The LE Secure Connections key generation function *f5* is used to generate derived keying material in order to create the LTK and keys for the commitment function f6 during the LE Secure Connections pairing process.

The definition of this key generation function makes use of the MAC function AES-CMAC_T with a 128-bit key T.

The inputs to function *f5* are:

W is 256 bits
N_1 is 128 bits
N_2 is 128 bits
A_1 is 56 bits
A_2 is 56 bits

The key (T) is computed as follows:

$$T = \text{AES-CMAC}_{SALT} (W)$$

SALT is the 128-bit value:

```
0x6C88 8391 AAF5 A538 6037 0BDB 5A60 83BE
```

Counter, keyID, N1, N2, A1, A2, and Length are concatenated and used as input *m* to the function AES-CMAC and T is used as the key *k*.
Counter is one octet. Length is two octets.

The string “btle” is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0110 0101
keyID[1] = 0110 1100
keyID[2] = 0111 0100
keyID[3] = 0110 0010
keyID    = 0x62746c65
```

The output of the key generation function *f5* is as follows:

f5(W, N1, N2, A1, A2) = AES-CMAC$_T$ (Counter = 0 || keyID ||N1 || N2|| A1|| A2|| Length = 256)||AES-CMAC$_T$ (Counter = 1 || keyID || N1 || N2|| A1|| A2 || Length = 256)

The least significant octet of Length becomes the least significant octet of the AES-CMAC input message *m* and the most significant octet of Counter becomes the most significant octet of the AES-CMAC input message *m*.

The LTK and MacKey are calculated as:

MacKey || LTK = f5(DHKey, N_master, N_slave, BD_ADDR_master, BD_ADDR_slave)

DHKey is the shared secret Diffie-Hellman key generated during LE Secure Connections pairing phase 2.

N_master is the random number sent by the master to the slave and N_slave is the random number sent by the slave to the master.

BD_ADDR_master is the device address of the master and BD_ADDR_slave is the device address of the slave. The device addresses are the values used during connection setup. The least significant bit in the most significant octet in both BD_ADDR_master and BD_ADDR_slave is set to 1 if the address is a random address and set to 0 if the address is a public address. The 7 most significant bits of the most significant octet in both BD_ADDR_master and BD_ADDR_slave are set to 0.

The LTK is the least significant 128 bits (Counter = 1) of *f5*. The MacKey (see Section 2.2.8) is the most significant 128 bits (Counter = 0) of *f5*.

A device can implement Diffie-Hellman key generation in the Host or can use the HCI_LE_Generate_DHKey command (see [Vol 2] Part E, Section 7.8.37) to generate the key in the Controller. Note: When using the HCI_LE_Generate_DHKey command, the device can only pair one remote device at a time.

2.2.8 LE Secure Connections Check Value Generation Function *f6*

The LE Secure Connections check value generation function *f6* is used to generate check values during authentication stage 2 of the LE Secure Connections pairing process.

The definition of the *f6* function makes use of the MAC function AES-CMAC$_W$ with a 128-bit key W.

The inputs to function *f6* are:

W is 128 bits

N1 is 128 bits

N2 is 128 bits

R is 128 bits

IOcap is 24 bits

A1 is 56 bits

A2 is 56 bits

N1, N2, R, IOcap, A1 and A2 are concatenated and used as input *m* to the function AES-CMAC and W is used as the key *k*.

The inputs to f6 are different depending on different association models:

Numeric Comparison/ Just Works	**Out-Of-Band**	**Passkey Entry**
Ea = *f6*(MacKey, Na, Nb, 0, IOcapA, A, B) Eb = *f6*(MacKey, Nb, Na, 0, IOcapB, B, A)	Ea = *f6*(MacKey, Na, Nb, rb, IOcapA, A, B) Eb = *f6*(MacKey, Nb, Na, ra, IOcapB, B, A)	Ea = *f6*(MacKey, Na20, Nb20, rb, IOcapA, A, B) Eb = *f6*(MacKey, Nb20, Na20, ra, IOcapB, B, A)

Table 2.2: Inputs to f6 for the different protocols

MacKey is the 128-bit MSBs of the output of f5.

Na is the random number sent by the master to the slave and Nb is the random number sent by the slave to the master.

IOcapA is the capabilities of the master and IOcapB is the capabilities of the slave. IOcapA and IOcapB are both three octets with the most significant octet as the AuthReq parameter, the middle octet as the OOB data flag and the least significant octet as the IO capability parameter. The AuthReq, OOB data flag and IO capability parameters are present in the Pairing Request and Pairing Response SMP packets.

In Passkey Entry, ra and rb are 6-digit passkey values expressed as a 128-bit integer. For instance, if the 6-digit value of ra is 131313 then

ra = 0x 00 00 00 00 00 00 00 00 00 00 00 00 00 02 00 f1

A is the device address of the master and B is the device address of the slave. The least significant bit in the most significant octet in both A and B is set to 1 if the address is a random address and set to 0 if the address is a public address. The 7 most significant bits of the most significant octet in both A and B are set to 0.

The output of the check value generation function *f6* is as follows:

f6(W, N1, N2, R, IOcap, A1, A2) =
$AES\text{-}CMAC_W$ (N1 || N2 || R || IOcap || A1 || A2)

The least significant octet of A2 becomes the least significant octet of the AES-CMAC input message *m* and the most significant octet of N1 becomes the most significant octet of the AES-CMAC input message *m*.

2.2.9 LE Secure Connections Numeric Comparison Value Generation Function *g2*

The LE Secure Connections numeric comparison value generation function *g2* is used to generate the numeric comparison values during authentication stage 1 of the LE Secure Connections pairing process.

The definition of *g2* makes use of the MAC function $AES\text{-}CMAC_X$ with 128-bit key X.

The inputs to function *g2* are:

U is 256 bits

V is 256 bits

X is 128 bits

Y is 128 bits

U, V, and Y are concatenated and used as input *m* to the function AES-CMAC and X is used as the key *k*.

The output of the numeric comparison value generation function *g2* is as follows:

$g2(U, V, X, Y) = AES\text{-}CMAC_X(U \,||\, V \,||\, Y) \bmod 2^{32}$

The least significant octet of Y becomes the least significant octet of the AES-CMAC input message *m* and the most significant octet of U becomes the most significant octet of the AES-CMAC input message *m*.

The numeric verification value is taken as the six least significant digits of the 32-bit integer *g2*(PKax, PKbx, Na, Nb) where PKax denotes the x-coordinate of the public key PKa of A and PKbx denotes the x-coordinate of the public key PKb of B. Na and Nb are nonces from devices A and B. The value is then

converted to decimal numeric value. The checksum used for numeric comparison is the least significant six digits.

Compare Value = *g2* (U, V, X, Y) mod 10^6

For example, if output = 0x 01 2e b7 2a then decimal value = 19838762 and the checksum used for numeric comparison is 838762.

2.2.10 Link Key Conversion Function *h6*

The function *h6* is used to convert keys of a given size from one key type to another key type with equivalent strength.

The definition of the *h6* function makes use of the hashing function AES-$CMAC_W$ with 128-bit key W.

The inputs to function *h6* are:

W is 128 bits

keyID is 32 bits

keyID is used as input *m* to the hashing function AES-CMAC and the most significant 128-bits of W are used as the key *k* (2.2.5).

The output of *h6* is as follows:

h6(W, keyID) = AES-$CMAC_W$(keyID)

2.2.11 Link Key Conversion Function *h7*

The function *h7* is used to convert keys of a given size from one key type to another key type with equivalent strength.

The definition of the *h7* function makes use of the hashing function AES-$CMAC_{SALT}$ with 128-bit key SALT.

The inputs to function *h7* are:

SALT is 128 bits

W is 128 bits

W is used as input *m* to the hashing function AES-CMAC and SALT is used as the key *k* (2.2.5).

The output of *h7* is as follows:

h7(SALT, W) = AES-$CMAC_{SALT}$(W)

2.3 PAIRING METHODS

When pairing is started, the Pairing Feature Exchange shall be initiated by the initiating device. If the responding device does not support pairing or pairing cannot be performed then the responding device shall respond using the Pairing Failed message with the error code “Pairing Not Supported” otherwise it responds with a Pairing Response message.

The Pairing Feature Exchange is used to exchange IO capabilities, OOB authentication data availability, authentication requirements, key size requirements and which transport specific keys to distribute. The IO capabilities, OOB authentication data availability and authentication requirements are used to determine the key generation method used in Phase 2.

All of the LE legacy pairing methods use and generate 2 keys:

1. Temporary Key (TK): a 128-bit temporary key used in the pairing process which is used to generate STK (see Section 2.3.5.5).
2. Short Term Key (STK): a 128-bit temporary key used to encrypt a connection following pairing.

The LE Secure Connections pairing methods use and generate 1 key:

1. Long Term Key (LTK): a 128-bit key used to encrypt the connection following pairing and subsequent connections.

Authentication requirements are set by GAP, (see [Vol 3] Part C, Section 10.3). The authentication requirements include the type of bonding and man-in-the-middle protection (MITM) requirements.

The initiating device indicates to the responding device which transport specific keys it would like to send to the responding device and which keys it would like the responding device to send to the initiator. The responding device replies with the keys that the initiating device shall send and the keys that the responding device shall send. The keys that can be distributed are defined in Section 2.4.3. If the device receives a command with invalid parameters, it shall respond with Pairing Failed command with the error code “Invalid Parameters.”

2.3.1 Security Properties

Security properties provided by SM are classified into the following categories:

- LE Secure Connections pairing
- Authenticated MITM protection
- Unauthenticated no MITM protection
- No security requirements

LE Secure Connections pairing utilizes the P-256 elliptic curve.

In LE legacy pairing, Authenticated man-in-the-middle (MITM) protection is obtained by using the passkey entry pairing method or may be obtained using the out of band pairing method. In LE Secure Connections pairing, Authenticated man-in-the-middle (MITM) protection is obtained by using the passkey entry pairing method or the numeric comparison method or may be obtained using the out of band pairing method. To ensure that Authenticated MITM Protection is generated, the selected Authentication Requirements option must have MITM protection specified.

Unauthenticated no MITM Protection does not have protection against MITM attacks.

For LE Legacy Pairing, none of the pairing methods provide protection against a passive eavesdropper during the pairing process as predictable or easily established values for *TK* are used. If the pairing information is distributed without an eavesdropper being present then all the pairing methods provide confidentiality.

An initiating device shall maintain a record of the Security Properties for the distributed keys in a security database.

A responding device may maintain a record of the distributed key sizes and Security Properties for the distributed keys in a security database. Depending upon the key generation method and negotiated key size a responding device may have to reduce the key length (see Section 2.3.4) so that the initiator and responder are using identical keys.

Security properties of the key generated in phase 2 under which the keys are distributed shall be stored in the security database.

2.3.2 IO Capabilities

Input and output capabilities of a device are combined to generate its IO capabilities. The input capabilities are described in Table 2.3. The output capabilities are described in Table 2.4.

Capability	Description
No input	Device does not have the ability to indicate ‘yes’ or ‘no’
Yes / No	Device has at least two buttons that can be easily mapped to 'yes' and 'no' or the device has a mechanism whereby the user can indicate either 'yes' or 'no' (see note below).
Keyboard	Device has a numeric keyboard that can input the numbers '0' through '9' and a confirmation. Device also has at least two buttons that can be easily mapped to 'yes' and 'no' or the device has a mechanism whereby the user can indicate either 'yes' or 'no' (see note below).

Table 2.3: User Input Capabilities

Note: 'yes' could be indicated by pressing a button within a certain time limit otherwise 'no' would be assumed.

Capability	Description
No output	Device does not have the ability to display or communicate a 6 digit decimal number
Numeric output	Device has the ability to display or communicate a 6 digit decimal number

Table 2.4: User Output Capabilities

The individual input and output capabilities are mapped to a single IO capability for that device which is used in the pairing feature exchange. The mapping is described in Table 2.5.

		Local output capacity	
		No output	**Numeric output**
Local input capacity	**No input**	NoInputNoOutput	DisplayOnly
	Yes/No	NoInputNoOutput[1]	DisplayYesNo
	Keyboard	KeyboardOnly	KeyboardDisplay

Table 2.5: I/O Capabilities Mapping

1. None of the pairing algorithms can use Yes/No input and no output, therefore NoInputNoOutput is used as the resulting IO capability.

2.3.3 OOB Authentication Data

An out of band mechanism may be used to communicate information which is used during the pairing process. The information shall be a sequence of Advertising Data structures (see [Vol 3] Part C, Section 11).

The OOB data flag shall be set if a device has the peer device's out of band authentication data. A device uses the peer device's out of band authentication data to authenticate the peer device. In LE legacy pairing, the out of band method is used if both the devices have the other device's out of band authentication data available. In LE Secure Connections pairing, the out of band method is used if at least one device has the peer device's out of band authentication data available.

2.3.4 Encryption Key Size

Each device shall have maximum and minimum encryption key length parameters which defines the maximum and minimum size of the encryption key allowed in octets. The maximum and minimum encryption key length parameters shall be between 7 octets (56 bits) and 16 octets (128 bits), in 1 octet (8 bit) steps. This is defined by a profile or device application.

The smaller value of the initiating and responding devices maximum encryption key length parameters shall be used as the encryption key size.

Both the initiating and responding devices shall check that the resultant encryption key size is not smaller than the minimum key size parameter for that device and if it is, the device shall send the Pairing Failed command with error code “Encryption Key Size”.

The encryption key size may be stored so it can be checked by any service that has minimum encryption key length requirements.

If a key has an encryption key size that is less than 16 octets (128 bits), it shall be created by masking the appropriate MSBs of the generated key to provide a resulting key that has the agreed encryption key size. The masking shall be done after generation and before being distributed, used or stored.
Note: When the BR/EDR link key is being derived from the LTK, the derivation is done before the LTK gets masked.

For example, if a 128-bit encryption key is

0x123456789ABCDEF0123456789ABCDEF0

and it is reduced to 7 octets (56 bits), then the resulting key is

0x00000000000000000003456789ABCDEF0.

2.3.5 Pairing Algorithms

The information exchanged in Phase 1 is used to select which key generation method is used in Phase 2.

When LE legacy pairing is used, the pairing is performed by each device generating a Temporary Key (*TK*). The method to generate *TK* depends upon the pairing method chosen using the algorithm described in Section 2.3.5.1. If Just Works is used then *TK* shall be generated as defined in Section 2.3.5.2. If Passkey Entry is used then *TK* shall be generated as defined in Section 2.3.5.3. If Out Of Band is used then *TK* shall be generated as defined in Section 2.3.5.4. The *TK* value shall be used in the authentication mechanism defined in Section 2.3.5.5 to generate the STK and encrypt the link.

2.3.5.1 Selecting Key Generation Method

If both devices have not set the MITM option in the Authentication Requirements Flags, then the IO capabilities shall be ignored and the Just Works association model shall be used.

In LE legacy pairing, if both devices have Out of Band authentication data, then the Authentication Requirements Flags shall be ignored when selecting the pairing method and the Out of Band pairing method shall be used. Otherwise, the IO capabilities of the device shall be used to determine the pairing method as defined in Table 2.8.

In LE Secure Connections pairing, if one or both devices have out of band authentication data, then the Authentication Requirements Flags shall be ignored when selecting the pairing method and the Out of Band pairing method shall be used. Otherwise, the IO capabilities of the device shall be used to determine the pairing method as defined in Table 2.8.

Table 2.6 defines the STK generation method when at least one of the devices does not support LE Secure Connections.

		Initiator			
		OOB Set	**OOB Not Set**	**MITM Set**	**MITM Not Set**
Responder	**OOB Set**	Use OOB	Check MITM		
	OOB Not Set	Check MITM	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.6: Rules for using Out-of-Band and MITM flags for LE legacy pairing

Table 2.7 defines the LTK generation method when both devices support LE Secure Connections.

		Initiator			
		OOB Set	**OOB Not Set**	**MITM Set**	**MITM Not Set**
Responder	**OOB Set**	Use OOB	Use OOB		
	OOB Not Set	Use OOB	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.7: Rules for using Out-of-Band and MITM flags for LE Secure Connections Pairing

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Display Only	Just Works Unauthenticated	Just Works Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated
Display YesNo	Just Works Unauthenticated	Just Works (For LE Legacy Pairing) Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry (For LE Legacy Pairing): responder displays, initiator inputs Authenticated
		Numeric Comparison (For LE Secure Connections) Authenticated			Numeric Comparison (For LE Secure Connections) Authenticated

Table 2.8: Mapping of IO Capabilities to Key Generation Method

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Keyboard Only	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator and responder inputs Authenticated	Just Works Unauthenticated	Passkey Entry: initiator displays, responder inputs Authenticated
NoInput NoOutput	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated
Keyboard Display	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated
		Numeric Comparison (For LE Secure Connections) Authenticated			Numeric Comparison (For LE Secure Connections) Authenticated

Table 2.8: Mapping of IO Capabilities to Key Generation Method

The generated key will either be an Authenticated or Unauthenticated key. If the out of band authentication method is used and the Out of Band mechanism is known to be secure from eavesdropping the key is assumed to be Authenticated; however, the exact strength depends upon the method used to transfer the out of band information. If the Out of Band method is used and the Out of Band mechanism is not secure from eavesdropping or the level of eavesdropping protection is unknown, the key shall be Unauthenticated. The mapping of IO capabilities to an authenticated or unauthenticated key is described in Table 2.8.

In LE legacy pairing,if the initiating device has Out of Band data and the responding device does not have Out of Band data then the responding device may send the Pairing Failed command with the error code “OOB Not Available” instead of the Pairing Response command.

If the key generation method does not result in a key that provides sufficient security properties then the device shall send the Pairing Failed command with the error code “Authentication Requirements”.

2.3.5.2 LE Legacy Pairing - Just Works

The Just Works STK generation method provides no protection against eavesdroppers or man in the middle attacks during the pairing process. If the attacker is not present during the pairing process then confidentiality can be established by using encryption on a future connection.

Both devices set the TK value used in the authentication mechanism defined in Section 2.3.5.5 to zero.

2.3.5.3 LE Legacy Pairing - Passkey Entry

The Passkey Entry STK generation method uses 6 numeric digits passed out of band by the user between the devices. A 6 digit numeric randomly generated passkey achieves approximately 20 bits of entropy.

If the IO capabilities of a device are DisplayOnly or if Table 2.8 defines that the device displays the passkey, then that device shall display a randomly generated passkey value between 000,000 and 999,999. The display shall ensure that all 6 digits are displayed – including zeros. The other device shall allow the user to input a value between 000,000 and 999,999.

If entry of Passkey in UI fails to occur or is cancelled then the device shall send Pairing Failed command with reason code “Passkey Entry Failed”.

For example, if the user entered passkey is ‘019655’ then *TK* shall be 0x00000000000000000000000000004CC7.

The passkey Entry method provides protection against active “man-in-the-middle” (MITM) attacks as an active man-in-the-middle will succeed with a probability of 0.000001 on each invocation of the method.

The Passkey Entry STK generation method provides very limited protection against eavesdroppers during the pairing process because of the limited range of possible TK values which STK is dependent upon. If the attacker is not present during the pairing process then confidentiality and authentication can be established by using encryption on a future connection.

The TK value shall then be used in the authentication mechanism defined in Section 2.3.5.5.

2.3.5.4 Out of Band

An out of band mechanism may be used to communicate information to help with device discovery, for example device address, and the 128-bit *TK* value used in the pairing process. The *TK* value shall be a 128-bit random number using the requirements for random generation defined in [Vol 2] Part H, Section 2.

If the OOB communication is resistant to MITM attacks, then this association method is also resistant to MITM attacks. Also, in the Out of Band method, the size of authentication parameter (*TK*) need not be restricted by what the user can comfortably read or type. For that reason, the Out of Band method can be more secure than using the Passkey Entry or Just Works methods. However, both devices need to have matching OOB interfaces.

MITM protection is only provided if an active man-in-the-middle chance of a successful attack has a probability of 0.000001 or less in succeeding.

2.3.5.5 LE Legacy Pairing Phase 2

The initiating device generates a 128-bit random number (*Mrand*).

The initiating device calculates the 128-bit confirm value (*Mconfirm*) using the confirm value generation function *c1* (see Section 2.2.3) with the input parameter *k* set to *TK*, the input parameter *r* set to *Mrand,* the input parameter *preq* set to Pairing Request command as exchanged with the peer device (i.e. without any modifications), the input parameter *pres* set to the Pairing Response command as exchanged with the peer device (i.e. without any modifications), the input parameter *iat* set to the initiating device address type, *ia* set to the initiating device address, *rat* set to the responding device address type and *ra* set to the responding device address:

> *Mconfirm* = *c1*(*TK*, *Mrand*,
> Pairing Request command, Pairing Response command,
> initiating device address type, initiating device address,
> responding device address type, responding device address)

Initiating and responding device addresses used for confirmation generation shall be device addresses used during connection setup, see [Vol 3] Part C, Section 9.3

The responding device generates a 128-bit random number (*Srand*).

The responding device calculates the 128-bit confirm value (Sconfirm) using the confirm value generation function c1 (see Section 2.2.3) with the input parameter *k* set to *TK*, the input parameter *r* set to *Srand*, the input parameter *preq* set to Pairing Request command, the input parameter *pres* set to the Pairing Response command, the input parameter *iat* set to the initiating device

address type, *ia* set to the initiating device address, *rat* set to the responding device address type and *ra* set to the responding device address:

> *Sconfirm* = *c1*(*TK*, *Srand*,
> Pairing Request command, Pairing Response command,
> initiating device address type, initiating device address,
> responding device address type, responding device address)

The initiating device transmits *Mconfirm* to the responding device. When the responding device receives *Mconfirm* it transmits *Sconfirm* to the initiating device. When the initiating device receives *Sconfirm* it transmits *Mrand* to the responding device.

The responding device verifies the *Mconfirm* value by repeating the calculation the initiating device performed, using the *Mrand* value received.

If the responding device's calculated *Mconfirm* value does not match the received *Mconfirm* value from the initiating device then the pairing process shall be aborted and the responding device shall send the Pairing Failed command with reason code "Confirm Value Failed".

If the responding device's calculated *Mconfirm* value matches the received *Mconfirm* value from the initiating device the responding device transmits *Srand* to the initiating device.

The initiating device verifies the received *Sconfirm* value by repeating the calculation the responding device performed, using the *Srand* value received.

If the initiating devices calculated *Sconfirm* value does not match the received *Sconfirm* value from the responding device then the pairing process shall be aborted and the initiating device shall send the Pairing Failed command with the reason code "Confirm Value Failed".

If the initiating device's calculated *Sconfirm* value matches the received *Sconfirm* value from the responding device the initiating device then calculates STK and tells the Controller to enable encryption.

STK is generated using the key generation function *s1* defined in Section 2.2.4 with the input parameter *k* set to *TK*, the input parameter r1 set to *Srand,* and the input parameter *r2* set to *Mrand*:

> STK = *s1*(*TK*, *Srand*, *Mrand*)

If the encryption key size is less than 128 bits then the STK shall be masked to the correct key size as described in Section 2.3.4.

The initiator shall use the generated STK to either enable encryption on the link or if encryption has already been enabled, perform the encryption pause procedure (see Section 2.4.4.1).

2.3.5.6 LE Secure Connections Pairing Phase 2

The Long Term Key is generated in LE Secure Connections pairing phase 2.

2.3.5.6.1 Public Key Exchange

Initially, each device generates its own Elliptic Curve Diffie-Hellman (ECDH) public-private key pair (phase 1). The public-private key pair contains a private (secret) key, and a public key. The private keys of devices A and B are denoted as SKa and SKb respectively. The public keys of devices A and B and denoted as PKa and PKb respectively. This key pair needs to be generated only once per device and may be computed in advance of pairing. A device may, at any time, choose to discard its public-private key pair and generate a new one, although there is not a requirement to do so.

Pairing is initiated by the initiating device sending its public key to the receiving device (phase 1a). The responding device replies with its own public key (phase 1b) These public keys are not regarded as secret although they may identify the devices. Note that phases 1a and 1b are the same in all three protocols.

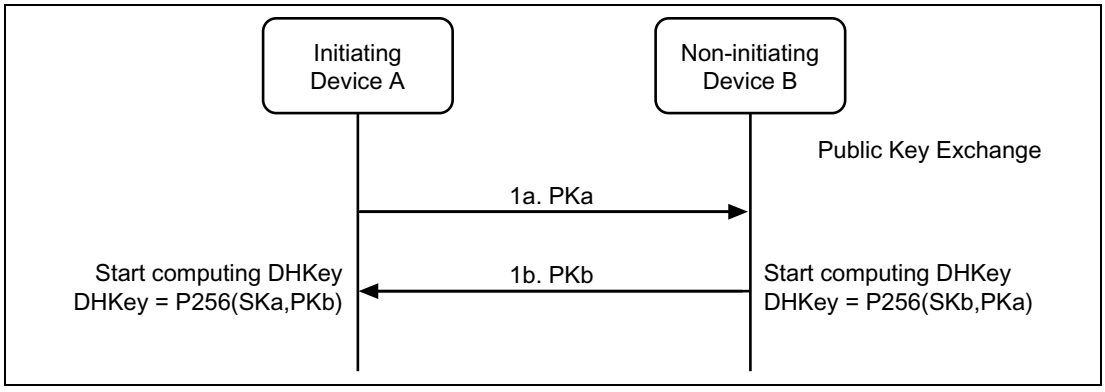

Figure 2.2: Public Key Exchange

After the public keys have been exchanged, the device can then start computing the Diffie-Hellman Key.

When the Security Manager is placed in a Debug mode it shall use the following Diffie-Hellman private / public key pair:

Private key: `3f49f6d4 a3c55f38 74c9b3e3 d2103f50 4aff607b eb40b799 5899b8a6 cd3c1abd`

Public key (X): `20b003d2 f297be2c 5e2c83a7 e9f9a5b9 eff49111 acf4fddb cc030148 0e359de6`

Public key (Y): `dc809c49 652aeb6d 63329abf 5a52155c 766345c2 8fed3024 741c8ed0 1589d28b`

Note: Only one side (initiator or responder) needs to set Secure Connections debug mode in order for debug equipment to be able to determine the LTK and, therefore, be able to monitor the encrypted connection.

2.3.5.6.2 Authentication Stage 1 – Just Works or Numeric Comparison

The Numeric Comparison association model will be used during pairing if the MITM bit is set to 1 in the Authentication Requirements in the Pairing Request PDU and/or Pairing Response PDU and both devices have IO capabilities set to either DisplayYesNo or KeyboardDisplay.

The sequence diagram of Authentication Stage 1 for the Just Works or Numeric Comparison protocol from the cryptographic point of view is shown in Figure 2.3.

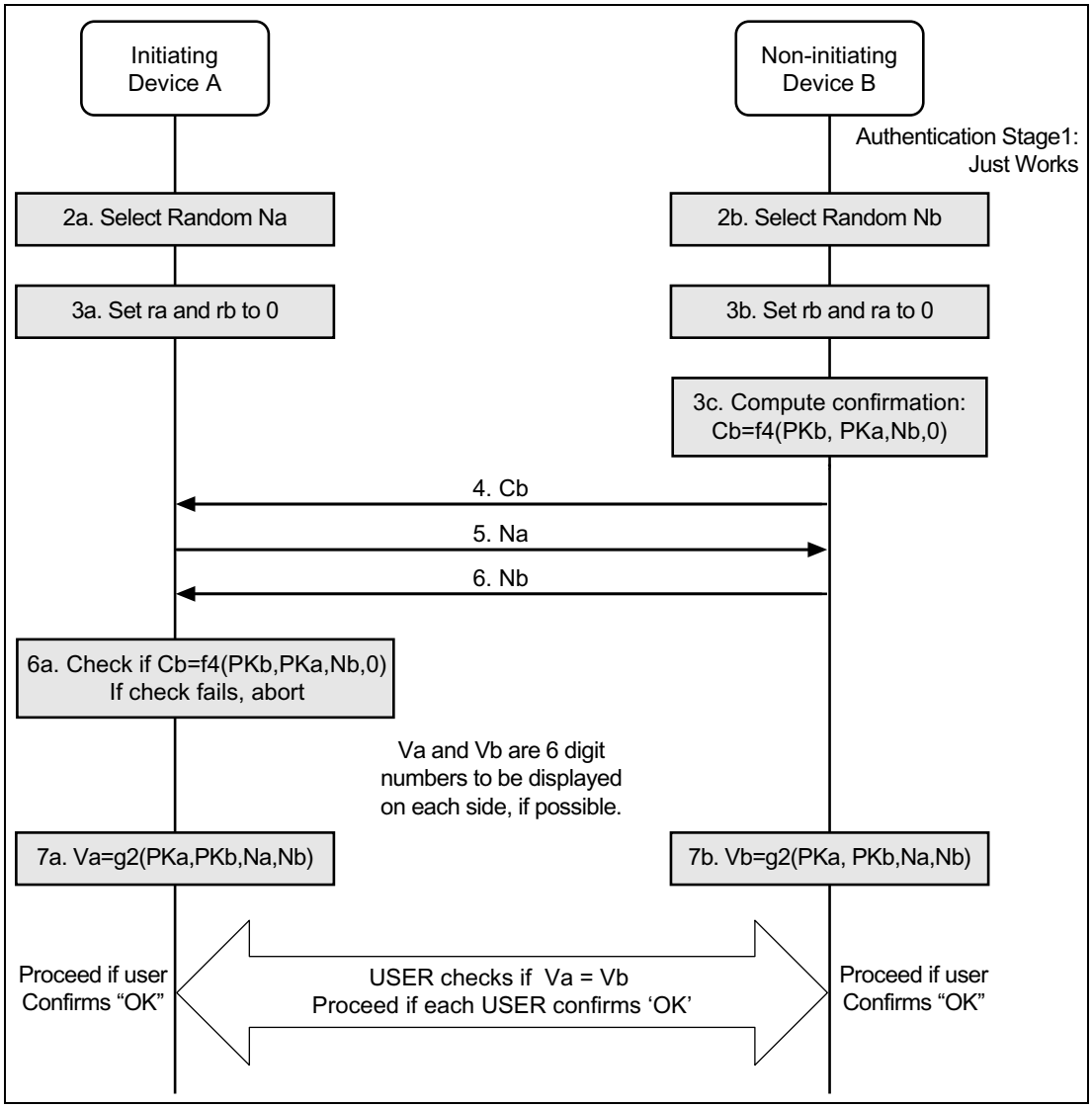

Figure 2.3: "Authentication Stage 1: Just Works or Numeric Comparison, LE Secure Connections

After the public keys have been exchanged, each device selects a pseudo-random 128-bit nonce (step 2). This value is used to prevent replay attacks and must be freshly generated with each instantiation of the pairing protocol. This value should be generated directly from a physical source of randomness or

with a good pseudo-random generator seeded with a random value from a physical source.

Following this the responding device then computes a commitment to the two public keys that have been exchanged and its own nonce value (step 3c). This commitment is computed as a one-way function of these values and is transmitted to the initiating device (step 4). The commitment prevents an attacker from changing these values at a later time.

The initiating and responding devices then exchange their respective nonce values (steps 5 and 6) and the initiating device confirms the commitment (step 6a). A failure at this point indicates the presence of an attacker or other transmission error and causes the protocol to abort. The protocol may be repeated with or without the generation of new public-private key pairs, but new nonces must be generated if the protocol is repeated.

When Just Works is used, the commitment checks (steps 7a and 7b) are not performed and the user is not shown the 6-digit values.

When Numeric Comparison is used, assuming that the commitment check succeeds, the two devices each compute 6-digit confirmation values that are displayed to the user on their respective devices (steps 7a, 7b, and 8). The user is expected to check that these 6-digit values match and to confirm if there is a match. If there is no match, the protocol aborts and, as before, new nonces must be generated if the protocol is to be repeated.

An active MITM must inject its own key material into this process to have any effect other than denial-of-service. A simple MITM attack will result in the two 6-digit display values being different with probability 0.999999. A more sophisticated attack may attempt to engineer the display values to match, but this is thwarted by the commitment sequence. If the attacker first exchanges nonces with the responding device, it must commit to the nonce that it will use with the initiating device before it sees the nonce from the initiating device. If the attacker first exchanges nonces with the initiating device, it must send a nonce to the responding device before seeing the nonce from the responding device. In each case, the attacker must commit to at least the second of its nonces before knowing the second nonce from the legitimate devices. It therefore cannot choose its own nonces in such a way as to cause the display values to match.

2.3.5.6.3 Authentication Stage 1 – Passkey Entry

The Passkey Entry protocol is used when SMP IO capability exchange sequence indicates that Passkey Entry shall be used.

The sequence diagram for Authentication Stage 1 for Passkey Entry from the cryptographic point of view is shown in Figure 2.4.

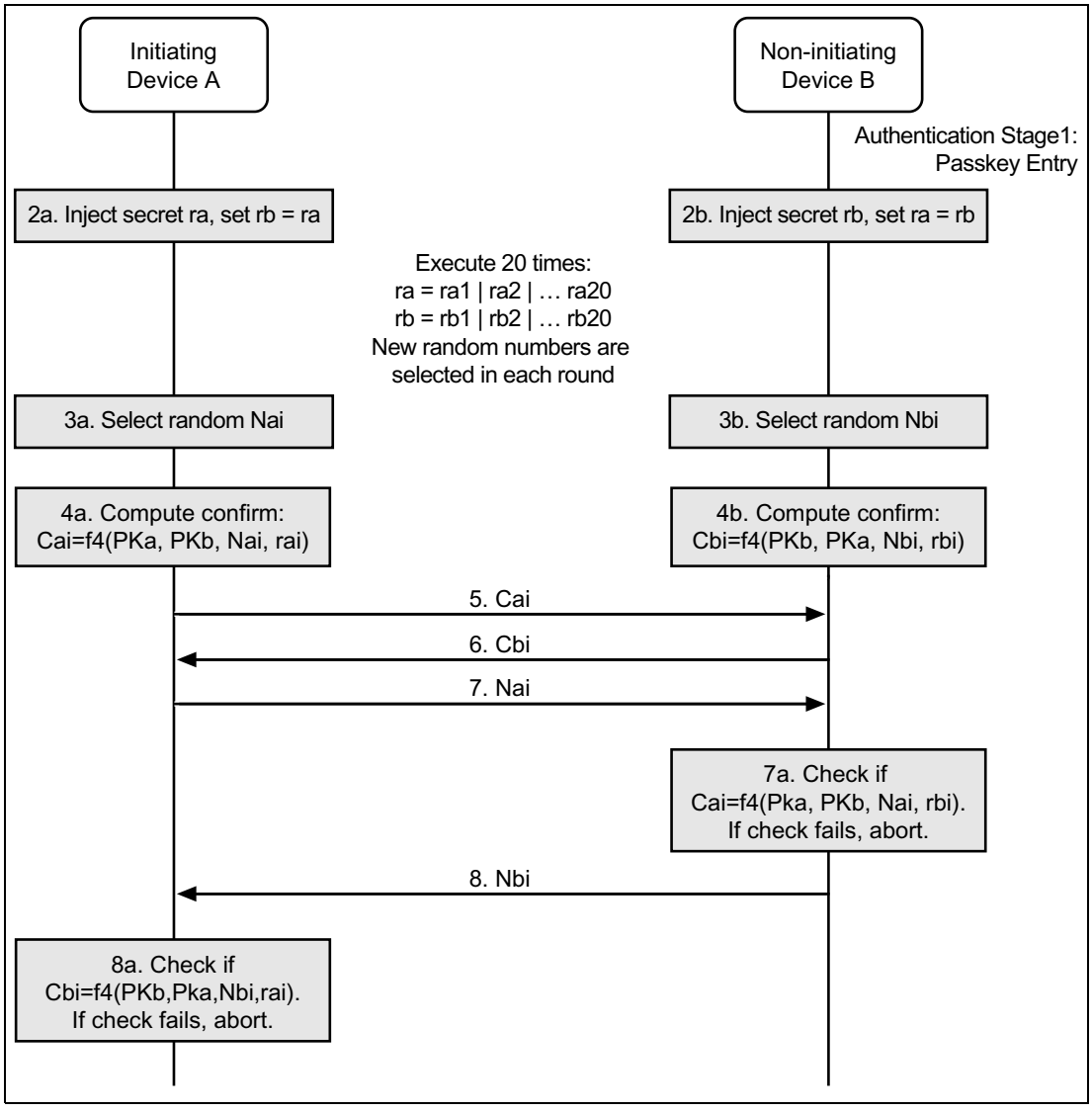

Figure 2.4: Authentication Stage 1: Passkey Entry, LE Secure Connections

The user inputs an identical Passkey into both devices. Alternately, the Passkey may be generated and displayed on one device, and the user then inputs it into the other (step 2). This short shared key will be the basis of the mutual authentication of the devices. Steps 3 through 8 are repeated *k* times for a *k*-bit Passkey — e.g., *k*=20 for a 6-digit Passkey (999999=0xF423F).

In Steps 3-8, each side commits to each bit of the Passkey, using a long nonce (128 bits), and sending the hash of the nonce, the bit of the Passkey, and both

public keys to the other party. The parties then take turns revealing their commitments until the entire Passkey has been mutually disclosed. The first party to reveal a commitment for a given bit of the Passkey effectively reveals that bit of the Passkey in the process, but the other party then has to reveal the corresponding commitment to show the same bit value for that bit of the Passkey, or else the first party will then abort the protocol, after which no more bits of the Passkey are revealed.

This "gradual disclosure" prevents leakage of more than 1 bit of un-guessed Passkey information in the case of a MITM attack. A MITM attacker with only partial knowledge of the Passkey will only receive one incorrectly-guessed bit of the Passkey before the protocol fails. Hence, a MITM attacker who engages first one side, then the other will only gain an advantage of at most two bits over a simple brute-force guesser which succeeds with probability 0.000001.

The long nonce is included in the commitment hash to make it difficult to brute force even after the protocol has failed. The public Diffie-Hellman values are included to tie the Passkey protocol to the original ECDH key exchange, to prevent a MITM from substituting the attacker's public key on both sides of the ECDH exchange in standard MITM fashion.

At the end of this stage, Na is set to Na20 and Nb is set to Nb20 for use in Authentication Stage 2.

2.3.5.6.4 Authentication Stage 1 – Out of Band

The Out-of-Band protocol is used when authentication information has been received by at least one of the devices and indicated in the OOB data flag parameter included in the SMP Pairing Request and SMP Pairing Response PDU. The mode in which the discovery of the peer device is first done in-band and then followed by the transmission of authentication parameters through OOB interface is not supported. The sequence diagram for Authentication Stage 1 for Out of Band from the cryptographic point of view is shown in Figure 2.5.

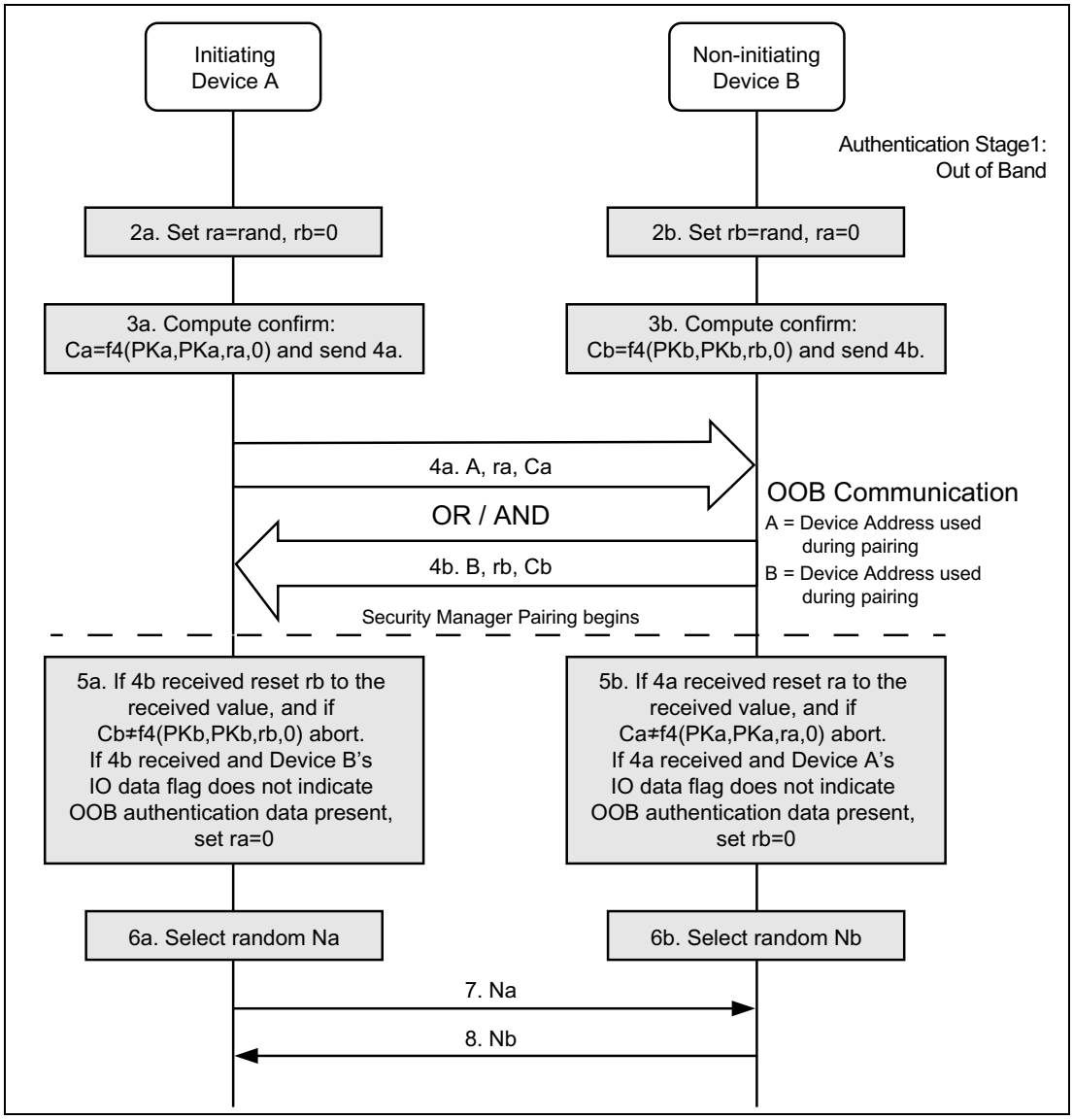

Figure 2.5: Authentication Stage 1: Out of Band, LE Secure Connections

Principle of operation. If both devices can transmit and/or receive data over an out-of-band channel, then mutual authentication will be based on the commitments of the public keys (Ca and Cb) exchanged OOB in Authentication stage 1. If OOB communication is possible only in one direction, then

authentication of the device receiving the OOB communication will be based on that device knowing a random number r sent via OOB. In this case, r must be secret: r can be created afresh every time, or access to the device sending r must be restricted. If r is not sent by a device, it is assumed to be 0 by the device receiving the OOB information in step 4a or 4b.

Roles of A and B. The OOB Authentication Stage 1 protocol is symmetric with respect to the roles of A and B. It does not require that device A always will initiate pairing and it automatically resolves asymmetry in the OOB communication.

Order of steps. The public key exchange must happen before the verification step 5. In the diagram the in-band public key exchange between the devices (step 1) is done before the OOB communication (step 4). But when the pairing is initiated by an OOB interface, public key exchange will happen after the OOB communication (step 1 will be between steps 4 and 5).

Values of ra and rb: Since the direction of the peer's OOB interface cannot be verified before the OOB communication takes place, a device should always generate and if possible transmit through its OOB interface a random number r to the peer. Each device applies the following rules locally to set the values of its own r and the value of the peer's r:

1. Initially, r of the device is set to a random number and r of the peer is set to 0 (step 2).
2. If a device has received OOB, it sets the peer's r value to what was sent by the peer (Step 5).
3. If the remote device's OOB data flag sent in the SMP Pairing Request or SMP Pairing Response is set to “OOB Authentication data not present”, it sets its own r value to 0 (Step 5)

2.3.5.6.5 Authentication Stage 2 and Long Term Key Calculation

The second stage of authentication then confirms that both devices have successfully completed the exchange. This stage is identical in all three protocols.

Each device computes the MacKey and the LTK using the previously exchanged values and the newly derived shared key (step 9). Each device then computes a new confirmation value that includes the previously exchanged values and the newly derived MacKey (step 10a and 10b). The initiating device then transmits its confirmation value, which is checked by the responding device (step 11). If this check fails, it indicates that the initiating device has not confirmed the pairing, and the protocol must be aborted. The responding device then transmits its confirmation value, which is checked by the initiating device (step 12). A failure indicates that the responding device has not confirmed the pairing and the protocol should abort.

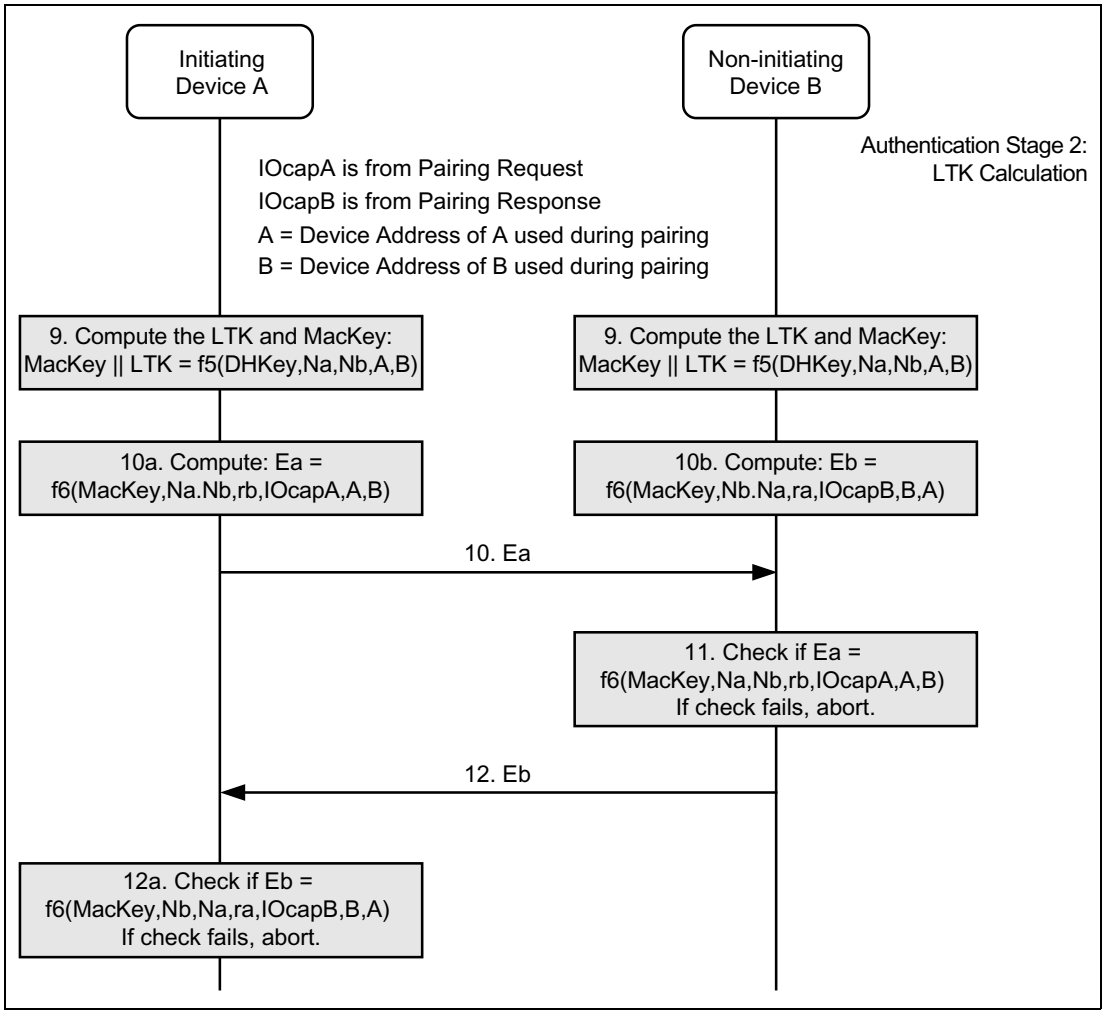

Figure 2.6: Authentication Stage 2 and Long Term Key Calculation

2.3.5.7 Cross-transport Key Derivation

When a pair of BR/EDR/LE devices support Secure Connections on a transport, the devices may optionally generate a key of identical strength for the other transport. There are two sequences:

- If Secure Connections pairing occurs first on the LE transport the procedures in Section 2.4.2.4 may be used.
- If Secure connections pairing occurs first on the BR/EDR transport the procedures in Section 2.4.2.5 may be used.

2.3.6 Repeated Attempts

When a pairing procedure fails a waiting interval shall pass before the verifier will initiate a new Pairing Request command or Security Request command to the same claimant, or before it will respond to a Pairing Request command or Security Request command initiated by a device claiming the same identity as the failed device. For each subsequent failure, the waiting interval shall be increased exponentially. That is, after each failure, the waiting interval before a new attempt can be made, could be for example, twice as long as the waiting interval prior to the previous attempt[1]. The waiting interval should be limited to a maximum.

The maximum waiting interval depends on the implementation. The waiting time shall exponentially decrease to a minimum when no new failed attempts are made during a certain time period. This procedure prevents an intruder from repeating the pairing procedure with a large number of different keys.

To protect a device's private key, a device should implement a method to prevent an attacker from retrieving useful information about the device's private key using invalid public keys. For this purpose, a device can use one of the following methods:

- Change its private key after three failed attempts from any BD_ADDR and after 10 successful pairings from any BD_ADDR; or after a combination of these such that 3 successful pairings count as one failed pairing; or
- Verify that the received public keys from any BD_ADDR are on the correct curve; or
- Implement elliptic curve point addition and doubling using formulas that are valid only on the correct curve.

1. Another appropriate integer value larger than 1 may be used.

2.4 SECURITY IN BLUETOOTH LOW ENERGY

Security shall be initiated by the Security Manager in the device in the master role. The device in the slave role shall be the responding device. The slave device may request the master device to initiate pairing or other security procedures, see Section 2.4.6.

The slave in the key distribution phase gives keys to the master so a reconnection can be encrypted, its random addresses can be resolved, or the master device can verify signed data from the slave.

The master may also provide keys to the slave device so a reconnection can be encrypted if the roles are reversed, the master's random addresses can be resolved, or the slave can verify signed data from the master.

2.4.1 Definition of Keys and Values

LE security uses the following keys and values for encryption, signing, and random addressing:

1. Identity Resolving Key (IRK) is a 128-bit key used to generate and resolve random addresses.
2. Connection Signature Resolving Key (CSRK) is a 128-bit key used to sign data and verify signatures on the receiving device.
3. Long Term Key (LTK) is a 128-bit key used to generate the contributory session key for an encrypted connection. Link Layer encryption is described in [Vol 6] Part B, Section 5.1.3.
4. Encrypted Diversifier (EDIV) is a 16-bit stored value used to identify the LTK distributed during LE legacy pairing. A new EDIV is generated each time a unique LTK is distributed.
5. Random Number (Rand) is a 64-bit stored valued used to identify the LTK distributed during LE legacy pairing. A new Rand is generated each time a unique LTK is distributed.

2.4.2 Generation of Distributed Keys

Any method of generation of keys that are being distributed that results in the keys having 128 bits of entropy can be used, as the generation method is not visible outside the slave device (see Section Appendix B). The keys shall not be generated only from information that is distributed to the master device or only from information that is visible outside of the slave device.

2.4.2.1 Generation of IRK

The Identity Resolving Key (IRK) is used for resolvable private address construction (see [Vol 3] Part C, Section 10.8.2). A master that has received IRK from a slave can resolve that slave's random device addresses. A slave

that has received IRK from a master can resolve that master's random device addresses. The privacy concept only protects against devices that are not part of the set to which the IRK has been given.

IRK can be assigned, or randomly generated by the device during manufacturing, or some other method could be used. If IRK is randomly generated then the requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used.

The encryption key size does not apply to IRK; therefore, its size does not need to be reduced before distribution.

2.4.2.2 Generation of CSRK

The Connection Signature Resolving Key (CSRK) is used to sign data in a connection. A device that has received CSRK can verify signatures generated by the distributing device. The signature only protects against devices that are not part of the set to which CSRK has been given.

CSRK can be assigned or randomly generated by the device during manufacturing, or some other method could be used. If CSRK is randomly generated then the requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used.

The encryption key size does not apply to CSRK, therefore its size does not need to be reduced before distribution.

2.4.2.3 LE Legacy Pairing - Generation of LTK, EDIV and Rand

Devices which support encryption in the Link Layer Connection State in the Slave Role shall be capable of generating LTK, EDIV, and Rand.

The EDIV and Rand are used by the slave device to establish a previously shared LTK in order to start an encrypted connection with a previously paired master device.

The generated LTK size must not exceed the negotiated encryption key size and its size may need to be reduced (see Section 2.3.4).

New values of LTK, EDIV, and Rand shall be generated each time they are distributed.

The slave device may store the mapping between EDIV, Rand and LTK in a security database so the correct LTK value is used when the master device requests encryption. Depending upon the LTK generation method additional information may be stored, for example the size of the distributed LTK.

The master device may also distribute EDIV, Rand, and LTK to the slave device which can be used to encrypt a reconnection if the device roles are reversed in a future connection.

2.4.2.4 Derivation of BR/EDR Link Key from LE LTK

The LTK from the LE physical transport can be converted to the BR/EDR link key for the BR/EDR transport as follows, using intermediate link key (ILK) as an intermediate value:

If at least one device sets CT2 = 0 then

1. ILK = *h6*(LTK, “tmp1”)
2. BR/EDR link key = *h6*(ILK, “lebr”)

If both devices set CT2 = 1 then

1. ILK = *h7*(SALT, LTK)
2. BR/EDR link key = *h6*(ILK, “lebr”)

The string “lebr” is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0111 0010
keyID[1] = 0110 0010
keyID[2] = 0110 0101
keyID[3] = 0110 1100
keyID    = 0x6c656272
```

The string “tmp1” is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0011 0001
keyID[1] = 0111 0000
keyID[2] = 0110 1101
keyID[3] = 0111 0100
keyID    = 0x746D7031
```

SALT is defined as follows:

```
SALT = 0x000000000000000000000000000000000746D7031
```

Note: If the LTK has an encryption key size that is less than 16 octets (128 bits), the BR/EDR link key is derived before the LTK gets masked.

2.4.2.5 Derivation of LE LTK from BR/EDR Link Key

The BR/EDR Link Key from the BR/EDR physical transport can be converted to the LTK for the LE transport as follows, using intermediate long term key (ILTK) as an intermediate value:

If at least one device sets CT2 = 0 then

1. ILTK = *h6*(Link Key, “tmp2”)
2. LTK = *h6*(ILTK, “brle”)

If both devices set CT2 = 1 then

1. ILTK = *h7*(SALT, Link Key)
2. LTK = *h6*(ILTK, “brle”)

The string “brle” is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0110 0101
keyID[1] = 0110 1100
keyID[2] = 0111 0010
keyID[3] = 0110 0010
keyID    = 0x62726c65
```

The string “tmp2” is mapped into keyID using extended ASCII as follows:

```
keyID[0] = 0011 0010
keyID[1] = 0111 0000
keyID[2] = 0110 1101
keyID[3] = 0111 0100
keyID    = 0x746D7032
```

The SALT is defined as follows:

```
SALT = 0x00000000000000000000000000000000746D7032
```

2.4.3 Distribution of Keys

Key distribution for LE Legacy Pairing and LE Secure Connections is described in the following sections.

2.4.3.1 LE Legacy Pairing Key Distribution

The slave may distribute to the master the following keys:

- LTK, EDIV, and Rand
- IRK
- CSRK

The master device may distribute to the slave the following keys:

- LTK, EDIV, and Rand
- IRK
- CSRK

The security properties of the distributed keys shall be set to the security properties of the STK that was used to distribute them. For example if STK has Unauthenticated no MITM Protection security properties then the distributed keys shall have Unauthenticated no MITM Protection security properties.

The link shall be encrypted or re-encrypted using STK generated in Phase 2 (see Section 2.4.4.1) before any keys are distributed.

Note: The distributed EDIV and Rand values are transmitted in clear text by the master device to the slave device during encrypted session setup.

The BD_ADDR that is received in the Identity Address Information command shall only be considered valid once a reconnection has occurred using the BD_ADDR and LTK distributed during that pairing. Once this is successful the BD_ADDR and the distributed keys shall be associated with that device in the security database.

A device may request encrypted session setup to use the LTK, EDIV, and Rand values distributed by the slave device when the key distribution phase has completed; however, this does not provide any additional security benefit. If an attacker has established the distributed LTK value then performing encrypted session setup to use the distributed values does not provide any protection against that attacker.

2.4.3.2 LE Secure Connections Key Distribution

The master and slave may distribute the following keys:

- IRK
- CSRK

The security properties of the distributed keys shall be set to the security properties of the LTK that was used to distribute them. For example if LTK has Unauthenticated no MITM Protection security properties then the distributed keys shall have Unauthenticated no MITM Protection security properties.

The link shall be encrypted or re-encrypted using LTK generated in Phase 2 (see Section 2.4.4.1) before any keys are distributed.

The BD_ADDR that is received in the Identity Address Information command shall only be considered valid once a reconnection has occurred using the BD_ADDR and LTK generated during that pairing. Once this is successful the BD_ADDR and the distributed keys shall be associated with that device in the security database.

2.4.4 Encrypted Session Setup

During the encrypted session setup the master device sends a 16-bit Encrypted Diversifier value, *EDIV,* and a 64-bit Random Number, *Rand*, distributed by the slave device during pairing, to the slave device. The master's Host provides the Link Layer with the Long Term Key to use when setting up the encrypted session. The slave's Host receives the *EDIV* and *Rand* values and provides a Long Term Key to the slave's Link Layer to use when setting up the encrypted link.

When both devices support LE Secure Connections, the *EDIV* and *Rand* are set to zero.

2.4.4.1 Encryption Setup using STK

To distribute LTK and other keys in pairing Phase 3 an encrypted session needs to be established (see Section 2.3.5.5).

The encrypted session is setup using STK generated in Phase 2 (see Section Section 2.3.5.5) as the Long Term Key provided to the Link Layer, (see [Vol 6] Part B, Section 5.1.3.1) *EDIV*, and *Rand* values shall be set to zero.

If the link is already encrypted then the encryption pause procedure is performed using STK generated in Phase 2 as the Long Term Key provided to the Link Layer (see [Vol 6] Part B, Section 5.1.3.2). *EDIV* and *Rand* values shall be set to zero.

2.4.4.2 Encryption Setup using LTK

The master device must have the security information (*LTK*, *EDIV*, and *Rand*) distributed by the slave device in LE legacy pairing or the LTK generated in LE Secure Connections to setup an encrypted session.

The master initiates the encrypted session using the security information; see [Vol 6] Part B, Section 5.1.3.1. If the link is already encrypted the encryption pause procedure is performed using the security information; see [Vol 6] Part B, Section 5.1.3.2.

In LE legacy pairing, the *EDIV* and *Rand* values are used to establish *LTK* which is used as the Long Term Key on the slave device. If LTK cannot be established from EDIV and Rand values then the slave shall reject the request to encrypt the link and may optionally disconnect the link.

The LTK size must not exceed the negotiated encryption key size and its size may need to be reduced (see Section 2.3.4).

When the security information is stored, subsequent encryption setups may fail if the remote device has deleted the security information. Table 2.9 defines what shall be done depending on the type of the security properties and whether or not bonding was performed when subsequent encryption setup fails.

Security Properties	Devices Bonded	Action to take when enabling encryption fails
Unauthenticated, no MITM protection	No	Depends on security policy of the device: • Option 1: Automatically initiate pairing • Option 2: Notify user and ask if pairing is ok. Option 1 is recommended.
Unauthenticated, no MITM protection	Yes	Notify user of security failure
Authenticated MITM protection	No	Depends on security policy of the device: • Option 1: Automatically initiate pairing • Option 2: Notify user and ask if pairing is ok. Option 2 is recommended.
Authenticated MITM protection	Yes	Notify user of security failure

Table 2.9: Action after encryption setup failure

2.4.5 Signing Algorithm

An LE device can send signed data without having to establish an encrypted session with a peer device. Data shall be signed using CSRK. A device performing signature verification must have received CSRK from the signing device. The sending device will use its CSRK to sign the transmitted data.

The following are inputs to the signing algorithm:

m is variable length

k is 128 bits

SignCounter is 32 bits

Signing shall be performed using the algorithm defined in the NIST Special Publication 800-38B (http://csrc.nist.gov/publications/PubsSPs.html) using AES-128 as the block cipher. NIST SP 800-38B defines the message authentication code (MAC) generation function:

$$MAC = CMAC(K, M, Tlen)$$

The bit length of the MAC (*Tlen*) shall be 64 bits. The key used for signature generation (*k*) shall be set to CSRK.

The message to be signed (*M*) by the CMAC function is the concatenation of the variable length message to be signed (*m*) and 4 octet string representing the 32-bit counter value (*SignCounter*) least significant octet first.

$$M = m \,||\, SignCounter$$

For example, if data to be signed is the 7 octet sequence '3456789ABCDEF1' and *SignCounter* is set to 67653874 (0x040850F2) then *M* is the octet sequence '3456789ABCDEF1F2500804'. Examples of CMAC generation using AES-128 as the block cipher are included in NIST Special Publication 800-38B Appendix.

The *SignCounter* shall be initialized to zero when CSRK is generated and incremented for every message that is signed with a given CSRK.

Note: If a device generates 100,000 signed events a day, a 32-bit counter will wrap after approximately 117 years.

The 64-bit result of the CMAC function is used as the result of the signing algorithm.

To verify a signature a device computes the MAC of a received message and *SignCounter* and compares it with the received MAC. If the MAC does not match then the signature verification has failed. If the MACs match then the signature verification has succeeded.

The device performing verification should store the last verified *SignCounter* in the security database and compare it with a received *SignCounter* to prevent replay attacks. If the received *SignCounter* is greater than the stored value then the message has not been seen by the local device before and the security database can be updated.

2.4.6 Slave Security Request

The slave device may request security by transmitting a Security Request command to the master. When a master device receives a Security Request command it may encrypt the link, initiate the pairing procedure, or reject the request.

The slave shall not send the Security Request command if the pairing procedure is in progress, or if the encryption procedure is in progress.

The Security Request command includes the required security properties. A security property of MITM protection required shall only be set if the slave's IO capabilities would allow the Passkey Entry association model to be used or out of band authentication data is available.

The master shall ignore the slave's Security Request if the master has sent a Pairing Request without receiving a Pairing Response from the slave or if the master has initiated encryption mode setup.

If pairing or encryption mode is not supported or cannot be initiated at the time when the slave's Security Request Command is received, then the master shall respond with a Pairing Failed Command with the reason set to "Pairing Not Supported."

After receiving a Security Request, the master shall first check whether it has the required security information to enable encryption; see Section 2.4.4.2. If this information is missing or does not meet the security properties requested by the slave, then the master shall initiate the pairing procedure. If the pairing procedure is successful, the master's security database is updated with the keys and security properties are distributed during the pairing procedure.

If the master has the required security information to enable encryption and it meets the security properties request by the slave, it shall perform encryption setup using LTK, see Section 2.4.4.2.

Figure 2.7 shows a summary of the actions and decisions that a master shall take when receiving a Security Request.

The slave shall check that any Pairing Request command received from the master after sending a Security Request command contains Authentication Requirements that meet the requested security properties.

If the slave requests a security property that is not Just Works and receives an encryption procedure request after sending a Security Request command then it shall check that any existing Security Information is of sufficient security properties.

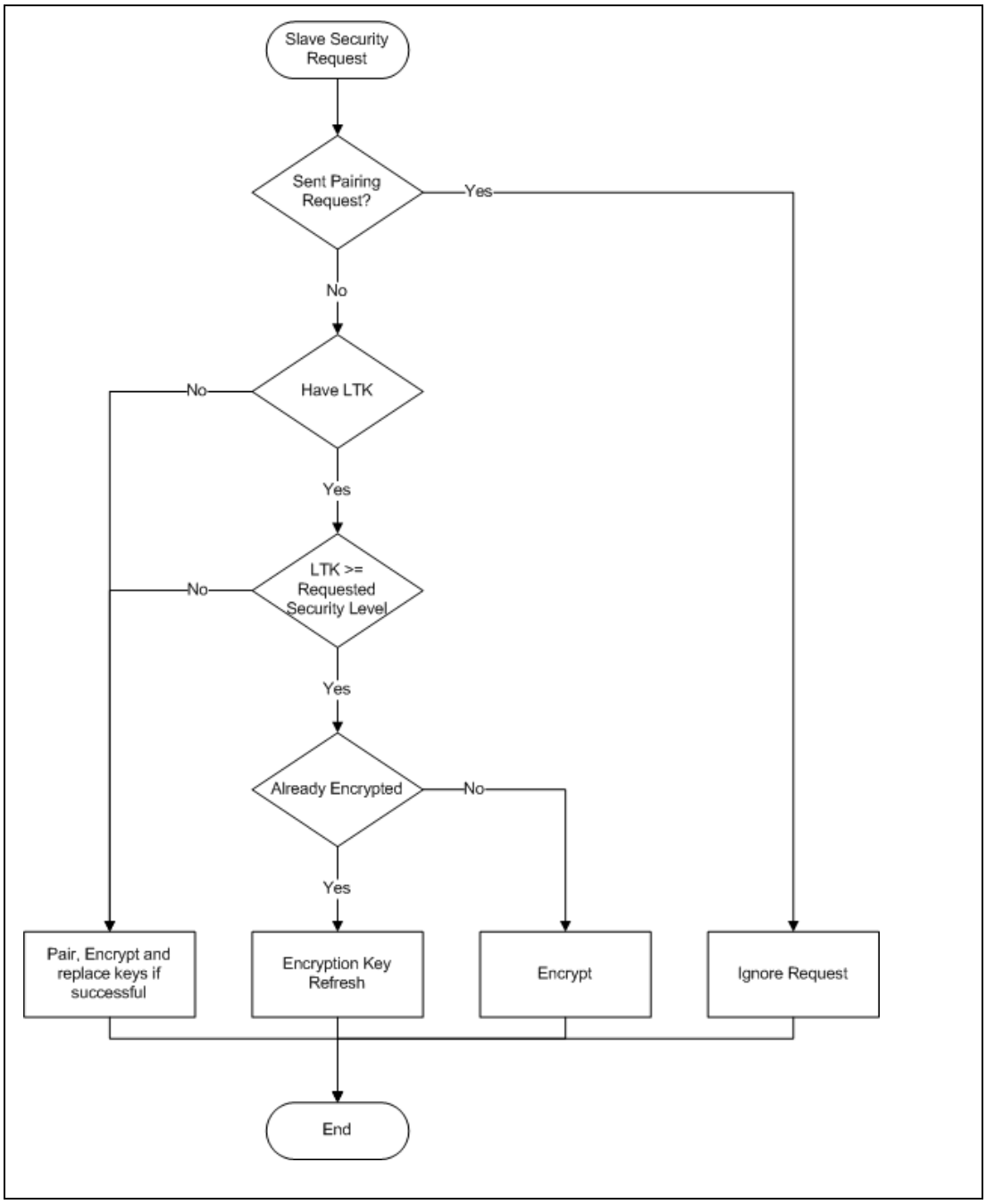

Figure 2.7: Master actions after receiving Security Request

3 SECURITY MANAGER PROTOCOL

3.1 INTRODUCTION

The Security Manager Protocol (SMP) is used for pairing and transport specific key distribution.

3.2 SECURITY MANAGER CHANNEL OVER L2CAP

All SMP commands are sent over the Security Manager Channel which is an L2CAP fixed channel (see [Vol 3] Part A, Section 2.1). The configuration parameters for the Security Manager Channel when LE Secure Connections is not supported shall be as shown below in Table 3.1.

Parameter	Value
MTU	23
Flush Timeout	0xFFFF (Infinite)
QoS	Best Effort
Mode	Basic Mode

Table 3.1: Security Manager Channel Configuration Parameters without LE Secure Connections

The configuration parameters for the Security Manager Channel when LE Secure Connections is supported shall be as shown below in Table 3.2.

Parameter	Value
MTU	65
Flush Timeout	0xFFFF (Infinite)
QoS	Best Effort
Mode	Basic Mode

Table 3.2: Security Manager Channel Configuration Parameters with LE Secure Connections

3.3 COMMAND FORMAT

The general format for all SMP commands is shown in Figure 3.1.

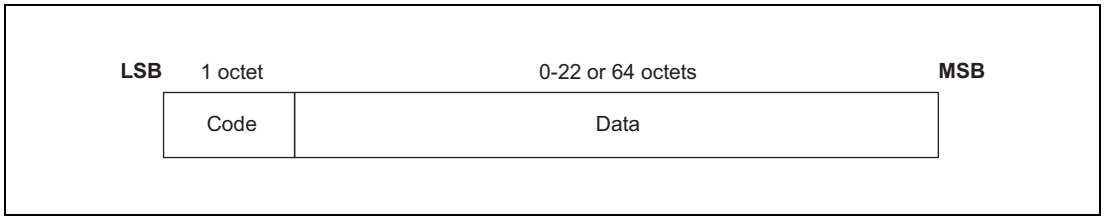

Figure 3.1: SMP Command Format

The following are the fields shown:

- *Code (1 octet)*

  The Code field is one octet long and identifies the type of command. Table 3.3 lists the codes defined by this document. If a packet is received with a Code that is reserved for future use it shall be ignored.

Code	Description	Logical Link Supported
0x00	Reserved for future use	
0x01	Pairing Request	LE-U, ACL-U
0x02	Pairing Response	LE-U, ACL-U
0x03	Pairing Confirm	LE-U
0x04	Pairing Random	LE-U
0x05	Pairing Failed	LE-U, ACL-U
0x06	Encryption Information	LE-U
0x07	Master Identification	LE-U
0x08	Identity Information	LE-U, ACL-U
0x09	Identity Address Information	LE-U, ACL-U
0x0A	Signing Information	LE-U, ACL-U
0x0B	Security Request	LE-U
0x0C	Pairing Public Key	LE-U
0x0D	Pairing DHKey Check	LE-U
0x0E	Pairing Keypress Notification	LE-U
0x0F – 0xFF	Reserved for future use	

Table 3.3: SMP Command Codes

- *Data (0 or more octets)*

  The Data field is variable in length. The Code field determines the format of the Data field.

If a device does not support pairing then it shall respond with a Pairing Failed command with the reason set to “Pairing Not Supported” (see Section 3.5.5) when any command is received. If pairing is supported then all commands shall be supported.

3.4 SMP TIMEOUT

To protect the Security Manager protocol from stalling, a Security Manager Timer is used. Upon transmission of the Security Request command or reception of the Security Request command, the Security Manager Timer shall be reset and restarted. Upon transmission of the Pairing Request command or reception of the Pairing Request command, the Security Manager Timer shall be reset and started.

The Security Manager Timer shall be reset when an L2CAP SMP command is queued for transmission.

When a Pairing process completes, the Security Manager Timer shall be stopped.

If the Security Manager Timer reaches 30 seconds, the procedure shall be considered to have failed, and the local higher layer shall be notified. No further SMP commands shall be sent over the L2CAP Security Manager Channel. A new Pairing process shall only be performed when a new physical link has been established.

3.5 PAIRING METHODS

The SMP commands defined in this section are used to perform Pairing Feature Exchange and key generation (see Section 2.1).

3.5.1 Pairing Request

The initiator starts the Pairing Feature Exchange by sending a Pairing Request command to the responding device. The Pairing Request command is defined in Figure 3.2.

The rules for handing a collision between a pairing procedure on the LE transport and a pairing procedure on the BR/EDR transport are defined in [Vol 3] Part C, Section 14.2.

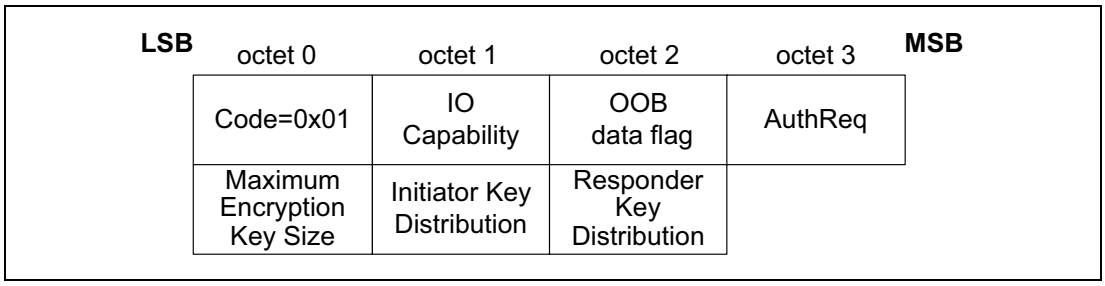

Figure 3.2: Pairing Request Packet

The following data fields are used:

- *IO Capability (1 octet)*

  Table 3.4 defines the values which are used when exchanging IO capabilities (see Section 2.3.2).

Value	Description
0x00	DisplayOnly
0x01	DisplayYesNo
0x02	KeyboardOnly
0x03	NoInputNoOutput
0x04	KeyboardDisplay
0x05-0xFF	Reserved for future use

Table 3.4: IO Capability Values

- *OOB data flag (1 octet)*

  Table 3.5 defines the values which are used when indicating whether OOB authentication data is available (see Section 2.3.3).

Value	Description
0x00	OOB Authentication data not present
0x01	OOB Authentication data from remote device present
0x02-0xFF	Reserved for future use

Table 3.5: OOB Data Present Values

- *AuthReq (1 octet)*

  The AuthReq field is a bit field that indicates the requested security properties (see Section 2.3.1) for the STK and LTK and GAP bonding information (see [Vol 3] Part C, Section 9.4).

  Figure 3.3 defines the authentication requirements bit field.

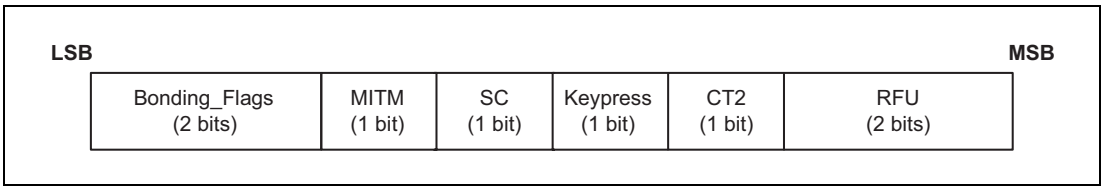

Figure 3.3: Authentication Requirements Flags

The Bonding_Flags field is a 2-bit field that indicates the type of bonding being requested by the initiating device as defined in Table 3.6.

Bonding_Flags b_1b_0	**Bonding Type**
00	No Bonding
01	Bonding
10	Reserved for future use
11	Reserved for future use

Table 3.6: Bonding Flags

The MITM field is a 1-bit flag that is set to one if the device is requesting MITM protection, otherwise it shall be set to 0. A device sets the MITM flag to one to request an Authenticated security property for the STK when using LE legacy pairing and the LTK when using LE Secure Connections.

The SC field is a 1 bit flag. If LE Secure Connections pairing is supported by the device, then the SC field shall be set to 1, otherwise it shall be set to 0. If both devices support LE Secure Connections pairing, then LE Secure Connections pairing shall be used, otherwise LE Legacy pairing shall be used.

The keypress field is a 1-bit flag that is used only in the Passkey Entry protocol and is ignored in other protocols. When both sides set that field to one, Keypress notifications shall be generated and sent using SMP Pairing Keypress Notification PDUs.

The CT2 field is a 1-bit flag that shall be set to 1 upon transmission to indicate support for the *h7* function. See sections 2.4.2.4 and 2.4.2.5.

- *Maximum Encryption Key Size (1 octet)*

  This value defines the maximum encryption key size in octets that the device can support. The maximum key size shall be in the range 7 to 16 octets.

- *Initiator Key Distribution / Generation (1 octet)*

  The Initiator Key Distribution / Generation field indicates which keys the initiator is requesting to distribute / generate or use during the Transport Specific Key Distribution phase (see Section 2.4.3). The Initiator Key Distribution / Generation field format and usage is defined in Section 3.6.1.

- *Responder Key Distribution / Generation (1 octet)*

The Responder Key Distribution / Generation field indicates which keys the initiator is requesting the responder to distribute / generate or use during the Transport Specific Key Distribution phase (see Section 2.4.3). The Responder Key Distribution / Generation field format and usage is defined in Section 3.6.1.

If Secure Connections pairing has been initiated over BR/EDR, the following fields of the SM Pairing Request PDU are reserved for future use:

- the IO Capability field,
- the OOB data flag field, and
- all bits in the Auth Req field except the CT2 bit.

3.5.2 Pairing Response

This command is used by the responding device to complete the Pairing Feature Exchange after it has received a Pairing Request command from the initiating device, if the responding device allows pairing. The Pairing Response command is defined in Figure 3.4.

The rules for handing a collision between a pairing procedure on the LE transport and a pairing procedure on the BR/EDR transport are defined in [Vol 3] Part C, Section 14.2.

If a Pairing Request is received over the BR/EDR transport when either cross-transport key derivation/generation is not supported or the BR/EDR transport is not encrypted using a Link Key generated using P256, a Pairing Failed shall be sent with the error code "Cross-transport Key Derivation/Generation not allowed" (0x0E).

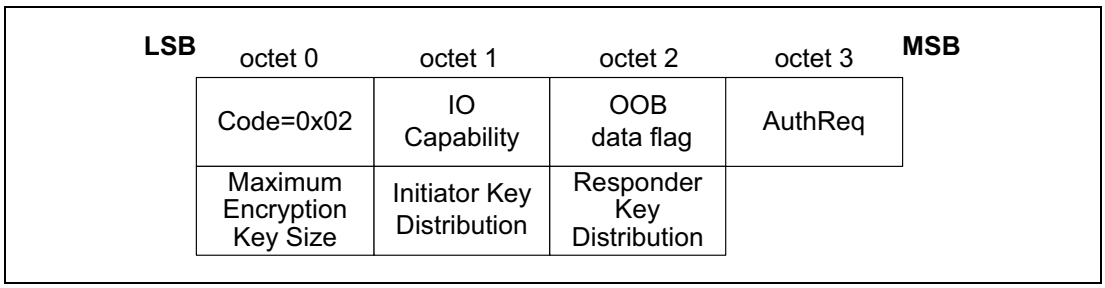

Figure 3.4: Pairing Response Packet

The following data fields are used:

- *IO Capability (1 octet)*

  Table 3.4 defines the values which are used when exchanging IO capabilities (see Section 2.3.2).

- *OOB data flag (1 octet)*

  Table 3.5 defines the values which are used when indicating whether OOB authentication data is available (see Section 2.3.3).

- *AuthReq (1 octet)*

  The AuthReq field is a bit field that indicates the requested security properties (see Section 2.3.1) for the STK or LTK and GAP bonding information (see [Vol 3] Part C, Section 9.4).

  Figure 3.3 defines the authentication requirements bit field.

  The Bonding_Flags field is a 2-bit field that indicates the type of bonding being requested by the responding device as defined in Table 3.6.

  The MITM field is a 1-bit flag that is set to one if the device is requesting MITM protection, otherwise it shall be set to 0. A device sets the MITM flag to one to request an Authenticated security property for the STK when using LE legacy pairing and the LTK when using LE Secure Connections.

  The SC field is a 1 bit flag. If LE Secure Connections pairing is supported by the device, then the SC field shall be set to 1, otherwise it shall be set to 0. If both devices support LE Secure Connections pairing, then LE Secure Connections pairing shall be used, otherwise LE Legacy pairing shall be used.

  The keypress field is a 1-bit flag that is used only in the Passkey Entry protocol and is ignored in other protocols. When both sides set that field to one, Keypress notifications shall be generated and sent using SMP Pairing Keypress Notification PDUs.

  The CT2 field is a 1-bit flag that shall be set to 1 upon transmission to indicate support for the *h7* function. See Sections 2.4.2.4 and 2.4.2.5.

- *Maximum Encryption Key Size (1 octet)*

  This value defines the maximum encryption key size in octets that the device can support. The maximum key size shall be in the range 7 to 16 octets.

- *Initiator Key Distribution (1 octet)*

  The Initiator Key Distribution field defines which keys the initiator shall distribute and use during the Transport Specific Key Distribution phase (see Section 2.4.3). The Initiator Key Distribution field format and usage are defined in Section 3.6.1.

- *Responder Key Distribution (1 octet)*

  The Responder Key Distribution field defines which keys the responder shall distribute and use during the Transport Specific Key Distribution phase (see Section 2.4.3). The Responder Key Distribution field format and usage are defined in Section 3.6.1.

If Secure Connections pairing has been initiated over BR/EDR, the following fields of the SM Pairing Response PDU are reserved for future use:

- the IO Capability field,
- the OOB data flag field, and
- all bits in the Auth Req field except the CT2 bit.

3.5.3 Pairing Confirm

This is used following a successful Pairing Feature Exchange to start STK Generation for LE legacy pairing and LTK Generation for LE Secure Connections pairing. The Pairing Confirm command is defined in Figure 3.5.

This command is used by both devices to send the confirm value to the peer device, see Section 2.3.5.5 for LE legacy pairing and Section 2.3.5.6 for LE Secure Connections pairing.

The initiating device starts key generation by sending the Pairing Confirm command to the responding device. If the initiating device wants to abort pairing it can transmit a Pairing Failed command instead.

The responding device sends the Pairing Confirm command after it has received a Pairing Confirm command from the initiating device.

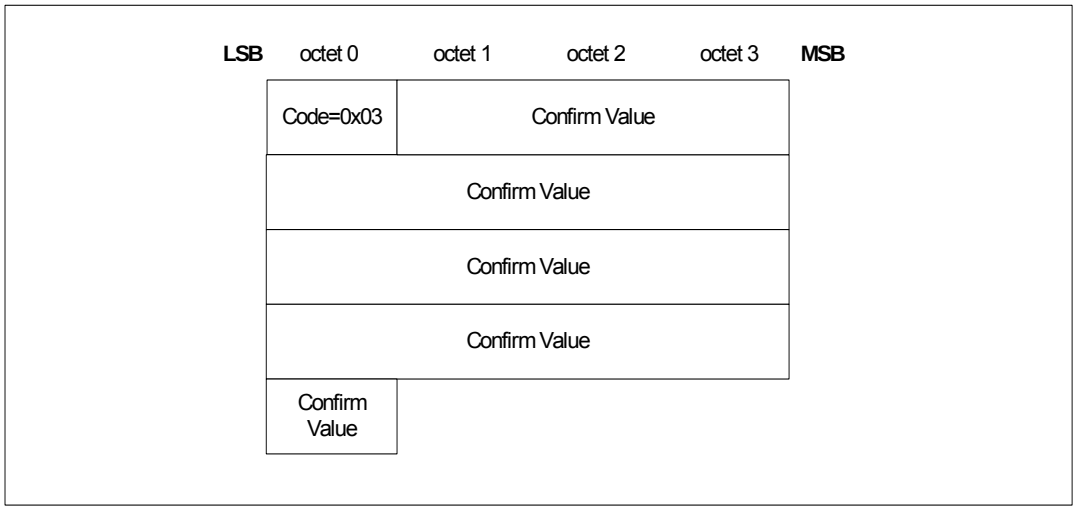

Figure 3.5: Pairing Confirm Packet

The following data field is used:

- *Confirm value (16 octets)*

  In LE legacy pairing, the initiating device sends *Mconfirm* and the responding device sends *Sconfirm* as defined in Section 2.3.5.5.
  In LE Secure Connections, Ca and Cb are defined in Section 2.2.6.

3.5.4 Pairing Random

This command is used by the initiating and responding device to send the random number used to calculate the Confirm value sent in the Pairing Confirm command. The Pairing Random command is defined in Figure 3.6.

The initiating device sends a Pairing Random command after it has received a Pairing Confirm command from the responding device.

In LE legacy pairing, the responding device shall send a Pairing Random command after it has received a Pairing Random command from the initiating device if the Confirm value calculated on the responding device matches the Confirm value received from the initiating device. If the calculated Confirm value does not match then the responding device shall respond with the Pairing Failed command.

In LE Secure Connections, the responding device shall send a Pairing Random command after it has received a Pairing Random command from the initiating device. If the calculated Confirm value does not match then the responding device shall respond with the Pairing Failed command.

The initiating device shall encrypt the link using the generated key (STK in LE legacy pairing or LTK in LE Secure Connections) if the Confirm value calculated on the initiating device matches the Confirm value received from the responding device. The successful encryption or re-encryption of the link is the signal to the responding device that key generation has completed successfully. If the calculated Confirm value does not match then the initiating device shall respond with the Pairing Failed command.

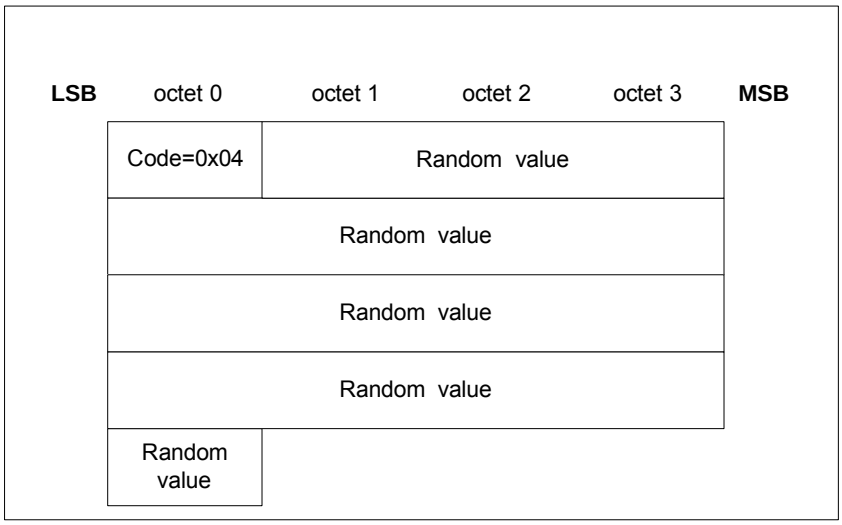

Figure 3.6: Pairing Random Packet

The following are the data fields:

- *Random value (16 octets)*

  In LE legacy pairing, the initiating device sends *Mrand* and the responding device sends *Srand* as defined in Section 2.3.5.5.
  In LE Secure Connections, the initiating device sends Na and the responding device sends Nb.

3.5.5 Pairing Failed

This is used when there has been a failure during pairing and reports that the pairing procedure has been stopped and no further communication for the current pairing procedure is to occur. The Pairing Failed command is defined in Figure 3.7.

Any subsequent pairing procedure shall restart from the Pairing Feature Exchange phase.

This command may be sent at any time during the pairing process by either device in response to a message from the remote device.

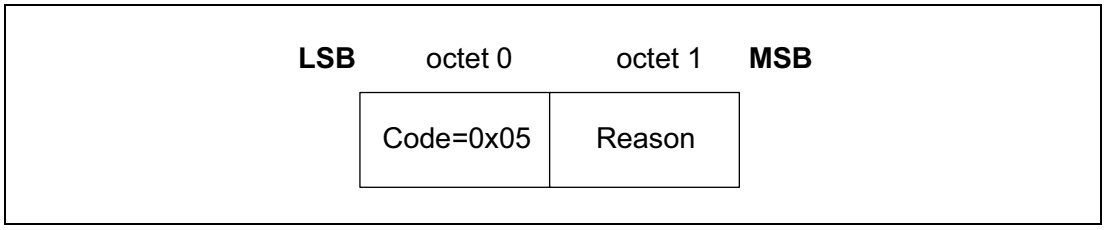

Figure 3.7: Pairing Failed Packet

The following data field is used:

- *Reason (1 octets)*

The Reason field indicates why the pairing failed. The reason codes are defined in Table 3.7.

Value	Name	Description
0x00		Reserved for future use
0x01	Passkey Entry Failed	The user input of passkey failed, for example, the user cancelled the operation
0x02	OOB Not Available	The OOB data is not available
0x03	Authentication Requirements	The pairing procedure cannot be performed as authentication requirements cannot be met due to IO capabilities of one or both devices
0x04	Confirm Value Failed	The confirm value does not match the calculated compare value
0x05	Pairing Not Supported	Pairing is not supported by the device
0x06	Encryption Key Size	The resultant encryption key size is insufficient for the security requirements of this device
0x07	Command Not Supported	The SMP command received is not supported on this device

Table 3.7: Pairing Failed Reason Codes

Value	Name	Description
0x08	Unspecified Reason	Pairing failed due to an unspecified reason
0x09	Repeated Attempts	Pairing or authentication procedure is disallowed because too little time has elapsed since last pairing request or security request
0x0A	Invalid Parameters	The Invalid Parameters error code indicates that the command length is invalid or that a parameter is outside of the specified range.
0x0B	DHKey Check Failed	Indicates to the remote device that the DHKey Check value received doesn't match the one calculated by the local device.
0x0C	Numeric Comparison Failed	Indicates that the confirm values in the numeric comparison protocol do not match.
0x0D	BR/EDR pairing in progress	Indicates that the pairing over the LE transport failed due to a Pairing Request sent over the BR/EDR transport in progress.
0x0E	Cross-transport Key Derivation/Generation not allowed	Indicates that the BR/EDR Link Key generated on the BR/EDR transport cannot be used to derive and distribute keys for the LE transport.
0x0F - 0xFF		Reserved for future use

Table 3.7: Pairing Failed Reason Codes

3.5.6 Pairing Public Key

This message is used to transfer the device's local public key (X and Y co-ordinates) to the remote device. This message is used by both the initiator and responder. This PDU is only used for Secure Connections.

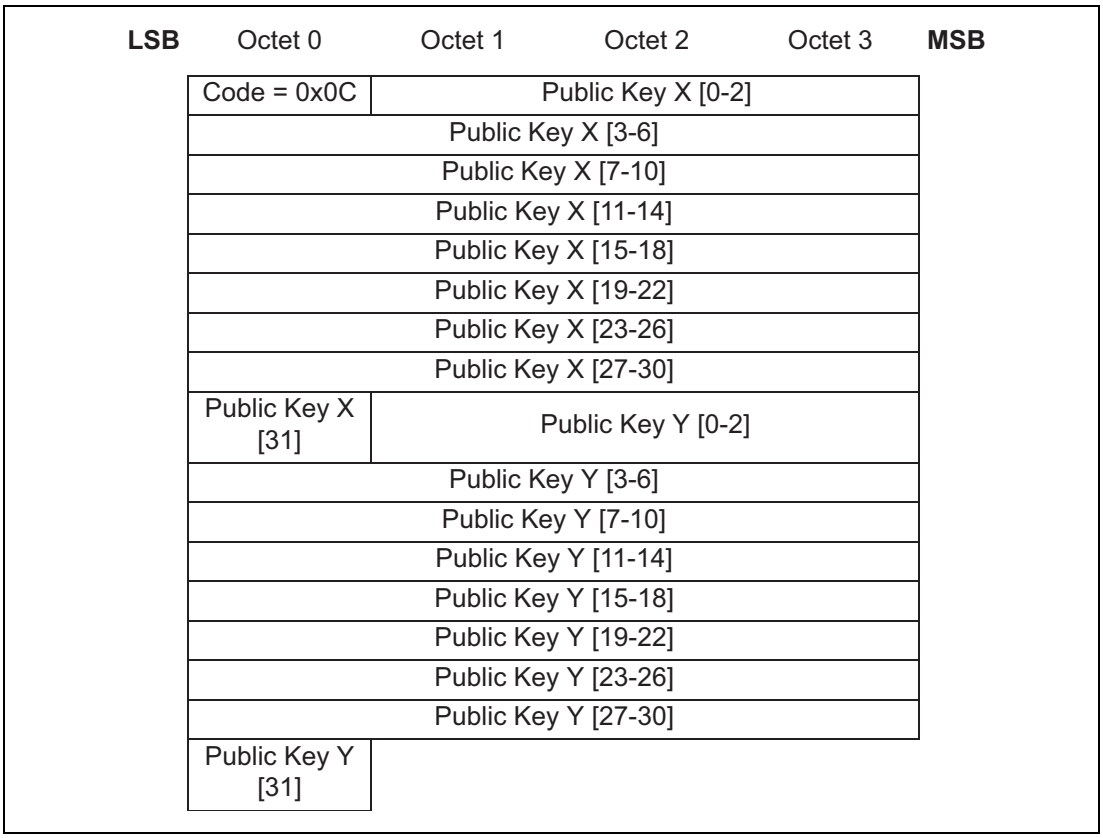

Figure 3.8: Pairing Public Key PDU

3.5.7 Pairing DHKey Check

This message is used to transmit the 128-bit DHKey Check values (Ea/Eb) generated using f6. This message is used by both initiator and responder. This PDU is only used for LE Secure Connections.

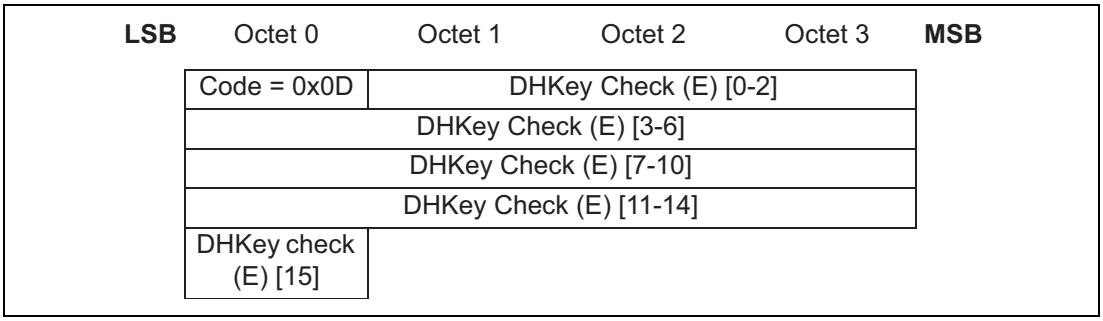

Figure 3.9: Pairing DHKey Check PDU

3.5.8 Keypress Notification

This message is used during the Passkey Entry protocol by a device with KeyboardOnly IO capabilities to inform the remote device when keys have been entered or erased.

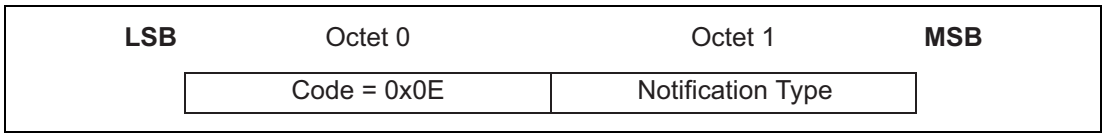

Figure 3.10: Pairing Keypress Notification PDU

Notification Type can take one of the following values:

Value	Parameter Description
0	Passkey entry started
1	Passkey digit entered
2	Passkey digit erased
3	Passkey cleared
4	Passkey entry completed
5-255	Reserved for future use

Table 3.8: Notification Type

3.6 SECURITY IN BLUETOOTH LOW ENERGY

3.6.1 Key Distribution and Generation

Bluetooth low energy devices can distribute keys from the slave to the master and from the master to the slave device. When using LE legacy pairing, the following keys may be distributed from the slave to the master:

- LTK using Encryption Information command
- EDIV and Rand using Master Identification command
- IRK using Identity Information command
- Public device or static random address using Identity Address Information command
- CSRK using Signing Information command

When using LE Secure Connections, the following keys may be distributed from the slave to the master:

- IRK using Identity Information command
- Public device or static random address using Identity Address Information command
- CSRK using Signing Information command

When using LE legacy pairing, the master may distribute to the slave the following key:

- LTK using Encryption Information command
- EDIV and Rand using Master Identification command
- IRK using Identity Information command
- Public device or static random address using Identity Address Information command
- CSRK using Signing Information command

When using LE Secure Connections, the master may distribute to the slave the following key:

- IRK using Identity Information command
- Public device or static random address using Identity Address Information command
- CSRK using Signing Information command

The keys which are to be distributed in the Transport Specific Key Distribution phase are indicated in the Key Distribution field of the Pairing Request and Pairing Response commands see Section 3.5.1 and Section 3.5.2.

The format of the Initiator Key Distribution / Generation field and Responder Key Distribution / Generation field in the Pairing Request and Pairing Response commands for LE is defined in Figure 3.11.

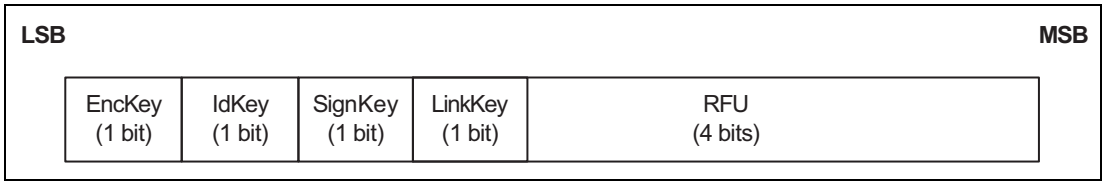

Figure 3.11: LE Key Distribution Format

The Key Distribution / Generation field has the following flags:

- In LE legacy pairing, EncKey is a 1-bit field that is set to one to indicate that the device shall distribute LTK using the Encryption Information command followed by EDIV and Rand using the Master Identification command.

  In LE Secure Connections pairing, when SMP is running on the LE transport, then the EncKey field is ignored. EDIV and Rand shall be set to zero and shall not be distributed.

  When SMP is running on the BR/EDR transport, the EncKey field is set to one to indicate that the device would like to derive the LTK from the BR/EDR Link Key. When EncKey is set to 1 by both devices in the initiator and responder Key Distribution / Generation fields, the procedures for calculating the LTK from the BR/EDR Link Key shall be used.
- IdKey is a 1-bit field that is set to one to indicate that the device shall distribute IRK using the Identity Information command followed by its public device or static random address using Identity Address Information.
- SignKey is a 1-bit field that is set to one to indicate that the device shall distribute CSRK using the Signing Information command.
- LinkKey is a 1-bit field. When SMP is running on the LE transport, the LinkKey field is set to one to indicate that the device would like to derive the Link Key from the LTK. When LinkKey is set to 1 by both devices in the initiator and responder Key Distribution / Generation fields, the procedures for calculating the BR/EDR link key from the LTK shall be used. Devices not supporting LE Secure Connections shall set this bit to zero and ignore it on reception. When SMP is running on the BR/EDR transport, the LinkKey field is reserved for future use.

The Initiator Key Distribution / Generation field in the Pairing Request command is used by the master to request which keys are distributed or generated by the initiator to the responder. The Responder Key Distribution / Generation field in the Pairing Request command is used by the master to request which keys are distributed or generated by the responder to the initiator. The Initiator Key Distribution / Generation field in the Pairing Response command from the slave defines the keys that shall be distributed or generated by the initiator to the responder. The Responder Key Distribution / Generation field in the Pairing Response command from the slave defines the

keys that shall be distributed or generated by the responder to the initiator. The slave shall not set to one any flag in the Initiator Key Distribution / Generation or Responder Key Distribution / Generation field of the Pairing Response command that the master has set to zero in the Initiator Key Distribution / Generation and Responder Key Distribution / Generation fields of the Pairing Request command.

When using LE legacy pairing, the keys shall be distributed in the following order:

1. LTK by the slave
2. EDIV and Rand by the slave
3. IRK by the slave
4. BD ADDR by the slave
5. CSRK by the slave
6. LTK by the master
7. EDIV and Rand by the master
8. IRK by the master
9. BD_ADDR by the master
10. CSRK by the master

When using LE Secure Connections, the keys shall be distributed in the following order:

1. IRK by the slave
2. BD ADDR by the slave
3. CSRK by the slave
4. IRK by the master
5. BD_ADDR by the master
6. CSRK by the master

If a key is not being distributed then the command to distribute that key shall not be sent.

Note: If a key is not distributed, then the capabilities that use this key will not be available. For example, if a LTK is not distributed from the slave to the master, then the master cannot encrypt a future link with that slave, therefore pairing would have to be performed again.

Note: The initiator should determine the keys needed based on the capabilities that are required by higher layer specifications. For example, if the initiator determines that encryption is required in a future link with that slave, then the initiator must request that slave's LTK is distributed by setting the EncKey bit to one in the Responder Key Distribution / Generation field of the Pairing Request command.

If EncKey, IdKey, and SignKey are set to zero in the Initiator Key Distribution / Generation and Responder Key Distribution / Generation fields, then no keys shall be distributed or generated and the link will be encrypted using the generated STK when using LE legacy pairing and LTK when using LE Secure Connections pairing.

Key distribution is complete in the device sending the final key when it receives the baseband acknowledgment for that key and is complete in the receiving device when it receives the final key being distributed.

3.6.2 Encryption Information

Encryption Information is used in the LE legacy pairing Transport Specific Key Distribution to distribute LTK that is used when encrypting future connections. The Encryption Information command is defined in Figure 3.12.

The Encryption Information command shall only be sent when the link has been encrypted or re-encrypted using the generated STK.

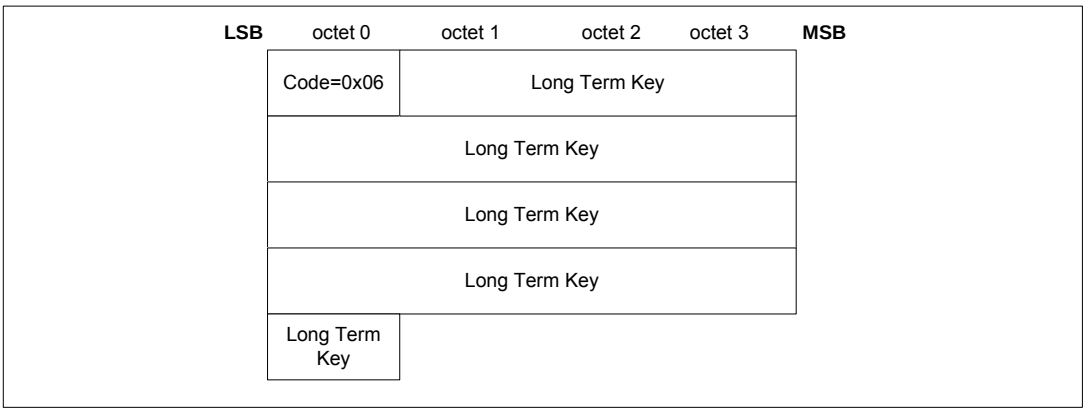

Figure 3.12: Encryption Information Packet

The following is the data field:

- *Long Term Key (16 octets)*

  The generated LTK value being distributed, see Section 2.4.2.3.

3.6.3 Master Identification

Master Identification is used in the LE legacy pairing Transport Specific Key Distribution phase to distribute EDIV and Rand which are used when encrypting future connections. The Master Identification command is defined in Figure 3.13.

The Master Identification command shall only be sent when the link has been encrypted or re-encrypted using the generated STK.

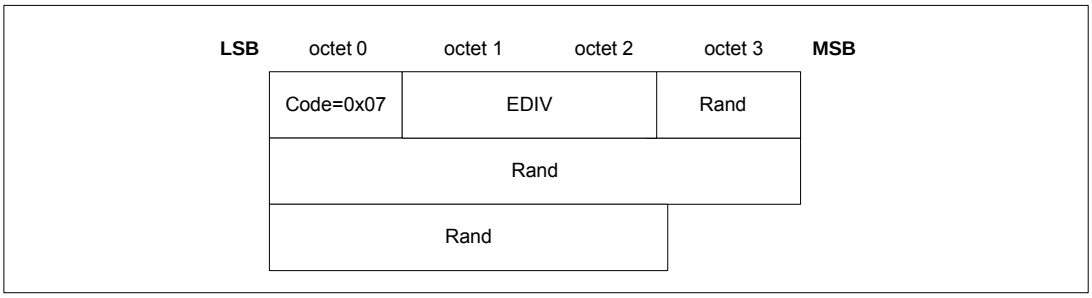

Figure 3.13: Master Identification Packet

The following data fields are used:

- *EDIV (2 octets)*
  The EDIV value being distributed (see Section 2.4.2.3).
- *Rand (8 octets)*
  64-bit Rand value being distributed (see Section 2.4.2.3).

3.6.4 Identity Information

Identity Information is used in the Transport Specific Key Distribution phase to distribute the IRK. The Identity Information command is defined in Figure 3.14.

The Identity Information command shall only be sent when the link has been encrypted or re-encrypted using the generated key.

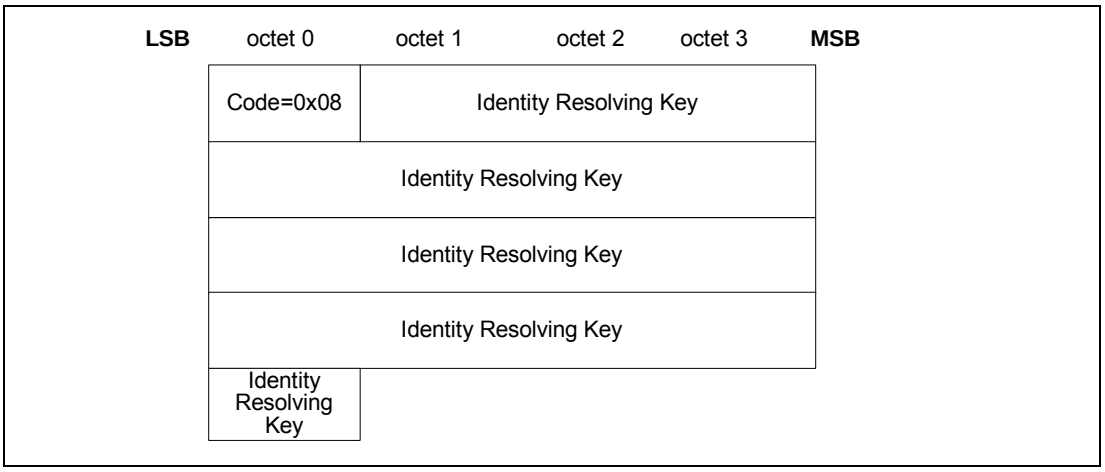

Figure 3.14: Identity Information Packet

The following are the data fields:

- *Identity Resolving Key (16 octets)*
  128-bit IRK value being distributed (see Section 2.4.2.1).

Note: An all zero Identity Resolving Key data field indicates that a device does not have a valid resolvable private address.

3.6.5 Identity Address Information

Identity Address Information is used in the Transport Specific Key Distribution phase to distribute its public device address or static random address. The Identity Address Information command is defined in Figure 3.15.

The Identity Address Information command shall only be sent when the link has been encrypted or re-encrypted using the generated key.

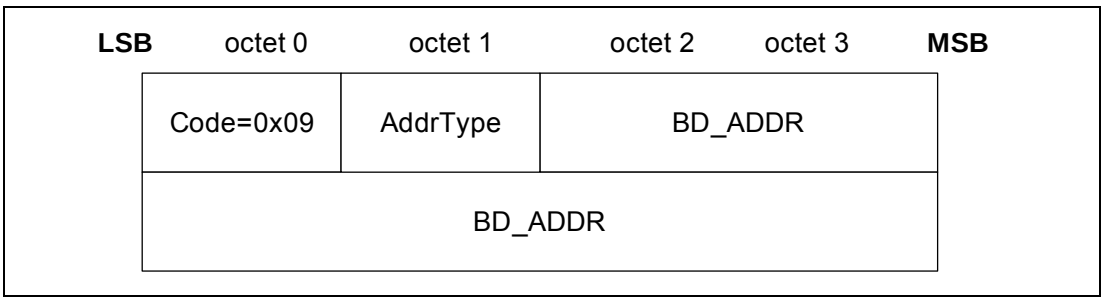

Figure 3.15: Identity Address Information Packet

The data fields are:

- *AddrType (1 octet)*

  If BD_ADDR is a public device address, then AddrType shall be set to 0x00. If BD_ADDR is a static random device address then AddrType shall be set to 0x01.

- *BD_ADDR (6 octets)*

  This field is set to the distributing device's public device address or static random address.

3.6.6 Signing Information

Signing Information is used in the Transport Specific Key Distribution to distribute the CSRK which a device uses to sign data. The Signing Information command is defined in Figure 3.16.

The Signing Information command shall only be sent when the link has been encrypted or re-encrypted using the generated key.

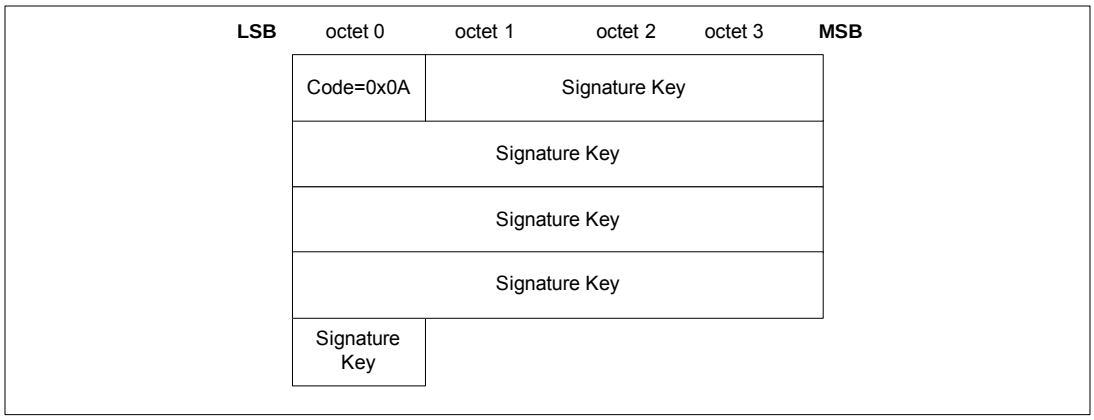

Figure 3.16: Signing Information Packet

The following data field is used:

- *Signature Key (16 octets)*
  128-bit CSRK that is being distributed; see Section 2.4.2.2.

3.6.7 Security Request

The Security Request command is used by the slave to request that the master initiates security with the requested security properties, see Section 2.4.6. The Security Request command is defined in Figure 3.17.

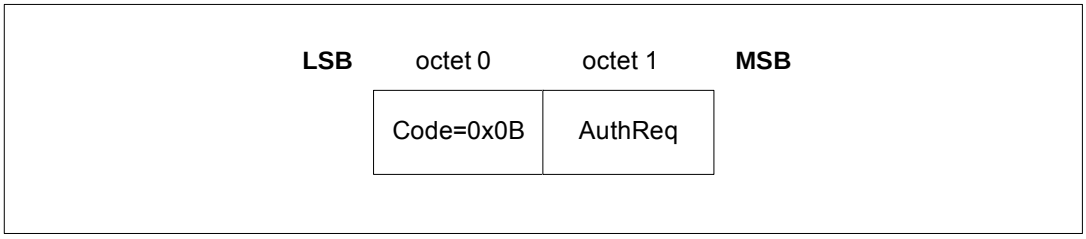

Figure 3.17: Security Request Packet

The following data field is used:

- *AuthReq (1 octet)*

  The AuthReq field is a bit field that indicates the requested security properties (see Section 2.3.1) for the STK or LTK and GAP bonding information (see [Vol 3] Part C, Section 9.4).

  Figure 3.3 defines the authentication requirements bit field.

  The Bonding_Flags field is a 2-bit field that indicates the type of bonding being requested by the responding device as defined in Table 3.6.

  The MITM field is a 1-bit flag that is set to one if the device is requesting MITM protection, otherwise it shall be set to 0. A device sets the MITM flag to one to request an Authenticated security property for the STK when using LE legacy pairing and the LTK when using LE Secure Connections.

  The SC field is a 1 bit flag. If LE Secure Connections pairing is supported by the device, then the SC field shall be set to 1, otherwise it shall be set to 0. If both devices support LE Secure Connections pairing, then LE Secure Connections pairing shall be used, otherwise LE Legacy pairing shall be used.

  The keypress field is a 1-bit flag that is used only in the Passkey Entry protocol and is ignored in other protocols. When both sides set that field to one, Keypress notifications shall be generated and sent using SMP Pairing Keypress Notification PDUs.

APPENDIX A EDIV AND RAND GENERATION

EDIV and Rand are used by the responding device to identify an initiator and recover LTK. This section provides an example of how the distributed EDIV value is a masked version of the real value (DIV) which is used to recover LTK. Other methods can be used that provide equal or higher levels of confidentially for DIV.

A.1 EDIV MASKING

The masking process uses a Diversifier Hiding Key (DHK) which is a 128-bit key that is never distributed.

DHK can be assigned, randomly generated by the device during manufacturing, part of a key hierarchy (see Appendix B, Section B.2.3) or some other method could be used, that results in DHK having 128 bits of entropy. If DHK is randomly generated then the requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used.

If DHK is changed then DIV values cannot be recovered from previously distributed EDIV values.

Section A.1.1 defines a cryptographic function that is used by the responding device when generating EDIV and recovering DIV.

Section A.1.2 describes how a responding device generates an EDIV value to be distributed to an initiating device and Section A.1.3 describes how the responding device recovers DIV from a distributed EDIV value.

A.1.1 DIV Mask generation function dm

DIV is masked before distribution and unmasked during the encryption session setup using the output of the DIV mask generation function *dm*.

The following are inputs to the DIV mask generation function *dm*:

k is 128 bits

r is 64 bits

padding is 64 bits

r is concatenated with padding to generate *r'* which is used as the 128-bit input parameter *plaintextData* to security function *e*:

r' = padding || r

The least significant octet of *r* becomes the least significant octet of *r'* and the most significant octet of *padding* becomes the most significant octet of *r'*.

For example, if the 64-bit value *r* is 0x123456789ABCDEF0 then *r'* is 0x0000000000000000123456789ABCDEF0.

The output of the DIV mask generation function *dm* is

$$dm(k, r) = e(k, r') \bmod 2^{16}$$

The output of the security function e is then truncated to 16 bits by taking the least significant 16 bits of the output of *e* as the result of *dm*.

A.1.2 EDIV Generation

The responding device generates a 64-bit random value, *Rand.* The *Rand* value is used to generate 16-bit Y using the DIV mask generation function *dm* with the input parameter *k* set to DHK and the input parameter *r* set to *Rand*.

$$Y = dm(DHK, Rand)$$

The responding device then masks the DIV value to be distributed by bitwise XORing it with Y to generate EDIV.

$$EDIV = Y \text{ xor } DIV$$

EDIV and Rand are distributed to an initiating device during the transport specific key distribution phase using the Master Identification command.

A.1.3 DIV Recovery

When the responding device receives a request to encrypt a session it calculates Y using the DIV mask generation function *dm* with the input parameter *k* set to DHK and the input parameter *r* set to *Rand.* The Y value is bitwise XORed with *EDIV* from the initiator to recover DIV.

$$DIV = Y \text{ xor } EDIV$$

The recovered DIV value can then used to recover LTK which is used to enable encryption on the link.

APPENDIX B KEY MANAGEMENT

The security provided by different methods can vary and care should be taken to ensure that a chosen method is suitable for a device's requirements.

Section B.1 uses a database for managing the keys. Section B.2 uses a key hierarchy to manage the keys.

B.1 DATABASE LOOKUP

The LTK which is distributed is a 128-bit random number which is stored in a database, using EDIV as an index. There is no direct relationship between LTK and EDIV.

The requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used when generating LTK. This method provides an LTK with 128 bits of entropy.

CSRK, IRK, and other keys shall also be stored in the database. There is no relationship between the keys stored in the database or distributed LTKs, EDIVs, or Rands.

If the example EDIV and Rand generation method described inAppendix A, Section A.1 is used then the database shall be used to store DHK. DIV should be used as the index to recover LTK.

B.2 KEY HIERARCHY

A key hierarchy can be used to generate the keys.

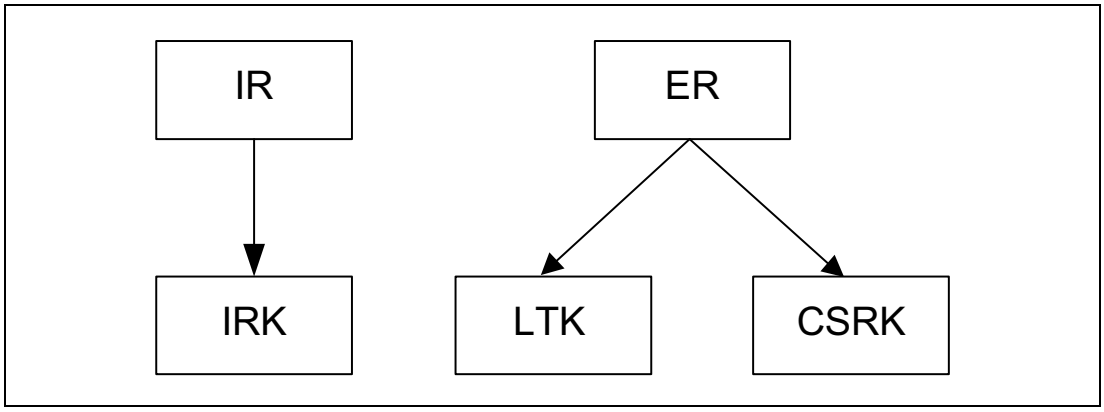

Figure B.1: Example Key Hierarchy

Figure B.1 is an example key hierarchy where LTK and CSRK are generated from a common ER key, and IRK is generated from a common IR key.

1. ER is a 128-bit key generated for each LE device that supports encrypted connections. It is used to generate LTK using EDIV; see Section B.2.2.
2. IR is a 128-bit key generated for each LE device that supports encrypted connections, uses random addresses or signing data. IR is used to generate IRK and CSRK, see Section B.2.3. It can also be used to generate DHK; see Appendix A.

New LTK, EDIV, Rand, and CSRK values shall be generated each time they are distributed. If ER is changed then any previously distributed LTK or CSRK keys will no longer be valid.

The distributed IRK shall be the same for all devices it is distributed to. If IR is changed then any previously distributed IRK keys will no longer be valid.

The distributing device only needs to store IR and ER. LTK, IRK, and CSRK can be regenerated when they are required. This reduces the storage requirements on the distributing device.

Appendix B.2.1 defines an example of the key diversifying function which can be used to generate LTK, IRK, CSRK, and other keys. Other implementations of this function can be used depending upon the exact security requirements of the device.

The NIST Special Publication 800-108 (http://csrc.nist.gov/publications/PubsSPs.html) defines key derivation functions which could be used instead of the example diversifying function *d1*.

B.2.1 Diversifying function d1

Diversified keys are generated with function *d1*. The diversifying function *d1* makes use of the security function *e*.

The following are inputs to diversifying function *d1*:

k is 128 bits

d is 16 bits

r is 16 bits

padding is 96 bits

d is concatenated with *r* and *padding* to generate *d',* which is used as the 128-bit input parameter *plaintextData* to security function *e*:

d' = padding || r || d

The least significant octet of *d* becomes the least significant octet of *d'* and the most significant octet of *padding* becomes the most significant octet of *d'*.

For example, if the 16-bit value *d* is 0x1234 and the 16-bit value *r* is 0xabcd, then *d'* is 0x000000000000000000000000abcd1234.

The output diversifying function *d1* is:

d1(k, d, r) = e(k, d')

The 128-bit output of the security function *e* is used as the result of diversifying function *d1*.

B.2.2 Generating Keys from ER

ER is used to generate LTK and CSRK. ER can be assigned, randomly generated by the device during manufacturing or some other method could be used, that results in ER having 128 bits of entropy. If ER is randomly generated then the requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used.

The EDIV and Rand generation method described in Appendix A shall be used. LTK is the result of the diversifying function *d1* with the ER as the input parameter *k*, the DIV as the input parameter *d*, and the value 0 as the input parameter *r*; see Section B.2.1.

LTK = *d1*(ER, DIV, 0)

LTK can be recovered from ER and DIV by repeating the calculation when LTK is required.

CSRK is the result of the diversifying function *d1* with the ER as the input parameter *k*, the DIV as the input parameter *d*, and the value 1 as the input parameter *r*; see Section B.2.1.

CSRK = *d1*(ER, DIV, 1)

CSRK can be recovered from ER and DIV by repeating the calculation when CSRK is required.

This method provides an LTK and CSRK with limited amount of entropy because LTK and CSRK are directly related to EDIV and may be less secure than other generation methods.

To reduce the probability of the same LTK or CSRK value being generated, the DIV values must be unique for each CSRK, LTK, EDIV, and Rand set that is distributed.

A method for preventing a malicious device from repeatedly pairing and collecting CSRK, LTK and DIV information, which could be used in a known plain text attack in ER, should be implemented.

Note: The generation of LTK using ER is only applicable when doing LE Legacy Pairing. The generation of CSRK using ER is applicable both when doing LE Legacy Pairing and LE Secure Connections Pairing.

B.2.3 Generating Keys from IR

IR can be used to generate IRK and other required keys. IR can be assigned, randomly generated by the device during manufacturing or some other method could be used, that results in IR having 128 bits of entropy. If IR is randomly generated then the requirements for random generation defined in [Vol 2] Part H, Section 2 shall be used.

IRK is the result of the diversifying function *d1* with IR as the input parameter *k* and the value 1 as the input parameter *d* and the value 0 as the input parameter r; see Section B.2.1.

IRK = *d1*(IR, 1, 0)

If the example EDIV and Rand generation method described in Appendix A, Section A.1 is used then DHK can be the result of diversifying function *d1* with IR as the input parameter *k* and the value 3 as the input parameter *d* and the value 0 as the input parameter r.

DHK = *d1*(IR, 3, 0)

Other keys can be generated by using different values for *k* as the input to the diversifying function *d1*. If the value of *k* is reused for a given IR then the resulting key will be the same.

Note: The generation of DHK using IR is only applicable when doing LE Legacy Pairing. The generation of IRK using IR is applicable both when doing LE Legacy Pairing and LE Secure Connections Pairing.

APPENDIX C MESSAGE SEQUENCE CHARTS

This section is informative and illustrates only the most common scenarios; it does not cover all possible alternatives. Furthermore, the message sequence charts do not consider errors over the air interface or Host interface.

A flow diagram of pairing is shown in Figure C.1. The process has 4 steps. Step 2 has a number of different options.

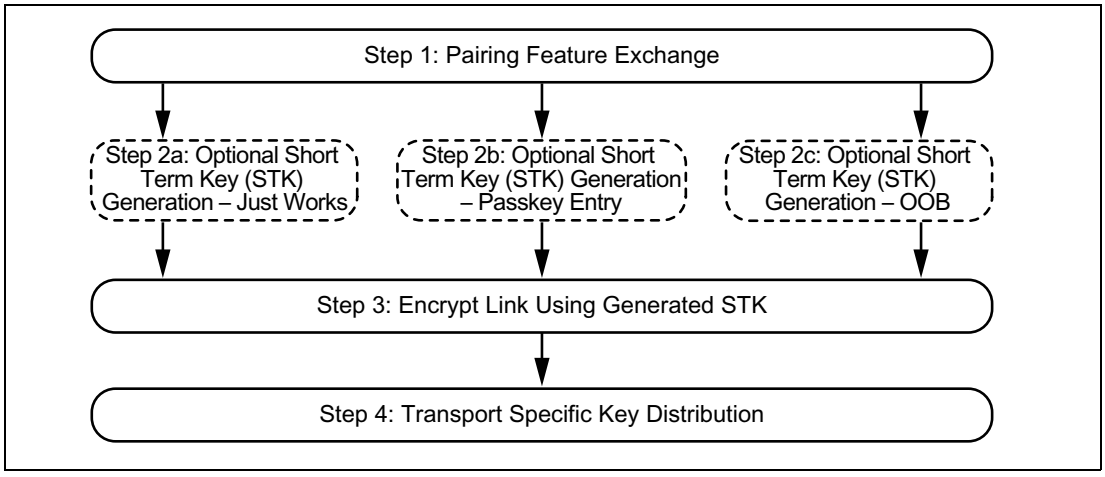

Figure C.1: Pairing Process Overview

Note: In all the MSCs, the Master device is also the Initiating Device and the Slave device is also the Responding (non-Initiating) Device.

C.1 PHASE 1: PAIRING FEATURE EXCHANGE

The master initiates the pairing procedure using Pairing Request command as shown in Figure C.2.

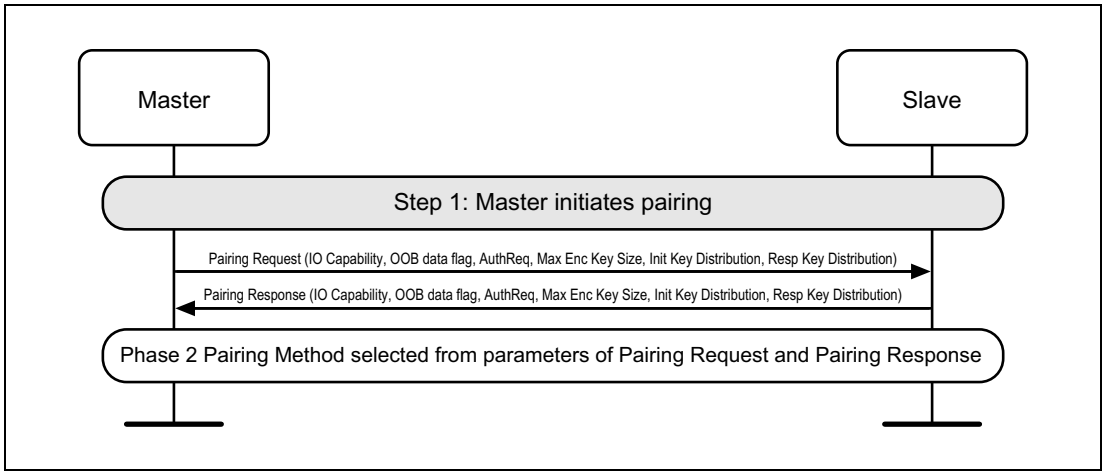

Figure C.2: Pairing initiated by master

C.1.1 Slave Security Request – Master Requests Pairing

The slave may request the master initiates security procedures. Figure C.3 shows an example where the slave requests security and the master initiates pairing in response.

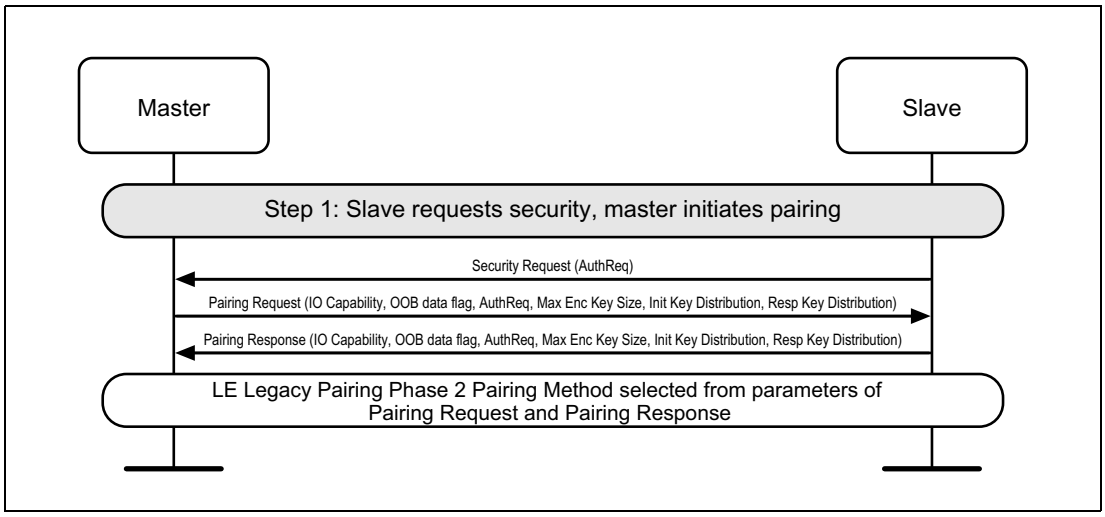

Figure C.3: Slave security request, master initiated pairing

C.2 PHASE 2: AUTHENTICATING AND ENCRYPTING

After Pairing Feature Exchange has completed a pairing method is selected one of the possible short term key generation sequences are used. This can be Just Works, Passkey Entry or Out of Band pairing method.

C.2.1 LE Legacy Pairing

The following sub-sections include message sequence charts for LE legacy pairing.

C.2.1.1 Legacy Phase 2: Short Term Key Generation – Just Works

After Pairing Feature Exchange has completed a pairing method is selected. Figure C.4 shows the Just Works pairing method.

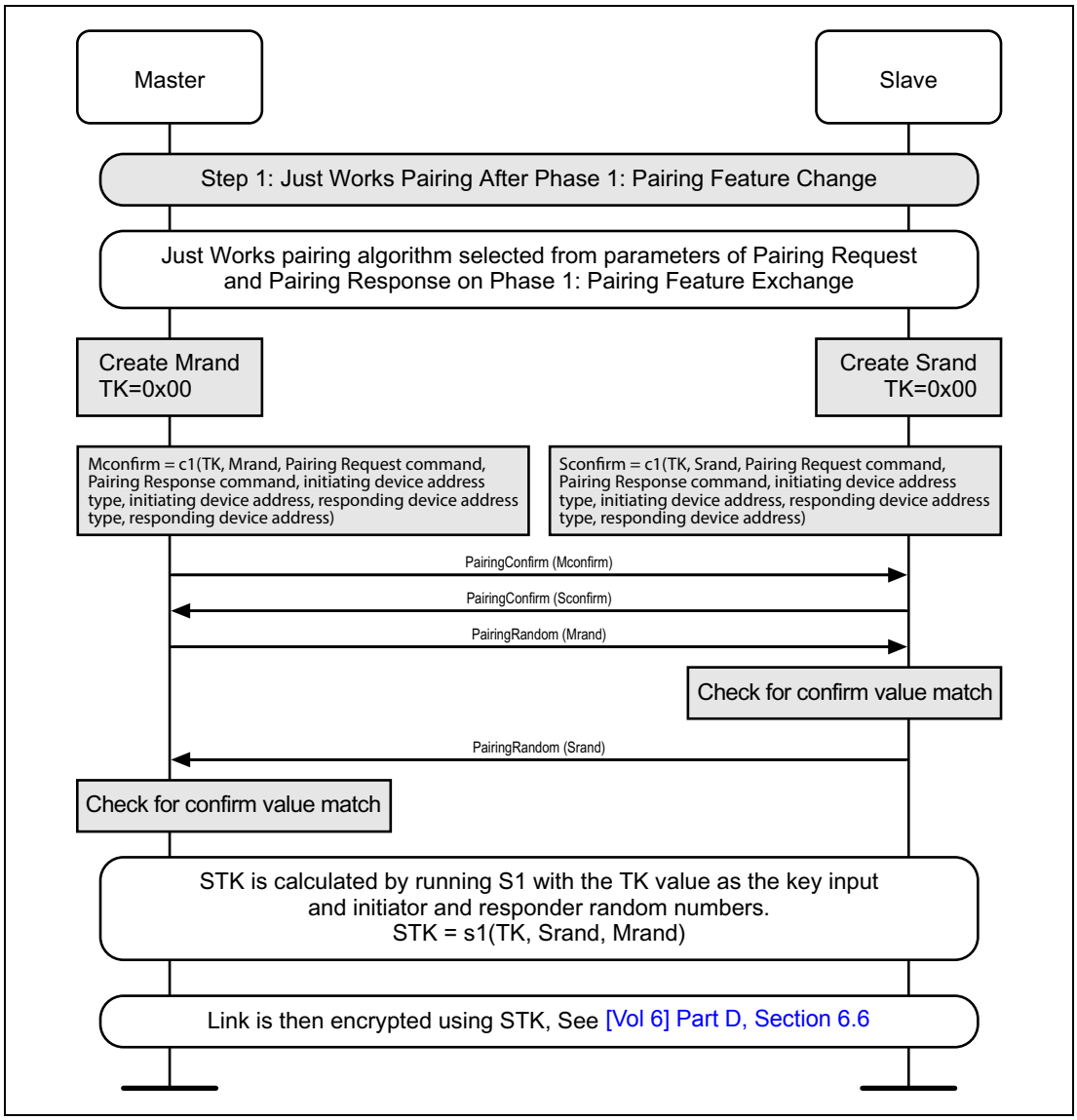

Figure C.4: Legacy Just Works Pairing Method

C.2.1.2 Legacy Phase 2: Short Term Key Generation – Passkey Entry

After Pairing Feature Exchange has completed, a pairing method is selected. Figure C.5 shows the Passkey Entry pairing method.

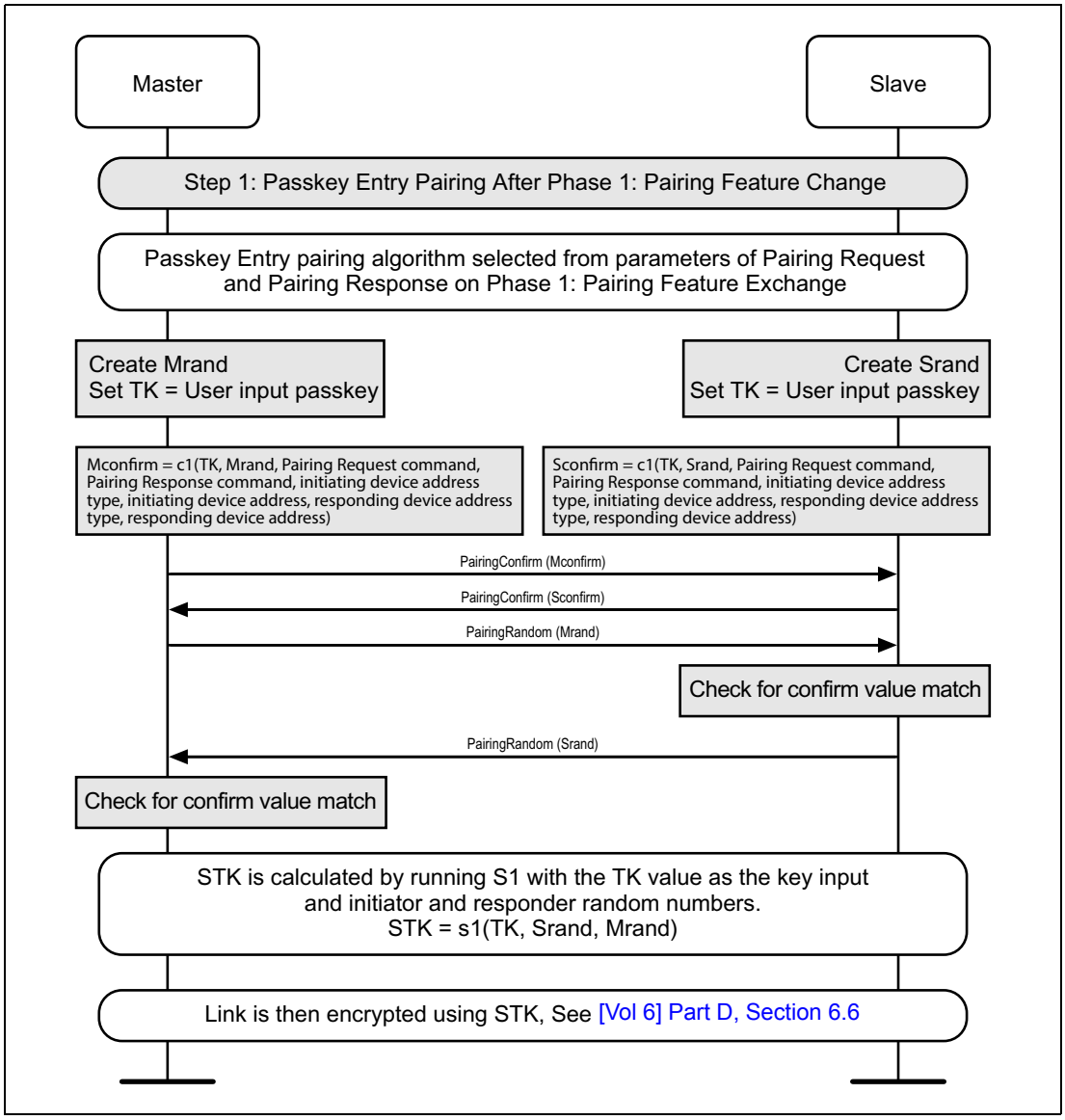

Figure C.5: Legacy Passkey Entry Pairing Method

C.2.1.3 Legacy Phase 2: Short Term Key Generation – Out of Band

After Pairing Feature Exchange has completed, a pairing method is selected. Figure C.6 shows the Out of Band pairing method.

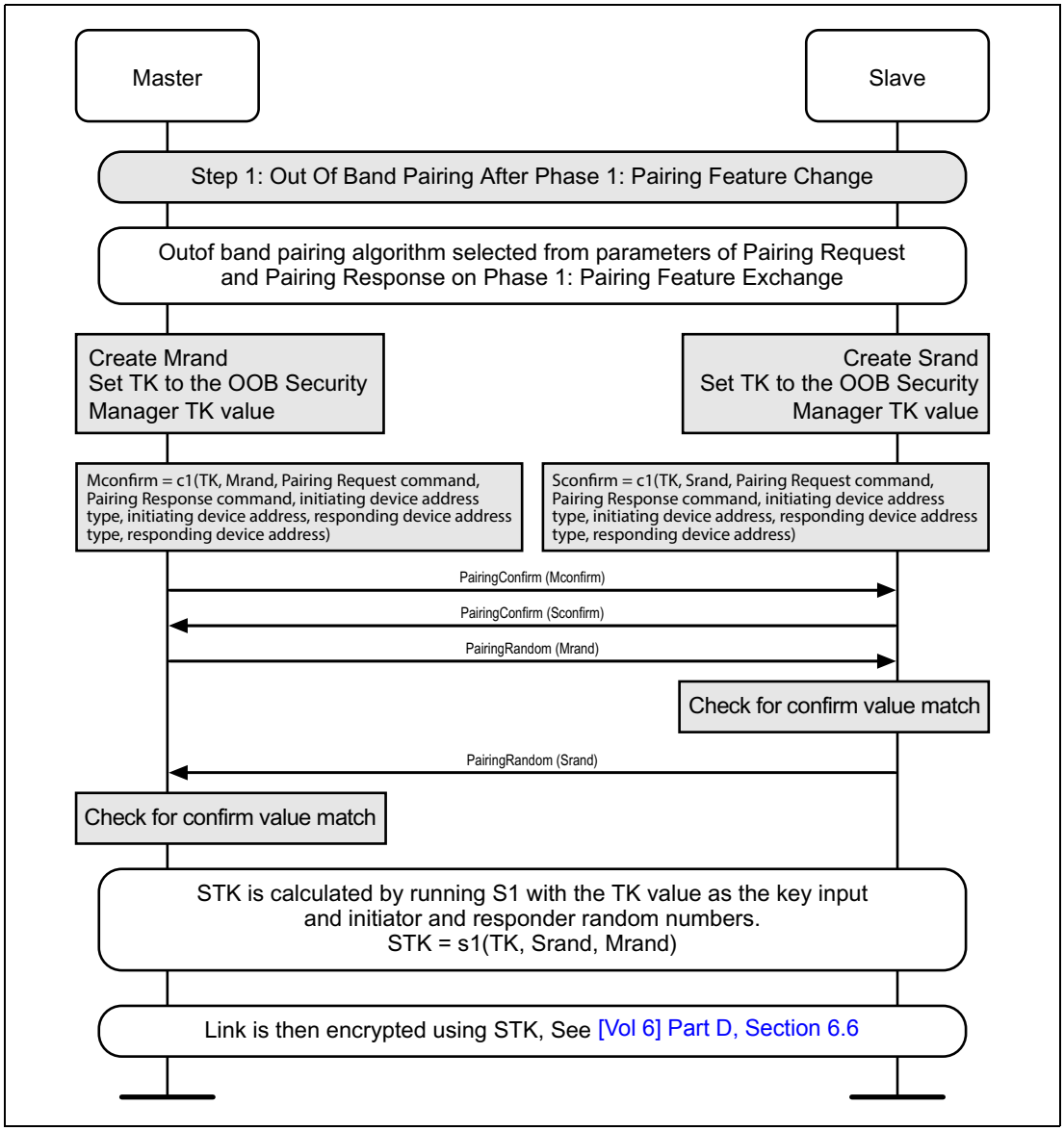

Figure C.6: Legacy OOB Pairing Method

C.2.2 LE Secure Connections

The following sub-sections include message sequence charts for LE Secure Connections.

C.2.2.1 Public Key Exchange

In Step 1a and 1b, the two devices exchange public keys. The master sends its public key to the slave followed by slave sending its public key to the master.

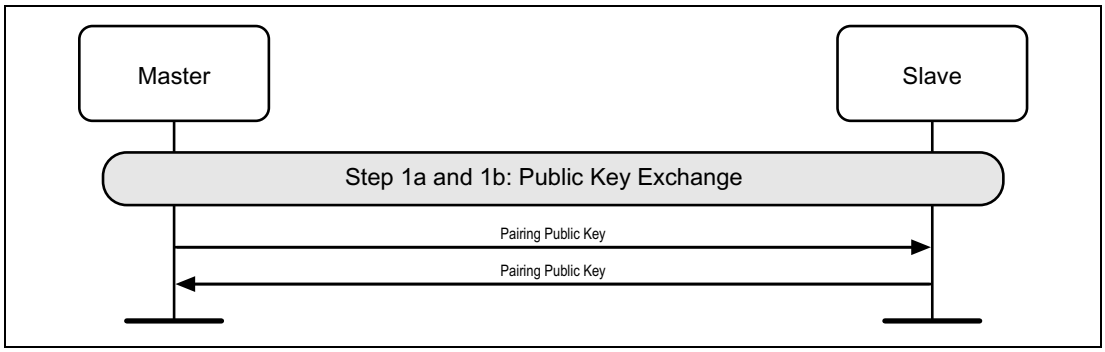

Figure C.7: Pairing Phase 2 - Public Key Exchange

C.2.2.2 Authentication Stage 1

The following sub-sections include message sequence charts for the success and failure cases in each association model.

C.2.2.2.1 Successful Numeric Comparison (or Just Works)

The numeric comparison step will be done when both devices have output capabilities, or if one of the devices has no input or output capabilities.
If both devices have output capabilities, this step requires the displaying of a user confirmation value. This value should be displayed until the end of step 2.
If one or both devices do not have output capabilities, the same protocol is used but the Hosts will skip the step asking for the user confirmation.

Note: The sequence for Just Works is identical to that of Numeric Comparison with the exception that the Host will not show the numbers to the user.

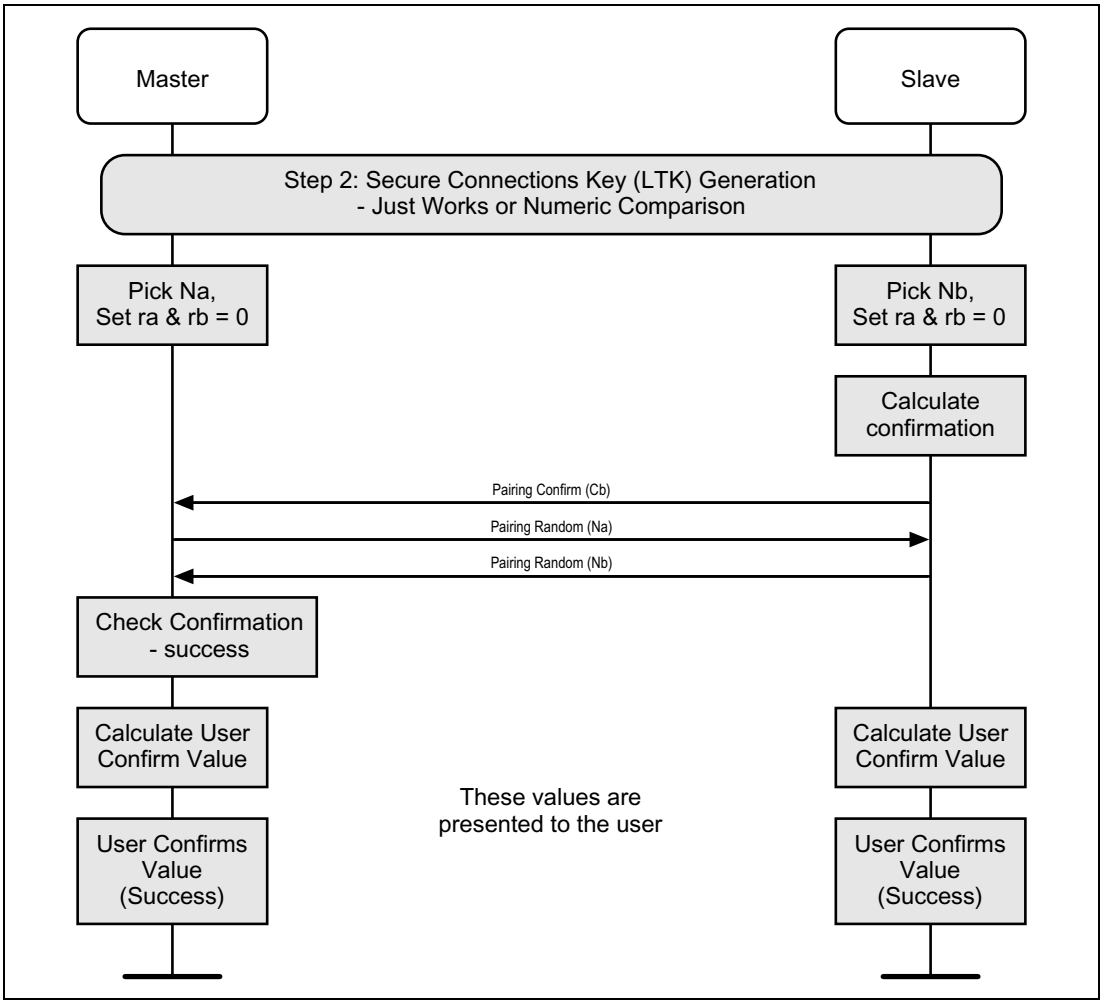

Figure C.8: Pairing Phase 2, Authentication Stage 1, Successful Numeric Comparison

C.2.2.2.2 Numeric Comparison – Confirm Check failure on the Initiator side

If the Confirm value calculated by the Initiator is not equal to the Commitment value received from the Responder, the Initiator will abort Pairing process by sending Pairing Failed with reason “Confirm Value Failed”.

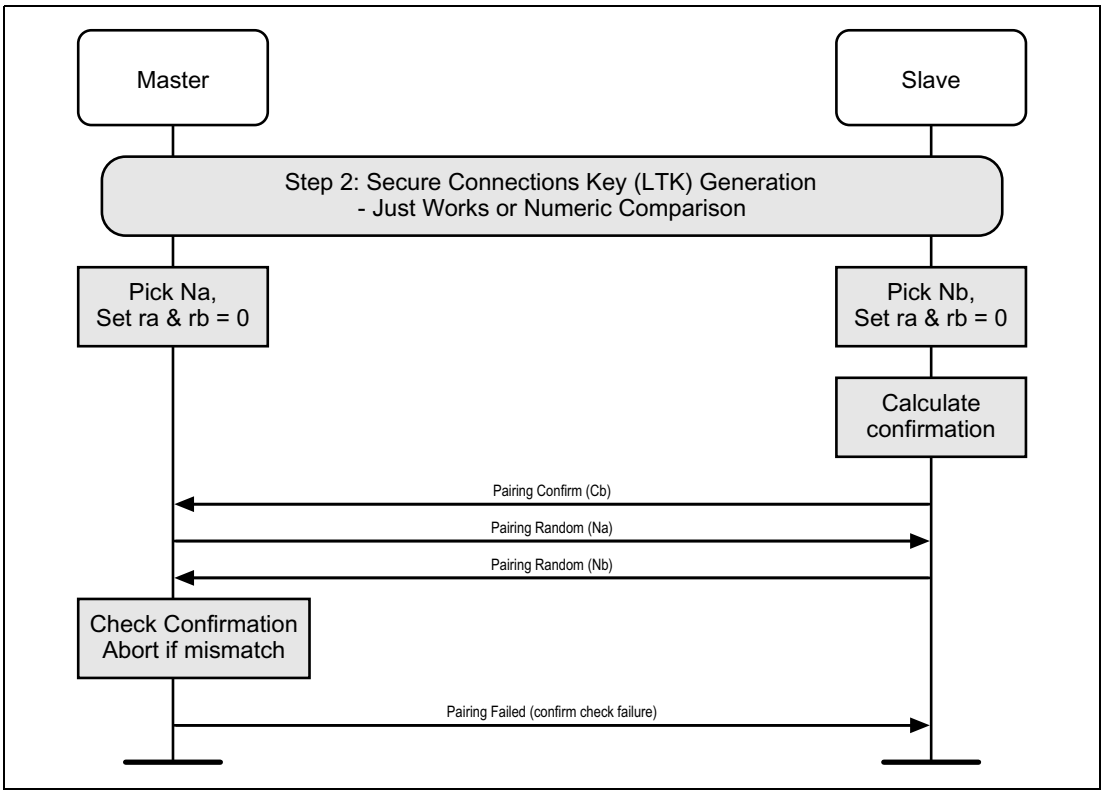

Figure C.9: Pairing Phase 2, Authentication Stage 1, Numeric Comparison – Confirm Check failure on Initiator side

C.2.2.2.3 Numeric Comparison Failure on Initiator Side

If the numeric comparison fails on the initiating side due to the user indicating that the confirmation values do not match, Pairing is terminated.

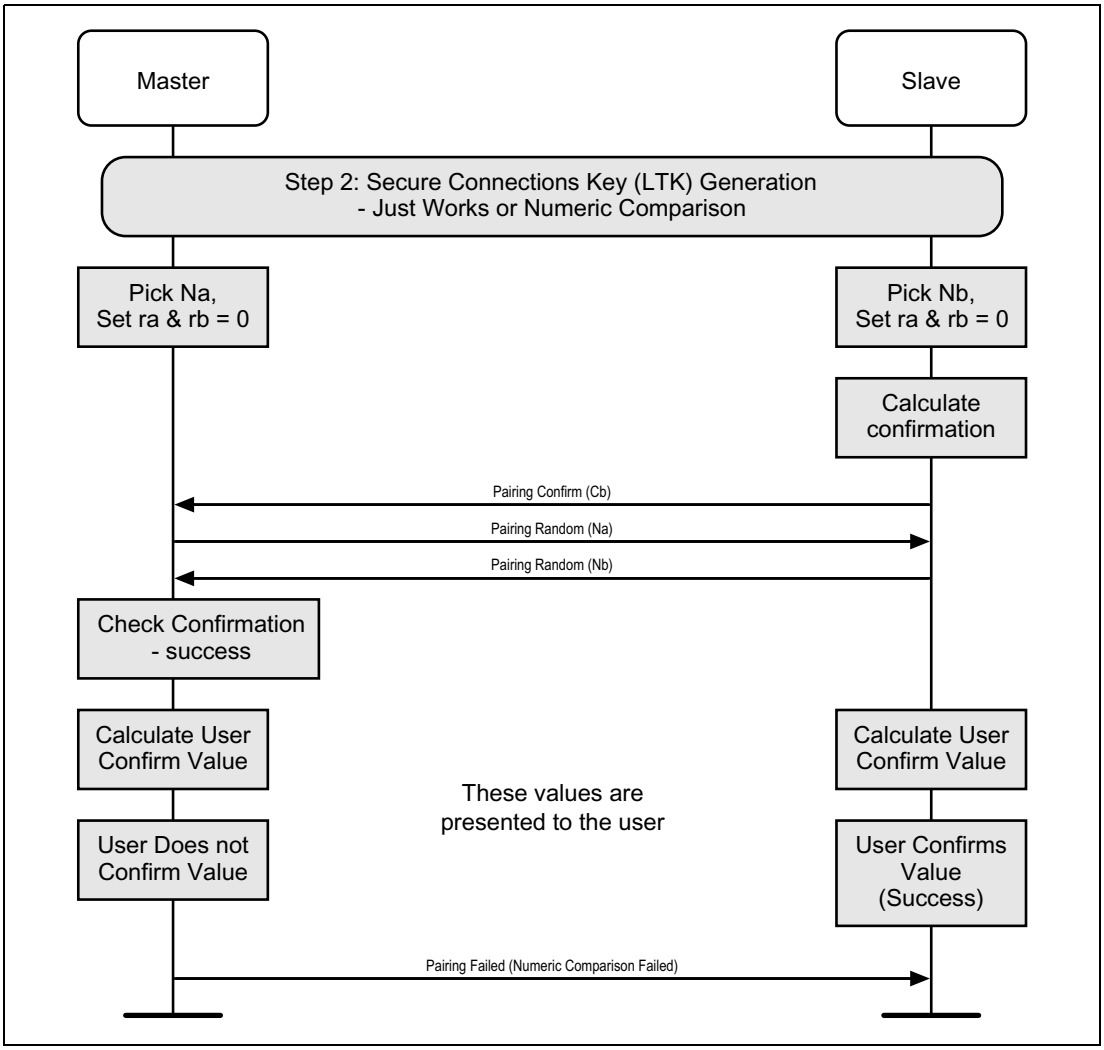

Figure C.10: Pairing Phase 2, Authentication Stage 1, Numeric Comparison Failure on Initiator Side

C.2.2.2.4 Numeric Comparison Failure on Responding Side

If the numeric comparison fails on the responding side due to the user indicating that the confirmation values do not match, Pairing is terminated.

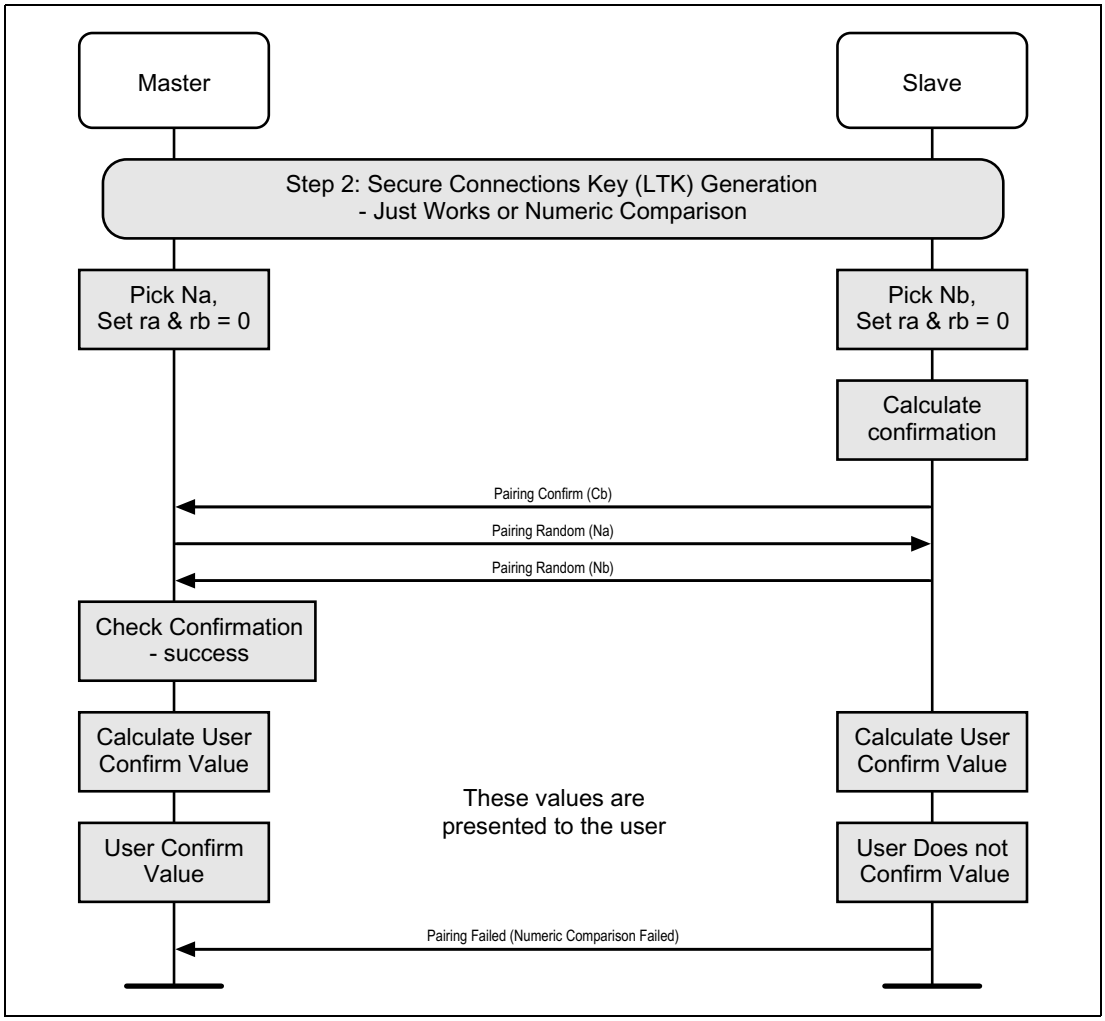

Figure C.11: Pairing Phase 2, Authentication Stage 1, Numeric Comparison Failure on Responding Side

C.2.2.2.5 Successful Passkey Entry

The Passkey Entry step is used in two cases: when one device has numeric input only and the other device has either a display or numeric input capability. In this step, one device display a number to be entered by the other device or the user enters a number on both devices. Key press notification messages are shown during the user input phase.

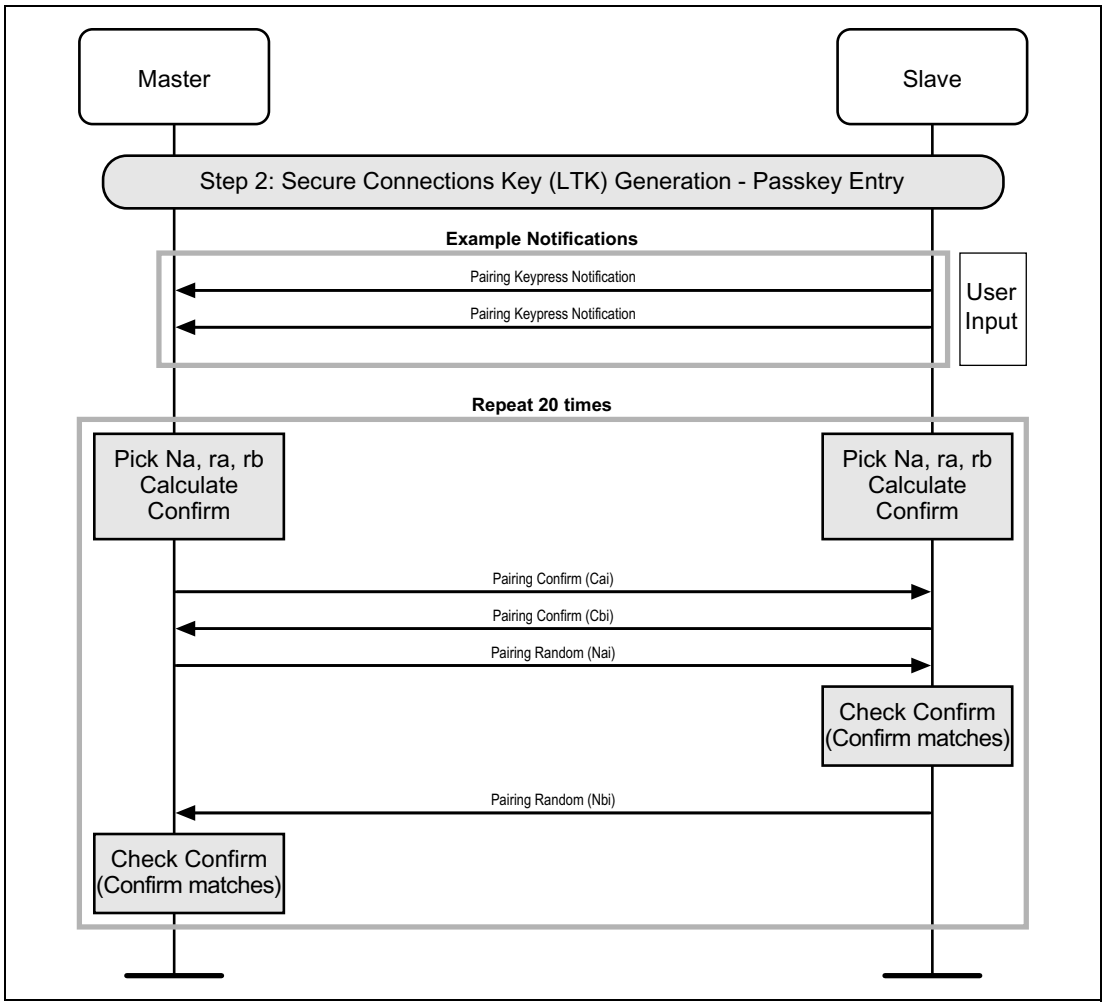

Figure C.12: Pairing Phase 2, Authentication Stage 1, Successful Passkey Entry

Note: Passkey Entry may prolong pairing experience because of the time required to execute 20 repetitions over SMP.

C.2.2.2.6 Passkey Entry – Confirm Check failure on the Responder side

If during one of the 20 repetitions, the Confirm calculated by the Responder is not equal to the one received from the Initiator, the Responder will abort the Pairing process by sending Pairing Failed with reason “Confirm Value Failed”.

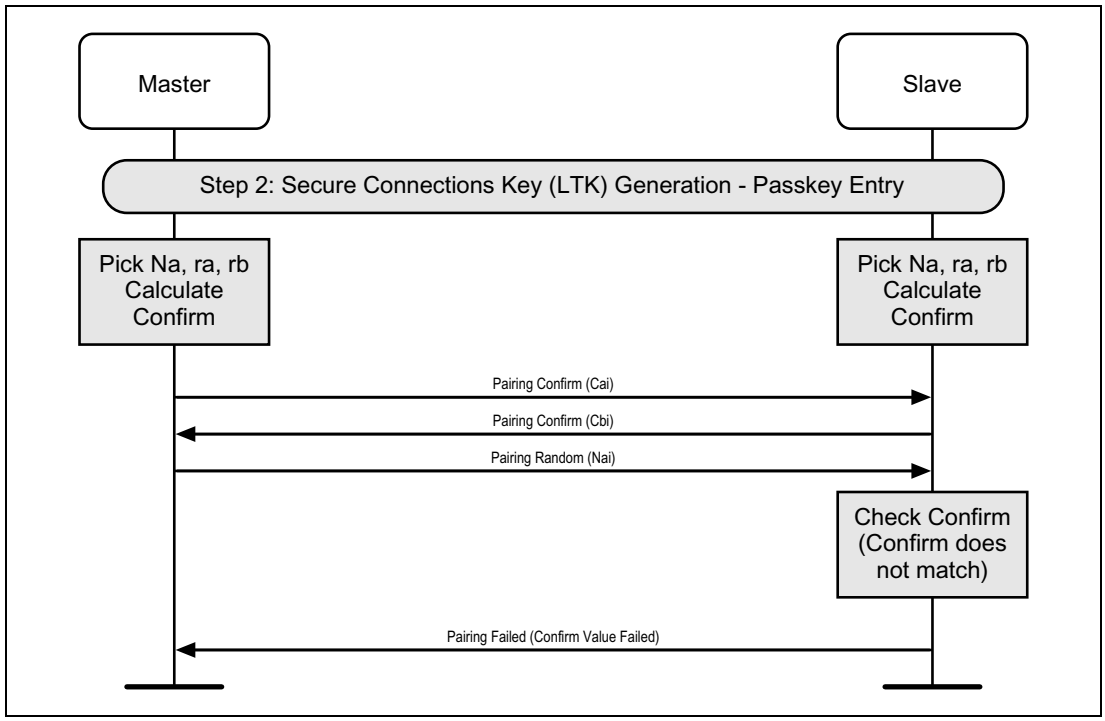

Figure C.13: Pairing Phase 2, Authentication Stage 1, Passkey Entry – Confirm Check failure on Responder side

C.2.2.2.7 Passkey Entry – Confirm Check failure on the Initiator side

If during one of the 20 repetitions, the Confirm calculated by the Initiator is not equal to the one received from the Responder, the Initiator will abort the Pairing process by sending Pairing Failed with reason “Confirm Value Failed”.

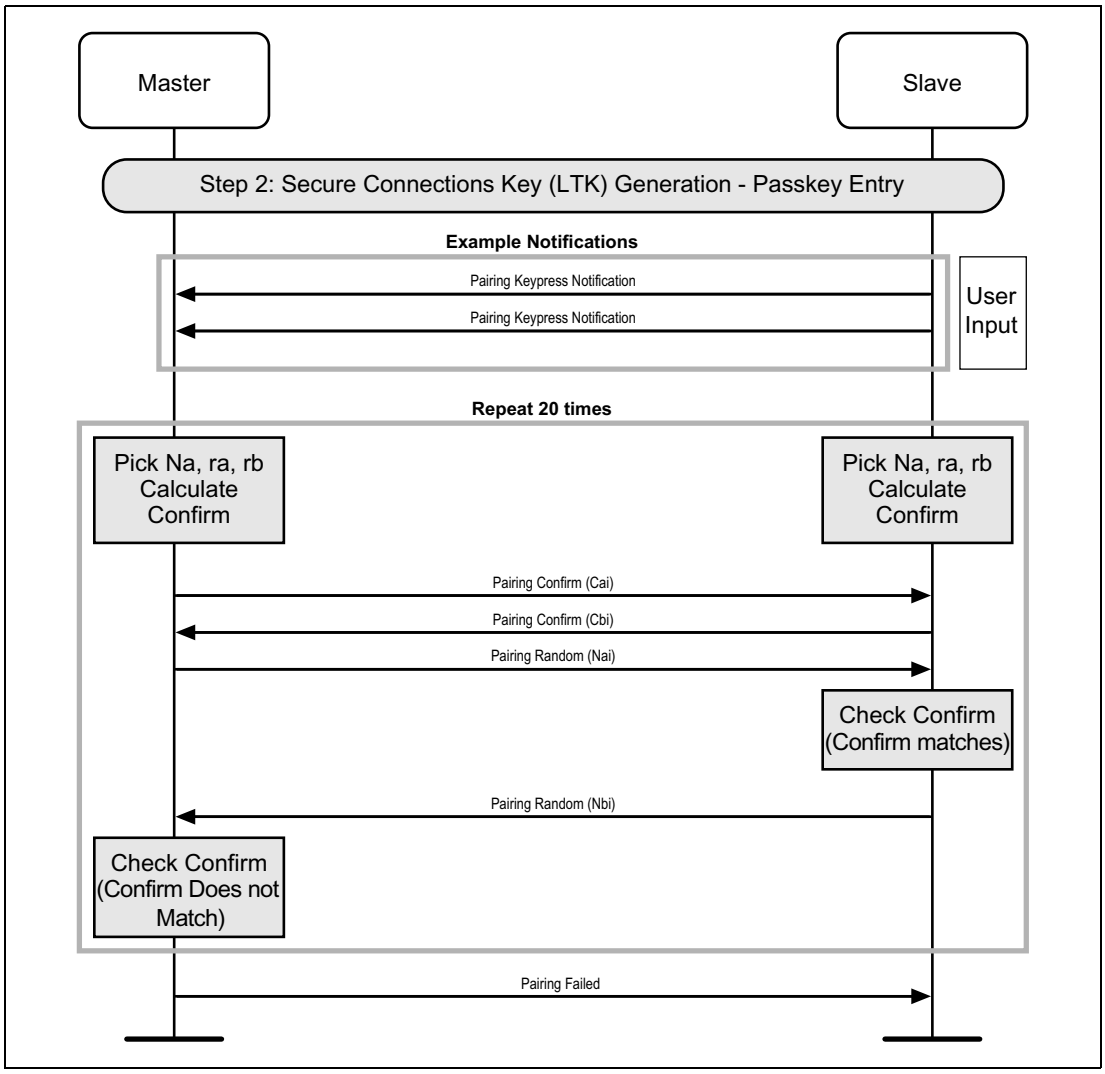

Figure C.14: Pairing Phase 2, Authentication Stage 1, Passkey Entry – Confirm Check failure on Initiator side

C.2.2.2.8 Passkey Entry Failure on Responding Side

If the passkey entry fails on the responding side, Pairing is terminated.

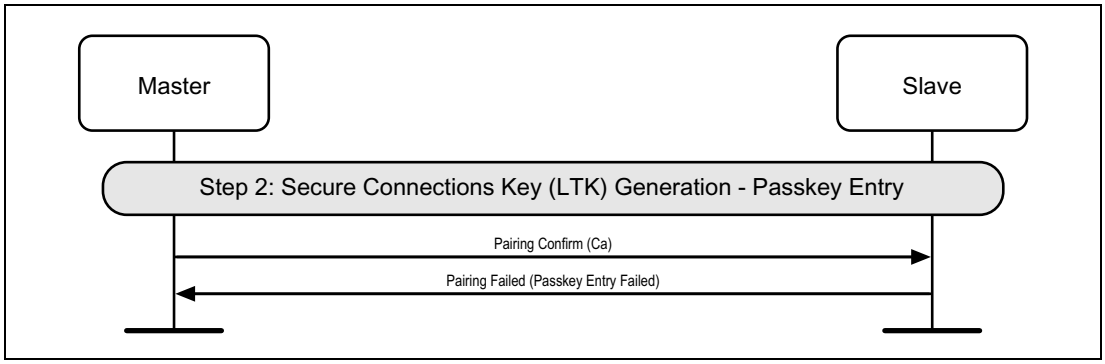

Figure C.15: Pairing Phase 2, Authentication Stage 1, Passkey Entry Failure on Responding Side

C.2.2.2.9 Passkey Entry Failure on Initiator Side

If the passkey entry fails on the initiating side, Pairing is terminated.

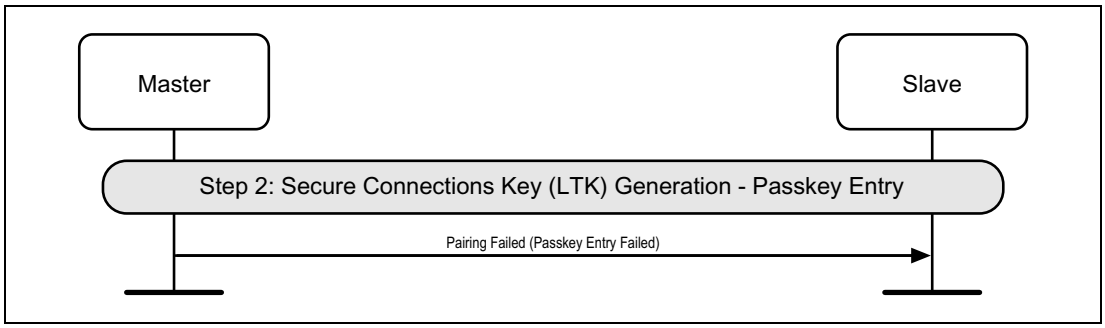

Figure C.16: Pairing Phase 2, Authentication Stage 1, Passkey Entry Failure on Initiator Side

C.2.2.2.10 Successful Out of Band

The OOB authentication will only be done when at least one device has some OOB information to use. This step requires no user interaction.

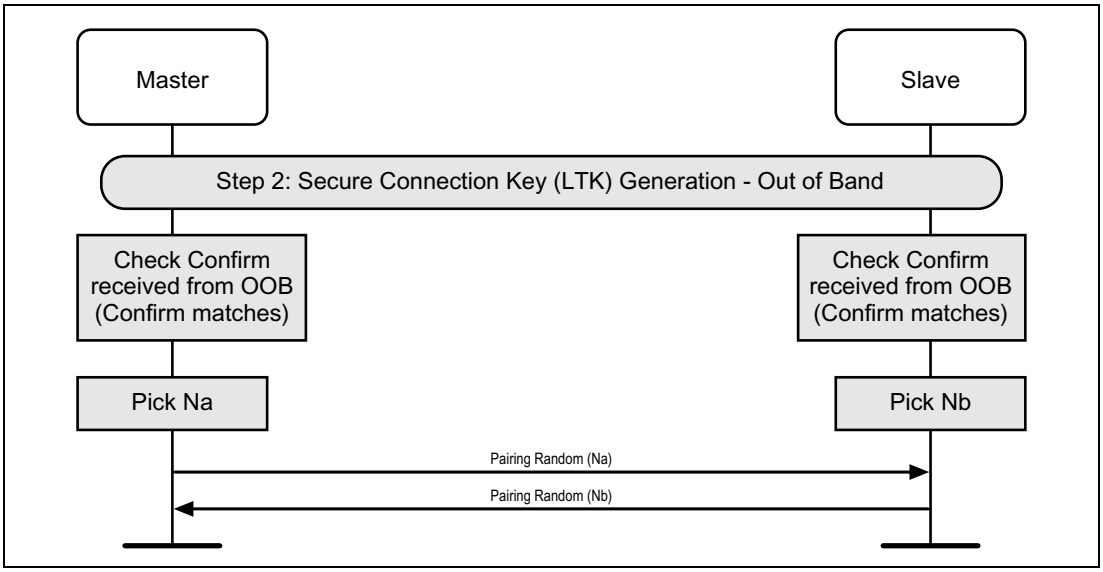

Figure C.17: Pairing Phase 2, Authentication Stage 1, Successful Out of Band

C.2.2.2.11 Out of Band – Confirm Check failure on the Responder side

If the Confirm value received from OOB is not equal to the calculated Confirm value, the Responder will abort the Pairing process by sending Pairing Failed with reason “Confirm Value Failed”.

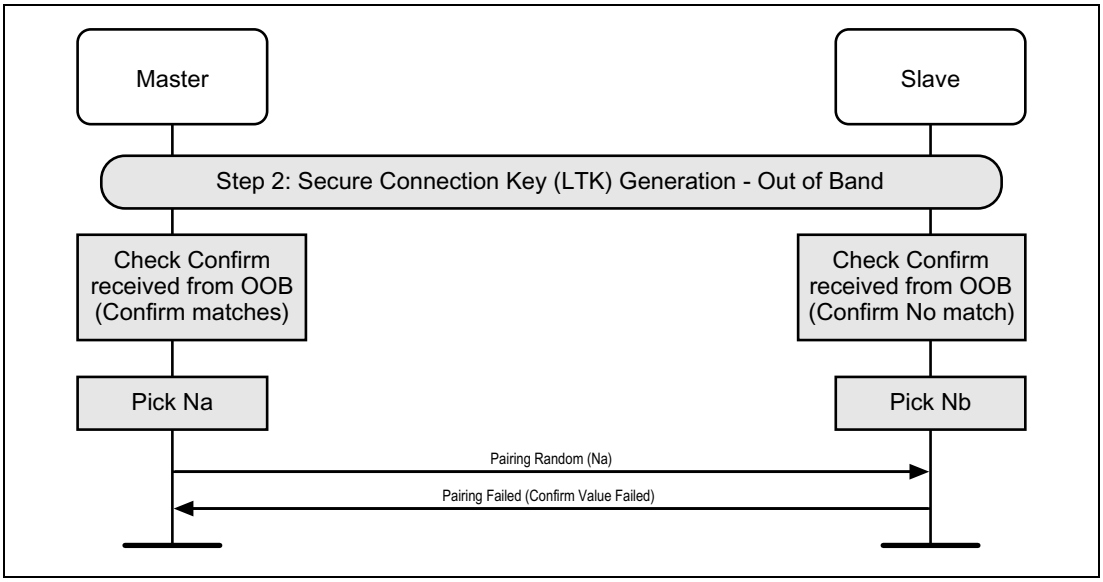

Figure C.18: Pairing Phase 2, Authentication Stage 1, Out of Band – Confirm Check failure on Responder side

C.2.2.2.12 Out of Band - Confirm Check failure on the Initiating side

If the Confirm value received from OOB is not equal to the calculated Confirm value, the Initiator will abort the Pairing process by sending Pairing Failed with reason "Confirm Value Failed".

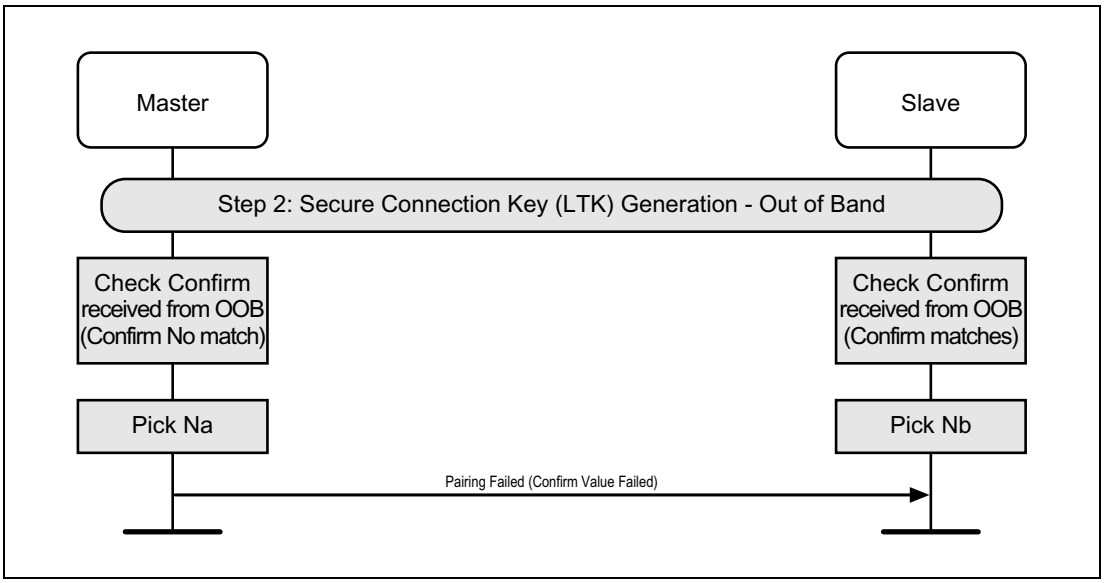

Figure C.19: Pairing Phase 2: Authentication Stage 1, Out of Band - Confirm Check failure on Initiator side"

C.2.2.2.13 Out of Band Failure on Initiator side (OOB information not available)

If the initiating side does not have the responder's OOB information, Pairing is terminated.

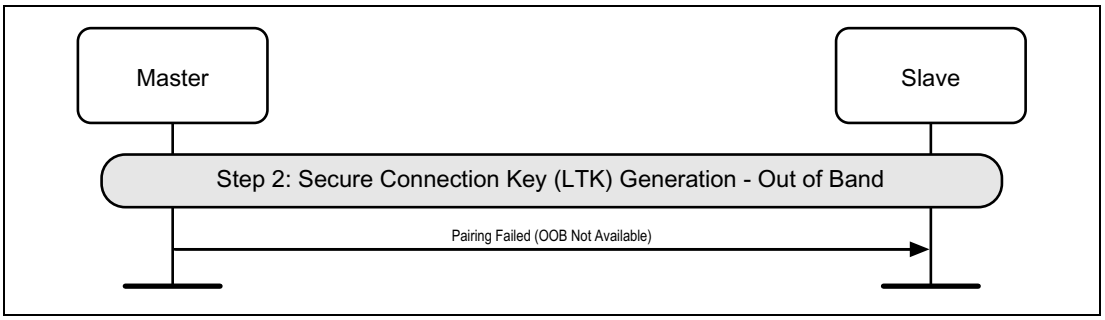

Figure C.20: Pairing Phase 2, Authentication Stage 1, Out of Band Failure on Initiator Side

C.2.2.2.14 Out of Band Failure on Responding side (OOB information not available)

If the responding side does not have the initiator's OOB information, Pairing is terminated.

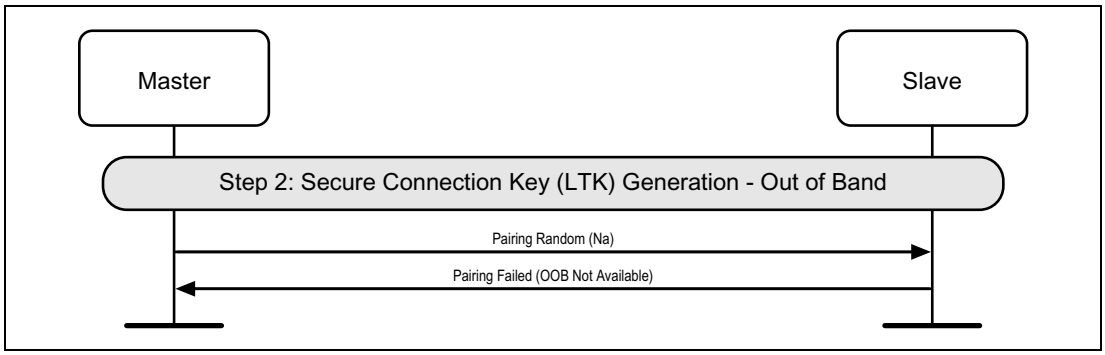

Figure C.21: Pairing Phase 2, Authentication Stage 1, Out of Band Failure on Responding Side

C.2.2.3 Long Term Key Calculation

Once the DHKey generation is complete, the Long Term Key (LTK) is calculated from the DHKey.

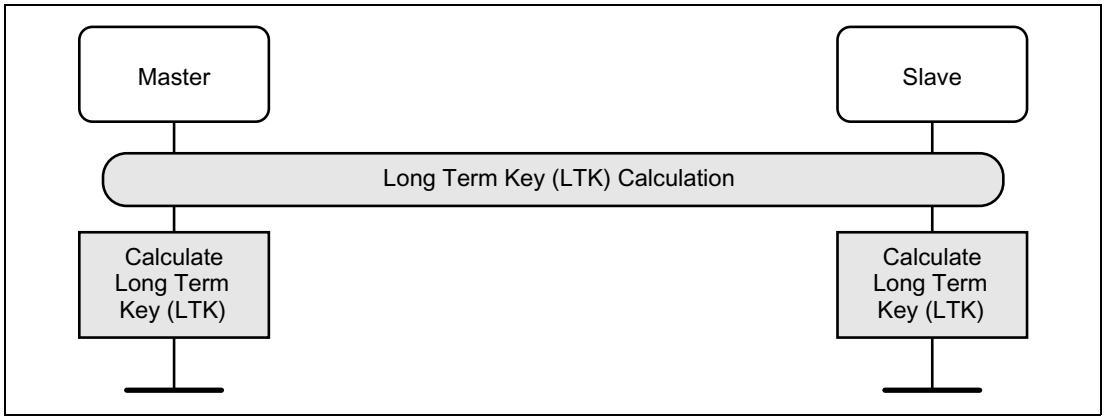

Figure C.22: Long Term Key Calculation

C.2.2.4 Authentication Stage 2 (DHKey checks)

Once the LTK calculation has completed, the DHKey value generated is checked. If this succeeds, then both devices would have finished displaying information to the user about the process, and therefore the Host can stop displaying this information.

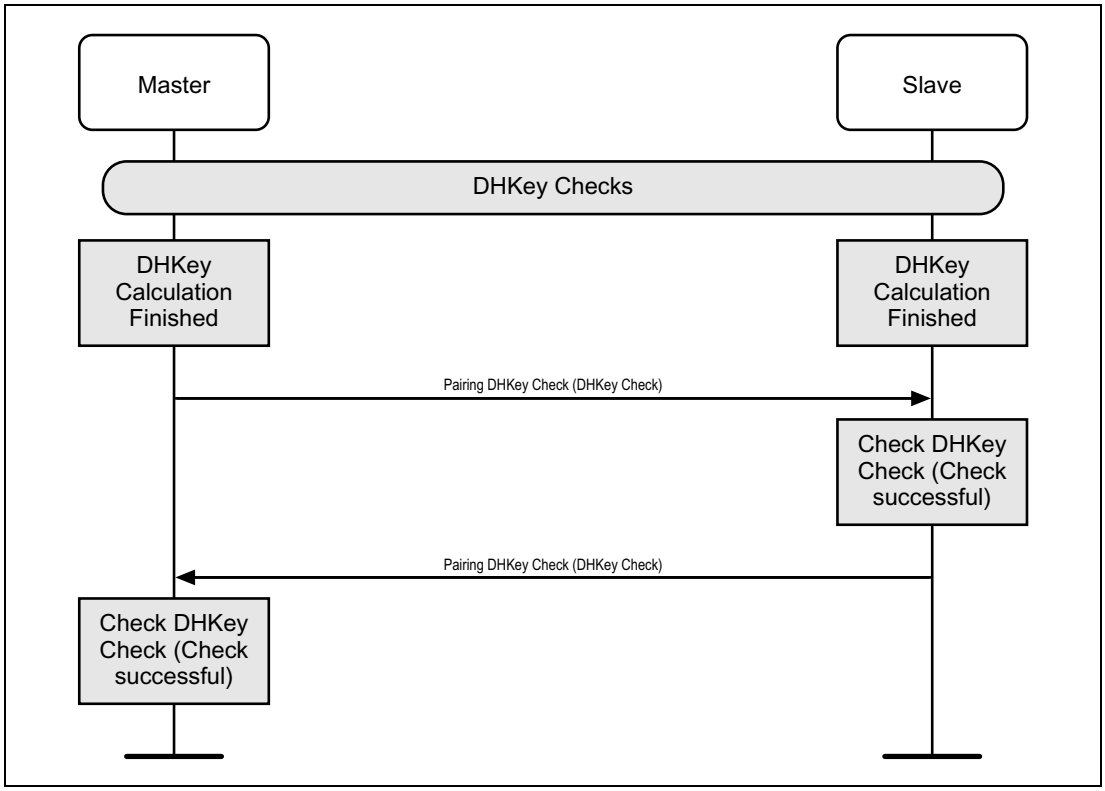

Figure C.23: Pairing Phase 2, Authentication Stage 2, DHKey checks

C.3 PHASE 3: TRANSPORT SPECIFIC KEY DISTRIBUTION

After short term key generation and the link has been encrypted, transport specific keys are distributed. Figure C.24 shows an example of all keys and values being distributed by Master and Slave.

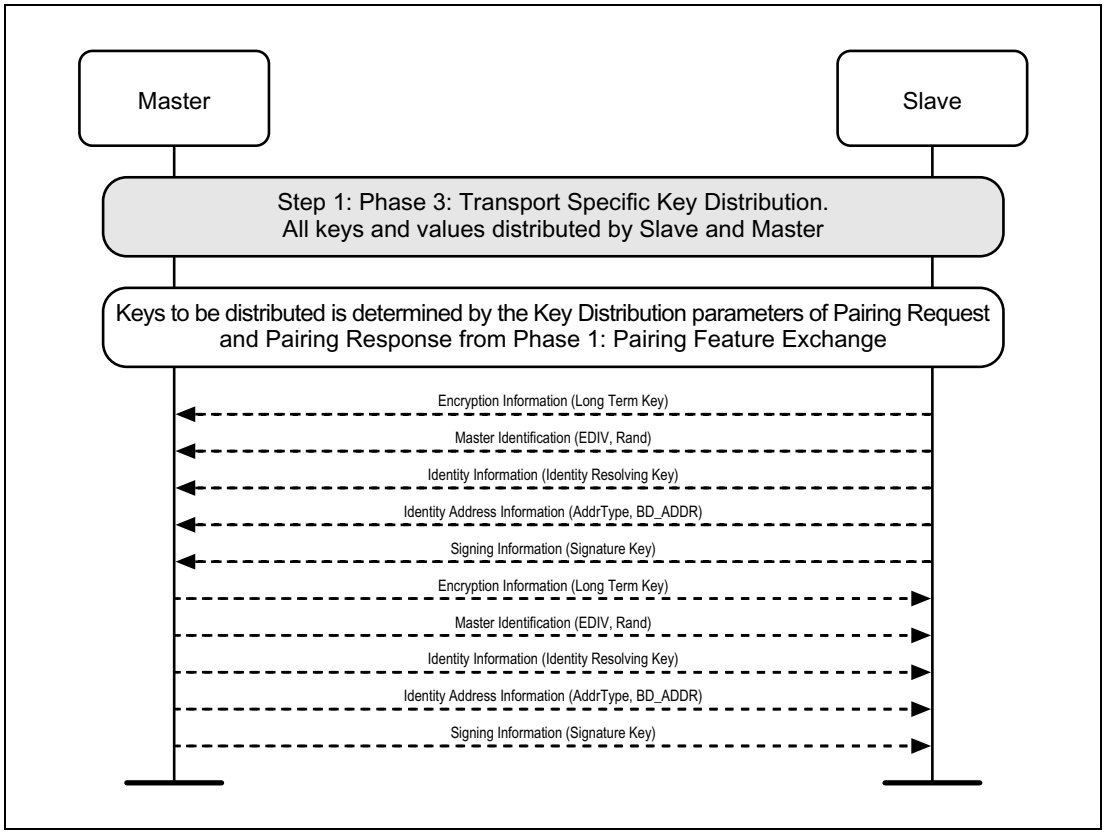

Figure C.24: Transport Specific Key Distribution

C.4 SECURITY RE-ESTABLISHED USING PREVIOUSLY DISTRIBUTED LTK

Devices may re-establish security using a previously distributed LTK. The master device always initiates the encryption procedures, and therefore there are two possible sequences: master initiated and slave requested.

C.4.1 Master Initiated Security - Master Initiated Link Layer Encryption

The master initiates encryption procedures. There is no SM signaling to enable this; the master initiates Link Layer encryption only. See [Vol 6] Part D, Section 6.6.

C.4.2 Slave Security Request - Master Initiated Link Layer Encryption

The slave may request the master initiates security procedures. Figure C.25 shows an example where the slave requests security and the master initiates Link Layer encryption.

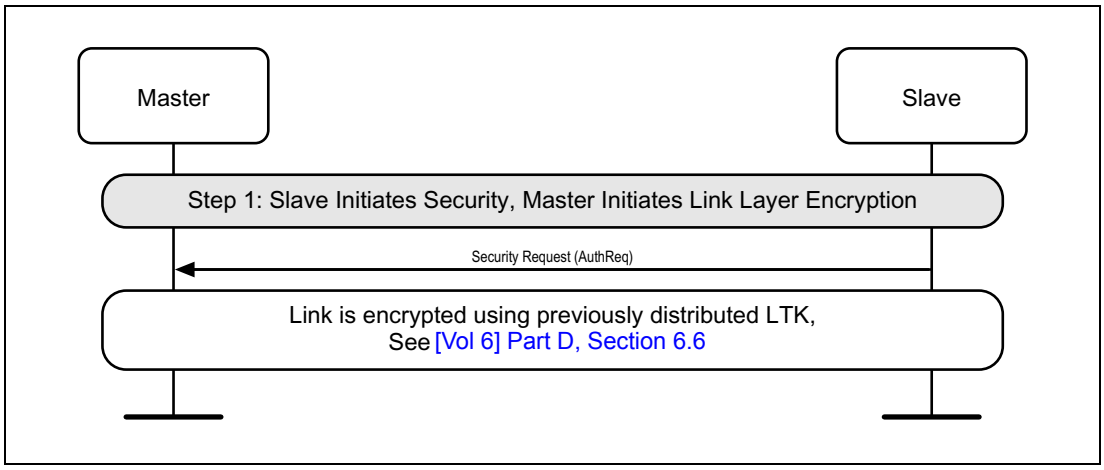

Figure C.25: Slave security request, master initiates Link Layer encryption

C.5 FAILURE CONDITIONS

The following sequences show possible failure conditions and their associated signaling.

C.5.1 Pairing Not Supported by Slave

If the slave device does not support pairing or pairing cannot be performed the slave can reject the request from the master. Figure C.26 shows the slave rejecting a Pairing Request command from the master.

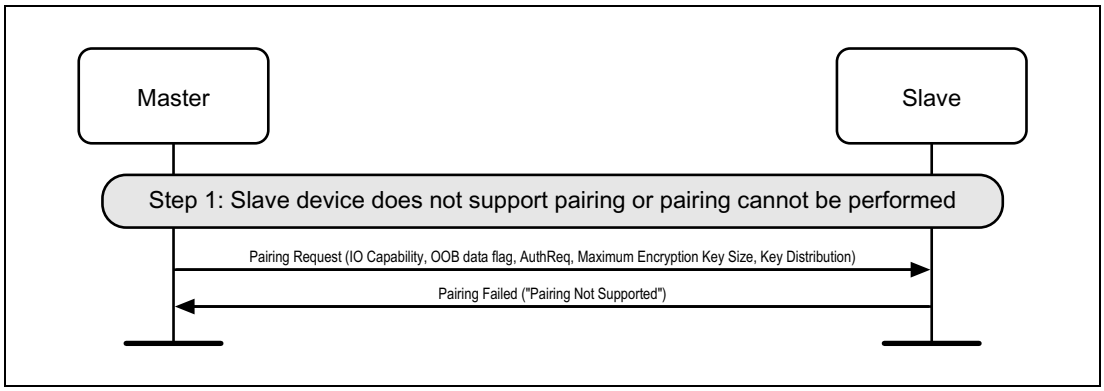

Figure C.26: Slave rejects pairing attempt

C.5.2 Master Rejects Pairing Because of Key Size

During Pairing Feature Exchange the size of the Encryption Key is negotiated. Figure C.27 shows an example where the master terminates the pairing procedure because the resulting key size is not acceptable.

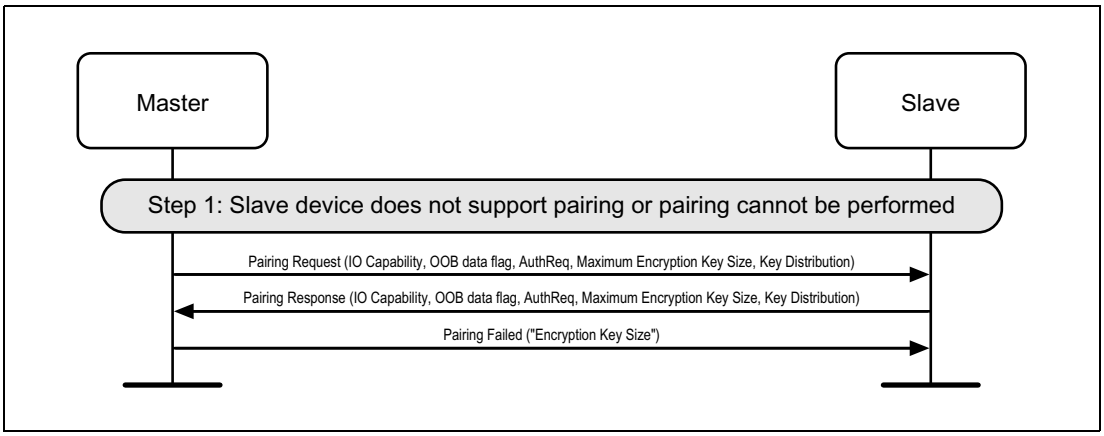

Figure C.27: Master rejects pairing because of key size

C.5.3 Slave Rejects Pairing Because of Key Size

During Pairing Feature Exchange the size of the Encryption Key is negotiated. Figure C.28 shows an example where the slave terminates the pairing procedure because the resulting key size is not acceptable.

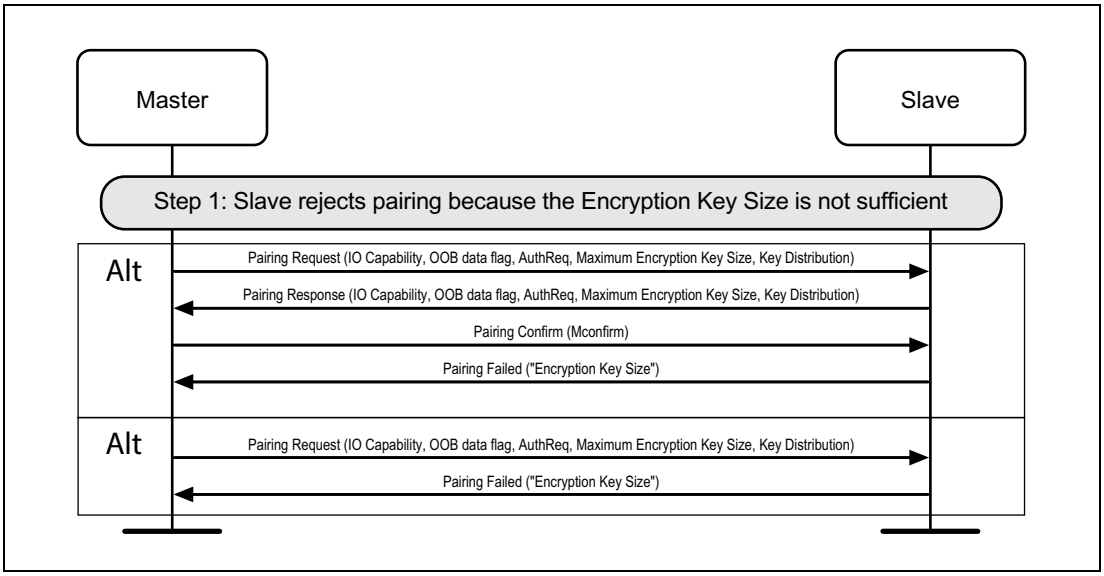

Figure C.28: Slave rejects pairing because of key size

C.5.4 Passkey Entry Failure on Master

During Passkey Entry pairing the user enters a passkey on both devices. Figure C.29 shows an example where the passkey entry fails on the master device.

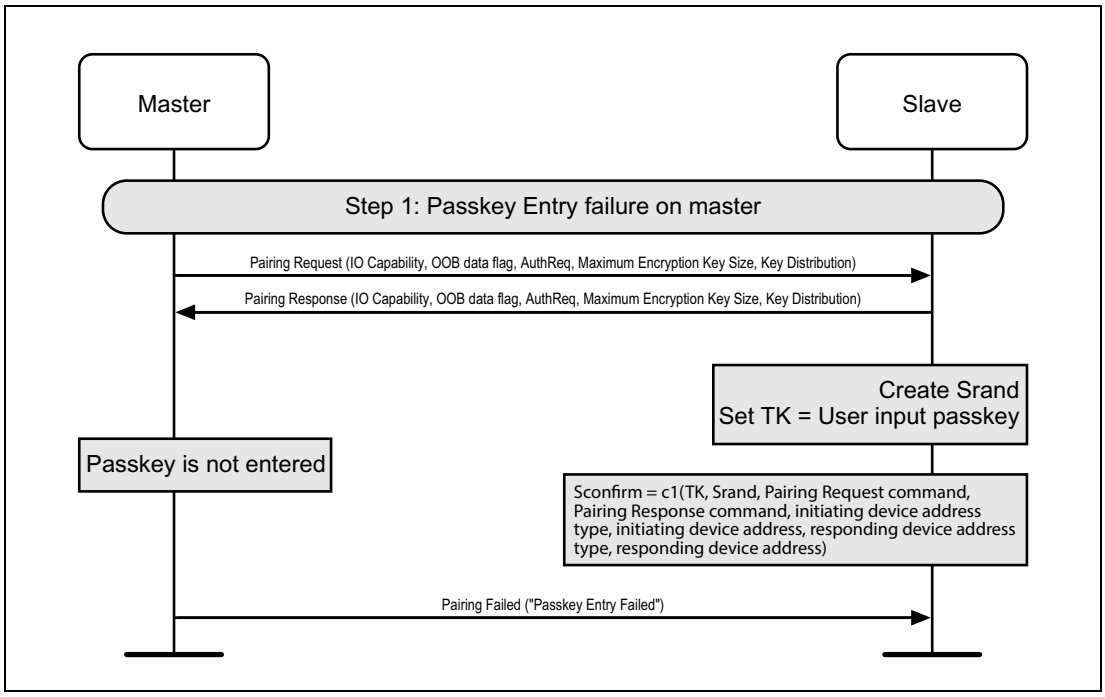

Figure C.29: Passkey Entry failure on master

C.5.5 Passkey Entry Failure on Slave

During Passkey Entry pairing the user enters a passkey on both devices. Figure C.30 shows an example where the passkey entry fails on the slave device.

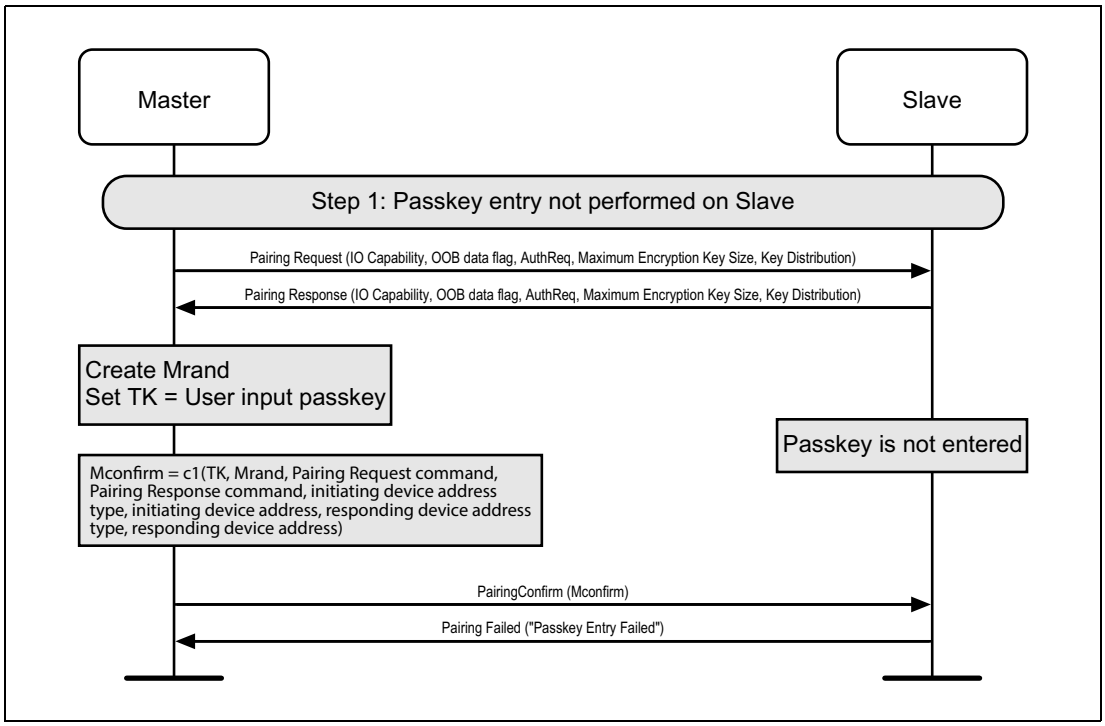

Figure C.30: Passkey Entry failure on slave

C.5.6 Slave Rejects Master's Confirm Value

During Passkey Entry pairing the user enters a passkey on both devices. Figure C.31 shows an example where a different passkey is entered on both devices. This sequence could also occur if any of the inputs to c1 (Passkey, Mrand, Srand, Pairing Request command, Pairing Response command, address types or addresses) are incorrect or altered.

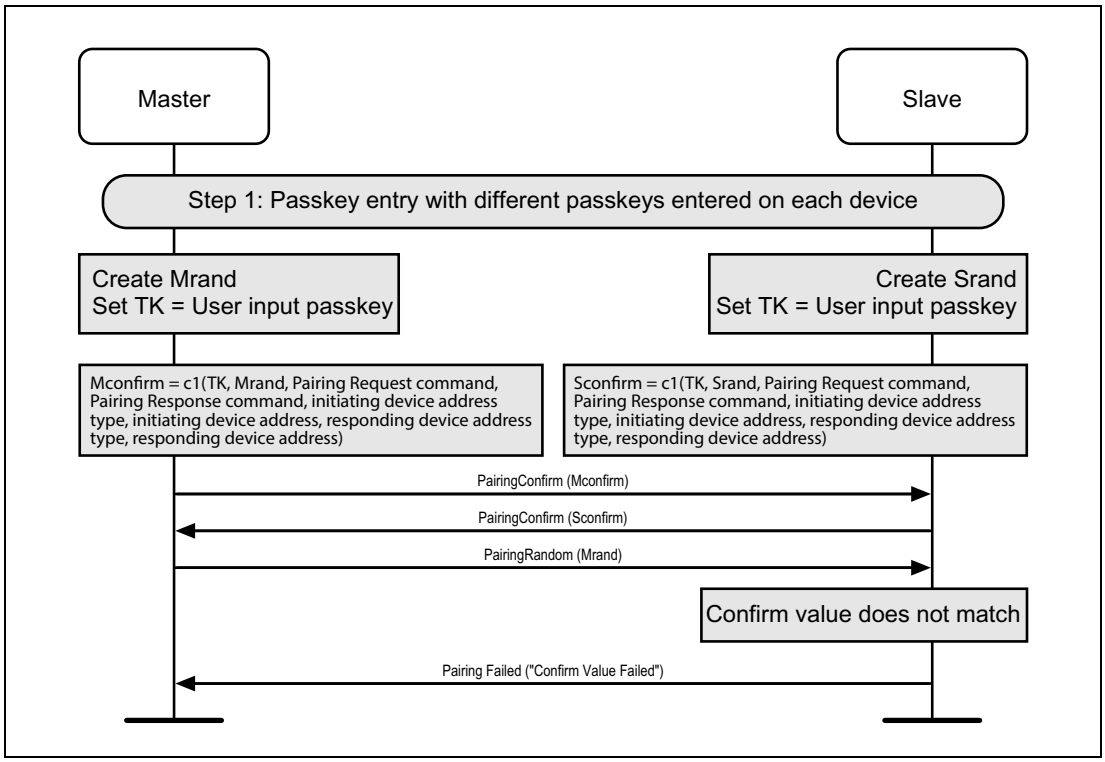

Figure C.31: Different Passkeys entered

C.5.7 Master Rejects Slave's Confirm Value

During all the pairing methods the master and slave device send random numbers and confirm values. Figure C.32 shows an example where the master device rejects pairing because it cannot verify the confirm value from the slave because any of the inputs to c1 (Passkey, Mrand, Srand, Pairing Request command, Pairing Response command, address types or addresses) are incorrect or altered.

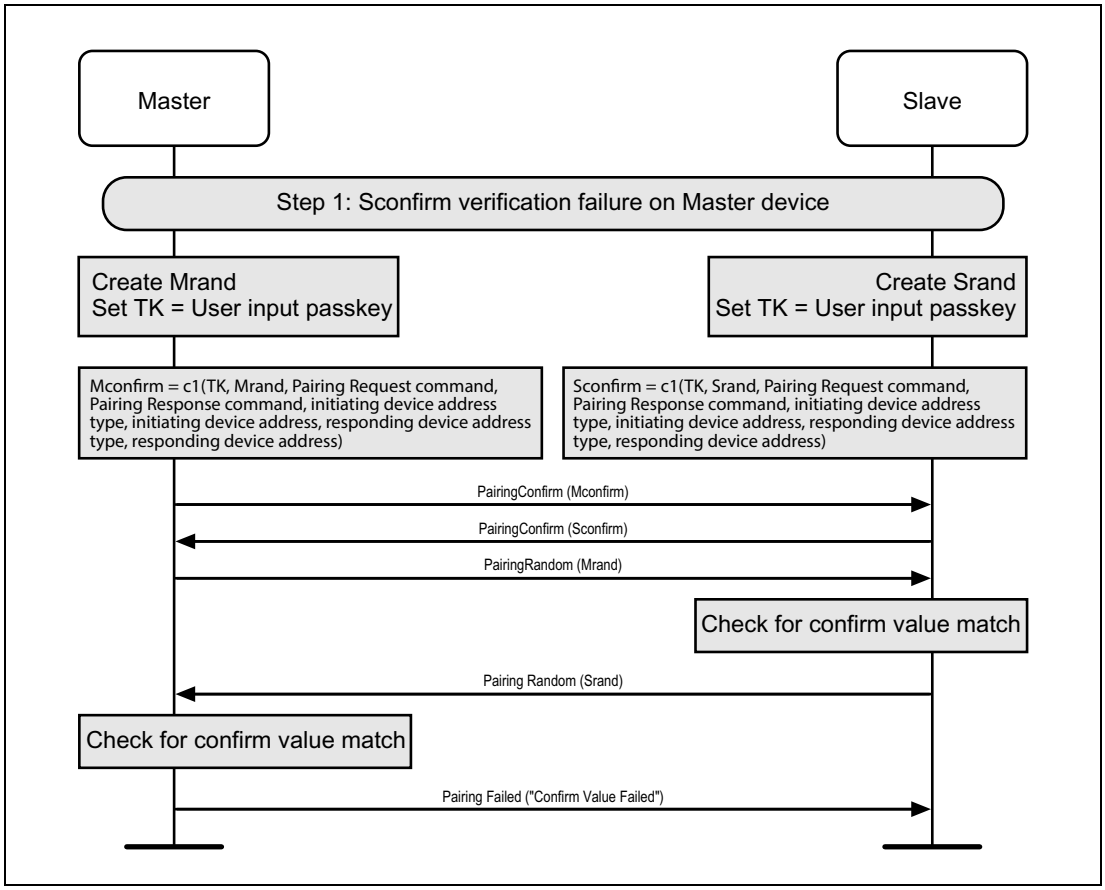

Figure C.32: Master rejects Sconfirm value from slave

APPENDIX D SAMPLE DATA

In each data set in this section, the bytes are ordered from most significant on the left to least significant on the right. ‘M’ represents the message byte array for which the AES CMAC is calculated.

D.1 AES-CMAC RFC4493 TEST VECTORS

The following test vectors are referenced from RFC4493.

```
K                   2b7e1516 28aed2a6 abf71588 09cf4f3c
Subkey Generation
AES_128(key,0)      7df76b0c 1ab899b3 3e42f047 b91b546f
K1                  fbeed618 35713366 7c85e08f 7236a8de
K2                  f7ddac30 6ae266cc f90bc11e e46d513b
```

D.1.1 Example 1: Len = 0

```
M           <empty string>
AES_CMAC    bb1d6929 e9593728 7fa37d12 9b756746
```

D.1.2 Example 2: Len = 16

```
M           6bc1bee2 2e409f96 e93d7e11 7393172a
AES_CMAC    070a16b4 6b4d4144 f79bdd9d d04a287c
```

D.1.3 Example 3: Len = 40

```
M0          6bc1bee2 2e409f96 e93d7e11 7393172a
M1          ae2d8a57 1e03ac9c 9eb76fac 45af8e51
M2          30c81c46 a35ce411
AES_CMAC    dfa66747 de9ae630 30ca3261 1497c827
```

D.1.4 Example 4: Len = 64

```
M0          6bc1bee2 2e409f96 e93d7e11 7393172a
M1          ae2d8a57 1e03ac9c 9eb76fac 45af8e51
M2          30c81c46 a35ce411 e5fbc119 1a0a52ef
M3          f69f2445 df4f9b17 ad2b417b e66c3710
AES_CMAC    51f0bebf 7e3b9d92 fc497417 79363cfe
```

D.2 *f4* LE SC CONFIRM VALUE GENERATION FUNCTION

U	20b003d2 f297be2c 5e2c83a7 e9f9a5b9
	eff49111 acf4fddb cc030148 0e359de6
V	55188b3d 32f6bb9a 900afcfb eed4e72a
	59cb9ac2 f19d7cfb 6b4fdd49 f47fc5fd
X	d5cb8454 d177733e ffffb2ec 712baeab
Z	0x00
M0	20b003d2 f297be2c 5e2c83a7 e9f9a5b9
M1	eff49111 acf4fddb cc030148 0e359de6
M2	55188b3d 32f6bb9a 900afcfb eed4e72a
M3	59cb9ac2 f19d7cfb 6b4fdd49 f47fc5fd
	00
AES_CMAC	f2c916f1 07a9bd1c f1eda1be a974872d

D.3 *f5* LE SC KEY GENERATION FUNCTION

DHKey(W)	ec0234a3 57c8ad05 341010a6 0a397d9b 99796b13 b4f866f1 868d34f3 73bfa698
T	3c128f20 de883288 97624bdb 8dac6989
keyID	62746c65
N1	d5cb8454 d177733e ffffb2ec 712baeab
N2	a6e8e7cc 25a75f6e 216583f7 ff3dc4cf
A1	00561237 37bfce
A2	00a71370 2dcfc1
Length (LTK)	0100
M0	0162746c 65d5cb84 54d17773 3effffb2
M1	ec712bae aba6e8e7 cc25a75f 6e216583
M2	f7ff3dc4 cf005612 3737bfce 00a71370
M3	2dcfc101 00
AES_CMAC (MacKey)	69867911 69d7cd23 980522b5 94750a38
M0	0062746c 65d5cb84 54d17773 3effffb2
M1	ec712bae aba6e8e7 cc25a75f 6e216583
M2	f7ff3dc4 cf005612 3737bfce 00a71370
M3	2dcfc101 00
AES_CMAC	2965f176 a1084a02 fd3f6a20 ce636e20

D.4 *f6* LE SC CHECK VALUE GENERATION FUNCTION

N1	d5cb8454 d177733e ffffb2ec 712baeab
N2	a6e8e7cc 25a75f6e 216583f7 ff3dc4cf
MacKey	2965f176 a1084a02 fd3f6a20 ce636e20
R	12a3343b b453bb54 08da42d2 0c2d0fc8
IOcap	010102
A1	00561237 37bfce
A2	00a71370 2dcfc1
M0	d5cb8454 d177733e ffffb2ec 712baeab
M1	a6e8e7cc 25a75f6e 216583f7 ff3dc4cf
M2	12a3343b b453bb54 08da42d2 0c2d0fc8
M3	01010200 56123737 bfce00a7 13702dcf
M4	c1
AES_CMAC	e3c47398 9cd0e8c5 d26c0b09 da958f61

D.5 *g2* LE SC NUMERIC COMPARISON GENERATION FUNCTION

U	20b003d2 f297be2c 5e2c83a7 e9f9a5b9
	eff49111 acf4fddb cc030148 0e359de6
V	55188b3d 32f6bb9a 900afcfb eed4e72a
	59cb9ac2 f19d7cfb 6b4fdd49 f47fc5fd
X	d5cb8454 d177733e ffffb2ec 712baeab
Y	a6e8e7cc 25a75f6e 216583f7 ff3dc4cf
M0	20b003d2 f297be2c 5e2c83a7 e9f9a5b9
M1	eff49111 acf4fddb cc030148 0e359de6
M2	55188b3d 32f6bb9a 900afcfb eed4e72a
M3	59cb9ac2 f19d7cfb 6b4fdd49 f47fc5fd
M4	a6e8e7cc 25a75f6e 216583f7 ff3dc4cf
AES_CMAC	1536d18d e3d20df9 9b7044c1 2f9ed5ba
g2	2f9ed5ba

D.6 *h6* LE SC LINK KEY CONVERSION FUNCTION

Key	ec0234a3 57c8ad05 341010a6 0a397d9b
keyID	6c656272
M	6c656272
AES_CMAC	2d9ae102 e76dc91c e8d3a9e2 80b16399

D.7 *ah* RANDOM ADDRESS HASH FUNCTIONS

IRK	ec0234a3 57c8ad05 341010a6 0a397d9b
prand	00000000 00000000 00000000 00708194
M	00000000 00000000 00000000 00708194
AES_128	159d5fb7 2ebe2311 a48c1bdc c40dfbaa
ah	0dfbaa

D.8 *h7* LE SC LINK KEY CONVERSION FUNCTION

Key	ec0234a3 57c8ad05 341010a6 0a397d9b
SALT	00000000 00000000 00000000 746D7031
AES_CMAC	fb173597 c6a3c0ec d2998c2a 75a57011

D.9 LTK TO LINK KEY CONVERSION USING CT2=1

```
LTK             368df9bc e3264b58 bd066c33 334fbf64
Link Key        287ad379 dca40253 0a39f1f4 3047b835
```

D.10 LTK TO LINK KEY CONVERSION USING CT2=0

```
LTK             368df9bc e3264b58 bd066c33 334fbf64
Link Key        bc1ca4ef 633fc1bd 0d8230af ee388fb0
```

D.11 LINK KEY TO LTK CONVERSION USING CT2=1

```
Link Key        05040302 01000908 07060504 03020100
LTK             e85e09eb 5eccb3e2 69418a13 3211bc79
```

D.12 LINK KEY TO LTK CONVERSION USING CT2=0

```
Link Key        05040302 01000908 07060504 03020100
LTK             a813fb72 f1a3dfa1 8a2c9a43 f10d0a30
```

Host Controller Interface

[Transport Layer]

Specification of the Bluetooth® System

Specification Volume 4

Covered Core Package Version: 5.0
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Revision History

The Revision History is shown in the [Vol 0] Part C, Appendix.

Contributors

The persons who contributed to this specification are listed in the [Vol 0] Part C, Appendix.

Web Site

This specification can also be found on the official Bluetooth web site:
https://www.bluetooth.org/en-us/specification/adopted-specifications

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UART TRANSPORT LAYER

This document describes the UART transport layer (between the Host and the Host Controller). HCI command, event, and data packets flow through this layer, but the layer does not decode them.

CONTENTS

1 GENERAL

The objective of this HCI UART Transport Layer is to make it possible to use the Bluetooth HCI over a serial interface between two UARTs on the same PCB. The HCI UART Transport Layer assumes that the UART communication is free from line errors.

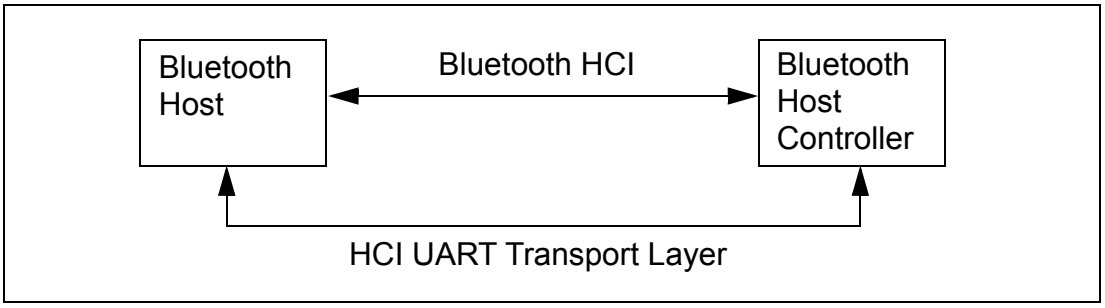

Figure 1.1: HCI UART Transport Layer

2 PROTOCOL

There are four kinds of HCI packets that can be sent via the UART Transport Layer; i.e. HCI Command Packet, HCI Event Packet, HCI ACL Data Packet and HCI Synchronous Data Packet (see [Vol 2] Part E, Host Controller Interface Functional Specification). HCI Command Packets can only be sent to the Bluetooth Host Controller, HCI Event Packets can only be sent from the Bluetooth Host Controller, and HCI ACL/Synchronous Data Packets can be sent both to and from the Bluetooth Host Controller.

HCI does not provide the ability to differentiate the four HCI packet types. Therefore, if the HCI packets are sent via a common physical interface, a HCI packet indicator has to be added according to Table 2.1 below.

HCI packet type	HCI packet indicator
HCI Command Packet	0x01
HCI ACL Data Packet	0x02
HCI Synchronous Data Packet	0x03
HCI Event Packet	0x04

Table 2.1: HCI packet indicators

The HCI packet indicator shall be sent immediately before the HCI packet. All four kinds of HCI packets have a length field, which is used to determine how many bytes are expected for the HCI packet. When an entire HCI packet has been received, the next HCI packet indicator is expected for the next HCI packet. Over the UART Transport Layer, only HCI packet indicators followed by HCI packets are allowed.

3 RS232 SETTINGS

The HCI UART Transport Layer uses the following settings for RS232:

Baud rate:	**manufacturer-specific**
Number of data bits:	8
Parity bit:	no parity
Stop bit:	1 stop bit
Flow control:	RTS/CTS
Flow-off response time:	manufacturer specific

Table 3.1: RS232 Settings

Flow control with RTS/CTS is used to prevent temporary UART buffer overrun. It should not be used for flow control of HCI, since HCI has its own flow control mechanisms for HCI commands, HCI events and HCI data.

If CTS is 1, then the Host/Host Controller is allowed to send.
If CTS is 0, then the Host/Host Controller is not allowed to send.

The flow-off response time defines the maximum time from setting RTS to 0 until the byte flow actually stops.

The RS232 signals should be connected in a null-modem fashion; i.e. the local TXD should be connected to the remote RXD and the local RTS should be connected to the remote CTS and vice versa.

4 ERROR RECOVERY

If the Host or the Host Controller lose synchronization in the communication over RS232, then a reset is needed. A loss of synchronization means that an incorrect HCI packet indicator has been detected, or that the length field in an HCI packet is out of range.

If the UART synchronization is lost in the communication from Host to Host Controller, then the Host Controller shall send a Hardware Error Event to tell the Host about the synchronization error. The Host Controller will then expect to receive an HCI_Reset command from the Host in order to perform a reset. The Host Controller will also use the HCI_Reset command in the byte stream from Host to Host Controller to re-synchronize.

If the UART synchronization is lost in the communication from Host Controller to Host, then the Host shall send the HCI_Reset command in order to reset the Host Controller. The Host shall then re-synchronize by looking for the HCI Command Complete event for the HCI_Reset command in the byte stream from Host Controller to Host.

See [Vol 2] Part E for HCI commands and HCI events in the Bluetooth Specification v1.2 or later.

USB TRANSPORT LAYER

This document describes the USB transport layer (between a Host and the Host Controller). HCI commands flow through this layer, but the layer does not decode the commands.

CONTENTS

1 OVERVIEW

This document discusses the requirements of the Universal Serial Bus (USB) interface for Bluetooth hardware. Readers should be familiar with USB, USB design issues, Advanced Configuration Power Interface (ACPI), the overall Bluetooth architecture, and the basics of the radio interface.

The reader should also be familiar with the Bluetooth Host Controller Interface.

Referring to Figure 1.1 through Figure 1.3, notice that this document discusses the implementation details of the two-way arrow labeled “USB Function.”

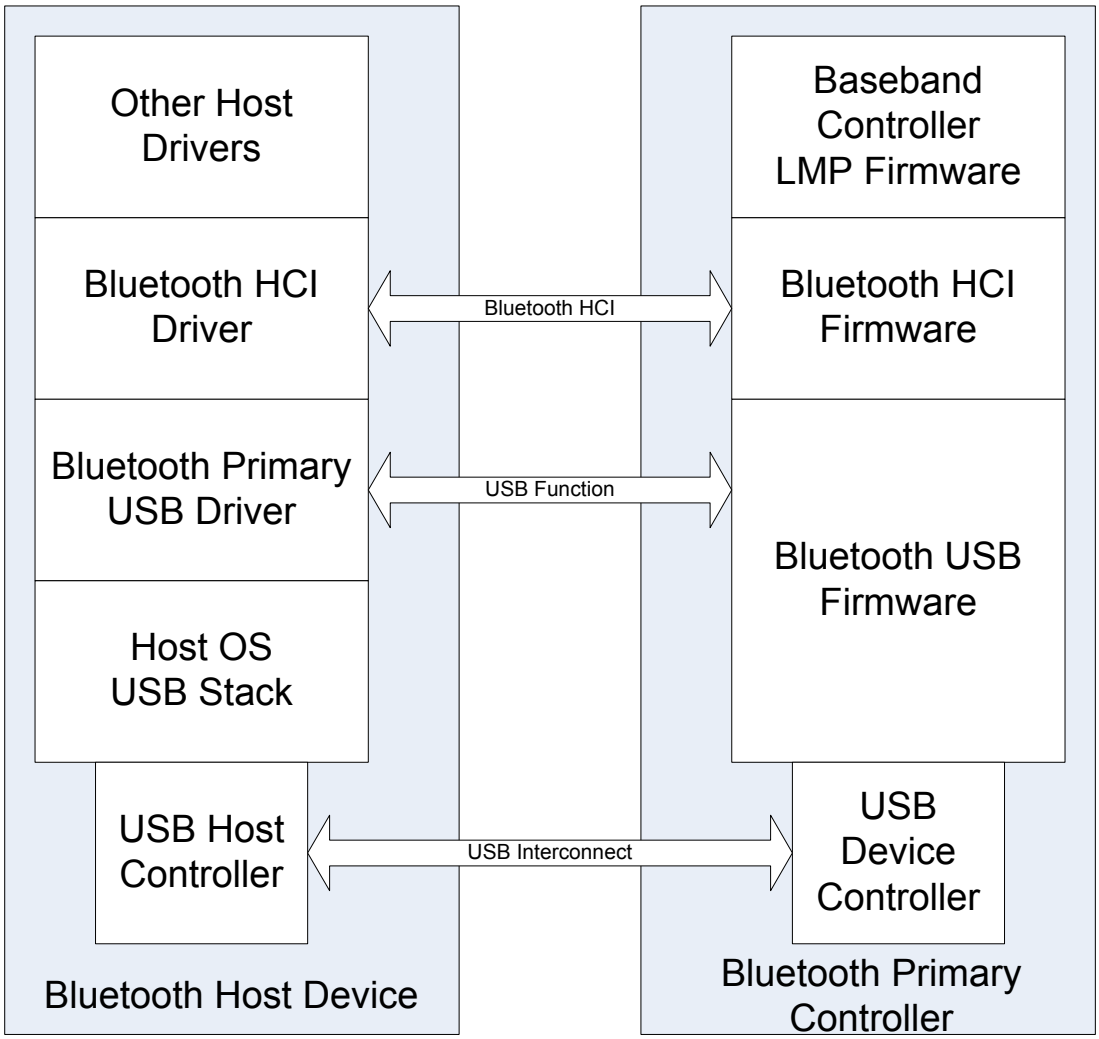

Figure 1.1: Relationship between the Host and Bluetooth Primary Controller

This document also specifies implementation of two other configurations:

- USB-connected AMP Controller (PAL, MAC, PHY)
- USB-connected composite (multifunction) device that combines a Primary Controller and an AMP Controller.

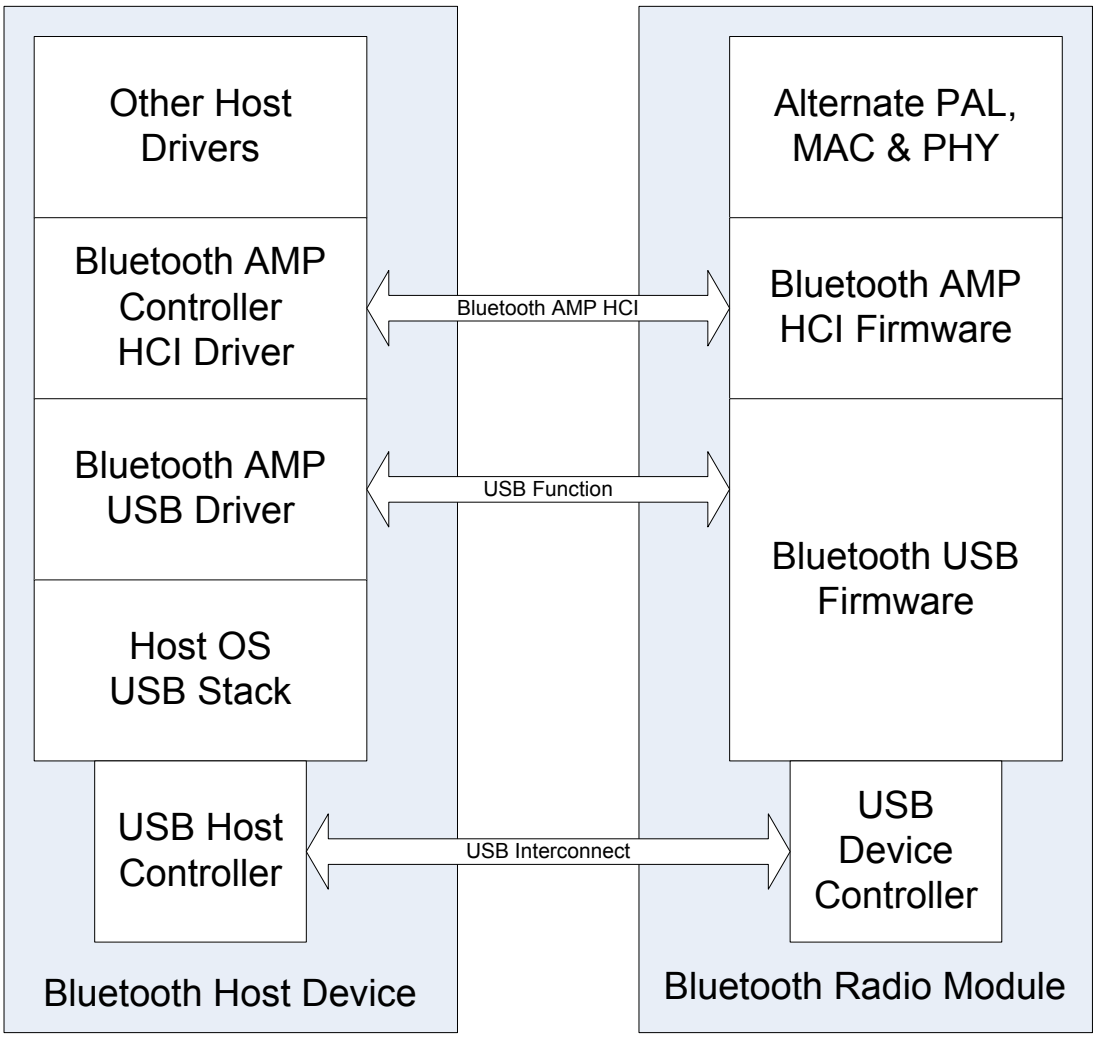

Figure 1.2: Relationship between the Host and an AMP Controller

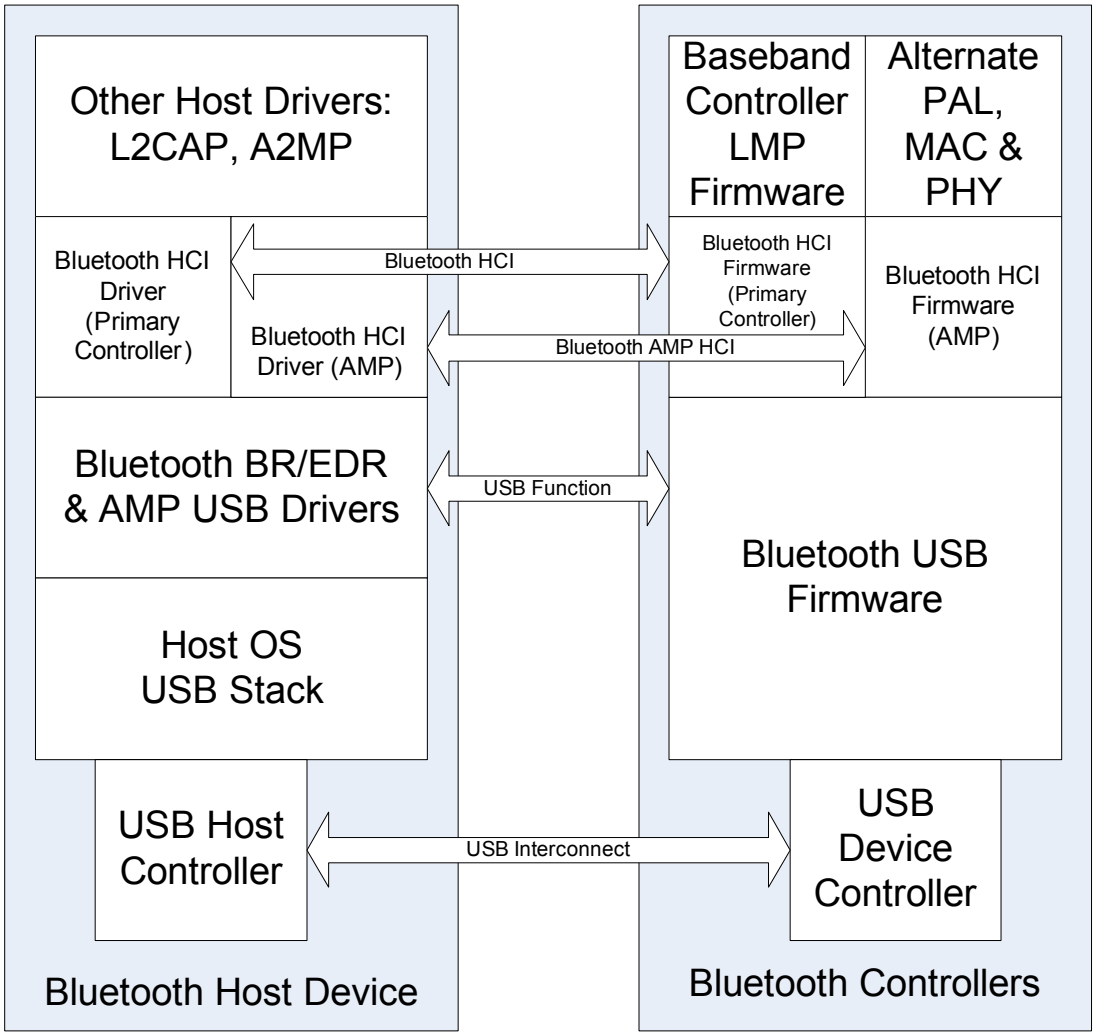

Figure 1.3: Relationship between Host and a Composite BR/EDR and AMP Controller

The USB hardware can be embodied in one of several ways:

1. As a USB dongle (e.g. cabled USB)
2. As a USB module integrated into the product and connected internally via a cable or connector
3. Integrated onto the motherboard of a notebook PC or other device and connected via circuit board traces with standard USB, Inter-Chip USB or High Speed Inter-Chip USB
4. Integrated as a subsystem on a single-chip System-on-Chip (SoC) design connected on-chip as part of a compound device.

Finally, for an overview of the connection that is established between two Bluetooth devices, reference Figure 1.4.

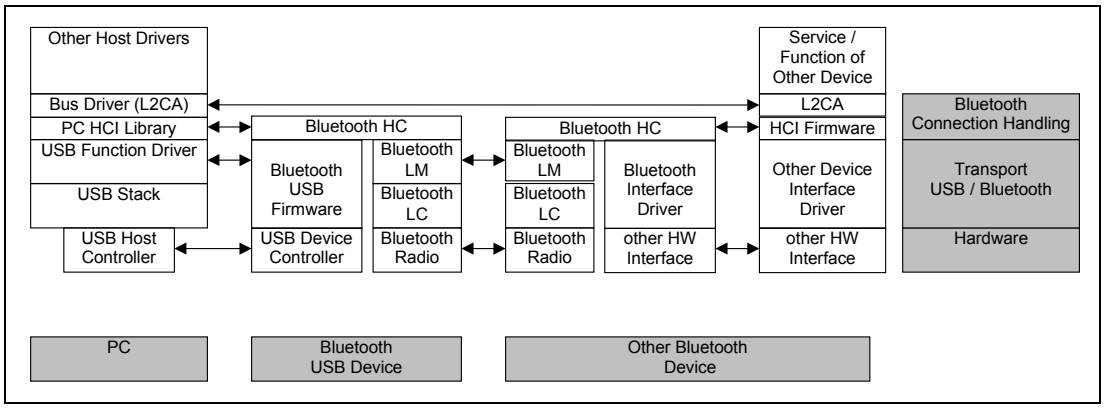

Figure 1.4: Flow of data from one Bluetooth device to another

2 USB ENDPOINT EXPECTATIONS

This section outlines specific USB endpoints that are required in order to function properly with the Host. This section assumes a basic familiarity with USB. The endpoint numbers (labeled ‘Suggested Endpoint Address’ below) may be dynamically recognized upon driver initialization – this depends on the implementation.

2.1 DESCRIPTOR OVERVIEW

The UniversalSerial Bus is intended for high data rates. USB defines several physical layers, ranging from 1.5 Mb/s to several Gb/s of bus bandwidth. A Bluetooth USB device should provide a USB transport with sufficient bus bandwidth to support the Bluetooth radio transports included in the device.

There are two USB Controller types:

- Primary Controller
- AMP Controller

2.1.1 Primary Controller Descriptors

The Primary Controller configuration consists of two interfaces. The first interface has no alternate settings and contains the bulk and interrupt endpoints. The second interface provides scalable isochronous bandwidth. The recommended configuration for the second interface has four alternate settings that provide different bandwidth. The default interface is empty so that the device is capable of scaling down to zero isochronous bandwidth.

An HCI packet consisting of an HCI header and HCI data shall be contained in one USB Transfer. A USB transfer is defined by the USB specification as one or more USB transactions that contain the data from one IO request. For example, an ACL data packet containing 256 bytes (both HCI header and HCI data) would be sent over the bulk endpoint in one IO request. That IO request will require four 64-byte full speed USB Transactions or a single 256-byte High-speed USB Transaction, and forms a Transfer. If the Maximum Packet Size for the endpoint on which the transfer is sent is 64 bytes, then that IO request will require four 64-byte USB transactions.

The endpoints are spread across two interfaces so that when adjusting isochronous bandwidth consumption (via select interface calls), any pending bulk and/or interrupt transactions do not have to be terminated or resubmitted.

Table 2.1 and the following example calculations illustrate recommended endpoint descriptor parameter values and how they are derived. The maximum packet sizes for control endpoints, interrupt endpoints and bulk endpoints may be any value allowed by the relevant USB core specifications. The maximum packet size for isochronous endpoints must be large enough to accommodate

the maximum average traffic; they may be set to accommodate the largest HCI transfer, subject to the capabilities of the Controller. In Table 2.1, the service interval is assumed to be 1 millisecond, for USB Full Speed (FS) frames.

Examples:

1. For a single 8 kHz audio channel with of 64 kb/s CVSD audio the Host may break HCI data into one USB transfers for each USB frame (e.g. 1 ms); in that case, the max packet size must be at least 11 = 3 octet HCI header + 8 octets of data. To reduce HCI header overhead, a common strategy (see Table 2.2) is to consolidate 3 ms of data into a 27 octet HCI packet of 24 octets of data + 3 octets of HCI header. These HCI packets can be exchanged as a single USB transfer on 3 ms intervals; this requires a max packet size of 27/3 = 9 octets per 1 millisecond USB Full Speed Frame.
2. For two 8 kHz audio channels of 64 kb/s CVSD audio the Host may double the payload size of each HCI packet, which would be 3 octets HCI header + 48 octets of data = 51 octets. Posting these at 3 ms intervals requires 51/3 = 17 octets of maximum packet size.
3. For one 16 kHz audio channel the HCI packets need to be large enough to accommodate single octet (128 kb/s) or 2-octet (256 kb/s) encoding. On 3 ms intervals, these would have to be (48+3)/3 = 17 octets or (96+3)/3 = 33 octets respectively.
4. For one mSBC[1] compressed wideband audio channel the HCI packets will be 3 octets of HCI header + 60 octets of data. If the Controller can support a maximum packet size of 63 (or 64) octets, an entire mSBC frame may be exchanged in one USB transaction. If the maximum packet size is smaller than 63 octets, additional latency will be introduced. The USB Host Controller will reserve bandwidth that will only be used when the Bluetooth Host or Controller has data to transfer.
5. For combinations of audio channels, if the max packet size can accommodate the largest HCI packets, there is also sufficient bandwidth for the audio channels that have smaller HCI packets. See example 4 above.

1. For information about modified Sub Band Codec (mSBC), see Hands-Free Profile v1.6 or later

The following table outlines a recommended configuration for a USB Full Speed device.

Interface Number	Alternate Setting	Suggested Endpoint Address	Endpoint Type	Suggested Max Packet Size	USB Polling Interval/HCI Packet Interval
HCI Commands					
N/A	N/A	0x00	Control	8/16/32/64	NA
HCI Events					
0	0	0x81	Interrupt (IN)	16	variable
ACL Data					
0	0	0x82	Bulk (IN)	32/64	variable
0	0	0x02	Bulk (OUT)	32/64	variable
No active voice channels (for USB compliance)					
1	0	0x83	Isoch (IN)	0	NA
1	0	0x03	Isoch (OUT)	0	NA
One 8 kHz voice channel with 8-bit encoding					
1	1	0x83	Isoch (IN)	9	1 ms/3 ms
1	1	0x03	Isoch (OUT)	9	1 ms/3 ms
Two 8 kHz voice channels with 8-bit encoding or one 8 kHz voice channel with 16-bit encoding					
1	2	0x83	Isoch (IN)	17	1 ms/3 ms
1	2	0x03	Isoch (OUT)	17	1 ms/3ms
Three 8 kHz voice channels with 8-bit encoding					
1	3	0x83	Isoch (IN)	25	1 ms/3ms
1	3	0x03	Isoch (OUT)	25	1 ms/3ms
Two 8 kHz voice channels with 16-bit encoding or one 16 kHz voice channel with 16-bit encoding					
1	4	0x83	Isoch (IN)	33	1 ms/3 ms

Table 2.1: USB Primary firmware interface and endpoint settings

Interface Number	Alternate Setting	Suggested Endpoint Address	Endpoint Type	Suggested Max Packet Size	USB Polling Interval/HCI Packet Interval
1	4	0x03	Isoch (OUT)	33	1 ms/3 ms
Three 8 kHz voice channels with 16-bit encoding or one 8 kHz voice channel with 16-bit encoding and one 16 kHz voice channel with 16-bit encoding					
1	5	0x83	Isoch (IN)	49	1 ms/3 ms
1	5	0x03	Isoch (OUT)	49	1 ms/3 ms
One mSBC voice channel					
1	6	0x83	Isoch (IN)	63	1 ms/7.5 ms
1	6	0x03	Isoch (OUT)	63	1 ms/7.5 ms

Table 2.1: USB Primary firmware interface and endpoint settings

The following two examples are used to demonstrate the flow of data given the described endpoints.

Number of voice channels	Duration of voice data	Encoding
One	3 ms per IO Request	8-bit

Time (ms)	USB data (header refers to HCI header) (Receive & Send from the Host)	Queued data (read / write)	Time (ms)	Air data	Amount Received/ Sent (ms)
0	Receive 0 bytes Send 9 bytes (3 header, 6 data)	0 / 6	0	Send 0	0 / 0
		10 / 6	0.625	Receive 10	1.25 / 0
1	Receive 0 bytes Send 9 bytes (9 bytes HCI data)	10 / 15	1.25	Send 0	1.25 / 0
		20 / 15	1.875	Receive 10	2.50 / 0
2	Receive 0 bytes Send 9 bytes (9 bytes HCI data)	20 / 24	2.50	Send 0	2.50 / 0
		30 / 24	3.125	Receive 10	3.75 / 0

Table 2.2: Example USB single-channel voice traffic data flow

Time (ms)	USB data (header refers to HCI header) (Receive & Send from the Host)	Queued data (read / write)	Time (ms)	Air data	Amount Received/ Sent (ms)
3	Receive 9 bytes (3 header, 6 data) Send 9 bytes (3 header, 6 data)	24 / 20	3.75	Send 10	3.75 / 1.25
4	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	25 / 29	4.375	Receive 10	5.0 / 1.25
5	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	16 / 28	5.0	Send 10	5.0 / 2.50
		26 / 28	5.625	Receive 10	6.25 / 2.50
6	Receive 9 bytes (3 header, 6 data) Send 9 bytes (3 header, 6 data)	20 / 24	6.25	Send 10	6.25 / 3.75
		30 / 24	6.875	Receive 10	7.5 / 3.75
7	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	21 / 23	7.5	Send 10	7.5 / 5.0
8	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	22 / 32	8.125	Receive 10	8.75 / 5.0
		22 / 22	8.75	Send 10	8.75 / 6.25
9	Receive 9 bytes (3 header, 6 data) Send 9 bytes (3 header, 6 data)	26 / 28	9.375	Receive 10	10.0 / 6.25
10	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	17 / 27	10	Send 10	10.0 / 7.5
		27 / 27	10.625	Receive 10	11.25 / 7.5
11	Receive 9 bytes (9 bytes data) Send 9 bytes (9 bytes HCI data)	18 / 26	11.25	Send 10	11.25 / 8.75

Table 2.2: Example USB single-channel voice traffic data flow

Convergence is expected because the radio is sending out an average of eight bytes of voice data every one ms and USB is sending eight bytes of voice data every one ms.

Number of voice channels	Duration of voice data	Encoding
Two	3 ms per IO Request	8-bit

Time (ms	USB data (header refers to HCI header) (Receive & Send from the Host)	Queued data (read / write)	Time (ms)	Air data	Amount Received / Sent (ms)
0	Receive 0 bytes for Channel #1 Send 17 bytes (3 header, 14 data) for Channel #1	C1- 0/14 C2- 0/0	0	Send 0 for C1	C1- 0/0 C2- 0/0
		C1- 20/ 14 C2- 0/0	0.625	Receive 20 for C1	C1- 2.5/0 C2- 0/0
1	Receive 0 bytes for Channel #1 Send 17 bytes (17 bytes HCI data) for Channel #1	C1- 20/ 31 C2- 0/0	1.25	Send 0 for C2	C1- 2.5/0 C2- 0/0
		C1- 20/ 31 C2- 20/0	1.875	Receive 20 for C2	C1- 2.5/0 C2- 2.5/0
2	Receive 0 bytes for Channel #1 Send 17 bytes (17 bytes HCI data) for Channel #1	C1- 20/ 28 C2- 20/0	2.50	Send 20 for C1	C1- 2.5/2.5 C2- 2.5/0
		C1- 40/ 28 C2- 0/0	3.125	Receive 20 for C1	C1- 5.0/2.5 C2- 2.5/0
3	Receive 0 bytes for Channel #2 Send 17 bytes (3 header, 14 data) for Channel #2	C1- 40/ 28 C2- 20/ 14	3.75	Send 0 for C2	C1- 5.0/2.5 C2- 2.5/0
4	Receive 0 bytes for Channel #2 Send 17 bytes (17 bytes HCI data) for Channel #2	C1- 40/ 28 C2- 40/ 31	4.375	Receive 20 for C2	C1- 5.0/2.5 C2- 5.0/0
5	Receive 0 bytes for Channel #2 Send 17 bytes (17 bytes HCI data) for Channel #2	C1- 40/8 C2- 40/ 48	5.0	Send 20 for C1	C1- 5.0/5.0 C2- 5.0/0
		C1- 60/8 C2- 40/ 48	5.625	Receive 20 for C1	C1- 7.5/5.0 C2- 5.0/0
6	Receive 17 bytes (3 header, 14 data) for Channel #1 Send 17 bytes (3 header, 14 data) for Channel #1	C1- 46/ 22 C2- 40/ 28	6.25	Send 20 for C2	C1- 7.5/5.0 C2- 5.0/2.5

Table 2.3: Example USB dual-channel voice traffic data flow

Time (ms	USB data (header refers to HCI header) (Receive & Send from the Host)	Queued data (read / write)	Time (ms)	Air data	Amount Received / Sent (ms)
		C1- 46/ 22 C2- 60/ 28	6.875	Receive 20 for C2	C1- 7.5/5.0 C2- 7.5/2.5
7	Receive 17 bytes (17 bytes data) for Channel #1 Send 17 bytes (17 bytes HCI data) for Channel #1	C1- 29/ 19 C2- 60/ 28	7.5	Send 20 for C1	C1- 7.5/7.5 C2- 7.5/2.5
8	Receive 17 bytes (17 bytes data) for Channel #1 Send 17 bytes (17 bytes HCI data) for Channel #1	C1- 32/ 36 C2- 60/ 28	8.125	Receive 20 for C1	C1- 10/7.5 C2- 7.5/2.5
		C1- 32/ 36 C2- 60/8	8.75	Send 20 for C2	C1- 10/7.5 C2- 7.5/5.0
9	Receive 17 bytes (3 header, 14 data) for Channel #2 Send 17 bytes (3 header, 14 data) for Channel #2	C1- 32/ 36 C2- 54/ 22	9.375	Receive 20 for C2	C1- 10/7.5 C2- 10/5.0
10	Receive 17 bytes (17 bytes data) for Channel #2 Send 17 bytes (17 bytes HCI data) for Channel #2	C1- 32/ 16 C2- 37/ 39	10	Send 20 for C1	C1- 10/10 C2- 10/5.0
		C1- 52/ 16 C2- 37/ 39	10.625	Receive 20 for C1	C1- 12.5/ 10 C2- 10/5.0
11	Receive 17 bytes (17 bytes data) for Channel #2 Send 17 bytes (17 bytes HCI data) for Channel #2	C1- 52/ 16 C2- 20/ 36	11.25	Send 20 for C2	C1- 12.5/ 10 C2- 10/7.5

Table 2.3: Example USB dual-channel voice traffic data flow

2.1.2 AMP Controller Descriptors

The AMP Controller configuration consists of one interface. That interface (interface N - see device descriptors) has no alternate settings and contains the bulk and interrupt endpoints.

An HCI packet, consisting of an HCI header and HCI data, shall be contained in one USB transfer.

Interface Number	Alternate Setting	Suggested Endpoint Address	Endpoint Type	Suggested Max Packet Size
HCI Commands				
N/A	N/A	0x00	Control	64
HCI Events				
N	0	0x81	Interrupt (IN)	512
AMP Data				
N	0	0x82	Bulk (IN)	512
N	0	0x02	Bulk (OUT)	512

Table 2.4: USB AMP firmware interface and endpoint settings

NOTE: Endpoint addresses are reported by the device in the Endpoint Descriptors.

2.2 CONTROL ENDPOINT EXPECTATIONS

Endpoint 0 is used to configure and control the USB device. Endpoint 0 will also be used to allow the Host to send HCI-specific commands to the Host Controller. HCI Command packets should be sent with the following parameters:

bmRequestType = 0x20 (Host-to-device class request, device as target)

bRequest = 0x00

wValue = 0x00

wIndex = 0x00

Some Host devices on the market set bRequest to 0xE0. Hence, for historical reasons, if the Bluetooth Controller firmware receives a class request over this endpoint, it should treat the packet as an HCI command packet regardless of the value of bRequest, wValue and wIndex.

All HCI Control Packets delivered to Endpoint 0 are addressed in the Setup Data structure (See 9.3 of [2]). This structure contains fields which determine the destination within the device. The bmRequestType can be used to select the Device or the Interface. If Interface is selected, the wIndex parameter must select the Index for the targeted Bluetooth Controller.

2.2.1 Single Function Primary Controller

For a single function Primary Controller, the Host should address HCI command packets to the Device. HCI command packets should be sent with the following parameters:

Parameter	Value	description
bmRequestType	0x20	Host-to-device class request, device as target
bRequest	0x00	
wValue	0x00	
wIndex	0x00	

Table 2.5: HCI command packet addressing for single-function Primary Controllers

Note: For historical reasons, if the Primary Controller firmware receives a packet over this endpoint, it should treat the packet as an HCI command packet regardless of the value of bRequest, wValue and wIndex. Some Host devices set bRequest to 0xE0.

2.2.2 Primary Controller Function in a Composite Device

For a Primary Controller included in a composite (multi-function) device, the Host should address HCI control packets to the Interface of the Primary Controller. HCI command packets should be sent with the following parameters:

Parameter	Value	description
bmRequestType	0x21	Host-to-Interface class request, interface as target
bRequest	0x00	
wValue	0x00	
wIndex	IF#	This is the actual Interface number within the composite device.

Table 2.6: HCI command packet addressing for composite device Primary Controllers

If the Host system driver addresses USB requests containing HCI command packets to the Device (see Section 2.2.1) instead of to the Interface, the device implementation shall recognize these HCI command packets and correctly route them to the Primary Controller function, to ensure correct operation of the Primary Controller function and avoid malfunctions in other functions contained in the composite device.

2.2.3 AMP Controller

For any AMP Controller, either in a single function device or included in a composite device, the Host shall address HCI control packets to the Interface

of the AMP Controller. HCI command packets shall be sent with the following parameters:

Parameter	Value	description
bmRequestType	0x21	Host-to-Interface class request, interface as target
bRequest	0x2B	Arbitrary value chosen to identify requests targeted to an AMP Controller function.
wValue	0x00	
wIndex	IF#	This is the actual Interface number within the compos-ite device.

Figure 2.1: HCI command packet addressing for single-function AMP Controller

2.3 BULK ENDPOINTS EXPECTATIONS

Data integrity is a critical aspect for ACL data. This, in combination with bandwidth requirements, is the reason for using a bulk endpoint. Multiple 64-byte packets can be shipped per USB Frame (1 millisecond, full speed) or 512-byte packets per USB Microframe (125 microseconds, high-speed), across the bus.

Suggested bulk max packet size is 64 bytes for full-speed, or 512 bytes for high speed.

Bulk has the ability to detect errors and correct them. In order to avoid starvation, a flow control model similar to the shared endpoint model is recommended for the Host Controller.

2.4 INTERRUPT ENDPOINT EXPECTATIONS

An interrupt endpoint is necessary to ensure that events are delivered in a predictable and timely manner. Event packets can be sent across USB with a guaranteed latency.

The interrupt endpoint should have an interval of 1 ms (full speed). For a Controller using USB high-speed the interrupt interval may have an interval of 125 microseconds.

The USB software and firmware requires no intimate knowledge of the events passed to the Host Controller.

2.5 ISOCHRONOUS ENDPOINTS EXPECTATIONS

These isochronous endpoints transfer synchronous data to and from the Host Controller of the radio.

Time is the critical aspect for this type of data. The USB firmware should transfer the contents of the data to the Host Controllers' synchronous FIFOs. If the FIFOs are full, the data should be overwritten with new data.

These endpoints have a one (1) ms interval, as required by Chapter 9 of the USB Specification, Versions 1.0 and 1.1.

The radio is capable of three (3) 64Kb/s voice channels (and can receive the data coded in different ways – 16-bit linear audio coding is the method that requires the most data). A suggested max packet size for this endpoint would be at least 64 bytes. (It is recommended that max packet sizes be on power of 2 boundaries for optimum throughput.) However, if it is not necessary to support three voice channels with 16-bit coding, 32 bytes could also be considered an acceptable max packet size.

3 CLASS CODE

A class code will be used that is specific to all USB Bluetooth devices. This will allow the proper driver stack to load, regardless of which vendor built the device.

3.1 BLUETOOTH CODES

The values shown in the following tables shall be used in the Device Descriptor for Bluetooth Controller devices with USB HCI transport.

Code	Label	Value	Description
Class	bDeviceClass	0xE0	Wireless Controller
Subclass	bDeviceSubClass	0x01	RF Controller
Protocol	bDeviceProtocol	0x01	Bluetooth Primary Controller

Table 3.1: USB Codes for Primary Controllers

Code	Label	Value	Description
Class	bDeviceClass	0xE0	Wireless Controller
Subclass	bDeviceSubClass	0x01	RF Controller
Protocol	bDeviceProtocol	0x04	Bluetooth AMP Controller

Table 3.2: USB Codes for AMP Controllers

These values should also be used in the interface descriptors for the interfaces described in Section 2.1 and as described in the following sections.

3.1.1 Single Function Primary Controller

Set the Class, Subclass, and Protocol values for the Device Descriptor and for each Interface Descriptor which applies to the Primary Controller as defined in Table 3.1.

3.1.2 Single Function AMP Controller

Set the Class, Subclass, and Protocol values for the Device Descriptor and for each Interface Descriptor which applies to the AMP Controller as defined in Table 3.2.

3.1.3 Composite Bluetooth Primary and AMP Controller

Set the Class, Subclass, and Protocol values for the Device Descriptor as defined in the USB Interface Association Descriptor (IAD) ECN.

Set the Class, Subclass, and Protocol values for each Interface Descriptor which applies to the Primary Controller as defined in Table 3.1.

Code	Label	Value	Description
Class	bDeviceClass	0xEF	Miscellaneous
Subclass	bDeviceSubClass	0x02	Common Class
Protocol	bDeviceProtocol	0x01	Interface Association Descriptor

Table 3.3: USB Codes for composite devices using IAD

Set the Class, Subclass, and Protocol values for the each Interface Descriptor which applies to the AMP Controller as defined in Table 3.2.

3.1.4 Composite Device Including Bluetooth Primary and AMP Controller

Set the Class, Subclass, and Protocol values for the Device Descriptor to as defined in Table 3.3.

Set the Class, Subclass, and Protocol values for each Interface Descriptor which applies to the Primary Controller as defined in Table 3.1.

Set the Class, Subclass, and Protocol values for the each Interface Descriptor which applies to the AMP Controller as defined in Table 3.2.

4 DEVICE FIRMWARE UPGRADE

Firmware upgrade capability is not a required feature. If implemented, the firmware upgrade should be compliant with the “Universal Serial Bus Device Class Specification for Device Firmware Upgrade” (version 1.1 or later) available on the USB Forum web site at http://www.usb.org.

5 LIMITATIONS

5.1 POWER SPECIFIC LIMITATIONS

Some USB Host Controllers in portable devices will not receive power while the system is in a sleep mode. For example, many PCs do not supply power to the USB port in system power states S3 or S4, as defined in ACPI. Hence, USB wake-up can only occur when the system is in S1 or S2. Furthermore, all connections and state information of the USB Bluetooth Controller will be lost in the system sleep state if power is lost necessitating re-initialization when the device returns to the active state.

Some USB Host Controllers further continually snoop memory when a device is attached to see if there is any work that needs to be done. The snoop is typically performed every 1ms for USB full-speed devices. This prevents the processor from dropping into a low power state known as C3. Because the processor is not able to enter the C3 state, significant power consumption may occur. This is a major concern for battery-powered Hosts such notebook computers. Some Host Controllers are capable of scheduling polling of USB devices at short intervals while snooping the Host's memory much less frequently. Systems with such Host Controllers may be able to greatly increase the percentage of time spent in the C3 state even if Bluetooth connections are maintained.

A feature called Link Power Management is also recommended for implementation by Bluetooth devices. It is described in an ECN (Engineering Change Notice) from the USB Implementers' Forum.

5.2 OTHER LIMITATIONS

Data corruption may occur across isochronous endpoints. Endpoints one and two may suffer from data corruption.

USB provides 16-CRC on all data transfers. The USB has a bit error rate of 10^{-13}.

Note that when a dongle is removed from the system, the radio will lose power (assuming this is a bus-powered device). This means that devices will lose connection.

6 BLUETOOTH COMPOSITE DEVICE IMPLEMENTATION

A USB Composite contains multiple independent functions. This section describes how to implement Bluetooth functions within a USB Composite device. This may require the use of Interface Association Descriptors (IAD) to aggregate multiple Interfaces. This also requires the Host to address USB requests to the specific Interface (see [1]).

6.1 CONFIGURATIONS

There are several ways that Bluetooth Controller functions may be included in a USB composite device:

- Primary Controller and AMP Controller (see Section 6.3)
- Primary Controller in a multi-radio device
- Primary Controller in a device also containing non-radio functions (e.g. memory)
- AMP Controller in a multi-radio device

6.2 USING USB INTERFACE ASSOCIATION DESCRIPTORS FOR A PRIMARY CONTROLLER FUNCTION

A Primary Controller ([Vol 1] Part A, Section 2) shall contain at least two interfaces:

- HCI Events and ACL data (3 endpoints)
- HCI SCO data (2 endpoints, multiple alternate settings)

A Primary Controller may also contain

- Device Firmware Upgrade (see [2])

When used in a USB Composite device, a Primary Controller function shall use an IAD descriptor to associate the provided interfaces. The following is an example IAD for a Primary function without Device Firmware Upgrade:

- It would be contained within a Configuration Descriptor set.
- It would be followed by two Interface Descriptors and associated Endpoint Descriptors.

Offset	Field	Size	Value	Description
0	bLength	1	0x08	Size of this descriptor in octets
1	bDescriptorType	1	0x0B	INTERFACE ASSOCIATION DESCRIPTOR

Table 6.1: Example Interface Association Descriptor used for a Primary Controller function

Offset	Field	Size	Value	Description
2	bFirstInterface	1	number	Interface number of the first interface associated with this device
3	bInterfaceCount	1	0x02	Number of contiguous interfaces associated with the function
4	bFunctionClass	1	0xE0	Wireless Controller
5	bFunctionSubClass	1	0x01	RF Controller
6	bFunctionProtocol	1	0x01	Bluetooth Primary Controller
7	iFunction	1	Index	Pointer to a name string for this function, if any is provide

Table 6.1: Example Interface Association Descriptor used for a Primary Controller function

6.3 COMBINED PRIMARY CONTROLLER FUNCTION AND SINGLE AMP CONTROLLER FUNCTION

An AMP Controller (see Volume 5) shall contain at least one interface:

- HCI Events and ACL Data (3 endpoints)

An AMP Controller may also contain

- Device Firmware Upgrade (see [2])

When used in a USB Composite device, an AMP Controller does not need IAD. If the device contains the Device Firmware Upgrade option as a separate Device function, an IAD is not needed. If the Device Firmware Upgrade option is bundled with the AMP Controller function, then an IAD is needed to bind the two interfaces.

A USB Composite device containing only a Primary Controller and an AMP Controller may include a Configuration Descriptor set with the following structure:

Offset	Field	Size	Value	Description
Configuration Descriptor				
0	bLength	1	0x09	Configuration Descriptor size
1	bDescriptorType	1	0x02	CONFIGURATION DESCRIPTOR
2	wTotalLength	2		Size of the entire bundle

Table 6.2: Example Configuration Descriptor used for a composite Primary and AMP Controller device

Offset	Field	Size	Value	Description
4	bNumInterfaces	1	0x03	Three Interfaces: IF#1 Primary events & ACL IF#2 Primary SCO or eSCO IF#3 AMP events & ACL
5	bConfigurationValue	1	0x01	
6	iConfiguration	1	Index	Reference to a string describing this.
7	bmAttributes	1		Attributes bitmap
8	MaxPower	1	0xFA	500 mA (i.e. 0xFA * 2 mA)
Interface Association Descriptor				
0	bLength	1	0x08	Interface Association Descriptor size
1	bDescriptorType	1	0x0B	INTERFACE ASSOCIATION DESCRIPTOR
2	bFirstInterface	1	IF#1	Interface number of the first interface associated with this device.
3	bInterfaceCount	1	0x03	Number of contiguous interfaces associated with the function.
4	bFunctionClass	1	0xE0	Wireless Controller
5	bFunctionSubClass	1	0x01	RF Controller
6	bFunctionProtocol	1	0x01	Bluetooth Primary Controller
7	iFunction	1	Index	Pointer to a name string for this function, if any is provided.
Primary Events & ACL Interface				
0	bLength	1	0x09	
1	bDescriptorType	1	0x04	INTERFACE DESCRIPTOR
2	bInterfaceNumber	1	IF#1	This is the first interface in the device.
3	bAlternateSetting	1	0x00	This is the first setting for this interface.
4	bNumEndpoints	1	0x03	INT, Bulk OUT (ACL), Bulk IN (ACL)
5	bFunctionClass	1	0xE0	Wireless Controller
6	bFunctionSubClass	1	0x01	RF Controller
7	bFunctionProtocol	1	0x01	Bluetooth Primary Controller
8	iInterface	1	Index	Pointer to a name string for this interface, if any is provided.
	Details omitted	*varies*		INT ENDPOINT DESCRIPTOR
	Details omitted	*varies*		BULK OUT ENDPOINT DESCIPTOR

Table 6.2: Example Configuration Descriptor used for a composite Primary and AMP Controller device

Offset	Field	Size	Value	Description
	Details omitted	*varies*		BULK IN ENDPOINT DESCIPTOR
Primary Controller SCO Interface				
0	bLength	1	0x09	
1	bDescriptorType	1	0x04	INTERFACE DESCRIPTOR
2	bInterfaceNumber	1	IF#2	This is the second interface in the device.
3	bAlternateSetting	1	0x00	This is the first setting for this interface.
4	bNumEndpoints	1	0x02	Isoch OUT (SCO), Isoch IN (SCO)
5	bFunctionClass	1	0xE0	Wireless Controller
6	bFunctionSubClass	1	0x01	RF Controller
7	bFunctionProtocol	1	0x01	Bluetooth Primary Controller
8	iInterface	1	Index	Pointer to a name string for this interface, if any is provided.
	Details omitted	*varies*		ISOCH OUT ENDPOINT DESCRIPTOR
	Details omitted	*varies*		ISOCH IN ENDPOINT DESCRIPTOR
AMP Controller: Events & ACL Interface				
0	bLength	1	0x09	
1	bDescriptorType	1	0x04	INTERFACE DESCRIPTOR
2	bInterfaceNumber	1	IF#3	This is the third interface in the device.
3	bAlternateSetting	1	0x00	This is the first setting for this interface.
4	bNumEndpoints	1	0x03	INT, Bulk OUT (ACL), Bulk IN (ACL)
5	bFunctionClass	1	0xE0	Wireless Controller
6	bFunctionSubClass	1	0x01	RF Controller
7	bFunctionProtocol	1	0x04	Bluetooth AMP Controller
8	iInterface	1	Index	Pointer to a name string for this interface, if any is provided.
	Details omitted	*varies*		INT ENDPOINT DESCRIPTOR
	Details omitted	*varies*		BULK OUT ENDPOINT DESCIPTOR
	Details omitted	*varies*		BULK IN ENDPOINT DESCIPTOR

Table 6.2: Example Configuration Descriptor used for a composite Primary and AMP Controller device

7 REFERENCES

[1] USB 2.0, http://www.usb.org/developers/docs/docs, including:
1. Interface Association Descriptors ECN
2. Inter-Chip USB Supplement 1.0
3. High Speed Inter-Chip USB Supplement 1.0
4. Link Power Management 1.0

[2] USB Device Firmware Upgrade 1.1

SECURE DIGITAL (SD) TRANSPORT LAYER

This document describes the SD transport layer (between the Host and Controller). HCI command, event and data packets flow through this layer, but the layer does not decode them. The Bluetooth SD Transport layer is defined in a document owned and maintained by the Secure Digital Association. Information regarding that document is described herein.

CONTENTS

1 INTRODUCTION

This document discusses the requirements of the Secure Digital (SD) interface for Bluetooth hardware. Readers should be familiar with SD, SD design issues, and the overall Bluetooth architecture. The reader should also be familiar with the Bluetooth Host Controller Interface.

The SD Bluetooth Protocol is documented in the SDIO Card Type-A Specification for Bluetooth, which is owned and maintained by the Secure Digital Association (SDA). The full specification is available to members of the SDA that have signed all appropriate SD NDA and license requirements. The SDA also makes a Non-NDA version available, the Simplified Version of: SDIO Card Type-A Specification for Bluetooth. There are no changes to the SDA document to comply with the requirements of the Bluetooth SIG.

2 GOALS

2.1 HARDWARE GOALS

The Bluetooth SD transport interface specification is designed to take advantage of both the SD Physical Transport bus and the packet orientation of the Bluetooth HCI protocol. Thus, all data is transferred in blocks as packets. Since the block size used on the SD bus may be smaller than the HCI packet, a segmentation and recombination protocol is defined.

SDIO [2] provides different data rate options, including different bit path widths and clock rates. Systems using SDIO should choose options that provide sufficient bandwidth to support the needs of the Controller, both for device control (HCI commands and events) and for data (ACL, SCO).

The specification supports SDIO-connected Controller:

- Primary Controller
- AMP Controller
- Multifunction Controller incorporating some combination of Primary and AMP Controllers.

2.2 SOFTWARE GOALS

The Bluetooth SD transport interface specification is designed for non-embedded solutions. It is assumed that the Host software does not necessarily have a priori knowledge of the SD Bluetooth device.

The interface is not designed for embedded applications where much of the information passed via the interface is known in advance.

The SDA also defines a Bluetooth interface for embedded applications where the Controller contains protocol layers above HCI (RFComm, SDP etc.). This specification is called SDIO Card Type-B Specification for Bluetooth. Information about this specification can be obtained from the SDA:

http://www.sdcard.org.

2.3 CONFIGURATION GOALS

The SDIO Card Specification [2] defines SDIO Standard Function Codes in Table 6-4:

0x2 This function supports the SDIO Type-A for Bluetooth standard interface

0x3 This function supports the SDIO Type-B for Bluetooth standard interface

0x9 This function supports the SDIO Type-A for Bluetooth AMP standard interface

The SDIO Card Type-A Specification for Bluetooth [3] specifies how to implement a Primary Controller. Table 2.1 defines Service ID codes to route HCI messages (codes 0x01 - 0x04). An AMP Controller shall conform to [3] except for one Service ID code:

SDIO Type-A service ID	Primary Controller	AMP Controller
0x00	reserved for future use	reserved for future use
0x01	HCI Command Packet	HCI Command Packet
0x02	ACL Data	ACL Data: Best Effort and Guaranteed Logical Links
0x03	SCO Data	reserved for future use
0x04	HCI Event Packet	HCI Event Packet
0x05-0xFF	Reserved as per [3]	Reserved as per [3]

Table 2.1: Bluetooth SDIO Controller Service ID codes

2.4 CONFIGURATION FOR MULTIPLE CONTROLLERS

An SDIO device may contain one or more Controllers as defined in [3]. These Controller functions shall conform to the requirements of [2] section 6.12.

3 PHYSICAL INTERFACE DOCUMENTS

This specification references the SD SDIO Card Type-A Specification for Bluetooth. This SDA document defines the Bluetooth HCI for all SD devices that support an HCI level interface. Any SD Bluetooth device claiming compliance with the SD Bluetooth Transport must support this interface and additionally adhere to its device type specification, which is set by the Secure Digital Association. The SDIO Card Type-A Specification for Bluetooth document is based on the SDIO Card Specification, which in turn is based on the SD Memory Card Specification: Part 1 Physical Layer Specification. All of these documents are copyrighted by the SDA and are available ONLY to SDA member companies that have signed the appropriate NDA documents with the SDA. As an introduction to the SD Bluetooth Type A specification, the SDA has created 'Simplified' versions of each of these documents. The simplified versions do not contain enough information to fully implement a device, however they do contain enough information to convey the structure and intent of the specifications.

Applicable SDA Documents available to members of the SDA:

SD Memory Card Specification: Part 1 Physical Layer Specification

SDIO Card Specification

SDIO Card Type-A Specification for Bluetooth.

Applicable Simplified SDA Documents available to non-members and members of the SDA:

Simplified Version of: SD Memory Card Specification: Part 1 Physical Layer Specification

Simplified Version of: SDIO Card Specification:

Simplified Version of: SDIO Card Type-A Specification for Bluetooth

More information on the Secure Digital Association and the SD specifications can be found at the SDA website at. http://www.sdcard.org.

4 COMMUNICATION

4.1 OVERVIEW

Figure 4.1 below is a diagram of the communication interface between a Bluetooth SD device and the Bluetooth Host protocol stack. Modifications to this diagram might be needed for operating systems that do not support a miniport model:

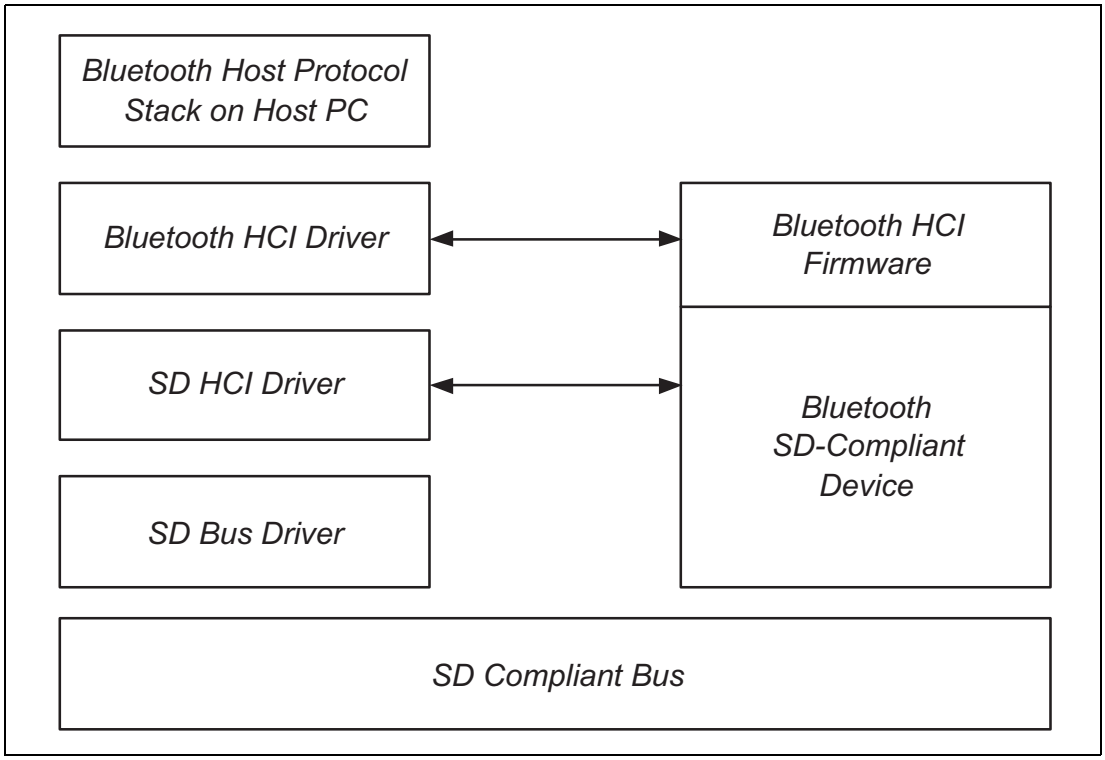

Figure 4.1: SD Communication Diagram

APPENDIX A ACRONYMS AND ABBREVIATIONS

Acronym	Description
HCI	Host Controller Interface
NDA	Non-Disclosure Agreement
OS	Operating System
SD	Secure Digital
SDA	Secure Digital Association
SDIO	Secure Digital Input/Output
SDP	Service Discovery Protocol
SIG	Special Interest Group

Table 4.1: Acronyms and Abbreviations

APPENDIX B RELATED DOCUMENTS

A) Bluetooth Core Specification v1.2 or later.

B) Applicable SDA Documents available to members of the SDA:

[1] B.1) SD Memory Card Specification: Part 1 Physical Layer Specification

[2] B.2) SDIO Card Specification

[3] B.3) SDIO Card Type-A Specification for Bluetooth

[4] B.4) SDIO Card Type-B Specification for Bluetooth

[5] B.5) SDIO Card Physical Test Specification

[6] B.5) SDIO Host Physical Test Specification

[7] B.6) SD Bluetooth Type A Test Specification

These documents are available to members of the SDA in the "Members Only" section of the SDA web site (https://www.sdcard.org/members/). See http://www.sdcard.org/developers/join/ for information on joining the SDA..

C) Applicable Simplified SDA Documents available to non-members and members of the SDA:

C.1) Simplified Version of: SD Memory Card Specification:
Part 1 Physical Layer Specification
https://www.sdcard.org/downloads/pls/

C.2) Simplified Version of: SDIO Card Specification
https://www.sdcard.org/downloads/pls/

C.3) Simplified Version of: SDIO Card Type-A Specification for Bluetooth
https://www.sdcard.org/downloads/pls/

APPENDIX C TESTS

The SDA has defined formal test procedures for SDIO Type A Bluetooth cards (Controller) and Hosts. It is expected that both Controllers and Hosts will comply with all test requirements set forth by the SDA in accordance with the rules of the SDA. The Bluetooth SIG does not require any formal testing to comply with SIG requirements. The test document names are listed in Appendix B.

C.1 TEST SUITE STRUCTURE

There are two types of tests defined for the HCI SD Transport Layer:

1. Functional Tests
2. Protocol Tests

Tests of both types are defined for both the Host and Controller.

The purpose of the functional tests is to verify that the SD Bluetooth Type A Specification, SDIO Standard and SD Physical Standard have been implemented according to the specifications. These tests and the test environment for these tests are defined in documents provided by the SDA.

The purpose of the protocol tests are to verify that the Bluetooth Controller SD implementation or the Host implementation are according to the SD Bluetooth Type A specification.

The test environment for the protocol tests consists of the tester and the Device Under Test (DUT) as illustrated in Figure C.1 below.

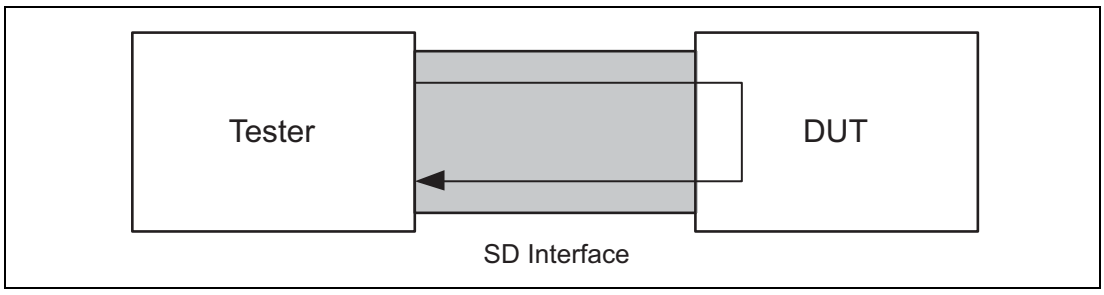

Figure C.1: Protocol Test Environment

The tester is typically a PC with an SD interface. The DUT is placed into local loopback mode and standard HCI commands are used to drive the tests. The test results are verified in the tester.

THREE-WIRE UART TRANSPORT LAYER

This document describes the Three-Wire UART transport layer (between the Host and Controller). HCI command, event and data packets flow through this layer, but the layer does not decode them.

CONTENTS

1 GENERAL

The HCI Three-Wire UART Transport Layer makes it possible to use the Bluetooth HCI over a serial interface between two UARTs. The HCI Three-Wire UART Transport Layer assumes that the UART communication may have bit errors, overrun errors or burst errors. See also Part A, UART Transport Layer.

2 OVERVIEW

The HCI Three-Wire UART Transport Layer is a connection based protocol that transports HCI commands, events, ACL and Synchronous packets between the Host and the Controller. Packet construction is in done in two steps. First, it adds a packet header onto the front of every HCI Packet which describes the payload. Second, it frames the packets using a SLIP protocol. Finally, it sends this packet over the UART interface.

The SLIP layer converts an unreliable octet stream into an unreliable packet stream. The SLIP layer places start and end octets around the packet. It then changes all occurrences of the frame start or end octet in the packet to an escaped version.

The packet header describes the contents of the packet, and if this packet needs to be reliably transferred, a way of identifying the packet uniquely, allowing for retransmission of erroneous packets.

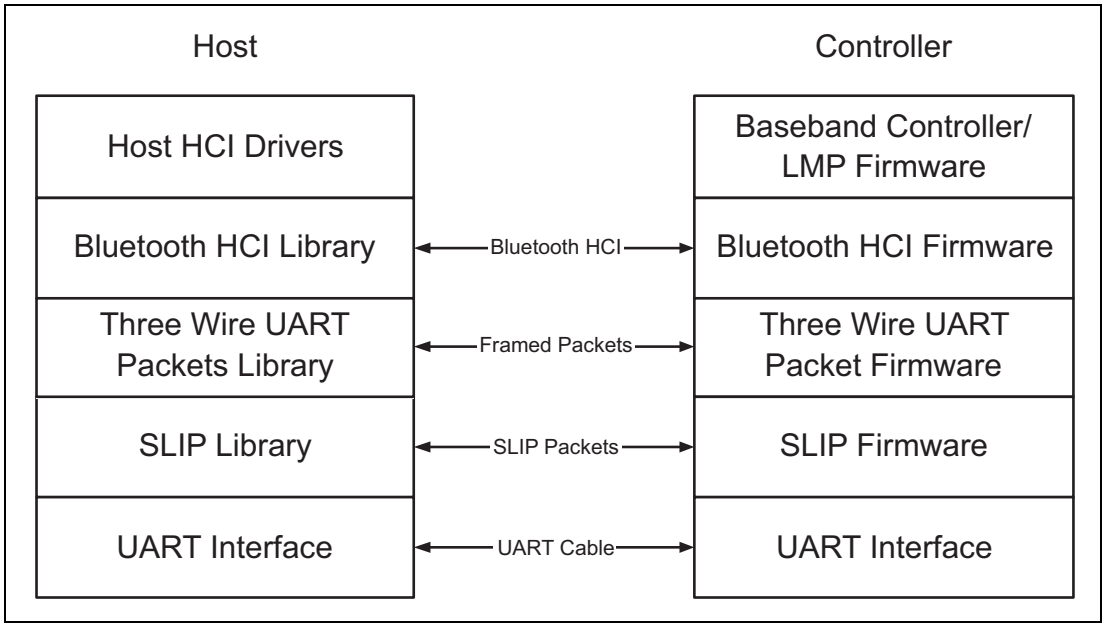

Figure 2.1: The Relationship Between the Host and the Controller

3 SLIP LAYER

The SLIP layer places packet framing octets around each packet being transmitted over the Three-Wire UART Transport Layer. This delimits the packets and allows packet boundaries to be detected if the receiver loses synchronization. The SLIP layer is based upon the RFC 1055 Standard [1].

3.1 ENCODING A PACKET

The SLIP layer performs octet stuffing on the octets entering the layer so that specific octet codes which may occur in the original data do not occur in the resultant stream.

The SLIP layer places octet 0xC0 at the start and end of every packet it transmits. Any occurrence of 0xC0 in the original packet is changed to the sequence 0xDB 0xDC before being transmitted. Any occurrence of 0xDB in the original packet is changed to the sequence 0xDB 0xDD before being transmitted. These sequences, 0xDB 0xDC and 0xDB 0xDD are SLIP escape sequences. All SLIP escape sequences start with 0xDB. All SLIP escape sequences are listed in Table 3.1.

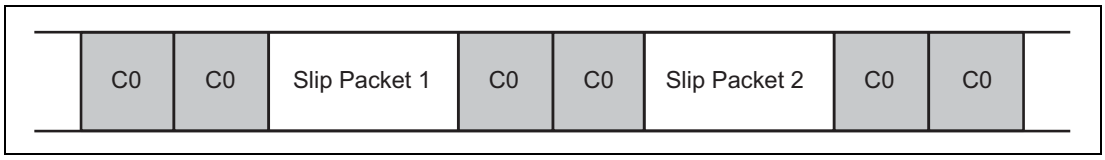

Figure 3.1: SLIP Packets with 0xC0 at the Start and End of Each Packet

3.2 DECODING A PACKET

When decoding a SLIP stream, a device will first be in an unknown state, not knowing if it is at the start of a packet or in the middle of a packet. The device must therefore discard all octets until it finds a 0xC0. If the 0xC0 is followed immediately by a second 0xC0, then the device will discard the first 0xC0 as it was presumably the end of the last packet, and the second 0xC0 was the start of the next packet. The device will then be in the decoding packet state. It can then decode the octets directly changing any SLIP escape sequences back into their unencoded form. When the device decodes the 0xC0 at the end of the packet, it will calculate the length of the SLIP packet, and pass the packet data into the packet decoder. The device will then seek the next packet. If the device does not receive an 0xC0 for the start of the next packet, then all octets up to and including the next 0xC0 will be discarded.

SLIP Escape Sequence	Unencoded form	Notes
0xDB 0xDC	0xC0	
0xDB 0xDD	0xDB	
0xDB 0xDE	0x11	Only valid when OOF Software Flow Control is enabled
0xDB 0xDF	0x13	Only valid when OOF Software Flow Control is enabled

Table 3.1: SLIP Escape Sequences

4 PACKET HEADER

Every packet that is sent over the Three-Wire UART Transport Layer has a packet header. It also has an optional Data Integrity Check at the end of the payload. The Transport Layer does not support packet segmentation and reassembly. Each transport packet will contain at most one higher layer packet.

A packet consists of a Packet Header of 4 octets, a Payload of 0 to 4095 octets, and an optional Data Integrity Check of 2 octets. See Figure 4.1.

The Packet header consists of a Sequence Number of 3 bits, an Acknowledge Number of 3 bits, a Data Integrity Check Present bit, a Reliable Packet bit, a Packet Type of 4 bits, a Payload Length of 12 bits and an 8 bit Header Checksum. See Figure 4.2.

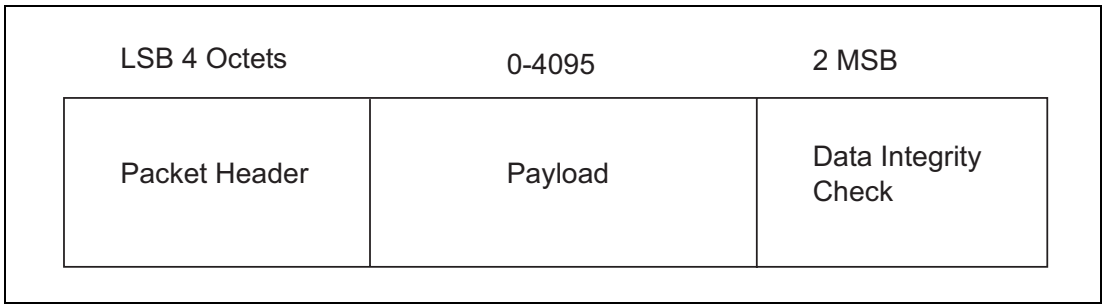

Figure 4.1: Packet Format

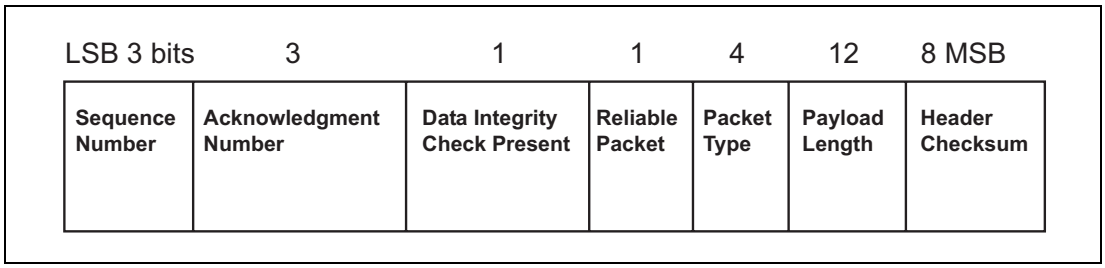

Figure 4.2: Packet Header Format

4.1 SEQUENCE NUMBER

For unreliable packets this field will be set to 0 on transmit and ignored on receive.

Each new reliable packet will be assigned a sequence number which will be equal to the sequence number of the previous reliable packet plus one modulo eight. A packet will use the same sequence number each time it is retransmitted.

4.2 ACKNOWLEDGE NUMBER

The acknowledge number must be set to the sequence number of the next reliable packet this device expects to receive. See Section 6.4.

4.3 DATA INTEGRITY CHECK PRESENT

If a 16 bit CCITT-CRC Data Integrity Check is appended to the end of the payload, this bit shall be set to 1.

4.4 RELIABLE PACKET

If this bit it set to 1, then this packet is reliable. This means that the sequence number field is valid, and the receiving end must acknowledge its receipt. If this bit is set to 0, then this packet is unreliable.

4.5 PACKET TYPE

There are four kinds of HCI packets that can be sent via the Three-Wire UART Transport Layer; these are HCI Command Packet, HCI Event Packet, HCI ACL Data Packet and HCI Synchronous Data Packet (see “Host Controller Interface Functional Specification” in the Bluetooth Core Specification v1.2 or later). HCI Command Packets can be sent only to the Controller, HCI Event Packets can be sent only from the Controller, and HCI ACL/ Synchronous Data Packets can be sent both to and from the Controller.

HCI packet coding does not provide the ability to differentiate the four HCI packet types. Therefore, the Packet Type field is used to distinguish the different packets. The acceptable values for this Packet Type field are given in Table 4.1.

HCI Packet Type	Packet Type
Acknowledgment Packets	0
HCI Command Packet	1
HCI ACL Data Packet	2
HCI Synchronous Data Packet	3
HCI Event Packet	4
Reserve	5-13
Vendor Specific	14
Link Control Packet	15

Table 4.1: Three-Wire UART Packet Type

HCI Command Packets, HCI ACL Data Packets and HCI Event Packets are always sent as reliable packets. HCI Synchronous Data Packets are sent as unreliable packets unless HCI Synchronous Flow Control is enabled, in which case they are sent as reliable packets.

In addition to the four HCI packet types, other packet types are defined. One packet type is defined for pure Acknowledgment Packets, and one additional packet type is to support link control. One packet type is made available to vendors for their own use. All other Three-Wire UART Packet Types are reserved for future use.

4.6 PAYLOAD LENGTH

The payload length is the number of octets in the payload data. This does not include the length of the packet header, or the length of the optional data integrity check.

4.7 PACKET HEADER CHECKSUM

The packet header checksum validates the contents of the packet header against corruption. This is calculated by setting the Packet Header Checksum to a value such that the 2’s complement sum modulo 256 of the four octets of the Packet Header including the Packet Header Checksum is 0xFF.

5 DATA INTEGRITY CHECK

The Data Integrity Check field is optional. It can be used to ensure that the packet is valid. The Data Integrity Check field is appended onto the end of the packet. Each octet of the Packet Header and Packet Payload is used to compute the Data Integrity Check.

5.1 16 BIT CCITT-CRC

The CRC is defined using the CRC-CCITT generator polynomial

$g(D) = D^{16} + D^{12} + D^5 + 1$

(see Figure 5.1)

The CRC shift register is filled with 1s before calculating the CRC for each packet. Octets are fed through the CRC generator least significant bit first.

The most significant parity octet is transmitted first (where the CRC shift register is viewed as shifting from the least significant bit towards the most significant bit). Therefore, the transmission order of the parity octets within the CRC shift register is as follows:

x[8] (first), x[9],..., x[15], x[0], x[1],..., x[7] (last)

where x[15] corresponds to the highest power CRC coefficient and x[0] corresponds to the lowest power coefficient.

The switch S shall be set in position 1 while the data is shifted in. After the last bit has entered the LFSR, the switch shall be set in position 2, and the registers contents shall be read out for transmission.

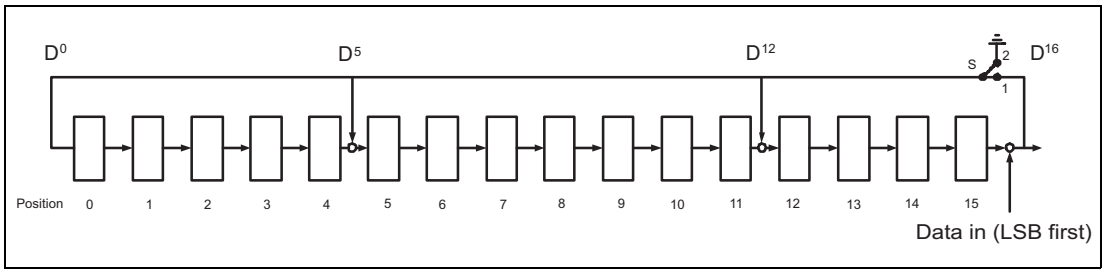

Figure 5.1: The LFSR Circuit Generating the CRC

6 RELIABLE PACKETS

To allow the reliable transmission of packets through the transport, a method needs to be defined to recover from packet errors. The Host or Controller can detect a number of different errors in the packet.

6.1 HEADER CHECKSUM ERROR

The header of the packet is protected by a Packet Header Checksum. If the 2's complement sum modulo 256 of the four octets of the header is not 0xFF, then the packet has an unrecoverable error and all information contained in the packet shall be discarded.

6.2 SLIP PAYLOAD LENGTH ERROR

The length of the SLIP packet shall be checked against the Packet Payload Length. If the Data Integrity Check Present bit is set to 1, then the SLIP packet length should be 6 + Packet Payload Length. If the Data Integrity Check Present bit is set to 0, then the SLIP packet length should be 4 + Packet Payload Length. If this check fails, then all information contained in the packet shall be discarded. The SLIP packet length is the length of the data received from the SLIP layer after the SLIP framing, and SLIP escape codes have been processed.

6.3 DATA INTEGRITY CHECK ERROR

The packet may have a Data Integrity Check at the end of the payload. This is controlled by the Data Integrity Check Present bit in the header. If this is set to 1, then the Data Integrity Check at the end of the payload is checked. If this is different from the value expected, then the packet shall be discarded. If the link is configured to not use data integrity checks, and a packet is received with the Data Integrity Check Present bit set to 1, then the packet shall be discarded.

6.4 OUT OF SEQUENCE PACKET ERROR

Each device keeps track of the sequence number it expects to receive next. This will be one more than the sequence number of the last successfully received reliable packet, modulo eight. If a reliable packet is received which has the expected sequence number, then this packet shall be accepted.

If a reliable packet is received which does not have the expected sequence number, then the packet shall be discarded.

6.5 ACKNOWLEDGMENT

Whenever a reliable packet is received, an acknowledgment shall be generated.

If a packet is available to be sent, the Acknowledgment Number of that packet shall be updated to the latest expected sequence number.

If a requirement to send an acknowledgment value is pending, but there are no other packets available to be sent, the device can send a pure Acknowledgment Packet. This is an Unreliable Packet, with the Packet Type set to 0, Payload Length set to 0, and the Sequence Number set to 0. The Acknowledge Number must be set correctly.

The maximum number of reliable packets that can be sent without acknowledgment defines the sliding window size of the link. This is configured during link establishment. See Sections 8.6, 8.7 and 8.8.

6.6 RESENDING PACKETS

A Reliable Packet shall be resent until it is acknowledged. Devices should refrain from resending packets too quickly to avoid saturating the link with retransmits. See Section 12.1.2.

6.7 EXAMPLE RELIABLE PACKET FLOW

Figure 6.1 shows the transmission of reliable packets between two devices. Device A sends a packet with a Sequence Number of 6, and an Acknowledgment Number of 3. Device B receives this packet correctly, so needs to generate an acknowledgment. Device B then sends a packet with Sequence Number 3 with its Acknowledgment Number set to the next expected packet Sequence Number from Device A of 7.

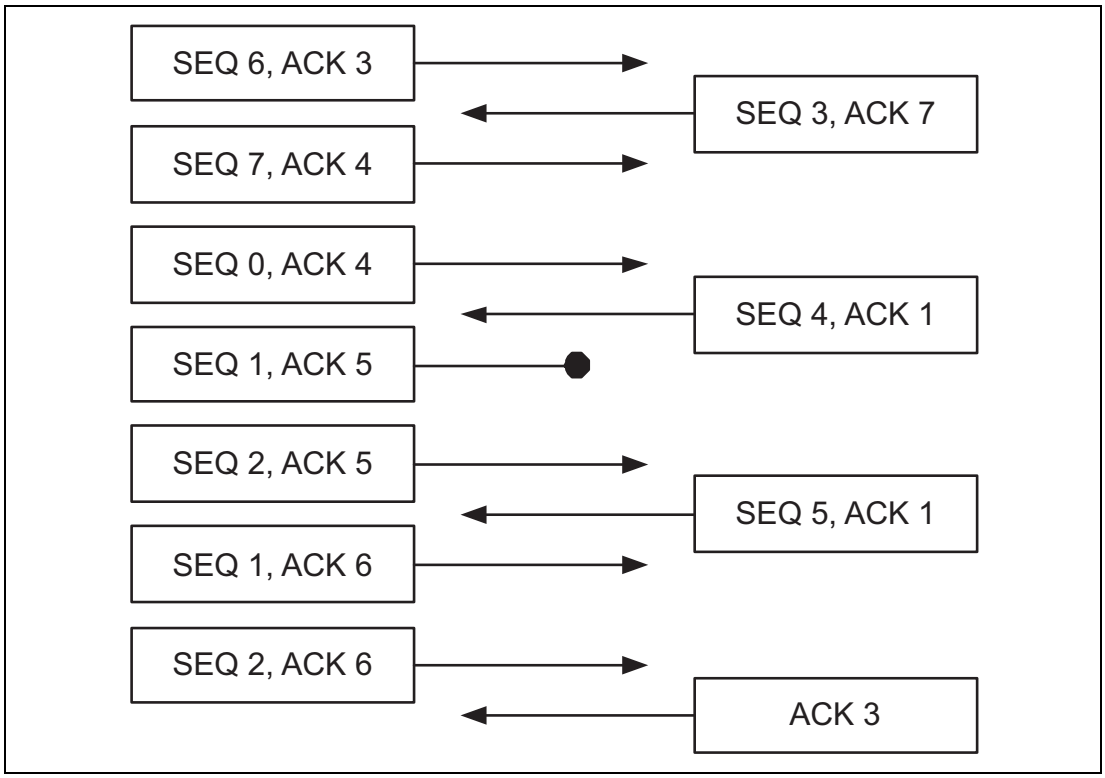

Figure 6.1: Message Diagram Showing Transmission of Reliable Packets

Device A receives a packet with Sequence Number 3 and an Acknowledgment Number of 7. Device A was expecting this sequence number so needs to generate an acknowledgment. The Acknowledgment Number of 7 is one greater than the last Sequence Number that was sent, meaning that this packet was received correctly (see Section 6.6).

Device A sends two packets, Sequence Numbers 7 and 0. Both packets have the Acknowledgment Number of 4, the next sequence number it expects from Device B. Device B receives the first correctly, and increments its next expected sequence number to 0. It then receives the second packet correctly, and increments the next expected sequence number to 1.

Device B sends a packet with Sequence Number 4, and the Acknowledgment Number of 1. This will acknowledge both of the previous two packets sent by Device A.

Device A now sends two more packets, Sequence Numbers 1 and 2. Unfortunately, the first packet is corrupted. Device B receives the first packet, and discovers the error, so discards this packet (see Section 6.1, Section 6.2 or Section 6.3). It must generate an acknowledgment of this erroneously received reliable packet. Device B then receives the second packet. This is received out of sequence, as it is currently expecting Sequence Number 1, but has received Sequence Number 2 (see Section 6.4). Again, it must generate an acknowledgment.

Device B sends another packet with Sequence Number 5. It is still expecting a packet with Sequence Number 1 next, so the Acknowledgment Number is set to 1. Device A receives this, and accepts this packet.

Device A has not had either of its last two packets acknowledged, so it must resend them (see 6.6). It does this, but must update the Acknowledgment Number of the original packets that were sent (see Section 6.5). The Sequence Numbers of these packets must stay the same (see Section 4.1).

Device B receives these packets correctly, and schedules the sending of an acknowledgment. Because Device B doesn't have any data packets that need to be sent, it sends a pure Acknowledgment Packet (see Section 6.5).

7 UNRELIABLE PACKETS

To allow the transmission of unreliable packets through the transport, the following method shall be used.

7.1 UNRELIABLE PACKET HEADER

An unreliable packet header always has the Reliable Packet bit set to 0. The sequence number shall be set to 0. The Data Integrity Check Present, Acknowledgment Number, Packet Type, Payload Length and Packet Header Checksum shall all be set the same as a Reliable Packet.

7.2 UNRELIABLE PACKET ERROR

If a packet that is marked as unreliable and the packet has an error, then the packet shall be discarded.

8 LINK ESTABLISHMENT

Before any packets except Link Control Packets can be sent, the Link Establishment procedure must be performed. This ensures that the sequence numbers are initialized correctly, it also ensures that the two sides are using the same baud rate, allow detection of peer reset, and allows the device to be configured.

Link Establishment is defined by a state machine with three states: Uninitialized, Initialized and Active. When the transport is first started, the link is in the Uninitialized State. There are four messages that are defined: SYNC, SYNC RESPONSE, CONFIG and CONFIG RESPONSE. All four link establishment messages shall be sent with the Data Integrity Present flag set to 0.

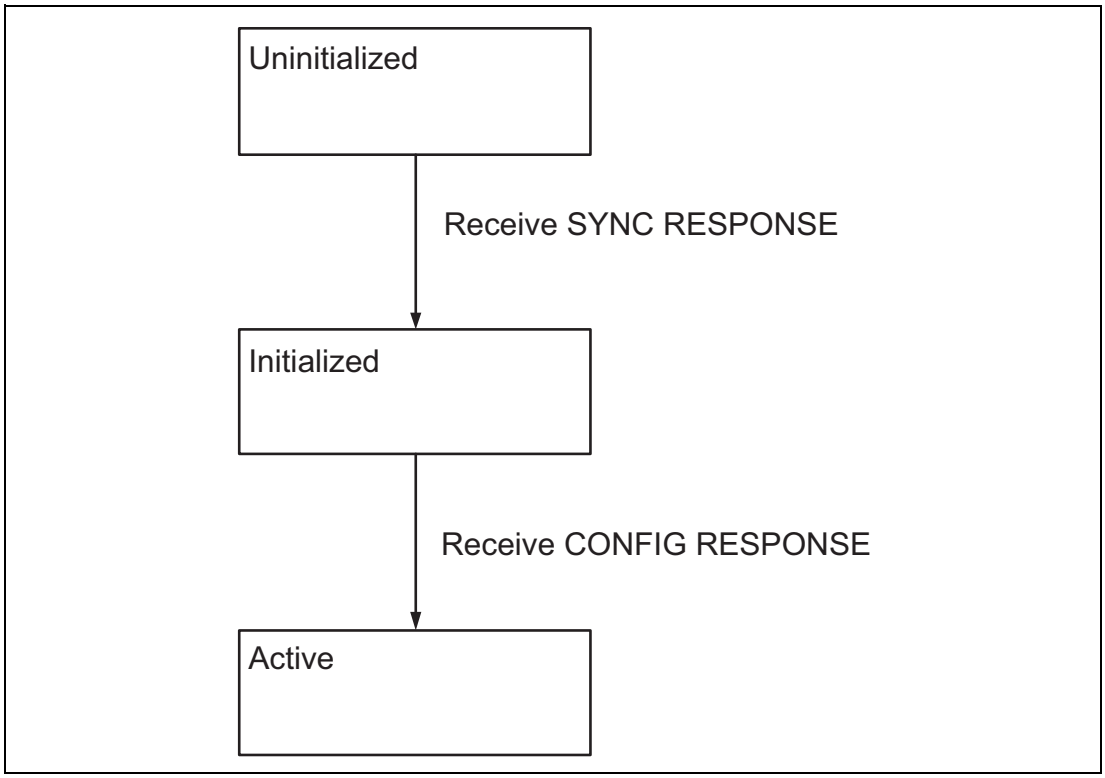

Figure 8.1: Link Establishment State Diagram

8.1 UNINITIALIZED STATE

In the Uninitialized State a device periodically[1] sends SYNC messages. If a SYNC message is received, the device shall respond with a SYNC RESPONSE message. If a SYNC RESPONSE message is received, the device shall move to the Initialized State. In the Uninitialized State only SYNC and SYNC RESPONSE messages are valid, all other messages that are received must be discarded. If an invalid packet is received, the device shall respond with a SYNC message. The device shall not send any acknowledgment packets in the Uninitialized State[2].

In the Uninitialized State the Controller may wait until it receives a SYNC message before sending its first SYNC message. This allows the Host to control when the Controller starts to send data.

The SYNC message can be used for automatic baud rate detection. It is assumed that the Controller shall stay on a single baud rate, while the Host could hunt for the baud rate. Upon receipt of a SYNC RESPONSE message, the Host can assume that the correct baud rate has been detected.

8.2 INITIALIZED STATE

In the Initialized State a device periodically sends CONFIG messages. If a SYNC message is received, the device shall respond with a SYNC RESPONSE message. If a CONFIG message is received, the device shall respond with a CONFIG RESPONSE message. If a CONFIG RESPONSE message is received, the device will move to the Active State. All other messages that are received must be ignored.

8.3 ACTIVE STATE

In the Active State, a device can transfer higher layer packets through the transport. If a CONFIG message is received, the device shall respond with a CONFIG RESPONSE message. If a CONFIG RESONSE message is received, the device shall discard this message.

If a SYNC message is received while in the Active State, it is assumed that the peer device has reset. The local device should therefore perform a full reset of the upper stack, and start Link Establishment again at the Uninitialized State.

Upon entering the Active State, the first packet sent shall have its SEQ and ACK numbers set to zero.

1. During link establishment, various messages are sent periodically. It is suggested to send 4 messages per second.
2. Any packet that was erroneous would normally be acknowledged, as the recipient does not know if the packet was a reliable packet or not. The recipient cannot do this in the Uninitialized State, as it is possible to receive corrupt data while the Uninitialized state.

8.4 SYNC MESSAGE

The SYNC message is an unreliable message sent with the Packet Type of 15 and a Payload Length of 2.

The payload is composed of the octet pattern 0x01 0x7E[1].

Figure 8.2: Sync Message Format

8.5 SYNC RESPONSE MESSAGE

The SYNC RESPONSE message is an unreliable message sent with the Packet Type of 15 and a Payload Length of 2. The payload is composed of the octet pattern 0x02 0x7D.

Figure 8.3: Sync Response Message Format

8.6 CONFIG MESSAGE

The CONFIG message is an unreliable message sent with the Packet Type of 15 and a Payload Length of 2 plus the size of the Configuration Field. The payload is composed of the octet pattern 0x03 0xFC and the Configuration Field.

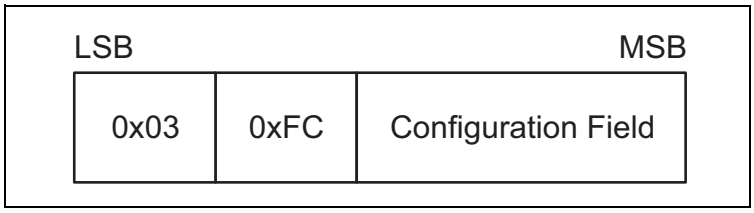

Figure 8.4: Configuration Message Format

1. The second octet for all Link Control Packets equals the least significant 7 bits of the first octet, inverted, with the most significant bit set to ensure even parity.

8.7 CONFIG RESPONSE MESSAGE

The CONFIG RESPONSE message is an unreliable message sent with the Packet Type of 15 and a Payload Length of 2 plus the size of the Configuration Field. The payload is composed of the octet pattern 0x04 0x7B and the Configuration Field.

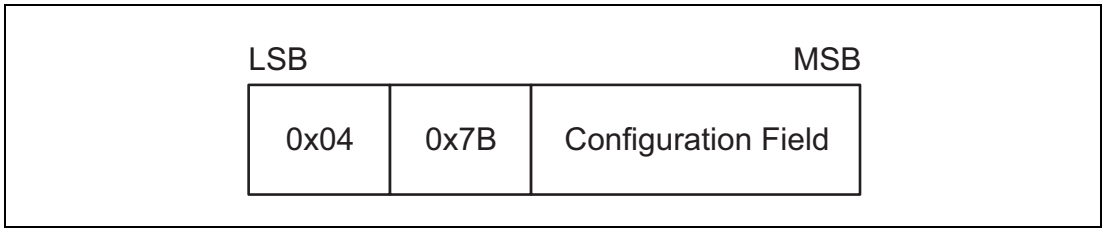

Figure 8.5: Configuration Response Message Format

8.8 CONFIGURATION FIELD

The Configuration Field contains the Version Number, Sliding Window Size, the Data Integrity Check Type, and if Out Of Frame (OOF) Software Flow Control is allowed.

The Configuration Field in a CONFIG message sent by the Host determines what the Host can transmit and accept. The Configuration Field in a CONFIG RESPONSE message sent by the Controller determines what the Host and Controller shall transmit and can expect to receive.

The Controller sends CONFIG messages without a Configuration Field. The Host sends CONFIG RESPONSE messages without a Configuration Field.

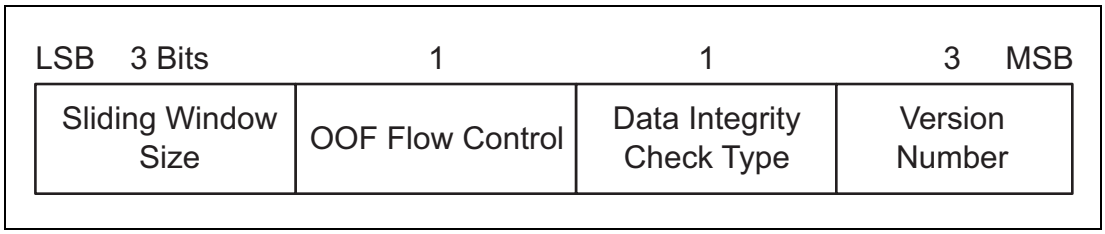

Figure 8.6: Configuration Field Detail

To allow for future extension of the Configuration Field, the size of the message determines the number of significant Configuration Octets in the payload. Future versions of this specification may use extra octets. Any bits that are not included in the message shall be set to 0. Any bits that are not defined are reserved for future use.

A device shall not change the values if sends in the Configuration Field during Link Establishment.

8.8.1 Configuration Messages

The CONFIG – CONFIG RESPONSE message sequence configures the link in both directions. Until a CONFIG RESPONSE message is received only unreliable Link Establishment messages may be sent. Once CONFIG RESPONSE message has been received all other packet types may be sent, and received messages passed up to the Host.

The CONFIG and CONFIG RESPONSE messages contain a set of options for both devices on the link. The Host sends a CONFIG message with the set of options that the Host would like to use. The Controller responds with a CONFIG RESPONSE message with the set of options that the Host and the Controller will use. This means that the Controller is in full control of the set of options that will be used for all messages sent by both the Host and Controller.

8.8.2 Sliding Window Size

This is the maximum number of reliable packets a sender of the CONFIG message can send without requiring an acknowledgment. The value of this field shall be in the range one to seven. The value in the CONFIG RESPONSE message shall be less than or equal to the value in the CONFIG message. For example, the Host may suggest a window size of five in its CONFIG message and the Controller may respond with a value of three in its CONFIG RESPONSE message, but not six or seven. Both devices will then use a maximum sliding window size of three.

8.8.3 Level of Data Integrity Check

The CONFIG message contains a bit field describing the types of Data Integrity Checks the sender is prepared to transmit. The peer will select the one it is prepared to use and send its choice in the CONFIG RESPONSE message.

If data integrity checks are not required, then the Data Integrity Check Present bit shall be set to 0 by the Host and Controller.

Level of Data Integrity	Parameter Description for CONFIG Message
0	No Data Integrity Check is supported.
1	16 bit CCITT-CRC may be used.

Table 8.1: Data Integrity Check Type in the CONFIG Message

Level of Data Integrity	Parameter Description for CONFIG RESPONSE Message
0	No Data Integrity Check must be used.
1	16 bit CCITT-CRC may be used.

Table 8.2: Data Integrity Check Type in the CONFIG RESPONSE Message

8.8.4 Out of Frame Software Flow Control

By default, the transport uses no flow control except that mandated by the HCI Functional Specification and the flow control achieved by not acknowledging reliable Host messages. If Software Flow Control is to be used, this needs to be negotiated.

The CONFIG message specifies whether the sender of the CONFIG message is prepared to receive Out of Frame Software Flow Control messages. The CONFIG RESPONSE message specifies whether the peer can send Out of Frame Software Flow Control messages. The CONFIG RESPONSE message may have the field set to 1 only if the CONFIG message had it set to 1. (See Section 10.1)

8.8.5 Version Number

The Version Number of this protocol shall determine which facilities are available to be used.

The CONFIG message specifies the Version Number supported by the Host. The CONFIG RESPONSE message specifies the Version Number that shall be used by the Host and Controller when sent by the Controller. The value in the CONFIG RESPONSE message shall be less than or equal to the value in the CONFIG message. The Version Numbers are enumerated in Table 8.3. This specification is version 1.0 (Version Number = 0).

Version Number	Parameter Description for CONFIG and CONFIG RESPONSE Message
0	Version 1.0 of this Protocol
1-7	Reserved for future use

Table 8.3: Version Number in the CONFIG and CONFIG RESPONSE message

9 LOW POWER

After a device is in the Active State, either side of the transport link may wish to enter a low power state. Because recovery from a loss of synchronization is possible, it is allowable to stop listening for incoming packets at any time.

To make the system more responsive after a device has entered a low power state, a system of messages is employed to allow either side to notify the other that they are entering a low power state and to wake a device from that state. These messages are sent as Link Control Packets. It is optional for a device to support the Sleep message. The Wakeup and Woken messages are mandatory.

9.1 WAKEUP MESSAGE

The Wakeup message shall be the first message sent whenever the device believes that the other side is asleep. The device shall then repeatedly send the Wakeup message until the Woken message is received. There must be at least a one character gap between the sending of each Wakeup message to allow the UART to resynchronize. The Wakeup message is an unreliable message sent with a Packet Type of 15, and a Payload Length of 2. The payload is composed of the octet pattern 0x05 0xFA. The Wakeup message shall be used after a device has sent a Sleep message. It is mandatory to respond to the Wakeup message.

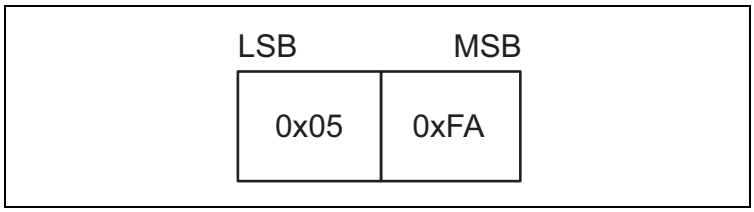

Figure 9.1: Wakeup Message Payload Format

9.2 WOKEN MESSAGE

The Woken message shall be sent whenever a Wakeup message is received even if the receiver is currently not asleep. Upon receiving a Woken message, a device can determine that the other device is not in a low power state and can send and receive data. The Woken message is an unreliable message sent with a Packet Type of 15, and a Payload Length of 2. The payload is composed of the octet pattern 0x06 0xF9.

Figure 9.2: Woken Message Payload Format

9.3 SLEEP MESSAGE

A Sleep message can be sent at any time after Link Establishment has finished. It notifies the other side that this device is going into a low power state, and that it may also go to sleep. If a device sends a Sleep message it shall use the Wakeup / Woken message sequence before sending any data. If a device receives a Sleep message, then it should use the Wakeup / Woken message sequence before sending any data. The Sleep message is an unreliable message sent with a Packet Type of 15, and a Payload Length of 2. The payload is composed of the octet pattern 0x07 0x78.

The sending of this message is optional. The receiver of this message need not go to sleep, but cooperating devices may be able to schedule sleeping more effectively with this message.

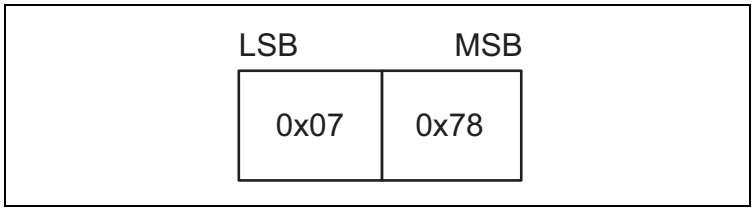

Figure 9.3: Sleep Message Payload Format

10 OUT OF FRAME CONTROL

It is possible to embed information in the SLIP data stream after a SLIP ESCAPE character that can allow for Software Flow Control. This feature is optional and must be negotiated in the Link Establishment configuration messages.

10.1 SOFTWARE FLOW CONTROL

If Software Flow Control is enabled, then the standard XON / XOFF (0x11 and 0x13) characters will control the flow of data over the transport. To allow the XON / XOFF characters to be sent in the payload, they shall be escaped as follows: 0x11 shall be changed to 0xDB 0xDE, 0x13 shall be changed to 0xDB DF. This means that the XON / XOFF characters in the data stream are used only by software flow control.

If Software Flow Control is disabled, then the SLIP escape sequences 0xDB 0xDE and 0xDB 0xDF are undefined. In this case, the original octets of 0x11 and 0x13 shall not be changed. Flow control should always be provided by the tunneled protocols, e.g. HCI Flow Control. Flow control is still available using the standard Sequence Number / Acknowledge Number. This can be done by not acknowledging packets until traffic can resume.

11 HARDWARE CONFIGURATION

The HCI Three-Wire UART Transport uses the following configurations.

11.1 WIRES

There are three wires used by the HCI Three-Wire UART Transport. These are Transmit, Receive, and Ground.

11.1.1 Transmit & Receive

The transmit line from one device shall be connected to the receive line of the other device.

11.1.2 Ground

A common ground reference shall be used.

11.2 HARDWARE FLOW

Hardware flow control may be used. The signaling shall be the same as a standard RS232 flow control lines. If used, the signals shall be connected in a null-modem fashion; for example, the local RTS shall be connected to the remote CTS and vice versa.

11.2.1 RTS & CTS

Request to Send indicates to the remote side that the local device is able to accept more data.

Clear to Send indicates if the remote side is able to receive data.

(See ITU.T recommendations V.24 [2] and V.28 [3])

12 RECOMMENDED PARAMETERS

12.1 TIMING PARAMETERS

Because this transport protocol can be used with a wide variety of baud rates, it is not possible to specify a single timing value. However, it is possible to specify the time based on the baud rate in use. If T_{max} is defined as the maximum time in seconds it will take to transmit the largest packet over this transport, T_{max} can be expressed as:

T_{max} = maximum size of a packet in bits / baud rate

The maximum size of a packet in bits is either the number of bits in a 4095 octet packet (32,760) or less if required in an embedded system or as determined by the Host or Controller[1]. Thus, at a baud rate of 921,600 and the maximum packet size of 4095 octets, T_{max} is: (4095*10) / 921,600 = 44.434ms.

12.1.1 Acknowledgment of Packets

It is not necessary to acknowledge every packet with a pure acknowledgment packet if there is a data packet that will be sent soon. The recommended maximum time before starting to send an acknowledgment is 2 * T_{max}.

12.1.2 Resending Reliable Packets

A reliable packet must be resent until it is acknowledged. The recommended time between starting to send the same packet is 3 * T_{max}.

1. This can be determined using the HCI_Read_Buffer_Size command.

13 REFERENCES

[1] [IETF RFC 1055: Nonstandard for transmission of IP datagrams over serial lines: SLIP – http://www.ietf.org/rfc/rfc1055.txt

[2] ITU Recommendation V.24: List of definitions for interchange circuits between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) – http://www.itu.int/rec/recommendation.asp

[3] ITU Recommendation V.28: Electrical characteristics for unbalanced double-current interchange circuits – http://www.itu.int/rec/recommendation.asp

Core System Package

[AMP Controller volume]

Specification of the Bluetooth® System

Specification Volume 5

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The Revision History is shown in the [Vol 0] Part C, Appendix.

Contributors

The persons who contributed to this specification are listed in the [Vol 0] Part C, Appendix.

Web Site

This specification can also be found on the official Bluetooth web site:
https://www.bluetooth.org/en-us/specification/adopted-specifications

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802.11 PROTOCOL ADAPTATION LAYER FUNCTIONAL SPECIFICATION

This document specifies the Protocol Adaptation Layer for the IEEE 802.11 conformant Alternate MAC/PHY.

CONTENTS

1 INTRODUCTION

This Part of the Bluetooth Core Specification describes the operation of the Protocol Adaptation Layer (PAL) for a Controller incorporating an 802.11 device compliant with the 2007 edition of the IEEE 802.11 Standard (see [1]) including support for High Throughput (HT) MAC and PHY extensions. In this Part, specific references in [1] will be given by clause number.

The 802.11 PAL defines the protocol state machines, data encapsulation methods, event triggers, and data structures in support of the use of an 802.11 AMP.

1.1 ORGANIZATION OF THE 802.11 PAL

To aid understanding of functional descriptions, Figure 1.1 shows the organization of the 802.11 PAL. This structure is informative.

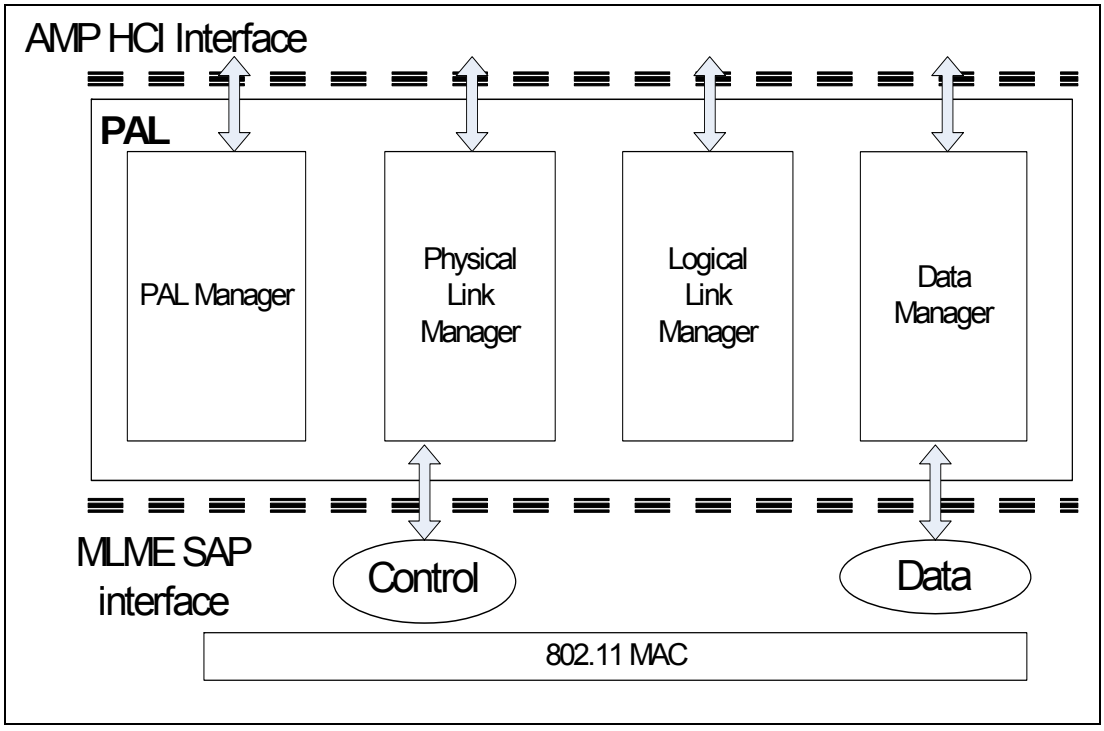

Figure 1.1: Internal structure of the 802.11 PAL

The upper edge of the 802.11 PAL provides a single instance of the logical HCI with AMP functionality. The behavior of the PAL is defined at this interface in terms of logical HCI operations. Implementations may optionally use a physical HCI transport.

For clarity of description, the lower edge of the PAL uses services including those defined in [1] clause 10.3.

The PAL Manager implements operations that are global to the PAL. This includes responding to Host requests for AMP info and PAL version as well as performing PAL reset.

The Physical Link Manager implements operations on physical links. Physical link semantics are defined in Section 3. Supported operations include physical link creation and acceptance, and deletion of physical links. Supported operations at the MAC interface include PHY channel selection and security establishment and maintenance.

The Logical Link Manager implements operations on logical links. Logical link semantics are defined in Section 4. Each logical link exists with respect to a single physical link. Supported operations include creation and deletion of logical links and changes to QoS parameters for those logical links. At the MAC interface this includes the mapping of extended flow specifications to user priorities.

The Data Manager performs operations on data packets and is described in Section 5. Each data packet is associated with exactly one extended flow specification and therefore exactly one logical link. Supported operations include transmit, receive and buffer management operations such as flush events. At the MAC interface this includes interactions with the MAC transmit and receive operations and determination of the next packet to send on any particular link.

2 AMP HOST CONTROLLER INTERFACE

A number of elements used in HCI commands and events are defined to be AMP-type specific. This section describes the values to be used for the 802.11 PAL.

Octet ordering conventions for parameters and fields in this section shall be as defined in HCI, [Vol 2] Part E, Section 5.2.

2.1 READ LOCAL VERSION INFORMATION COMMAND

Two return parameter values from this HCI command are defined to be AMP-type specific. For the 802.11 PAL they shall be as follows.

PAL _Version *Size: 1 Octet*

Value	Parameter Description
0xXX	Version of the current PAL in the Controller. See Bluetooth Assigned Numbers.

PAL_Sub-version: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	In an 802.11 PAL this value is vendor specific.

2.2 READ LOCAL AMP INFO COMMAND

See [Vol 2] Part E, Section 7.5.7.

There are six return parameters for the Read Local AMP Info command which are 802.11 AMP specific.

Total_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	An upper bound on the total data rate that can be achieved by the AMP for applications. It accounts for the total bandwidth provided by the HCI transport. No sustained combination of transmit and receive operations shall exceed this value. This may be used to help in AMP selection and admission control. Expressed in kb/s. For testing purposes, the achievable throughput deliverable to applications by an ERP or OFDM PHY shall be assumed to be no more than 30000 kb/s and for the HT PHY shall be assumed to be no more than 50000 kb/s.

Max_Guaranteed_Bandwidth: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	An upper bound on the maximum data rate as seen by the application that the AMP can guarantee for a logical channel. Any request made by an application above this level would be rejected. It accounts for any bandwidth limitations of the HCI transport. No sustained combination of transmit and receive operations shall exceed this value. This can be used to help in AMP selection and admission control. Expressed in kb/s. The Max_Guaranteed_Bandwidth parameter value returned shall be no greater than the Total_Bandwidth parameter. This value is not a guarantee of bandwidth and should be interpreted as an upper bound on the sum of the bandwidths of all active flow specs.

Min_Latency: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	The Min_Latency parameter value is the practical lower bound on the service latency that can be provided by the 802.11 AMP. The lower bound of the service latency is the time from when a frame is issued to the AMP HCI until the MAC starts transmitting the frame with no contention window back off. This shall be equal to the AMP HCI minimum latency + DIFS + CWmin where the DIFS and CWmin are as given in [1] clause 9.2.10.

Max_PDU_Size: *Size: 4 Octets*

Value	Parameter Description
	An upper bound on the size of L2CAP PDU which may be provided for transmission or reception on this AMP. The Host shall not require the AMP to transport L2CAP PDUs larger than this value. Expressed in octets. The Maximum PDU Size parameter described in [[Vol 3] Part A, Section 5.4] for any connection over this AMP should not exceed this value. The Max_PDU_Size parameter returned shall be Max80211PALPDUSize.

Controller_Type: *Size: 1 Octet*

Value	Parameter Description
0x01	802.11 AMP

PAL_Capabilities: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Bit 0: "Service Type = Guaranteed" is not supported by PAL = 0 "Service Type = Guaranteed" is supported by PAL = 1 Bits 15-1: Reserved (See L2CAP, [Vol 3] Part A, Section 5.6)

Bit 0 of the PAL_Capabilities parameter shall be set to 1 if the local 802.11 AMP device is capable of using the Enhanced Distributed Channel Access (EDCA) mechanisms (see [1] clause 9.9.1), otherwise it shall be set to 0.

AMP_ASSOC_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	AMP_ASSOC maximum length for this AMP Controller.

The 802.11 PAL shall set this to Max80211AMPASSOCLen.

Max_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	Maximum time period, in microseconds, which the AMP device may use to attempt to transmit a frame on a guaranteed logical link. This value is the sum of the durations of all 802.11 transmission attempts for a given frame. It should be chosen with the expectation that the 802.11 MAC may be denied access to the medium for a given transmission attempt. This may be due to interference from collocated radios, or otherwise. If the Controller is configured to retry frames for an unbounded time (there is no flushing at all), then the PAL shall set this value to 0xFFFFFFFF.

Best_Effort_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	The typical time period, in microseconds, which the AMP device may use to attempt to transmit a frame on a best effort logical link. This value is the sum of the duration of all 802.11 transmission attempts for a given frame. It should be chosen with the expectation that the 802.11 MAC is usually able to access the medium for each attempt. The value shall not exceed the value given in Max_Flush_Timeout. If the Controller is configured to retry frames for an unbounded time (i.e. there is no flushing at all), then the PAL shall set this value to 0xFFFFFFFF.

2.3 RESET COMMAND

See [Vol 2] Part E, Section 7.3.2.

In addition to setting the HCI parameters to their default values, when the 802.11 PAL receives an AMP HCI_Reset command it shall delete all existing AMP physical links. Note: Non AMP links should not be deleted.

2.4 READ FAILED CONTACT COUNTER COMMAND

When the 802.11 PAL receives an HCI Read_Failed_Contact_Counter command it shall return the number of consecutive incidents in which the remote device didn't respond after the flush timeout had expired, and the L2CAP packet that was currently being transmitted was automatically flushed. The Failed Contact Counter is specific to each logical link.

2.5 READ LINK QUALITY COMMAND

See [Vol 2] Part E, Section 7.5.3.

The meaning of the Link_Quality parameter in the Read Link Quality command is as shown below.

Link_Quality: *Size: 1 Octet*

Value	Parameter Description
0xXX	In an 802.11 AMP this unsigned 8-bit value shall be the Link Quality Indicator value. It shall be 0 if the Link Quality Indicator value is not available. Range: 0x00 ≤ N ≤ 0xFF

2.6 READ RSSI COMMAND

See [Vol 2] Part E, Section 7.5.4.

The meaning of the RSSI parameter in the Read RSSI command is as shown below.

RSSI: *Size: 1 Octet*

Value	Parameter Description
0xXX	This value is a signed 8-bit value, and is interpreted as an indication of arriving signal strength at the antenna measured in dBm. The value shall be 0x81 (-127 dBm) if the signal strength indication is not available.

2.7 SHORT RANGE MODE COMMAND

When the Host determines that the AMP peers may have insufficient separation to obtain full AMP throughput, it may enable Short Range Mode in the PAL. The Short Range Mode command may be used by the Host to indicate to the PAL whether or not to operate in Short Range Mode.

When in Short Range Mode, the PAL shall limit to ShortRangeModePowerMax the transmit power in dBm (measured at the antenna) for all 802.11 AMP ERP-OFDM frames transmitted by the device on the given physical link, as necessary to prevent exceeding the maximum input signal level of the peer. If the Host does not enable Short Range Mode or if the Host sets Short Range Mode to disabled, the PAL shall assume it may set the maximum transmit power for the link as it deems appropriate, respecting regulatory limits. If the AMP device is not able to limit its transmit power due to other existing connections then it may use a transmit power greater than ShortRangeModePowerMax in order to preserve those connections.

The meaning of the Short Range Mode parameter of the HCI_Short_Range_Mode command is as follows:

Short Range Mode: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x00–Short range mode shall be disabled in the PAL (default) 0x01–Short range mode shall be enabled in the PAL. 0x02...0xFF - Reserved for future use

When the AMP Controller receives the Short_Range_Mode command, it shall indicate a Command Status event. Later, after the MAC programming is completed, the Controller shall generate a Short_Range_Mode_Change_Completed event. See Section 2.13.

2.8 WRITE BEST EFFORT FLUSH TIMEOUT COMMAND

Best_Effort_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	0x00000000–0xFFFFFFFE: Best Effort Flush Timeout value in microseconds. 0xFFFFFFFF: No Best Effort Flush Timeout used (default)

2.9 READ BEST EFFORT FLUSH TIMEOUT COMMAND

Best_Effort_Flush_Timeout: *Size: 4 Octets*

Value	Parameter Description
0xXXXXXXXX	0x00000000–0xFFFFFFFE: Best Effort Flush Timeout value in microseconds. 0xFFFFFFFF: No Best Effort Flush Timeout used (default)

2.10 PHYSICAL LINK LOSS EARLY WARNING EVENT

Implementation of this event is not required for 802.11 AMPs.

2.11 PHYSICAL LINK RECOVERY EVENT

Implementation of this event is not required for 802.11 AMPs.

2.12 CHANNEL SELECTED EVENT

See [Vol 2] Part E, Section 7.7.52.

When an HCI Channel Selected event is indicated by the PAL with successful status, it signifies the local 802.11 MAC has been configured to start operating on the selected channel.

Subsequent to the HCI Channel Selected event, the initiating AMP device shall create an AMP_ASSOC containing its MAC address TLV, and with only the selected channel in its PCL and/or PCLv2 TLV (see sections 2.14.4 and 2.14.7). Other TLVs may optionally be included. The Host may obtain this AMP_ASSOC by issuing one or more HCI_Read_Local_AMP_ASSOC commands.

2.13 SHORT RANGE MODE CHANGE COMPLETE EVENT

See [Vol 2] Part E, Section 7.7.60.

After the PAL is notified of a change of state in Short Range Mode, it shall program the 802.11 device accordingly, unless the exceptions in Section 2.7 are in effect. When it has finished making such changes to the MAC configuration, or if the PAL has changed the state of the Short Range Mode autonomously, the PAL shall indicate this to the Host by indicating the Short Range Mode Change Complete event. The Short_Range_State parameter identifies the new configuration to the Host.

2.14 DATA STRUCTURES

2.14.1 AMP_ASSOC Structure

The AMP_ASSOC is an AMP type specific structure and appears in various HCI commands and events. The AMP_ASSOC structure used by the 802.11 PAL shall be composed of Type-Length-Value (TLV) triplets.

The general format of such a TLV, shown in Table 2.1, shall be a one-octet TypeID field, a two-octet Length field, and a variable length Value field. The length of the Value field in octets shall be exactly equal to the unsigned number represented by the Length field. A TLV with zero in its Length field shall contain no Value field. If an implementation does not have support for a triplet in a received AMP_ASSOC, it shall ignore the triplet and continue processing any remaining triplets.

The Length field is 2 octets in length and shall be ordered in the AMP_ASSOC according to [Vol 2] Part B, Section 6.2. The Value field shall be interpreted as a stream of octets.

The TypeID of 0xFF shall be reserved for use in debugging.

TypeID	Length	Value
1 octet	2 octets	Variable number of octets

Table 2.1: TLV format

The set of defined TypeIDs is given in Table 2.2.

TypeID codepoint	Description	AMP_ASSOC inclusion
0x00	Reserved for future use	not applicable
0x01	MAC Address	Mandatory
0x02	Preferred Channel List	Mandatory for Responder; Mandatory for Initiator if last HCI Write Remote AMP Assoc command did not include a PCLv2 (typeID 0x06), else Optional
0x03	Connected Channel List	Optional
0x04	802.11 PAL Capabilities List	Optional
0x05	802.11 PAL version	Mandatory
0x06	Preferred Channel List v2	Optional if PCL (typeID 0x02) is included in AMP_Assoc. else Mandatory
0x07 - 0xFE	Reserved for future use	not applicable

Table 2.2: Requirements on contents of AMP_Assoc messages

TypeID codepoint	Description	AMP_ASSOC inclusion
0xFF	Reserved for use in debugging	not applicable

Table 2.2: Requirements on contents of AMP_Assoc messages

2.14.2 MAC Address

The PAL shall use the following TLV to report the IEEE MAC address of its local 802.11 MAC. The bit ordering of the address is given in [1] clause 7.1.1.

MAC_Address_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x01	MAC Address TypeID

MAC_Address_Length: *Size: 2 Octets*

Value	Parameter Description
0x0006	MAC Address Length

MAC_Address_Specifier: *Size: 6 Octets*

Value	Parameter Description
0xXXXXXXXXXXXX	MAC Address specifier

2.14.3 802.11 PAL Capabilities

The 802.11 PAL Capabilities is a bit field of supported capabilities of the sending device.

802.11_PAL_Capabilities_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x04	802.11 PAL Capabilities TypeID

802.11_PAL_Capabilities_Length: *Size: 2 Octets*

Value	Parameter Description
0x0004	802.11 PAL Capabilities Length

802.11_PAL_Capabilities_Specifier: *Size: 4 Octets*

Bit format	Parameter Description
Bit 0	When set, signifies PAL capable of utilizing received Activity Reports
Bit 1	When set, signifies PAL is capable of utilizing scheduling information received in an Activity Report

Bit format	Parameter Description
Bit 2	When set, signifies 802.11 MAC and PHY is compliant with HT operation as specified in [1].
Bits 3..31	Reserved for future use

The 802.11 PAL Capabilities TLV is optional to include in the AMP_ASSOC. If an 802.11 PAL Capabilities TLV does not appear in an AMP_ASSOC, then the receiver shall interpret this as receiving an 802.11 PAL Capabilities TLV with a Value field containing the default value of all zeros.

2.14.4 Preferred Channel List

The Preferred Channel List (PCL) is a set of channels supported and usable by the sending device. The receiver of the PCL shall interpret the contents of the list with the assumption that the list is arranged in order of most preferred channel to least preferred channel. The format of the list is identical to the 802.11 Country information element, excluding the 802.11 information, element identifier, length, and pad fields. See [1] clause 7.3.2.9.

Preferred_Channel_List_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x02	Preferred Channel List TypeID

Preferred_Channel_List_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length of Preferred Channel List

Preferred_Channel_List_Specifier: *Size: Variable*

Value	Parameter Description
0xXX..XX	List of preferred 802.11 channels. See Section 3.2.3 for details.

The channels are described by table entries in [1], Annex J, tables J-1, J-2, and J-3. For backward compatibility, the Preferred Channel List Specifier shall use table indices in the inclusive range [1-12] to describe US channels, [1-4] to describe EU country channels, and [1-32] to describe Japan channels.

2.14.5 Connected Channel List

The Connected Channel List (CCL) specifies the channels which may currently be in use by the sending device. If multiple channels are listed, the ordering gives no implied preference. The format of the list is the same as the PCL, see section 2.14.4.

The Connected Channel TLV is optional to include in the AMP_ASSOC. If it is not included, then the receiver shall assume there are no channels which are currently in use by the sending device.

Connected_Channel_List_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x03	Connected Channel List TypeID

Connected_Channel_List_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length of Connected Channel List

Connected_Channel_List_Specifier: *Size: Variable*

Value	Parameter Description
0xXXXXXXXX	List of 802.11 channels currently in use by the sending device. See Section 3.2.3 for details.

For backward compatibility, the Connected Channel List Specifier shall use table indices in the inclusive range [1-12] to describe US channels, [1-4] to describe EU country channels, and [1-32] to describe Japan channels.

2.14.6 802.11 PAL Version

An AMP endpoint may need to discover the version of the remote PAL. The information in the 802.11 PAL Version TLV shall be composed of the PAL_Version from the HCI_Read_Local_Version_Information command, the Bluetooth SIG Company Identifier (see Assigned Numbers, [4]) for the provider of the PAL, and the PAL_Sub-version from the HCI_Read_Local_Version_Information command. The Company Identifier and PAL Sub-version parameters shall use the octet ordering as given in [Vol 2] Part B, Section 6.2.

802.11_PAL_Version_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x05	802.11 PAL Version TypeID

802.11_PAL_Version_Length: *Size: 2 Octets*

Value	Parameter Description
0x0005	Length of 802.11 PAL Version specifier

802.11_PAL_Version_Specifier: *Size: 1 Octet*

Value	Parameter Description
0xXX	PAL Version

802.11_PAL_Company_Identifier: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	SIG Company identifier of 802.11 PAL vendor

802.11_PAL_Sub_Version: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	PAL Sub-version specifier

2.14.7 Preferred Channel List v2

The Preferred Channel List v2 (PCLv2) TLV specifies the channels supported and usable by the sending device. The format of the list is identical to the 802.11 Country information element syntax, excluding the 802.11 infor-mation element identifier, length, country string and pad fields. See [1] clause 7.3.2.9. The receiver of a PCLv2 TLV shall interpret the contents of the list with the assumption that the list is arranged in order of most preferred channel to least preferred channel.

The PCLv2 may include channels with 20 MHz width, 40 MHz width, or both. Channels are expressed as triplets of two types: the operating type contains a table index from Table 3.8 below, and the sub-band type contains a channel range. The PCLv2 shall contain at least one operating triplet. Country strings are not used in the PCLv2, so the operating triplet appears directly following the TLV length field. Sub-band triplets may be used to refine the list of chan-nels expressed by the preceding operating triplet.

If a PCLv2 TLV is not included in the AMP Get AMP Assoc Request message from a responder, then the initiating PAL shall not assume that the responder has the ability to interpret PCLv2 TLVs. In this case the initiator shall include a PCL in the AMP_Assoc in the AMP Create Physical Link Request, and the PCLv2 TLV is optional. If an implementation supports PCLv2 TLVs and if it receives a PCLv2 from its peer, then it shall ignore any PCL it receives.

Preferred_Channel_Listv2_TypeID: *Size: 1 Octet*

Value	Parameter Description
0x06	Preferred Channel List v2 TypeID

Preferred_Channel_Listv2_Length: *Size: 2 Octets*

Value	Parameter Description
0xXXXX	Length of Preferred Channel Listv2.

Preferred_Channel_Listv2_Specifier: *Size: Variable*

Value	Parameter Description
0xXXXXXXXX	List of preferred channels, including 40 MHz channels if supported. See Section 3.2.3 for details.

2.15 CONNECTION ACCEPT TIMEOUT CONFIGURATION PARAMETER

See [Vol 2] Part E, Section 6.7.

The default value of the Connection Accept Timeout used by the 802.11 PAL shall be 5 seconds.

2.16 ENABLE DEVICE UNDER TEST MODE

If the device under test supports 40 MHz channels, the HCI_Enable_Device_Under_Test_Mode command (see [Vol 2] Part E, Section 7.6.3) change the state of the PAL so that it will always utilize 40 MHz channel widths for connections if 40 MHz operation is supported by the AMP peer.

When an HCI_Read_Local_AMP_Assoc is issued following this command, the AMP ASSOC which is returned shall include at least one channel which is 40 MHz in width in the PCLv2 (see above). When an HCI_Write_Remote_AMP_ASSOC is issued following this command, and if the AMP ASSOC included in that Write_Remote_AMP_ASSOC command contains 40 MHz channels, then the selected channel shall be a 40 MHz channel.

When the Host issues the HCI_Enable_Device_Under_Test_Mode command, the PAL shall advertise or choose 40 MHz channels, depending on its role. When serving as the Initiator, the PAL shall choose one of the 40 MHz channels offered by the Responder. When serving as the Responder, the PAL shall offer at least one 40 MHz channel in its PCLv2.

The described effect of the HCI_Enable_Device_Under_Test_Mode is removed when the Host issues an HCI_Reset command.

3 PHYSICAL LINK MANAGER

A physical link joins an initiating device and a responding device. The initiating device is the device on which the HCI_Create_Physical_Link command was issued. The responding device is the one on which the HCI_Accept_Physical_Link command was issued. Physical link creation collisions are resolved at a higher level, by the AMP Manager.

Support for the 802.11 ERP (see clause 19 of [1]) shall be mandatory for 802.11 AMP devices, but other PHY types may be supported. Channels 1 (2412 MHz) through 11 (2462 MHz) shall be supported for interoperability.

A physical link represents a transport between a single local 802.11 AMP device and a single remote device with a matching 802.11 AMP. The AMP may support multiple physical links (representing different remote devices) at one time. There is a unique binding between the 802.11 MAC addresses of the devices and the physical link.

For a physical link to exist in the CONNECTED state the two devices must have established a PTKSA as described in [1] clause 8.4.1.

3.1 PHYSICAL LINK STATE MACHINE

3.1.1 General rules

The behavior of the PAL with respect to physical links is described in terms of a finite state machine. The state machine describes the behavior of the PAL for an individual physical link; extension to multiple physical links is outside the scope of this document. The sequence of external stimulus and behavior at the logical HCI shall be as though this state machine is present in the implementation. Similarly, the sequence of stimulus and behavior at the 802.11 radio interface shall be as though this state machine is present in the implementation.

3.1.2 State Diagram

The possible state events and transitions are summarized in this diagram. The diagram itself is Informative.

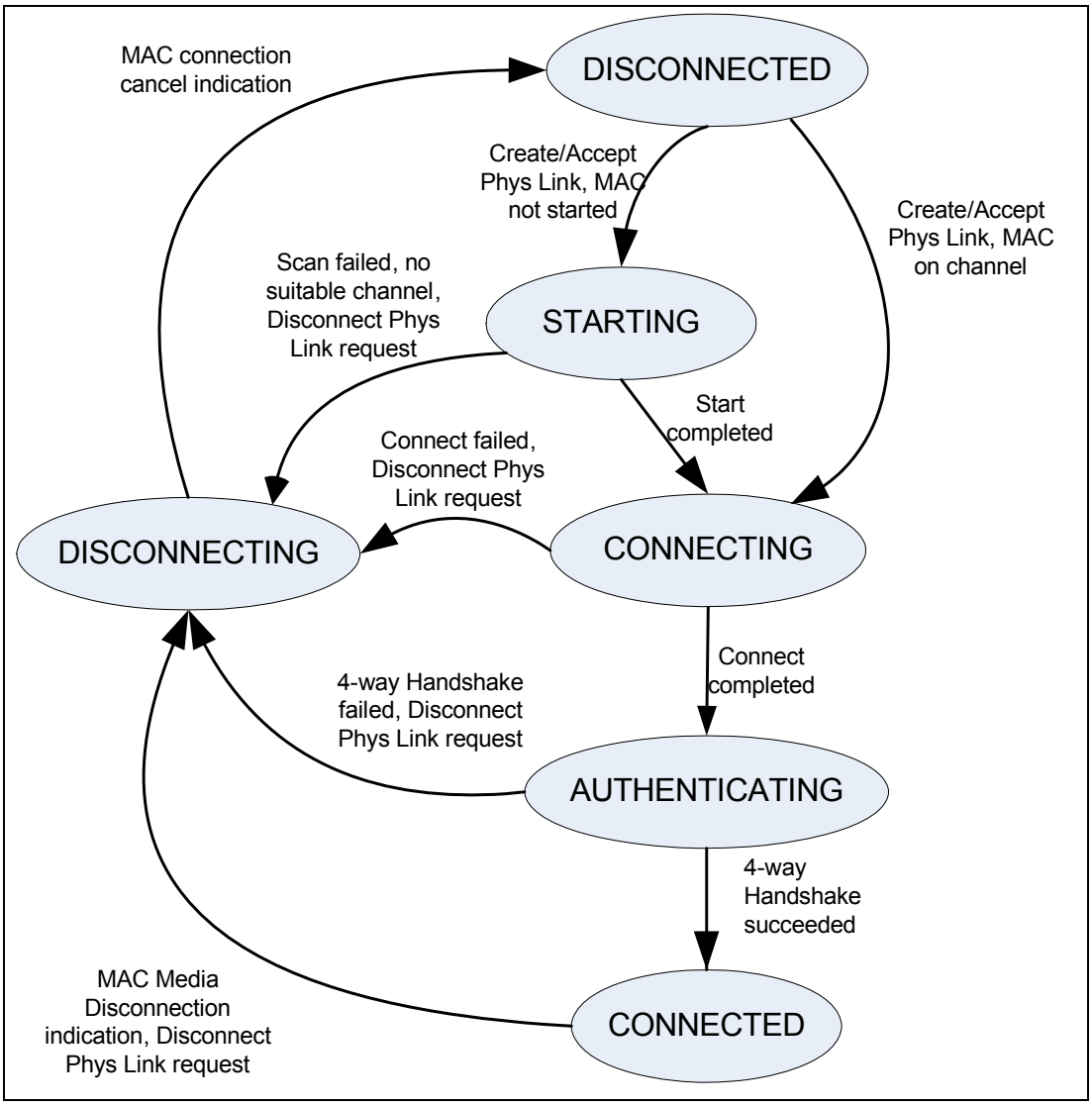

Figure 3.1: Physical Link finite state machine diagram

3.1.3 States

The following states have been defined to clarify the protocol. The states apply to an individual physical link. At power-up or reset, no physical links exist and the state is the DISCONNECTED state.

DISCONNECTED—The physical link is not active, and this is the initial state.

STARTING—Channel has been selected, the MAC is initializing.

CONNECTING—The initiating device waits for messages from the peer device; the responding device commences network connection operations.

AUTHENTICATING—The devices perform the security association process.

CONNECTED—A secure physical link has been established with the remote device.

DISCONNECTING—The PAL waits for the MAC to complete disconnection and return to the initial state.

3.1.4 Events

The following events may cause transitions in the state diagram.

Create/Accept Physical Link—HCI commands from the local Host which affect the state of a physical link.

Connection Accept Timeout—The timeout for this physical link create/accept has expired.

MAC Start Completed—The MAC has started operation on the given channel. This includes beaconing and listening for connections.

MAC Start Failed—The MAC has failed to start on the specified channel for any reason.

MAC Connect Completed—The MAC has completed the process of connecting to a peer in a specified channel.

MAC Connect Failed—The MAC fails to connect on the selected channel for any reason

MAC Media Disconnection Indication—MAC has signaled an existing connection is lost to a remote device.

MAC Connection Cancel Indication—MAC has completed the request to cancel a prior connection.

HCI Disconnect Physical Link Request—The Host has given a disconnect request to the PAL.

4-way Handshake Fails—The establishment of a secure link for this physical link has failed.

4-way Handshake Succeeds—The establishment of a secure link for this physical link has completed successfully.

3.1.5 Conditions

The following conditions are potential qualifiers for actions and state transitions to occur.

MAC not yet started in selected channel—The MAC is not beaconing in any PHY channel, or is beaconing in a different channel than the one specified.

MAC already in selected channel—The MAC is already beaconing in the selected PHY channel.

No suitable channel—No suitable channel can be selected, or the selected channel cannot be joined for any reason.

Device is initiator—Role of device is physical link initiator due to reception of Physical Link Create command.

Device is responder—Role of device is physical link responder due to reception of Physical Link Accept command.

3.1.6 Actions

In some cases, a state transition causes one or more of the following actions to occur. The actions for a state transition shall occur in their entirety before any subsequent state transition occurs, as follows.

Determine selected channel—Using information from the AMP_ASSOC of the remote device and preferences from the local device, select a channel

Set or clear Connection Accept Timeout —Start or stop the timer for the current physical link.

Set or clear NeedPhysLinkCompleteEvent, DiscRequested —Set or clear state variables which control subsequent behavior.

Set or PhysLinkCompleteStatus—Sets command status to be indicated to Host.

Signal MAC to start on channel—Command the MAC to start the process of connection on the specified channel.

Issue MAC connection command—Command the MAC to attempt to connect to the remote device.

Initiate 4-way handshake—Command the authenticator to send the first security message.

Send HCI event—send the indicated HCI event to the local Host.

Cancel MAC connect operation—This physical link no longer needs to be present on this channel. The PAL signals the MAC to delete the connection.

Signal MAC to disconnect peer—Command MAC to send disconnection frame to peer.

3.1.7 DISCONNECTED State

This is the initial state. No timers shall be active.

Event	Condition	Action	Next State
HCI_Create_-Physical_Link command	MAC not yet in selected chan-nel	Determine selected channel Request MAC to start on channel Set Connection Accept timeout Set NeedPhysLinkCompleteEvent Set PhysLinkCompleteStatus to 0x00 (no error)	STARTING
HCI_Create_-Physical_Link command	MAC already in selected channel	Determine selected channel Send HCI Channel Select event Set Connection Accept Timeout Set NeedPhysLinkCompleteEvent Set PhysLinkCompleteStatus to 0x00 (no error)	CONNECT-ING
HCI_Create_-Physical_Link command	No suitable channel	Determine selected channel Send HCI Physical Link Complete event with Status set to No Suitable Channel Found (0x39)	DISCON-NECTED
HCI_Accept_-Physical_Link command	MAC not yet in channel	Signal MAC to start on channel Set Connection Accept Timeout Set NeedPhysLinkCompleteEvent Set PhysLinkCompleteStatus to 0x00 (no error)	STARTING
HCI_Accept_-Physical_Link command	MAC already in that channel	Set Connection Accept Timeout Issue MAC connection command Set NeedPhysLinkCompleteEvent Set PhysLinkCompleteStatus to 0x00 (no error)	CONNECT-ING
HCI_Accept_-Physical_Link command	No suitable channel	Send HCI Physical Link Complete event with Status set to No Suitable Channel Found (0x39)	DISCON-NECTED

Table 3.1: DISCONNECTED State event table

3.1.8 STARTING State

This state is used to begin MAC operation, if required.

Event	Condition	Action	Next State
Connection Accept Timeout		SetPhysLinkCompleteStatus to Connection Accept Timeout (0x10)	DISCONNECTED
HCI_ Disconnect_ Physical_Link command		Indicate HCI Disconnection Physical Link Complete event with Status set to Success (0x00) and Reason set to Connection Terminated By Local Host (0x16) Clear Connection Accept Timeout Cancel MAC connect operation Set PhysLinkCompleteStatus to Unknown connection identifier (0x02)	DISCONNECTED
MAC Start Completed	Device is link originator	Issue HCI Channel Select event	CONNECTING
MAC Start Completed	Device is link responder	Issue MAC connection command	CONNECTING
MAC Start Failed		Clear Connection Accept Timeout Set PhysLinkCompleteStatus to MACConnection Failed(0x3F)	DISCONNECTED

Table 3.2: STARTING State event table

3.1.9 CONNECTING State

This state is used to cause the devices to start communication with each other, over the 802.11 media.

Event	Condition	Action	Next State
Connection Accept Time-out		Cancel MAC connect operation Set PhysLinkCompleteStatus to 0x10 (Connection Accept timeout)	DISCONNECTING
MAC Connect Completed	Device is responder		AUTHENTICATING
MAC Connect Completed	Device is initia-tor	Initiate four way handshake	AUTHENTICATING
HCI_ Disconnect_ Physical Link command		Indicate HCI Disconnection Physical Link Complete event with Status set to Success (0x00) and Reason set to Con-nection Terminated By Local Host (0x16) Set PhysLinkCompleteStatus to Unknown connection identi-fier (0x02) Clear Connection Accept Tim-eout Cancel MAC connect operation	DISCONNECTING
MAC Connect Failed		Cancel MAC connect operation Set PhysLinkCompleteStatus to MAC Connection Failed (0x3F)	DISCONNECTING

Table 3.3: CONNECTING State event table

3.1.10 AUTHENTICATING State

The AUTHENTICATING state is entered when the two devices have established an unsecured connection.

While in the AUTHENTICATING state the two devices shall perform the 802.11 RSN 4-way handshake as described in Section 3.5, establish a PTKSA, and insert key material into the MAC.

Event	Condition	Action	Next State
Connection Accept Timeout		Set PhysicalLinkCompleteStatus to 0x10 (MAC Connection Failed)	DISCONNECTING
HCI_ Disconnect_- Physical Link command		Indicate HCI Disconnection Physical Link Complete event with Status set to Success (0x00) and Reason set to Connection Terminated By Local Host (0x16) Set PhysLinkCompleteStatus to Unknown connection identifier (0x02 Clear Connection Accept Timeout Signal MAC to disconnect peer	DISCONNECTING
4-way Handshake Failed		Signal MAC to disconnect peer Set PhysLinkCompleteStatus to 0x05 (Authentication failure) Clear Connection Accept Timeout	DISCONNECTING
4-way Handshake Succeeded		Send HCI Physical Link Complete event with Status set to Success (0x00) Configure MAC with Link Supervision Timeout Clear Connection Accept Timeout Clear NeedPhysLink CompleteEvent	CONNECTED

Table 3.4: AUTHENTICATING State event table

3.1.11 CONNECTED State

The CONNECTED state is the operational state for the physical link.

Event	Condition	Action	Next State
HCI_ Disconnect_ Physical Link command		Indicate HCI Disconnection Physical Link Complete event with Status set to Success (0x00) and Reason set to Connection Terminated By Local Host (0x16) Clear Connection Accept Timeout Signal MAC to disconnect peer	DISCONNECTING
MAC Media Disconnection Indication		Indicate HCI Disconnection Logical Link Complete event for each logical link, with Status set to Success (0x00) and Reason set to Connection Terminated by remote Host Cancel MAC connect operation	DISCONNECTING

Table 3.5: CONNECTED State event table

3.1.12 DISCONNECTING State

This is a transit state to the DISCONNECTED state and is used to prevent the PAL from preparing to accept or create new connections while a given connection is being deleted by the PAL and the MAC. The PAL shall exit from this state when the MAC is ready to accept new connections.

Event	Condition	Action	Next State
MAC Connection Cancel Indication	PhysLinkCompleteEvent is set	Send HCI Physical Link Complete with status set to PhysLinkCompleteStatus	DISCONNECTED
MAC Connection Cancel Indication	PhysLinkCompleteEvent is clear		DISCONNECTED

Table 3.6: DISCONNECTING State event table

3.2 CHANNEL SELECTION

3.2.1 Overview

Peer to peer networks in 802.11 can incur long connection latency unless there is out of band coordination. Also, one or both of the AMP devices may already be connected to an external network and may therefore need to remain on a given channel. To solve these problems, the data structures and algorithms specified here may be used to provide a coordination service during the creation of the physical link.

An 802.11 channel should be chosen based on up-to-date dynamic information obtained from both AMP peers. The channel selection process is outside the scope of this document but the selected channel shall meet the following criteria:

- The channel shall be legally permitted for use according to local regulatory agencies. If no locale is known, then a common mode configuration shall be used. See Section 3.2.2.
- The channel shall not use a 40 MHz channel width in the 2.4 GHz ISM band.
- If the channel width is 20 MHz, then the channel shall be included in the PCL TLV and in the PCLv2 TLV, if present, in the AMP_ASSOC provided by the initiator in connection establishment. If the channel width is 40 MHz, then the channel shall be present in the PCLv2 TLV.
- The channel selection process should avoid forcing either AMP device to move its channel.
- The channel selection process should favor channels with least impact on BR/EDR operation.

There may be no suitable channel that the initiating PAL can select or the responding PAL may reject the selected channel. If the selection process cannot identify a channel, then the physical link establishment shall be aborted.

The selected channel is transmitted to the responding AMP manager as a field in the AMP_ASSOC parameter in the AMP Create Physical Link message, and given to the responding PAL via the HCI_Write_Remote_AMP_ASSOC command.

3.2.2 Regulatory

Even though IEEE 802.11 devices operate in unlicensed spectral bands, the unlicensed bands and the limits of allowable behavior in each band are specific to a country and enforced by spectrum regulatory bodies. There is a consistent set of rules for operation in the 2.4 GHz ISM band, as described in the following text.

802.11 AMP equipment providers interpret these rules in independent ways and meet the regulations with independent mechanisms so specification of an algorithm to implement regulatory compliance for all situations is beyond the scope of this document.

If an implementation has knowledge of local regulatory constraints then such an implementation may be able to improve certain characteristics of the AMP link, for example by selecting a 5 GHz channel of operation to provide better performance with the collocated BR/EDR radio.

3.2.3 Specification of Channel Identifiers

Tables specifying regulatory class identifiers, channel frequencies, widths and descriptors are given for three regulatory domains in [1] normative annex J. When using these tables, to resolve all ambiguity of channel identification in construction of a PCL TLV, the country string as specified in [4] and the regulatory class are needed. To support channel descriptions for countries not included in tables J-1, J-2, or J-3, the country string may be distinct from the locale known by the implementation, if any. The country string is only used to select a specific table from the set of tables listed above and is only used in the PCL TLV.

AMP devices may utilize 40 MHz channel width in the 5 GHz UNII band. As described in [1], 40 MHz channels are specified as two adjacent 20 MHz channels, one with a role of the primary channel and the other with a role of the extension channel. The role and relative positioning of the primary and extension channels are given in Table 3.7. The operating index is contained within an operating triplet.

Operating index	Channel Starting Frequency (GHz)	Channel Spacing (MHz)	Channel Set	Behavior Limits Set
1 – 80	NA	RFU	RFU	RFU
81	2.407	25	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	
82	NA	RFU	RFU	RFU
83	NA	RFU	RFU	RFU

Table 3.7: Channel set descriptions for PCLv2

Operating index	Channel Starting Frequency (GHz)	Channel Spacing (MHz)	Channel Set	Behavior Limits Set
84	NA	RFU	RFU	RFU
85-114	NA	RFU	RFU	RFU
115	5	20	36, 40, 44, 48	IndoorOnlyBehavor
116	5	40	36, 44	IndoorOnlyBehavior, PrimaryChannelLowerBehavior
117	5	40	40, 48	IndoorOnlyBehavior, PrimaryChannelUpperBehavior
118	5	20	52, 56, 60, 64	
119	5	40	52, 60	PrimaryChannelLowerBehavior
120	5	40	56, 64	PrimaryChannelUpperBehavor
121	5	20	100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140	
122	5	40	100, 108, 116, 124, 132	PrimaryChannelLowerBehavior
123	5	40	104, 112, 120, 128, 136	PrimaryChannelUpperBehavior
124	5	20	149, 153, 157, 161	NomadicBehavior
125	5	20	149, 153, 157, 161, 165, 169	LicenseExemptBehavior
126	5	40	149, 157	PrimaryChannelLowerBehavior
127	5	40	153, 161	PrimaryChannelUpperBehavior
128-191	NA	RFU	RFU	RFU
192-253	NA	Vendor Specific	Vendor Specific	Vendor Specific

Table 3.7: Channel set descriptions for PCLv2

Operating index	Channel Starting Frequency (GHz)	Channel Spacing (MHz)	Channel Set	Behavior Limits Set
254	2.407	25	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	Operating index for Bluetooth, 20 MHz operation only
255	NA	RFU	RFU	RFU

Table 3.7: Channel set descriptions for PCLv2

Multiple operating triplets may be given in the same PCL, PCLv2, or CCL TLVs. If sub-band triplets are given then they are to be assumed to modify the nearest preceding operating triplet. Sub-band triplets may be specified in any order, but they must not contain overlapping channel sets, as noted in [1] clause 7.3.2.9.

The PCL may be included in messages containing AMP_ASSOC fields exchanged over the BR/EDR link during construction of the physical link. The PCL shall contain exactly one country string and one or more operating triplets. If the current locale is unknown, then the non-country designator of 'XXX' (see definition of dot11CountryString in [1] normative Annex D) and regulatory class of 254 shall be used. The set of channels preferred when using this designator and regulatory index shall be channels 1 through 11 in the 2.4 GHz ISM band, with channel 1 the most preferred of the set. Supporting examples are given below.

The PCLv2 may be included in messages containing AMP_ASSOC fields exchanged over the BR/EDR link during construction of the physical link. The PCLv2 does not contain a country string. It shall contain one or more operating triplets and zero or more sub-band triplets. Note: For the channel descriptions given in Table 3.7, for a given operating index, not every associated channel may be legal to use in a given locale. It is up to each AMP implementation to maintain compliance with local regulatory rules. If the current locale is unknown, then the PCLv2 shall not be included in any AMP_ASSOC sent over the BR/EDR link.

The PCLv2 is included by the sender to describe both 20 MHz and 40 MHz channels and also contains the same 20 MHz channels as described in the required PCL TLV. However, the channels in the PCLv2 are specified using operating indices as given in Table 3.7, not the specific regulatory domain identifiers used in the PCL.

The CCL is used to inform the peer of the current channel usage of the sending AMP.

3.2.4 Channel List Examples

In the first example PCL, we assume the device does not know its locale and it prefers operation on channel 1 in the 2.4 GHz ISM band, although operation on channels 2 through 11 is acceptable. The absence of a specific sub-band triplet implies all channels 1 through 11 are acceptable.

Field	Value	Comments
Country String	'XXX'	Applies to entire table. Signifies non-country (mobile applications).
Regulatory Extension Identifier	201	
Regulatory Class	254	In context of Country String. Signifies 2.4 GHz ISM band channels 1 through 11 unless modified by specific channel list.
Coverage Class	0	Not used by AMPs.

Table 3.8: Simple preferred channel list

In the next example, assume the PAL again does not know its locale, but it prefers operation only on channels 6, 7 and 11, with 11 the most preferred.

Field	Value	Comments
Country String	'XXX'	Applies to entire table. Signifies non-country (mobile applications)
Regulatory Extension Identifier	201	
Regulatory Class	254	In context of Country String. Signifies 2.4 GHz ISM band channels 1 through 11 unless modified by specific channel list.
Coverage Class	0	Not used by AMPs.
First Channel	11	First sub-band triplet
Number of channels	1	
Maximum transmit power level	20	
First Channel	6	Second sub-band triplet
Number of channels	2	
Maximum transmit power level	20	

Table 3.9: Preferred channel list with non-contiguous channels

In the next example, assume the PAL knows that it is operating in the US and it has determined that all channels in the 2.4 GHz ISM band and 2 channels of 20 MHz width, 36 and 40, in the 5 GHz U-NII I band should be communicated to the other peer. It is also assumed that the PAL has determined that channels

in the 2.4 GHz band are preferred to the 5 GHz channels. The PAL would use the following PCL.

Field	Value	Comments
Country String	'US'	Applies to entire table.
Regulatory Extension Identifier	201	First operating triplet.
Regulatory Class	12	In context of Country String, specifies channels 1 through 11, inclusive, in 2.4 GHZ ISM band. Absence of specific channel list signifies all channels in this (FCC) regulatory class are available to the AMP.
Coverage Class	0	Not used by AMPs.
Regulatory Extension Identifier	201	Second operating triplet.
Regulatory Class	1	In context of Country String, specifies 20 MHz channel spacing. Presence of subsequent channel list signifies not all channels in the regulatory class are available to the AMP.
Coverage Class	0	Not used by AMPS.
First channel	36	First sub-band triplet.
Number of channels	2	Channels 36 and 40 are included, with channel 36 more preferred than channel 40.
Maximum transmit power level	20	Units in context of Country String (dBm, mW, etc).

Table 3.10: Mixed band preferred channel list example

In the next example consider the case of a PCL for Canada with 20 MHz channel numbers 36 and 40 and a PCLv2 with 40 MHz channel widths for channel pairs (36, 40) and (44, 48), as well as the 20 MHz channels in the PCL. Assume for this example that Canada uses the same channel descriptions as the US for the channels referenced. A country string of 'US' is used in the PCL in order to indicate we are drawing the channel descriptions from Table J-1 in [1]. The channel descriptor in the PCLv2 for the former channel pair shows that 36 is the primary channel, while the descriptor for the latter pair shows that 48 is the primary channel. The operating indices will be from the set {115, 116}. Note: 2.4 GHz channels are not included at all in this example, implying that only 5 GHz band channels will be used if any connection is made.

The PCL TLV and PCLv2 TLV are shown in the tables 3.11 and 3.12 below. In the PCLv2 TLV the 40 MHz pairs are shown first and the 20 MHz channels follow.

Field	Value	Comments
Country String	'US'	Applies to entire PCL
Regulatory Extension Identifier	201	First operating triplet
Regulatory Class	1	Specifies channels 36 - 48 inclusive, 20 MHz width. Will be further restricted by sub-band triplet
Coverage Class	0	Not used by AMPs
First channel	36	First sub-band triplet
Number of channels	2	Denotes channels 36, 40
Transmit power	20	

Table 3.11: Example preferred channel list TLV for Canada

Field	Value	Comments
Operating Extension Identifier	201	First operating triplet
Operating index	116	Specifies channels 36 and 44, inclusive, are to be considered primary channels with extension channels at the higher adjacent frequencies, i.e. channels 40 and 48 are extension channels.
Coverage Class	0	Not used by AMPs
First Channel	36	First sub-band triplet. Specifies 36 is primary and 40 is upper extension.
Number of Channels	1	There is one 40 MHz channel specified.
Transmit power	20	
Operating Extension Identifier	201	Operating triplet for the 20 MHz channels
Operating index	115	Specifies channels 36 – 48 inclusive, 20 MHz width.
Coverage Class	0	Not used by AMPs
First channel	36	Sub-band triplet
Number of channels	2	Denotes channels 36, 40
Transmit power	20	

Table 3.12: PCLv2 example

3.3 802.11 LINK CREATION

3.3.1 Starting the AMP Network

After the initiator has selected a channel of operation, the initiating PAL shall instruct the MAC to commence network operation, including beaconing. The 802.11 AMP devices shall use probe responses and/or beacons (respecting regulatory restrictions) to advertise MAC capabilities.

AMP devices shall use beacons to enable effective coexistence with neighboring 802.11 networks. For example, non-AMP devices can discover the existence of AMP networks and such devices can also determine the EDCA characteristics of the network. In regulatory domains where DFS operation is required, an AMP device may need to passively observe the channel to check for radar, as described in [1] clause 11.9, before it may start to beacon. For AMP operation, the maximum beacon period shall be Max80211BeaconPeriod.

The SSID information element for AMP devices shall be of the form 'AMP-xx-xx-xx-xx-xx-xx' (with no null termination and no quotes) where the "x" characters are replaced by the lowercase hexadecimal characters of the MAC address of the local 802.11 device. This is referred to here as the AMP SSID. For example, if the MAC address of a device is 00:01:02:0A:0B:0C, then the AMP SSID would be 'AMP-00-01-02-0a-0b-0c'.

AMP beacons shall be indicated as ESS-style beacons in the capability information field as described in [1] clause 7.3.1.4 and shall include the AMP SSID. Beacons shall be sent with standard beacon channel access semantics as given in [1] clause 11.1.2.1. The contents of the Address2 and Address3 fields for beacons and probe responses shall be the MAC address of the transmitting AMP node. Probe requests sent to AMP peers shall use the MAC address of the intended recipient as the content of the Address1 and Address3 fields. In [1] clause 7.2.3.1 contains the details of the format of 802.11 beacon frames and [1] clause 7.2.3.9 contains the details of the format of 802.11 probe response frames, including a list of the required information elements is specified.

3.3.1.1 HT Operation

The AMP peers shall maintain the HT protection field in the HT operation information element in their beacons according to [1]. When communicating with the initiator, the responder shall use the protection mechanism dictated by the initiator's beacon.

The HT features of Greenfield, Reduced Inter-Frame Space (RIFS), dual Clear to Send (CTS) protection and Phased Coexistence Operation (PCO) shall not be used in AMP links. The respective fields in the 802.11 HT operation information element shall be set to zero in transmitted MMPDUs and ignored in received MMPDUs.

When using a DFS channel, the AMP responder shall monitor the field which indicates Overlapping BSS (OBSS) non-HT stations are present in the HT operation element of the AMP initiator's beacon and adhere to the requirements in [1]. The AMP initiator shall be responsible for setting this field.

3.3.2 Establishing the 802.11 Link

AMP devices may choose to obtain the timebase of their peer through the timestamp field in 802.11 beacons and probe responses. The respective Target Beacon Transmission Time (TBTT) of the peers may be independent and occur at different times with respect to one another. The beacon period of the devices may be different from one another.

AMPs shall use RSN security. RSN security requires the use of 802.11 open authentication as specified in [1] clause 8.2.2.2. The AMP responder shall send the first frame of the 802.11 authentication transaction sequence with transaction ID of 1. Address fields Address1 and Address3 shall contain the initiator's address.The AMP initiator shall respond with an 802.11 authentication frame with transaction ID of 2. Address fields Address2 and Address3 shall contain the initiator's address.

AMPs shall use 802.11 (re)association frames to select features advertised by their peer. The AMP responder shall send an (re)association request frame. Address fields Address1 and Address3 shall contain the initiator's address.

The AMP initiator shall reply with an (re)association response frame. Address fields Address2 and Address3 shall contain the initiator's address. The frame body contents of both the (re)association request and response are given in [1] clause 7.2.3.4 and [1] clause 7.2.3.5, respectively.

After successful 802.11 (re)association, unencrypted security frames may be transmitted on the physical link.

3.3.3 Address Fields of Data Frames

The 802.11 AMP shall support the use of four address field frame format for all data frames after (re)association.

To use data frames with four address fields the AMP shall set the ToDS and FromDS bits in the FrameControl field equal to one. The addresses used for such frames shall be arranged as shown in Table 3.13. Because there is no frame forwarding by AMPs, the RA is the same as the DA and the TA is the same as the SA.

Field	Value
Address1	Receiver Address (RA)
Address2	Transmitter Address (TA)
Address3	Receiver Address (RA)
Address4	Transmitter Address (TA)

Table 3.13: Four address frame address fields

3.3.4 Admission Control

AMP devices should respond to probe requests with a probe response.

If Address2 of an 802.11 association request does not match the MAC address from the AMP Assoc received during construction of the current physical link or if the SSID in the association request does not match the AMP SSID of the receiving AMP device, then the receiving AMP device shall not transmit an 802.11 association response with a status code of 0 (success).

3.4 PHYSICAL LINK MAINTENANCE

After a physical link is created, an AMP device shall monitor the state of the link and provide an indication of link failure to the Host if no frames are received from the AMP physical link peer for a period of Link Supervision Timeout (LSTO). Correctly decrypted data frames received from the peer shall be evidence of an existing physical link, but this is not true for 802.11 ACK and CTS control frames.

If the PAL has not received a correctly decrypted data frame for a period less than LSTO, then it shall solicit a response from its peer in an attempt to receive the response before the expiration of LSTO. For this purpose, link supervision request/response protocol identifiers are given in Table 5.2 and may be used to construct link supervision data frames. When a PAL receives a data frame with a protocol identifier of Link Supervision Request, it shall reply by transmitting a data frame with a protocol identifier of Link Supervision Reply.

3.5 PHYSICAL LINK SECURITY

3.5.1 Obtaining Key Material

The Host provides key material for use with a physical link as the Dedicated_AMP_Link_Key parameter of the HCI_Create_Physical_Link or HCI_Accept_Physical_Link command. See [Vol 2] Part E, Section 5.2 for octet ordering of multi-octet HCI parameter values. The Dedicated_AMP_Link_Key parameter shall be interpreted by the PAL as a 256 bit integer and used directly as a Pairwise Master Key (PMK) by the two devices to create a PTK. Further key material is derived from the PTK.

3.5.2 Creating a PTK

The 802.11 4-way handshake is used to create a PTK from the PMK. See [1] clause 8.5.3.

Entities known as authenticator and supplicant are used to exchange security information in the 802.11 security architecture. Since the responding AMP device receives the 802.11 (re)association response frame, it shall serve the role of supplicant; the initiating AMP device shall serve the role of authenticator. The authenticator sends the first and third messages of the 4-way handshake and the supplicant sends the second and fourth messages. Only a single instance of the 4-way handshake is run by the 802.11 AMP to establish its secure connection.

If a 4-way handshake fails then the PAL physical link state machine shall transition to the DISCONNECTING state as described in Section 3.1.10.

The supported security configurations of the peers are given in the RSN information element in beacons or probe responses exchanged by the AMP devices. The PAL shall enforce the following restrictions:

- UseGroup (00:0F:AC:00), WEP-40 (00:0F:AC:01), TKIP (00:0F:AC:02), and WEP-104 (00:0F:AC:05) shall not be allowed as valid pairwise cipher suites.
- The group cipher shall be CCMP (00:0F:AC:04)
- The only valid AKMP shall be PSK (00:0F:AC:02) or a vendor-specific AKMP.
- The NoPairwise bit (B1) of the RSN Capabilities field shall be set to zero.
- The Management Frame Protection Required (MFPR) bit (B6) of the RSN Capabilities field shall be set to zero. Note: This does not prevent the use of Management Frame Protection.

The supplicant shall ensure a proper intersection of capabilities exists subject to the constraints above. It may also choose a set according to its policy requirements and may terminate a connection attempt if no policy match is

found. Either the supplicant or the authenticator may terminate a connection after AMP Create Physical Link Response is sent by indicating an HCI Physical Link Complete event with an unsuccessful status code.

The AMP key received from the Host may be marked with a Link_Type of debug. If it is, then the local PAL may choose to use the key, or it may choose to refuse to establish the link, according to its own policy. The management of this debug key policy is outside the scope of this document.

The PAL shall use the AMP key as a Pairwise Master Key (PMK) according to the 802.11 key hierarchy described in [1] clause 8.5.1.2 and shall exchange nonces (as part of a 4-way handshake) to add liveness in the derivation of a Pairwise Transient Key (PTK). The PTK shall be derived specifically for a session started by the HCI_Create_Physical_Link_Request command and shall be deleted when the session is terminated by the HCI_Disconnect_Physical_Link command. The construction of the AAD used with CCMP shall include Address4 in the manner illustrated in [1] clause 8.3.3.3.2, Figure 8-17.

3.5.3 Using Encryption

Encryption keys are derived from the PTK and are inserted into the 802.11 MAC after the 4-way handshake has successfully completed. All data frames after this point are encrypted and this state persists until the physical link is deleted.

3.5.4 Refreshing a PTK

The PTKSA, if any, shall be discarded when the physical link to which it applies enters the DISCONNECTED state. At this point the Host may reestablish the connection which will cause the creation of a new PTKSA.

The PTKSA shall be discarded in the event its receive sequence counter becomes exhausted. Since this is a 48 bit counter, this is an unlikely event.

To establish a new PTK, the physical link shall be torn down and re-established.

3.5.5 Transporting Security Handshake Messages

Security handshake messages shall be sent after the physical link is created, but before any logical link is created between the two devices.

The SNAP header composed of the OUI of the Bluetooth SIG as shown in Table 5.1 and the protocol identifier given in Table 5.2 shall be used to distinguish AMP 4-way handshake messages from external security traffic.

3.6 PHYSICAL LINK SUPPORT FOR QOS

3.6.1 QoS Advertisement

If an AMP device supports 802.11 EDCA and is configured to use it, then it should indicate this to the Host by setting the Guaranteed_Service_Type_Supported field of the PAL_Capabilities parameter included in the HCI_Read_Local_AMP_Info command.

If QoS is offered by an AMP device, it shall advertise EDCA in beacon and probe response frames by including the EDCA Parameter Set information element, as given in [1] clause 7.3.2.29. Note: The EDCA Parameter Set information element is also included in (re)association response frames. For AMP devices, the use of the EDCA parameter set shall be as follows. The QoS Info field shall be zero. The ACI, AIFSN, and TXOPlimit values of the AC parameter record shall be as given in [1] Table 7-37. The ECWmin and ECWmax values are specific to the 802.11 PHY type and are documented in their appropriate clauses in [1]. The Admission Control Mandatory (ACM) bit should be zero.

The QoS Capability information element is described in [1] clause 7.3.2.35. The QoS Info field (see [1] clause 7.3.1.17) is contained in the QoS Capability information element as well as the first field of the EDCA Parameter Set information element. AMP devices shall not include the QoS Capability information element in beacons or probe responses.

The interpretation of the content of the QoS Info field is different depending on if the enclosing frame is a beacon or probe response, or if it is a (re)association request.

802.11 Information element	Frame(s) contained in
QoS Capability information element	Association Request, Reassociation Request
EDCA Parameter Set information element	Beacon, Probe Response, Association Response, Reassociation Response

Table 3.14: EDCA advertisement and negotiation

The EDCA AC parameters shall not change unless the physical link is torn down and re-established. Therefore the EDCA Parameter Set Update Count subfield of the QoS Info field in beacons and probe responses shall be zero.

3.6.2 Negotiation

To request the use of EDCA on the physical link an AMP device shall include a QoS Capability element in its (re)association request. If the AMP peer rejects the EDCA negotiation then the (re)association response frame shall have no EDCA Parameter Set element included. If the (re)association response frame has a status code of successful and the EDCA Parameter Set element is included, then the link shall be considered to support EDCA.

4 LOGICAL LINK MANAGER

A logical link provides a (possibly) bidirectional path for in-order delivery of L2CAP PDUs, with a specified set of traffic characteristics. Each logical link exists with respect to a specific physical link in the CONNECTED state.

A logical link is characterized by a pair of Extended Flow specification parameter sets, as described in [1]. An Extended Flow specification parameter set is referred to simply as a flow spec here.

Each logical link is classified as either Best Effort or Guaranteed. The logical link is known as Best Effort if either of its flow specs indicates Best Effort in its Service Type field. Otherwise, it is known as Guaranteed.

Support for Guaranteed links is optional; the PAL may reject any guaranteed flow spec. If 802.11 QoS (see Section 3.6.1) is not supported by both endpoints, then there is no traffic prioritization in the MAC.

4.1 LOGICAL LINK CREATION

Creation of a logical link is initiated by the HCI_Create_Logical_Link or HCI_Accept_Logical_Link command. If the physical link is not in state CONNECTED, the PAL shall send the HCI Logical Link complete event with status set to Command Disallowed (0x0C). The Controller shall indicate successful completion of the logical link creation using the HCI Logical Link Complete event, with Status set to Success (0x00).

4.1.1 Logical Link Handles

When a Logical Link is created or accepted the PAL shall create a Logical Link handle, or logical handle. The logical handle is included in HCI ACL data packets received from the HCI in the Handle field; the PAL may use the logical handle to help it select the egress physical link. If the Host delivers an HCI ACL data packet to the AMP Controller with an invalid Handle field, then the AMP shall discard the ACL data packet and the PAL may indicate a Number of Completed Blocks or Number of Completed Packets event (depending on the configuration of the Flow Control setting) using the Host-supplied logical handle.

When the PAL receives data frames from the MAC, it may use the source address to determine the physical link. It shall place the physical link handle corresponding to that link into the Handle field of the HCI ACL data packet before the packet is indicated to HCI. Note: The PAL is not required to determine a logical handle for frames it receives from the MAC.

4.1.2 Null Traffic Logical Links

Data frames may be discarded if attempted on a No Traffic flow.

4.1.3 Best Effort Logical Links

There is a single logical link used to transport all Best Effort traffic.

If EDCA was successfully negotiated during the physical link creation, the PAL shall map all egress frames marked with the Best Effort logical handle to a UP of either BEUserPrio0 or BEUserPrio1, inclusive. Otherwise, if EDCA is not used, no mapping is required and the UP shall be set to zero by the PAL.

4.1.4 Guaranteed Logical Links

Flow specs requesting guaranteed service may be accepted by the PAL if the physical link was negotiated with 802.11 QoS.

EDCA shall be used by the 802.11 AMP devices if supported and available for use by both devices. The PAL shall provide a priority field associated with each egress 802.11 frame. The priority field is interpreted by the MAC as a User Priority (UP) and is mapped to access category as specified in [1] clause 9.1.3.1.

If the 802.11 link was negotiated with QoS, then on receiving an HCI_Create_Logical_Link or HCI_Accept_Logical_Link command specifying a Guaranteed transmit flowspec the PAL shall use a UP with a value between MinGUserPrio and MaxGUserPrio, inclusive. The determination of precisely which UP to use is outside of the scope of this specification. A flow spec expresses maximum bandwidth as the product of inter-SDU arrival time and maximum SDU size. The PAL may use the specified maximum bandwidth or latency requirements from the flow spec to establish mappings of logical handles to UPs.

If a request for a guaranteed link cannot be mapped to a UP in the range specified above, it may be rejected.

The PAL shall reject all requests to establish a guaranteed logical link with a flow spec expressing a maximum bandwidth which is greater than the Total_Bandwidth parameter of the Read Local AMP Info command minus the sum of the requested maximum bandwidths of all existing guaranteed logical links.

The transmitter shall store the logical channel to UP mapping for application to future frame transmissions. The receiver shall create an HCI ACL data header and insert the physical link handle into the Handle field of the packet before indication to the Host.

4.2 LOGICAL LINK UPDATES

The Host may indicate a change of traffic requirements on a logical link by using the HCI_Flow_Spec_Modify command. An HCI_Flow_Spec_Modify command will not change the Service Type of the flow specs for a logical link.

When the PAL receives an HCI_Flow_Spec_Modify command, it should validate that the new flow spec requirements can be met with the available resources. If not, then the PAL should reject the command.

4.3 LOGICAL LINK DELETION

The PAL shall rely on upper layers to flush any frames before a logical link is deleted. See explicit flush in Section 5.3. The PAL may choose to re-use the same logical link identifier for new logical links even on the same physical link.

The PAL should recover any allocated QoS resources when the logical link is deleted. In particular, when deallocating resources for a flow spec which expressed a maximum bandwidth, the PAL should subtract that parameter from the total allocated bandwidth.

5 DATA MANAGER

5.1 ENCAPSULATION

The PAL shall advertise a maximum PDU length of Max80211PALPDUSize octets and each L2CAP PDU is transmitted by the MAC as a single MSDU. The MSDU boundary determines the L2CAP PDU boundary for the receiver.

Before transmission, the PAL shall remove the HCI header, add LLC and SNAP headers and insert an 802.11 MAC header. The LLC/SNAP frame format used by the 802.11 AMP is shown in Table 5.1.

	DSAP	SSAP	Control	OUI	Protocol	Frame Body
Value	0xAA	0xAA	0x03	00:19:58	XX:XX	
Octets	1	1	1	3	2	0-1492

Table 5.1: 802.11 AMP LLC/SNAP encapsulation

The protocol identifiers shall be as shown in Table 5.2:

Value	Protocol Description	Logical Link
0x0000	Reserved for future use	N/A
0x0001	L2CAP ACL data	AMP-U
0x0002	Activity Report	AMP-C
0x0003	Security frames	AMP-C
0x0004	Link supervision request	AMP-C
0x0005	Link supervision reply	AMP-C
0x0006-0xFFFF	Reserved for future use	N/A

Table 5.2: Protocol Identifiers

All 802.11 data frames on the AMP link shall be sent with ToDS and FromDS bits in the Frame Control field both set to one. For a description of the Frame Control field, see [1] clause 7.1.3.1. If QoS was negotiated on the physical link between the peers then the QoS Control field shall be included in the MAC header, otherwise it shall not be included.

The receiving device can determine the physical link identity from the TA of the received frame. The receiving PAL shall decapsulate the frame from 802.11 and into the HCI ACL data encapsulation.

5.2 COEXISTENCE AND LOCAL INTERFERENCE

5.2.1 Interference from Collocated Radios

The BR/EDR radio, LE PHY and the ERP of 802.11 AMP operate in the 2.4GHz ISM band and mechanisms are required to help mitigate potential interference. The BR/EDR and LE radio subsystems on an 802.11 AMP capable device should employ AFH to attempt to avoid interference of overlapping transmissions on the medium.

Protocols specified in [1] are designed to mitigate interface from non-collocated radios.

On systems where the devices are collocated such that radio isolation is insufficient to mitigate interference, the use of the shared medium should be time-division multiplexed to ensure only one of the interfering radios will gain access to the medium. In the case of the BR/EDR radio and the 802.11 radio operating in the 2.4GHz band, the PAL should ensure that local high priority BR/EDR traffic such as SCO, eSCO and ACL packets carrying A2DP information have higher priority over potentially interfering local 802.11 AMP packets. The PAL may ensure this prioritization through many ways including employing the methods described in [3] but the exact methods are outside the scope of this document.

Interference can also arise between the 802.11 AMP radio and collocated licensed band radios (LBRs) operating in adjacent bands to the ISM spectrum. Due to 802.11 AMP transmissions, the collocated LBR may be unable to receive transmissions from its peer LBR. Again the use of the medium should be time-division multiplexed to ensure only one of the radios will gain access to the medium at one time. In the case of the 802.11 AMP radio and an LBR, the PAL should ensure that the local LBR packets have higher priority over potentially interfering local 802.11 AMP packets. Although the exact methods are outside the scope of this document, similar collocated radio interference mitigation mechanisms as described above may be used.

5.2.2 Unavailability of Remote Peer

Distributed AMP devices may experience 802.11 performance degradation due to simultaneous BR/EDR activity occurring at one of the AMP peers. Local interference mitigation schemes (see Section 5.2.1) employing time-divided access to the medium will result in the 802.11 radio being periodically unavailable to its peer. The PAL attempting to transmit to a periodically unavailable AMP device may employ techniques to allow its transmissions to consume minimal airtime and power while still achieving acceptable performance for its own transmissions and those of neighboring networks.

When a physical link is created, the PAL shall configure the 802.11 MAC to use RTS/CTS signaling by default. This behavior may be modified by using Activity Reporting as given in Section 5.2.3.

5.2.3 Activity Reports

AMP Activity Reports provide an optional mechanism for the 802.11 PAL to inform its 802.11 AMP peer of events which may result in the 802.11 device being unavailable to receive 802.11 traffic. Activity Reports may also be used to inform a peer of the absence of local interference thereby allowing the remote peer to disable its RTS/CTS signaling.

Examples of simultaneous traffic include, but are not limited to:

1. BR/EDR SCO/eSCO streams
2. 802.11 traffic required to maintain an external 802.11 connection
3. Traffic from other collocated radios such as LBRs in the 2.3 or 2.5 GHz band (including WiMax, LTE, and UMB)

When Activity Reports are used, it is the PAL which is aware of its unavailability which may generate the interference information. The PAL can determine the information to include in the Activity Report through methods including, for example, the PTA model described in [3]. In many systems with collocated radios there are PTA signals between the BR/EDR and 802.11 Controllers which may be used to generate this information.

The information shall be transferred between the communicating 802.11 PALs using a PAL Activity Report PDU encapsulated in an 802.11 data frame. The frame body of the Activity Report PDU following the LLC/SNAP header is shown in Table 5.3. It has a variable length.

Activity Report *Size: Variable*

Value	Octets	Description
ScheduleKnown	1	Bit 0: 1 if the sender knows the schedule of interference 0 if the sender does not know the schedule of interference
NumReports	1	The number of traffic reports in this PDU
StartTime	4	The absolute time of the start of possible unavailability of the peer, expressed as the least significant 32 bits of the 802.11 TSF of the transmitter of the PDU.
Duration	4	Duration of the active phase of the traffic in microseconds.
Periodicity	4	Periodicity of traffic in microseconds. May be zero to indicate aperiodic traffic.

Table 5.3: Activity Report

Processing of received Activity Reports is optional and support for it is advertised in the 802.11 PAL Capabilities field.

The ScheduleKnown field shall indicate to the receiver of the Activity Report whether or not the sender is aware of the schedule of subsequent data traffic.

- If the ScheduleKnown is set to zero, this shall signify the sender is aware of the presence of traffic but not its schedule, and the receiving PAL shall configure the MAC with RTS/CTS signaling for all traffic on the physical link to the sender.
- If the ScheduleKnown is set to one, the sender shall describe the schedule of interference in the subsequent fields; the receiver of the report may either schedule all 802.11 AMP traffic around this schedule, configure the MAC with RTS/CTS signaling, or both.

If a PAL knows there is no interference from collocated radios before or during establishment of a physical link, an Activity Report conveying this state should be sent at the earliest possible opportunity after the physical link is established.

The StartTime, Duration and Periodicity form an Activity Report triplet. The difference between the StartTime and the current TSF of the peer shall be interpreted as a signed 32 bit value. A negative value shall denote a time in the past. The NumReports value indicates the number of Activity Report triplets which follow. The Duration shall specify the amount of time (in microseconds) the PAL is in the mode specified. If the ScheduleKnown field is zero, there shall be no Activity Report triplets and the NumReports field shall be zero. If the Periodicity is non-zero, it shall be a value greater than the Duration.

An Activity Report may be created to describe a burst of interfering traffic by setting ScheduleKnown to one, NumReports to one, StartTime to the time the burst is predicted to start, Duration to the duration of the burst, and Periodicity to zero.

The PAL may inform its peer that interference is no longer present by sending an Activity Report with a ScheduleKnown field set to one, and a NumReports field set to zero. Upon reception of such an Activity Report frame, a receiving PAL may configure the MAC without RTS/CTS signaling.

The PAL may transmit an Activity Report frame periodically in order to correct clock drift between its TSF and the schedule of unavailability caused by the collocated radio. The most recent Activity Report shall supersede all others received.

5.3 EXPLICIT FLUSH

Explicit flush may be initiated at the HCI on any logical link by using the HCI_Enhanced_Flush command. Explicit flush discards all data frames for transmit on the indicated logical link.

5.4 AUTOMATIC FLUSH

If guaranteed logical links are supported, then automatic flush timeouts shall be supported by the 802.11 PAL.

5.5 QUALITY OF SERVICE VIOLATIONS

The PAL may generate a HCI QoS Violation event when it is determined that the parameters of the flow spec are not being met. This may occur for instance when a data packet has been queued for transmission on a Guaranteed logical link for longer than the Access Latency in the flow spec for transmitted traffic on that link. It can also occur when a data packet fails to receive an acknowledgment before the specified flush timeout.

6 CONSTANTS

Name	Value	Units	Description
Max80211PALPDUSize	1492	Octets	Maximum PDU size
Max80211AMPASSOCLen	672	Octets	Maximum length of AMP_ASSOC for this AMP
MinGUserPrio	4	N/A	Minimum value of user priority for guaranteed link
MaxGUserPrio	7	N/A	Maximum value of user priority for guaranteed link
BEUserPrio0	0	N/A	Best effort User Priority
BEUserPrio1	3	N/A	Best effort User Priority
Max80211BeaconPeriod	2000	milliseconds	Maximum value of AMP dot11BeaconPeriod MIB variable
ShortRangeModePowerMax	4	dBm	Maximum transmit power for ERP-OFDM frames when in Short Range Mode

Table 6.1: 802.11 PAL Constants

7 MESSAGE SEQUENCE CHARTS

The MSCs necessary to show the creation and deletion of physical and logical links can be found in [Vol 2] Part F, Section 4.16, as the sequencing of steps is determined by the logical HCI. However, an overview MSC for AMP physical link creation is given in Figure 7.1.

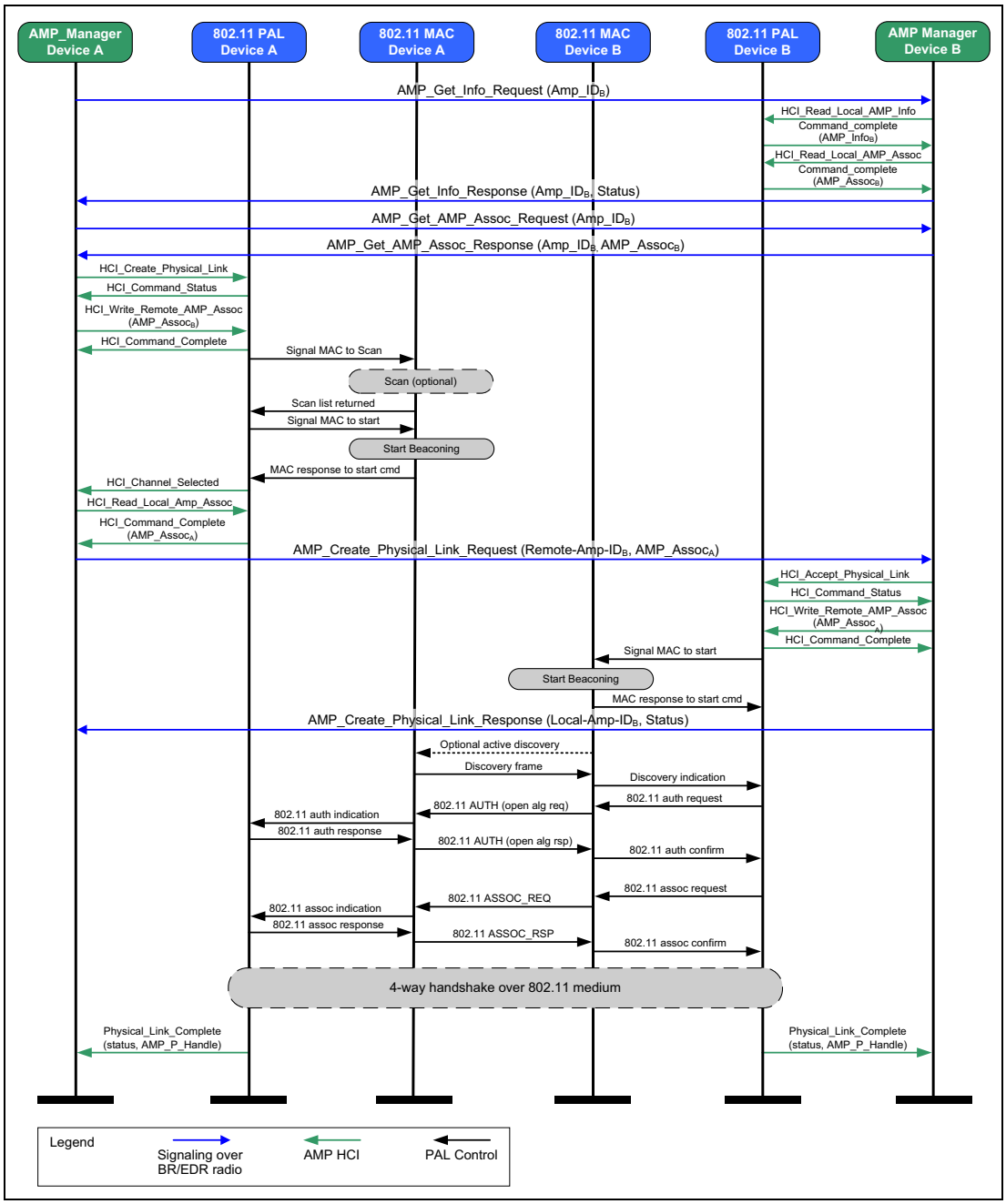

Figure 7.1: Overview MSC for physical link create/accept

8 REFERENCES

[1] IEEE 802.11-2007 Standard and the following amendments: Amendment 1 (Radio Resource Measurement), Amendment 2 (Fast BSS Transition), Amendment 3 (3650 MHz - 3700 MHz Operation in US), Amendment 4 (Protected Management Frames), and Amendment 5 (Enhancements for Higher Throughput)

[2] ISO/IEC 3166-2

[3] IEEE 802.15.2 Recommended Practice: Coexistence of WPAN with other wireless devices operating in unlicensed frequency bands

[4] Bluetooth SIG Company Identifiers https://www.bluetooth.org/en-us/specification/assigned-numbers/company-identifiers

APPENDIX A TEST SUPPORT

This section provides the details of the AMP test commands and events described in [Vol 2] Part E.

A.1 AMP TEST COMMAND

Command	OCF	Command Parameters	Return Parameters
HCI_AMP_Test	0x0009	Test Parameters	Status

Description:

This command is used to configure and start a test. This command shall be only valid in AMP Test Mode.

When a test scenario has completed or on receiving a HCI_AMP_Test_End command the AMP shall send a HCI AMP Test End event and the AMP returns to an idle state with the RX and TX off.

Test Parameters: *Size: 18 octets*

Value	Parameter Description
0xXX	Test Scenario 0x01 – Transmit single frames with following parameters 0x02 – Receive frames with following parameters All other values are reserved for future use
0xXX	Preamble 0x00 – ERP-OFDM preamble 0x01 – Short Preamble 0x02 – Long preamble All other values are reserved for future use
0xXX	Payload 0x00 – All Zeros payload 0x01 – All ones payload 0x02 – PRBS9. The PRBS9 sequence is reinitialized for every frame. Each PRBS9 payload is the same. 0x03 – PRBS15. The PRBS15 sequence is reinitialized for every frame. Each PRBS15 payload is the same. All other values are reserved for future use

0xXXXXXX	Country	Channel Descriptor For AMP type 802.11, the channel is completely described by a four-tuple of {Country, Operating Extension Identifier, Regulatory class, Channel number}. The Country identifier is an ISO/IEC-3166 three-octet field and the Extension Identifier is equal to 201. If the locale is unknown to the EUT, then it shall only allow channel numbers as given in Ref [2] Clause 18.4.6.2. Valid values are from 1 to 11. All other values are reserved for future use
0xC9	Operating Extension Identifier	
0xXX	Operating Class	
0xXX	Channel Number	
0xXX	Modulation 0x00 – ERP-DSSS 0x01 – ERP-CCK 0x02 – ERP-OFDM 0x03 – ERP-PBCC 0x04 – DSSS-OFDM 0x05 – OFDM All other values are reserved for future use	
0xXX	Rate (Mb/s) Transmission data rate of PSDU. See Ref [2] Clause 19.8.2 PHY MIB dot11SupportedDataratesTxValues The allowed data rates are dependent on the modulation selected. Ref [2] Table 19.1 Clause 19.2 and Clause 17.2.3.3. All other values are reserved for future use	
0xXXXX	Payload length 1 to 1500. All other values are reserved for future use	
0xXX	Transmit Power Control (TPC) Valid values are 1 to 8 as defined in the Ref [2] implementation dependent. All other values are reserved for future use	
0xXX	Duty Cycle 10 to 99% (default 50%) All other values are reserved for future use	
0xXXXX	Frame count 1 to 65525 – Number of frames to be transmitted. When the defined frame count has been transmitted the system returns to the idle state and the AMP Test End event is returned to the tester. On receiving the Test End command the AMP returns to idle state. All other values are reserved for future use	

0xXX	Scramble state 0x00 – OFF 0x01 – ON All other values are reserved for future use

Return Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP Test command succeeded
0x01-0xFF	Test command failed. See [Vol 2] Part D, Error Codes.

Event(s) Generated (unless masked away):

When the AMP receives the HCI_AMP_Test command, the AMP shall send the Command Status event to the AMP Test Manager which shall be routed to the tester.

The HCI AMP Start Test event shall be generated when the HCI_AMP_Test command has completed and the first data is ready to be sent or received.

The HCI Command Complete event shall not be sent by the AMP to indicate that this command has been completed. Instead the HCI AMP Start Test event shall indicate that this command has been completed.

When in a transmitter test scenario and the frames/bursts count have been transmitted the HCI AMP Test End event shall be sent.

A.1.1 Test Scenarios

All AMP Test Mode frames shall be AMP Test Mode data frames.

Single Frame Transmission

When the test scenario is set to transmit single frames the format shall be as defined by the parameters in the rest of the test configuration parameters. The interval between frames shall be as defined by the transmission interval time.

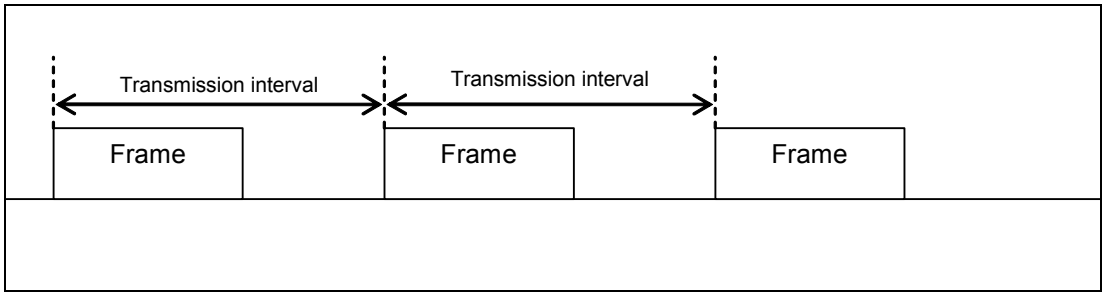

Figure A.1: Single Frame test transmission

The transmissions shall continue until the frame count is reached or a HCI_AMP_Test_End command is received; when a HCI AMP Test End event shall be sent to the tester via the AMP Test Manager.

The requirements of the frames are described in the AMP Test Mode data frame format section.

Receive Frames

When the test scenario is set to receive frames the AMP shall receive the frames defined in the other test scenario parameters and, when AMP receiver reports are configured, return receiver reports as defined to the tester via the AMP Test Manager.

A.1.2 Test Mode Data Frame Format

The frames transmitted in AMP Test Mode are not super frames. All frames shall be Data frames. The format of the frame agrees with the PHY frames in [2] section 19 with non connection AMP Test Mode fixed fields.

Source and Destination Address

When performing the AMP PHY non connection tests these fields are fixed according to the direction of the message. The AMP shall use a fixed address AMP_TEST_ADDRESS and shall expect to receive frames with an AMP_TESTER_ADDRESS.

Parameter	Address
AMP_TEST_ADDRESS	0x5555 (0101010101010101 binary)
AMP_TESTER_ADDRESS	0xAAAA (1010101010101010 binary)

These are fixed addresses for testing purposes only.

The AMP shall transmit frames in the transmit test scenarios with the SrcAddr set to the AMP_TEST_ADDRESS and the DestAddr set to the AMP_TESTER_ADDRESS.

The AMP shall receive test frames in the receiver test scenarios with the SrcAddr set to AMP_TESTER_ADDRESS and the DestAddr set to the AMP_TEST_ADDRESS.

A.2 AMP START TEST EVENT

Event	Event Code	Event Parameters
HCI_AMP_Start_Test	0x49	Status Test Scenario

Description:

The HCI AMP Start Test event shall be generated when the HCI_AMP_Test command has completed and the first data is ready to be sent or received.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	Test command succeeded
0x01-0xFF	Test command failed. See [Vol 2] Part D, Error Codes

Test Scenario: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x01 - Transmit single 0x02 – Receive frames All other values are reserved for future use

A.3 AMP TEST END EVENT

Event	Event Code	Event Parameters
HCI_AMP_Test_End	0x4A	Status Test Scenario

Description:

The HCI AMP Test End event shall be generated to indicate that the AMP has transmitted or received the number of frames/bursts configured.

If the Receiver reports are enabled an HCI AMP Receiver Report event shall be generated.

Event Parameters:

Status: *Size: 1 Octet*

Value	Parameter Description
0x00	AMP Test command succeeded
0x01-0xFF	Test command failed. See [Vol 2] Part D, Error Codes

Test Scenario: *Size: 1 Octet*

Value	Parameter Description
0xXX	0x01 - Transmit single 0x02 – Receive frames All other values are reserved for future use Test Scenario for which the test end event has been generated

Core System Package [Low Energy Controller volume]

Specification of the Bluetooth® System

Specification Volume 6

Covered Core Package Version: 5.0
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Revision History

The Revision History is shown in the [Vol 0] Part C, Appendix.

Contributors

The persons who contributed to this specification are listed in the [Vol 0] Part C, Appendix.

Web Site

This specification can also be found on the official Bluetooth web site:
https://www.bluetooth.org/en-us/specification/adopted-specifications

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PHYSICAL LAYER SPECIFICATION

This part of the specification describes the Bluetooth low energy physical layer.

CONTENTS

1 SCOPE

Bluetooth Low Energy (LE) devices operate in the unlicensed 2.4 GHz ISM (Industrial Scientific Medical) band. A frequency hopping transceiver is used to combat interference and fading.[1]

Two modulation schemes are defined. The mandatory modulation scheme (“1 Msym/s modulation”) uses a shaped, binary FM to minimize transceiver complexity. The symbol rate is 1 Msym/s. An optional modulation scheme (“2 Msym/s modulation”) is similar but uses a symbol rate of 2 Msym/s.

The 1 Msym/s modulation supports two PHYs:

- LE 1M, with uncoded data at 1 Mb/s;
- LE Coded, with the Access Address, Coding Indicator, and TERM1 fields of the packet coded at 125 kb/s and the payload coded at either 125 kb/s or 500 kb/s.

A device shall support the LE 1M PHY. Support for the LE Coded PHY is optional.

The 2 Msym/s modulation supports a single PHY:

- LE 2M, with uncoded data at 2 Mb/s

A Time Division Duplex (TDD) scheme is used in both modes. This specification defines the requirements for a Bluetooth radio for the Low Energy radio.

Requirements are defined for two reasons:

- Provide compatibility between radios used in the system
- Define the quality of the system

An LE radio shall have a transmitter or a receiver, or both.

The LE radio shall fulfill the stated requirements for the operating conditions declared by the equipment manufacturer (see Section A.1).

This specification is based on the established regulations for Europe, Japan, North America, Taiwan, South Korea and China. The standard documents listed below are only for information, and are subject to change or revision at any time.

1. Note that the transceiver defined in this Part does not meet the requirements for ‘frequency hopping’ in some governmental regulations. See the Bluetooth Low Energy Regulatory Aspects White Paper for more information.

The Bluetooth SIG maintains regulatory content associated with Bluetooth technology in the 2.4 GHz ISM band, posted at https://www.bluetooth.org/regulatory/newindex.cfm.

Europe:

Approval Standards: European Telecommunications Standards Institute, ETSI
Documents: EN 300 328, EN 300 440, EN 301 489-17

Japan:

Approval Standards: Japanese Radio Law, JRL
Documents: Japanese Radio Law: Article 4.3, Article 28, Article 29, Article 38

Radio Equipment Regulations: Article 5, Article 6, Article 7, Article 14, Article 24, Article 9.4, Article 49.20.1.C.2, Article 49.20.1.E.3
Radio Law Enforcement Regulations: Article 6.2, Article 6.4.4.1, Article 7

North America:

Approval Standards: Federal Communications Commission, FCC, USA
Documents: CFR47, Part 15: Sections 15.205, 15.209 and 15.247

Approval Standards: Industry Canada, IC, Canada
Documents: RSS-210 and RSS139

Taiwan:

Approval Standards: National Communications Commission, NCC
Documents: Low Power 0002 (LP0002); Low-power Radio-frequency Devices Technical Regulations

South Korea:

Approval Standards: Korea Communications Commission, KCC
Documents: Rules on Radio Equipment 2008-116

China:

Approval Standards: Ministry of Industry and Information Technology, MIIT
Documents: MIIT regulation [2002]353

2 FREQUENCY BANDS AND CHANNEL ARRANGEMENT

The LE system operates in the 2.4 GHz ISM band at 2400-2483.5 MHz. The LE system uses 40 RF channels. These RF channels have center frequencies 2402 + k * 2 MHz, where k = 0, ..., 39.

Regulatory Range	RF Channels
2.400-2.4835 GHz	f=2402+k*2 MHz, k=0, … ,39

Table 2.1: Operating frequency bands

3 TRANSMITTER CHARACTERISTICS

The requirements stated in this section are given as power levels at the antenna connector of the LE device. If the device does not have a connector, a reference antenna with 0 dBi gain is assumed.

Due to the difficulty in making accurate radiated measurements, systems with an integral antenna should provide a temporary antenna connector during LE PHY qualification testing.

For a transmitter, the output power level at the maximum power setting shall be within the limits defined in Table 3.1.

Minimum Output Power	Maximum Output Power
0.01 mW (-20 dBm)	100 mW (+20 dBm)

Table 3.1: Transmission power

Devices shall not exceed the maximum allowed transmit power levels set by the regulatory bodies that have jurisdiction over the locales in which the device is to be sold or intended to operate. Implementers should be aware that the maximum transmit power level permitted under a given set of regulations might not be the same for all modulation modes.

Note: The maximum output power for LE in v4.0, v4.1, and v4.2 is 10 mW.

Note: Using high transmit power in use cases where short ranges could be encountered may cause the receiver on the remote device to be saturated and result in link failure. Implementers should avoid use of high output power in such scenarios or employ a mechanism for switching between two or more transmit power levels in an attempt to establish, re-establish, or maintain connections.

The output power control of a device may be changed locally, for example to optimize the power consumption or reduce interference to other equipment.

Bluetooth devices may be informatively classified into power classes based on the highest output power the LE PHY supports, as defined in Table 3.2.

Power Class	Maximum Output Power (P_{max})	Minimum Output Power[1]
1	100 mW (+20 dBm)	10 mW (+10 dBm)
1.5	10 mW (+10 dBm)	0.01 mW (-20 dBm)
2	2.5 mW (+4 dBm)	0.01 mW (-20 dBm)
3	1 mW (0 dBm)	0.01 mW (-20 dBm)

Table 3.2: LE PHY power classes

1. Minimum output power at maximum power setting

3.1 MODULATION CHARACTERISTICS

The modulation is Gaussian Frequency Shift Keying (GFSK) with a bandwidth-bit period product BT=0.5. The modulation index shall be between 0.45 and 0.55. A binary one shall be represented by a positive frequency deviation, and a binary zero shall be represented by a negative frequency deviation.

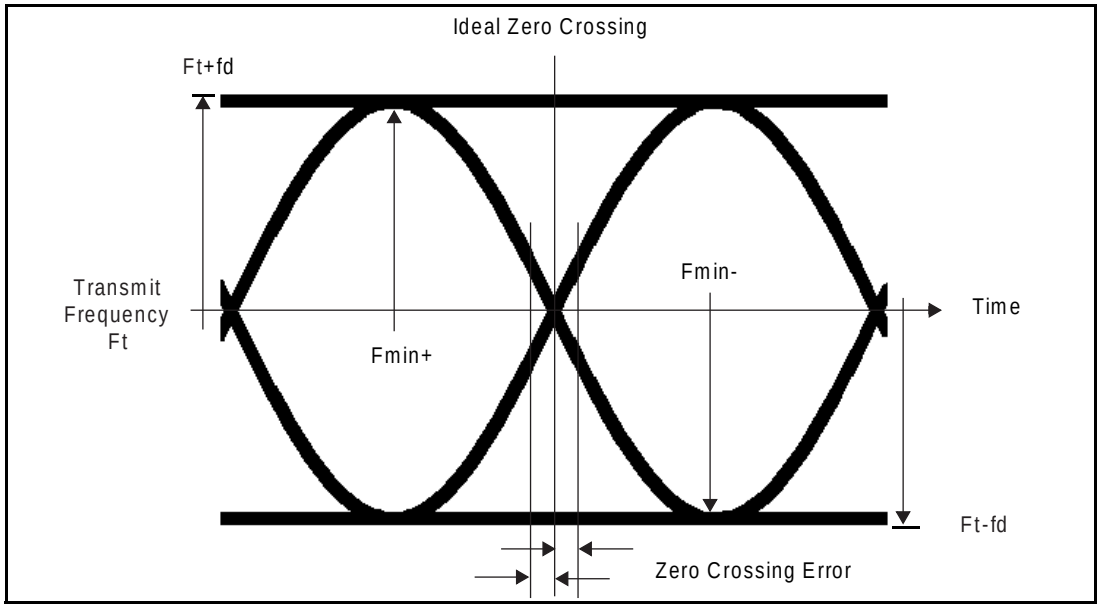

Figure 3.1: GFSK parameters definition

For each transmission the minimum frequency deviation,

$$F_{min} = \min \{ |F_{min+}| , F_{min-} \}$$

which corresponds to a 1010 sequence, shall be no smaller than ±80% of the frequency deviation with respect to the transmit frequency, which corresponds to a 00001111 sequence.

The minimum frequency deviation shall never be less than 185 kHz when transmitting at 1 megasymbol per second (Msym/s) symbol rate and never be less than 370 kHz when transmitting at 2 Msym/s symbol rate. The symbol timing accuracy shall be better than ±50 ppm.

The zero crossing error is the time difference between the ideal symbol period and the measured crossing time. This shall be less than ±1/8 of a symbol period.

3.1.1 Stable Modulation Index

An LE device with a transmitter that has a stable modulation index may inform the receiving LE device of this fact through the feature support mechanism (see [Vol 6] Part B, Section 4.6). The modulation index for these transmitters shall be between 0.495 and 0.505. A device shall only state that it has a stable modulation index if that applies to all LE transmitter PHYs it supports.

A transmitter that does not have a stable modulation index is said to have a standard modulation index.

3.2 SPURIOUS EMISSIONS

3.2.1 Modulation Spectrum

For products intended to comply with FCC part 15.247 rules, the minimum 6 dB bandwidth of the transmitter spectrum shall be at least 500 kHz using a resolution bandwidth of 100 kHz.

3.2.2 In-band Spurious Emission

An adjacent channel power is specified for channels at least 2 MHz from the carrier when transmitting with1 Msym/s modulation (applies to the LE 1M and LE Coded PHYs) or at least 4 MHz from the carrier when transmitting with 2 Msym/s modulation (applies to the LE 2M PHY). This adjacent channel power is defined as the sum of the measured power in a 1 MHz bandwidth.

The spectrum measurement shall be performed with a 100 kHz resolution bandwidth and an average detector. The device shall transmit on an RF channel with the center frequency M and the adjacent channel power shall be measured on a 1 MHz RF frequency N. The transmitter shall transmit a pseudo random data pattern in the payload throughout the test.

Frequency offset	Spurious Power
2 MHz (|M-N| = 2)	-20 dBm
3 MHz or greater (|M-N| ≥ 3)	-30 dBm

Table 3.3: Transmit Spectrum mask when transmitting with 1 Msym/s modulation

Frequency offset	Spurious Power
4 MHz (|M-N| = 4)	-20 dBm
5 MHz (|M-N| = 5)	-20 dBm
6 MHz or greater (|M-N| ≥ 6)	-30 dBm

Table 3.4: Transmit Spectrum mask when transmitting with 2 Msym/s modulation

Exceptions are allowed in up to three bands of 1 MHz width, centered on a frequency which is an integer multiple of 1 MHz. These exceptions shall have an absolute value of -20 dBm or less.

3.2.3 Out-of-band Spurious Emission

The equipment manufacturer is responsible for the ISM out-of-band spurious emissions requirements in the intended countries of sale.

3.3 RADIO FREQUENCY TOLERANCE

The deviation of the center frequency during the packet shall not exceed ±150 kHz, including both the initial frequency offset and drift. The frequency drift during any packet shall be less than 50 kHz. The drift rate shall be less than 400 Hz/µs.

The limits on the transmitter center frequency drift within a packet is shown in Table 3.5.

Parameter	Frequency Drift
Maximum drift	±50 kHz
Maximum drift rate[1]	400 Hz/µs

Table 3.5: Maximum allowable frequency drifts in a packet

1. The maximum drift rate is allowed anywhere in a packet.

4 RECEIVER CHARACTERISTICS

The reference sensitivity level referred to in this chapter is -70 dBm. The packet error rate corresponding to the defined bit error ratio (BER) shall be used in all receiver characteristic measurements.

4.1 ACTUAL SENSITIVITY LEVEL

The actual sensitivity level is defined as the receiver input level for which the BER specified in Table 4.1 is achieved.

Maximum Supported Payload Length (bytes)	BER (%)
≤ 37	0.1
≥ 38 and ≤ 63	0.064
≥ 64 and ≤ 127	0.034
≥ 128	0.017

Table 4.1: Actual sensitivity BER by maximum payload length

The actual sensitivity level of the receiver for a given PHY shall be as specified in Table 4.2. This shall apply with any transmitter compliant to the transmitter specification specified in Section 3 together with any combination of the following allowed parameter variations:

- Initial frequency offset
- Frequency drift
- Symbol rate
- Frequency deviation

PHY	Sensitivity (dBm)
LE Uncoded PHYs	≤ -70
LE Coded PHY with S=2 coding	≤ -75
LE Coded PHY with S=8 coding	≤ -82

Table 4.2: Receiver sensitivity for a given PHY

4.2 INTERFERENCE PERFORMANCE

The interference performance shall be measured with a wanted signal 3 dB over the reference sensitivity level. If the frequency of an interfering signal is outside of the band 2400-2483.5 MHz, the out-of-band blocking specification (see Section 4.3) shall apply. Both the desired and the interfering signal shall be reference signals as specified in Section 4.6. The BER shall be ≤0.1% for all the signal-to-interference ratios listed in Table 4.3, Table 4.4, Table 4.5, and Table 4.6:

Frequency of Interference	Ratio
Co-Channel interference, $C/I_{co\text{-}channel}$	21 dB
Adjacent (1 MHz) interference[1], $C/I_{1\ MHz}$	15 dB
Adjacent (2 MHz) interference[1], $C/I_{2\ MHz}$	-17 dB
Adjacent (≥3 MHz) interference[1], $C/I_{\geq 3\ MHz}$	-27 dB
Image frequency interference[1 2 3], C/I_{Image}	-9 dB
Adjacent (1 MHz) interference to in-band image frequency[1], $C/I_{Image\pm 1MHz}$	-15 dB

Table 4.3: Interference performance for LE 1M PHY

Frequency of Interference	Ratio
Co-Channel interference, $C/I_{co\text{-}channel}$	21 dB
Adjacent (2 MHz) interference[1], $C/I_{2\ MHz}$	15 dB
Adjacent (4 MHz) interference[1], $C/I_{4\ MHz}$	-17 dB
Adjacent (≥6 MHz) interference[1], $C/I_{\geq 6\ MHz}$	-27 dB
Image frequency interference[1 2 4], C/I_{Image}	-9 dB
Adjacent (2 MHz) interference to in-band image frequency[1], $C/I_{Image\pm 2MHz}$	-15 dB

Table 4.4: Interference performance for LE 2M PHY

Frequency of Interference	Ratio
Co-Channel interference, $C/I_{co\text{-}channel}$	12 dB
Adjacent (1 MHz) interference[1], $C/I_{1\ MHz}$	6 dB
Adjacent (2 MHz) interference[1], $C/I_{2\ MHz}$	-26 dB

Table 4.5: Interference performance for the LE Coded PHY with S=8 coding (125 kb/s data rate)

Frequency of Interference	Ratio
Adjacent (≥3 MHz) interference[1], $C/I_{\geq 3\ MHz}$	-36 dB
Image frequency interference[1 2 3], C/I_{Image}	-18 dB
Adjacent (1 MHz) interference to in-band image frequency[1], $C/I_{Image\pm 2MHz}$	-24 dB

Table 4.5: Interference performance for the LE Coded PHY with S=8 coding (125 kb/s data rate)

Frequency of Interference	Ratio
Co-Channel interference, $C/I_{co\text{-}channel}$	17 dB
Adjacent (1 MHz) interference[1], $C/I_{1\ MHz}$	11 dB
Adjacent (2 MHz) interference[1], $C/I_{2\ MHz}$	-21 dB
Adjacent (≥3 MHz) interference[1], $C/I_{\geq 3\ MHz}$	-31 dB
Image frequency interference[1 2 3], C/I_{Image}	-13 dB
Adjacent (1 MHz) interference to in-band image frequency[1], $C/I_{Image\pm 2MHz}$	-19 dB

Table 4.6: Interference performance for the LE Coded PHY with S=2 coding (500 kb/s data rate)

Notes:

1. If two adjacent frequency specifications from Table 4.3, Table 4.4, Table 4.5, or Table 4.6 (as appropriate) are applicable to the same frequency, the more relaxed specification applies.
2. In-band image frequency.
3. If the image frequency ≠ n*1 MHz, then the image reference frequency is defined as the closest n*1 MHz frequency for integer n.
4. If the image frequency ≠ n*2 MHz, then the image reference frequency is defined as the closest n*2 MHz frequency for integer n.

Any frequencies where the requirements are not met are called spurious response RF channels. Five spurious response RF channels are allowed with a distance of ≥2 MHz from the wanted signal when receiving with 1 Msym/s modulation and a distance of ≥4 MHz when receiving with 2 Msym/s modulation; different spurious response channels are allowed for the two modulation schemes. This excludes the image frequency with both 1 Msym/s and 2 Msym/s modulation, the image frequency ±1MHz with 1 Msym/s modulation, and the image frequency ±2 MHz with 2 Msym/s modulation. On these spurious response RF channels, a relaxed interference requirement C/I = -17 dB shall be met by both 1 Msym/s and 2 Msym/s modulation transmitters.

4.3 OUT-OF-BAND BLOCKING

The out-of-band blocking applies to interfering signals outside the band 2400-2483.5 MHz. The out-of-band suppression (or rejection) shall be measured with a wanted signal 3 dB over the reference sensitivity level. The interfering signal shall be a continuous wave signal. The desired signal shall be a reference signal as specified in Section 4.6, with a center frequency of 2426 MHz. The BER shall be ≤ 0.1%. The out-of-band blocking shall fulfill the following requirements:

Interfering Signal Frequency	Interfering Signal Power Level	Measurement resolution
30 MHz – 2000 MHz	-30 dBm	10 MHz
2003 – 2399 MHz	-35 dBm	3 MHz
2484 – 2997 MHz	-35 dBm	3 MHz
3000 MHz – 12.75 GHz	-30 dBm	25 MHz

Table 4.7: Out-of-band suppression (or rejection) requirements

Up to 10 exceptions are permitted, which are dependent upon the given RF channel and are centered at a frequency which is an integer multiple of 1 MHz:

- For at least 7 of these spurious response frequencies, a reduced interference level of at least -50 dBm is allowed in order to achieve the required BER ≤ 0.1%.
- For a maximum of 3 of the spurious response frequencies, the interference level may be lower.

4.4 INTERMODULATION CHARACTERISTICS

The actual sensitivity performance, BER ≤ 0.1%, shall be met under the following conditions:

- The wanted signal shall be at a frequency f_0 with a power level 6 dB over the reference sensitivity level. The wanted signal shall be a reference signal as specified in Section 4.6.
- A static sine wave signal shall be at a frequency f_1 with a power level of -50 dBm.
- An interfering signal shall be at a frequency f_2 with a power level of -50 dBm. The interfering signal shall be a reference signal as specified in Section 4.6.

When receiving with 1 Msym/s modulation, frequencies f_0, f_1 and f_2 shall be chosen such that $f_0 = 2*f_1 - f_2$ and
$| f_2-f_1 | = n * 1$ MHz, where n can be 3, 4, or 5.

When receiving with 2 Msym/s modulation, frequencies f_0, f_1 and f_2 shall be chosen such that
$f_0 = 2*f_1 - f_2$ and
$| f_2-f_1 | = n * 2$ MHz, where n can be 3, 4, or 5.

The system shall fulfill at least one of the three alternatives (n=3, 4, or 5); different modulation schemes can use different alternatives.

4.5 MAXIMUM USABLE LEVEL

The maximum usable input level the receiver can operate at shall be greater than -10 dBm, and the BER shall be less than or equal to 0.1% at -10 dBm input power. The input signal shall be a reference signal as specified in Section 4.6.

4.6 REFERENCE SIGNAL DEFINITION

The reference signal for LE is defined as:

Modulation = GFSK

Modulation index = 0.5 ± 1% for standard modulation index, 0.5 ± 0.5% for stable modulation index

BT = 0.5 ± 1%

Data Bit Rate =

- 1 Mb/s ±1 ppm for the LE 1M PHY
- 2 Mb/s ±1 ppm for the LE 2M PHY
- 125 kb/s ±1 ppm for the LE Coded PHY when using S=8 coding
- 500 kb/s ±1 ppm for the LE Coded PHY when using S=2 coding

Modulating Data for wanted signal = PRBS9

Modulating Data for interfering signal = PRBS15

Frequency accuracy better than ±1 ppm

4.7 STABLE MODULATION INDEX

An LE device may have a receiver that can take advantage of the fact that the remote device indicates support for the Stable Modulation Index - Transmitter feature (see [Vol 6] Part B, Section 4.6). Such a receiver is said to have stable modulation index support.

APPENDIX A TEST CONDITIONS

A.1 NORMAL OPERATING CONDITIONS (NOC)

A.1.1 Normal Temperature and Air Humidity

The normal operating temperature shall be declared by the product manufacturer. The nominal test temperature shall be within ±10°C of the normal operating temperature.

A.1.2 Nominal Supply Voltage

The nominal test voltage for the equipment under normal test conditions shall be the nominal supply voltage as declared by the product manufacturer.

LINK LAYER SPECIFICATION

This part of the specification describes the Bluetooth low energy Link Layer.

CONTENTS

1 GENERAL DESCRIPTION

1.1 LINK LAYER STATES

The operation of the Link Layer can be described in terms of a state machine with the following five states:

- Standby State
- Advertising State
- Scanning State
- Initiating State
- Connection State

The Link Layer state machine allows only one state to be active at a time. The Link Layer shall have at least one Link Layer state machine that supports one of Advertising State or Scanning State. The Link Layer may have multiple instances of the Link Layer state machine.

The Link Layer in the Standby State does not transmit or receive any packets. The Standby State can be entered from any other state.

The Link Layer in the Advertising State will be transmitting advertising channel packets and possibly listening to and responding to responses triggered by these advertising channel packets. A device in the Advertising State is known as an advertiser. The Advertising State can be entered from the Standby State.

The Link Layer in the Scanning State will be listening for advertising channel packets from devices that are advertising. A device in the Scanning State is known as a scanner. The Scanning State can be entered from the Standby State.

The Link Layer in the Initiating State will be listening for advertising channel packets from a specific device(s) and responding to these packets to initiate a connection with another device. A device in the Initiating State is known as an initiator. The Initiating State can be entered from the Standby State.

The Connection State can be entered either from the Initiating State or the Advertising State. A device in the Connection State is known as being in a connection.

Within the Connection State, two roles are defined:

- Master Role
- Slave Role

When entered from the Initiating State, the Connection State shall be in the Master Role. When entered from the Advertising State, the Connection State shall be in the Slave Role.

The Link Layer in the Master Role will communicate with a device in the Slave Role and defines the timings of transmissions.

The Link Layer in the Slave Role will communicate with a single device in the Master Role.

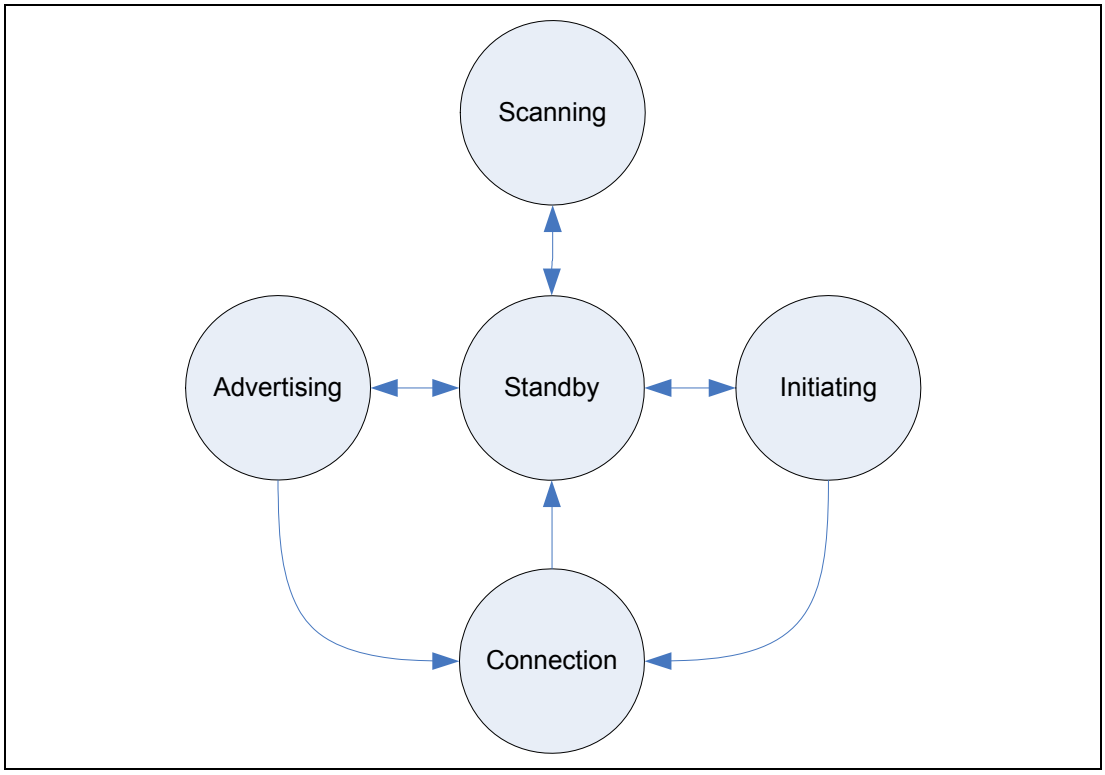

Figure 1.1: State diagram of the Link Layer state machine

1.1.1 Permitted State and Role Combination Restrictions

The Link Layer may optionally support multiple state machines. If it does support multiple state machines, then:

- The Link Layer in the Connection State may operate in the Master Role and Slave Role at the same time.
- The Link Layer in the Connection State operating in the Slave Role may have multiple connections.
- The Link Layer in the Connection State operating in the Master Role may have multiple connections.
- All other combinations of states and roles may also be supported.
- The Link Layer in the Connection State shall have at most one connection to another Link Layer in the Connection State.

A Link Layer implementation is not required to support all the possible state combinations that are allowed by this specification. However, if it supports a state or state combination given in the "combination A" column of Table 1.1, it shall also support the corresponding state or state combination in the "combination B" column.

Combination A	Combination B
Initiating plus any combination C of other states	Connection (Master role) plus the same combination C
Connection (Master role) plus Initiating plus any combination C of other states	Connection (Master role) to more than one device in the slave role plus the same combination C
Connectable or a directed advertising state plus any combination C of other states	Connection (Slave role) plus the same combination C
Connection (Slave role) plus Connectable or a directed advertising state plus any combination C of other states	Connection (Slave role) to more than one device in the Master role plus the same combination C

Table 1.1: Requirements on supported states and state combinations

In each case, the combination of other states C may be empty. Note that, in the last two rows, "other states" includes other Connectable or directed advertising states.

1.1.2 Devices supporting only some states

Devices supporting only some link layer states or only one of the two roles within the Connection State are not required to support features (including supporting particular PDUs, procedures, data lengths, or HCI commands or particular features of an HCI command) that are only used by a state or mode that the device does not support.

1.2 BIT ORDERING

The bit ordering when defining fields within the packet or Protocol Data Unit (PDU) in the Link Layer specification follows the Little Endian format. The following rules apply:

- The Least Significant Bit (LSB) corresponds to b_0
- The LSB is the first bit sent over the air
- In illustrations, the LSB is shown on the left side

Furthermore, data fields defined in the Link Layer, such as the PDU header fields, shall be transmitted with the LSB first. For instance, a 3-bit parameter X=3 is sent as:

$b_0 b_1 b_2 = 110$

Over the air, 1 is sent first, 1 is sent next, and 0 is sent last. This is shown as 110 in the specification.

Binary field values specified in this specification that follow the format 10101010b (e.g., the advertising channel Access Address in Section 2.1.2) are written with the MSB to the left. There are two basic formats: one for the LE Uncoded PHYs, described in Section 2.1, and one for the LE Coded PHY, described in Section 2.2.

Multi-octet fields, with the exception of the Cyclic Redundancy Check (CRC) and the Message Integrity Check (MIC), shall be transmitted with the least significant octet first. Each octet within multi-octet fields, with the exception of the CRC (see Section 3.1.1), shall be transmitted in LSB first order. For example, the 48-bit addresses in the advertising channel PDUs shall be transmitted with the least significant octet first, followed by the remainder of the five octets in increasing order.

Multi-octet field values specified in this specification (e.g. the CRC initial value in Section 2.3.3.1) are written with the most significant octet to the left; for example in 0x112233445566, the octet 0x11 is the most significant octet.

1.3 DEVICE ADDRESS

Devices are identified using a device address. Device addresses may be either a public device address or a random device address. A public device address and a random device address are both 48 bits in length.

A device shall use at least one type of device address and may contain both.

A device's Identity Address is a Public Device Address or Random Static Device Address that it uses in packets it transmits. If a device is using Resolvable Private Addresses, it shall also have an Identity Address.

1.3.1 Public Device Address

The public device address shall be created in accordance with [Vol 2] Part B, Section 1.2, with the exception that the restriction on LAP values does not apply unless the public device address will also be used as a BD_ADDR for a BR/EDR Controller.

1.3.2 Random Device Address

The random device address may be of either of the following two sub-types:

- Static address
- Private address.

The term random device address refers to both static and private address types.

The transmission of a random device address is optional. A device shall accept the reception of a random device address from a remote device.

1.3.2.1 Static Device Address

A static address is a 48-bit randomly generated address and shall meet the following requirements:

- The two most significant bits of the address shall be equal to 1
- At least one bit of the random part of the address shall be 0
- At least one bit of the random part of the address shall be 1

The format of a static address is shown in Figure 1.2.

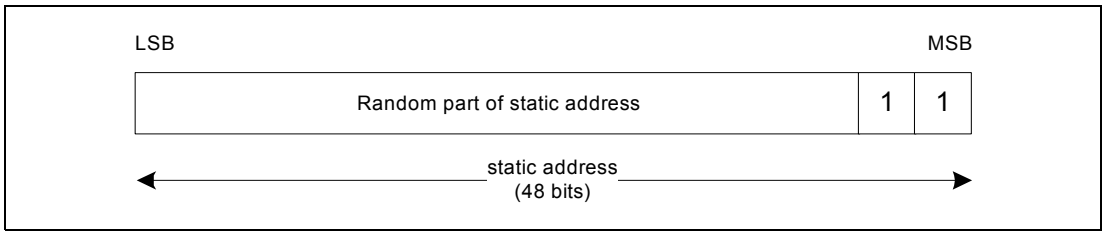

Figure 1.2: Format of static address

A device may choose to initialize its static address to a new value after each power cycle. A device shall not change its static address value once initialized until the device is power cycled.

Note: If the static address of a device is changed, then the address stored in peer devices will not be valid and the ability to reconnect using the old address will be lost.

1.3.2.2 Private Device Address Generation

The private address may be of either of the following two sub-types:

- Non-resolvable private address
- Resolvable private address

To generate a non-resolvable address, the device shall generate a 48-bit address with the following requirements:

- The two most significant bits of the address shall be equal to 0
- At least one bit of the random part of the address shall be 1
- At least one bit of the random part of the address shall be 0
- The address shall not be equal to the public address

The format of a non-resolvable private address is shown in Figure 1.3.

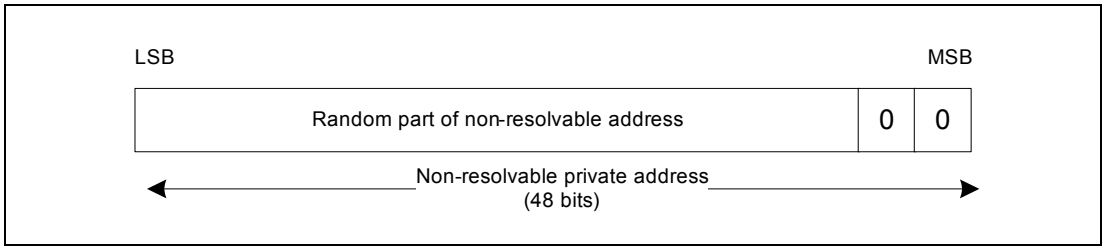

Figure 1.3: Format of non-resolvable private address

To generate a resolvable private address, the device must have either the Local Identity Resolving Key (IRK) or the Peer Identity Resolving Key (IRK). The resolvable private address shall be generated with the IRK and a randomly generated 24-bit number. The random number is known as *prand* and shall meet the following requirements:

- The two most significant bits of *prand* shall be equal to 0 and 1 as shown in Figure 1.4
- At least one bit of the random part of *prand* shall be 0
- At least one bit of the random part of *prand* shall be 1

The format of the resolvable private address is shown in Figure 1.4.

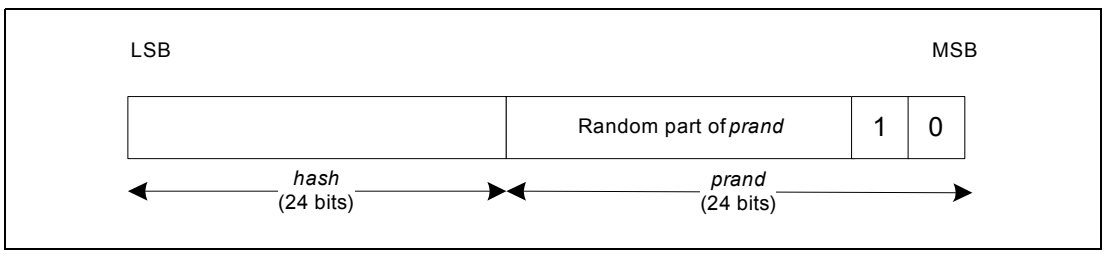

Figure 1.4: Format of resolvable private address

The hash is generated using the random address function *ah* defined in [Vol 3] Part H, Section 2.2.2 with the input parameter *k* set to the device's IRK and the input parameter *r* set to *prand*.

hash = *ah*(IRK, *prand*)

The prand and hash are concatenated to generate the random address (randomAddress) in the following manner:

randomAddress = *hash* || *prand*

The least significant octet of *hash* becomes the least significant octet of *randomAddress* and the most significant octet of *prand* becomes the most significant octet of *randomAddress*.

1.3.2.3 Private Device Address Resolution

A resolvable private address may be resolved if the corresponding device's IRK is available using this procedure. If a resolvable private address is resolved, the device can associate this address with the peer device.

The resolvable private address (*RPA*) is divided into a 24-bit random part (*prand*) and a 24-bit hash part (*hash*). The least significant octet of the *RPA* becomes the least significant octet of *hash* and the most significant octet of *RPA* becomes the most significant octet of *prand*. A *localHash* value is then generated using the random address hash function *ah* defined in [Vol 3] Part H, Section 2.2.2 with the input parameter *k* set to IRK of the known device and the input parameter *r* set to the *prand* value extracted from the *RPA*.

localHash = *ah*(IRK, *prand*)

The *localHash* value is then compared with the *hash* value extracted from *RPA*. If the *localHash* value matches the extracted *hash* value, then the identity of the peer device has been resolved.

If a device has more than one stored IRK, the device repeats the above procedure for each stored IRK to determine if the received resolvable private address is associated with a stored IRK, until either address resolution is successful for one of the IRKs or all have been tried.

Note: A device that cannot resolve a private address within T_IFS may respond on the reception of the next event.

A non-resolvable private address cannot be resolved.

1.4 PHYSICAL CHANNEL

As specified in [Vol 6] Part A, Section 2, 40 RF channels are defined in the 2.4GHz ISM band. These RF channels are allocated into three LE physical channels: advertising, periodic, and data. The advertising physical channel uses all 40 RF channels for discovering devices, initiating a connection and broadcasting data. These RF channels are divided into 3 RF channels, known as the "primary advertising channel", used for initial advertising and all legacy advertising activities, and 37 RF channels, known as the "secondary advertising channel", used for the majority of the communications involved. The data physical channel uses up to 37 (see Section 4.5.8) RF channels for communication between connected devices. Each of these RF channels is allocated a unique channel index (see Section 1.4.1). The periodic physical channel uses the same RF channels as the secondary advertising channel over the advertising physical channel.

Two devices that wish to communicate use a shared physical channel. To achieve this, their transceivers must be tuned to the same RF channel at the same time.

Given that the number of RF channels is limited, and that many Bluetooth devices may be operating independently within the same spatial and temporal area, there is a strong likelihood of two independent Bluetooth devices having their transceivers tuned to the same RF channel, resulting in a physical channel collision. To mitigate the unwanted effects of this collision, each transmission on a physical channel starts with an Access Address that is used as a correlation code by devices tuned to the physical channel. This Access Address is a property of the physical channel. The Access Address is present at the start of every transmitted packet.

The Link Layer uses one physical channel at a given time.

Whenever the Link Layer is synchronized to the timing, frequency, and Access Address of a physical channel, it is said to be 'connected' on the data physical channel or ‘synchronized’ to the periodic physical channel (whether or not it is actively involved in communications over the channel).

1.4.1 Advertising and Data Channel Indices

Table 1.2 shows the mapping from PHY Channel to Channel Index and Channel Type. An '●' in the table below indicates the PHY channel and index are used by the specified channel type.

RF Channel	RF Center Frequency	Channel Index	Channel Type		
			Data	Primary Advertising	Secondary Advertising
0	2402 MHz	37		●	
1	2404 MHz	0	●		●
2	2406 MHz	1	●		●
...	…	…	…	…	…
11	2424 MHz	10	●		●
12	2426 MHz	38		●	
13	2428 MHz	11	●		●
14	2430 MHz	12	●		●
...	…	…	…	…	…
38	2478 MHz	36	●		●
39	2480 MHz	39		●	

Table 1.2: Mapping of PHY Channel to Channel Index and Channel Type

2 AIR INTERFACE PACKETS

LE devices shall use the packets as defined in the following sections.

2.1 PACKET FORMAT FOR THE LE UNCODED PHYS

The following packet format is defined for the LE Uncoded PHYs (LE 1M and LE 2M) and is used for both advertising channel packets and data channel packets.

This packet format is shown in Figure 2.1. Each packet consists of four mandatory fields. The mandatory fields are Preamble, Access Address, PDU, and CRC.

LSB MSB

Preamble (1 or 2 octets)	Access Address (4 octets)	PDU (2 to 257 octets)	CRC (3 octets)

Figure 2.1: Link Layer packet format for the LE Uncoded PHYs

The preamble is 1 octet when transmitting or receiving on the LE 1M PHY and 2 octets when transmitting or receiving on the LE 2M PHY. The Access Address is 4 octets. The PDU range is from 2 to 257 octets. The CRC is 3 octets.

The Preamble is transmitted first, followed by the Access Address, followed by the PDU followed by the CRC. The entire packet is transmitted at the same symbol rate (either 1 Msym/s or 2 Msym/s modulation).

Packets take between 44 and 2120 µs to transmit.

2.1.1 Preamble

All Link Layer packets have a preamble which is used in the receiver to perform frequency synchronization, symbol timing estimation, and Automatic Gain Control (AGC) training. The preamble is a fixed sequence of alternating 0 and 1 bits. For packets transmitted on the LE 1M PHY, the preamble is 8 bits; for packets transmitted on the LE 2M PHY, the preamble is 16 bits. The first bit of the preamble (in transmission order) shall be the same as the LSB of the Access Address. The preamble is shown in Figure 2.2.

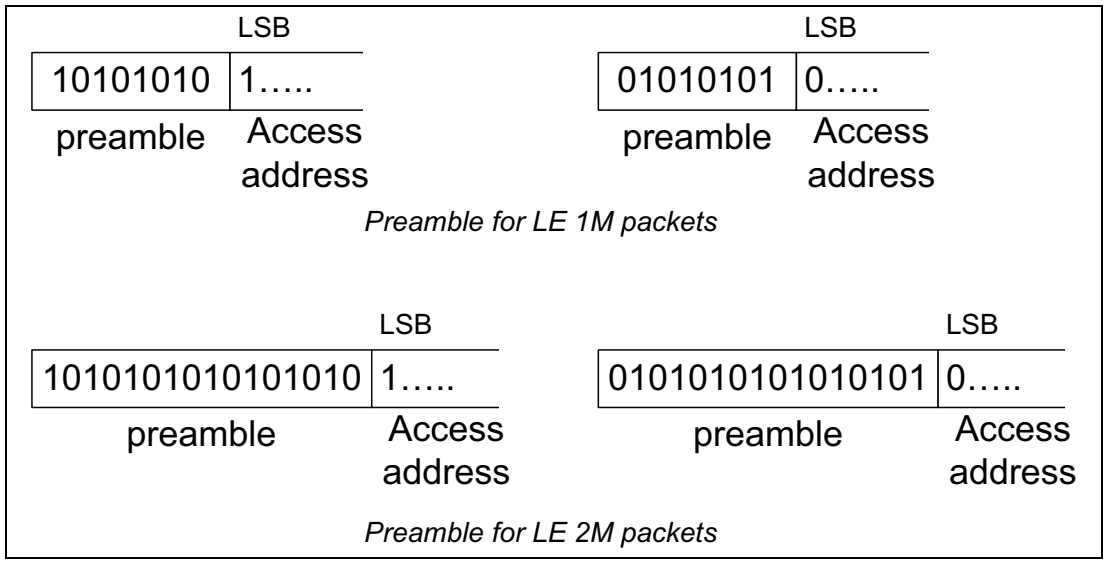

Figure 2.2: Preamble

2.1.2 Access Address

The AUX_SYNC_IND PDU, and any AUX_CHAIN_IND PDUs connected to it, shall use the Access Address (AA) value set in the SyncInfo field (see Section 2.3.4.6) contained in the AUX_ADV_IND PDU that describes the periodic advertising.

The Access Address for all other advertising channel packets shall be 10001110100010011011111011010110b (0x8E89BED6).

It is intended that each Link Layer connection between any two devices and each periodic advertisement has a different Access Address.

The Link Layer in the Initiating State shall generate a new Access Address for each initiating PDU it sends (see Section 2.3.3.1). The Link Layer in the Advertising State shall generate a new Access Address each time that it enables periodic advertising on an advertising set. The address is sent in the SyncInfo field (see Section 2.3.4.6) of PDUs referring to that periodic advertising.

The Access Address shall be a 32-bit value. Each time it needs a new Access Address, the Link Layer shall generate a new random value that meets the following requirements:

- It shall not be the Access Address for any existing Link Layer connection on this device.
- It shall not be the Access Address for any enabled periodic advertising.
- It shall have no more than six consecutive zeros or ones.
- It shall not be the advertising channel packets' Access Address.

- It shall not be a sequence that differs from the advertising channel packets' Access Address by only one bit.
- It shall not have all four octets equal.
- It shall have no more than 24 transitions.
- It shall have a minimum of two transitions in the most significant six bits.

The seed for the random number generator shall be from a physical source of entropy and should have at least 20 bits of entropy.

If the random number does not meet the above requirements, new random numbers shall be generated until the requirements are met.

On an implementation that also supports the LE Coded PHY (see Section 2.2, the Access Address shall also meet the following requirements:

- It shall have at least three ones in the least significant 8 bits.
- It shall have no more than eleven transitions in the least significant 16 bits.

2.1.3 PDU

The preamble and Access Address are followed by a PDU. When a packet is transmitted on either the primary or secondary advertising channel, the PDU shall be the Advertising Channel PDU as defined in Section 2.3. When a packet is transmitted on the data physical channel, the PDU shall be the Data Channel PDU as defined in Section 2.4.

2.1.4 CRC

At the end of every Link Layer packet there is a 24-bit CRC. It shall be calculated over the PDU. The CRC polynomial is defined in Section 3.1.1.

2.2 PACKET FORMAT FOR THE LE CODED PHY

The following packet format is defined for the LE Coded PHY and is used for both advertising channel packets and data channel packets. This packet format is shown in Figure 2.3.

.

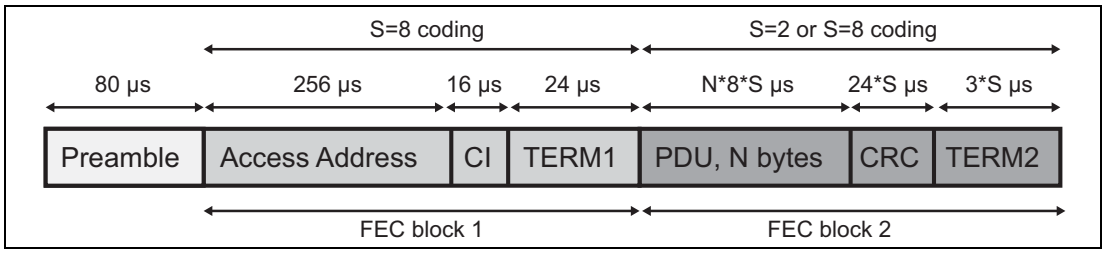

Figure 2.3: Link Layer packet format for the LE Coded PHY

Each packet consists of the Preamble, FEC block 1, and FEC block 2.

The Preamble is not coded.

The FEC block 1 consists of three fields: Access Address, Coding Indicator (CI), and TERM1. These shall use the S=8 coding scheme as defined in Section 3.3.1.

The CI field determines which coding scheme is used for FEC block 2.

The FEC block 2 consists of three fields: PDU, CRC, and TERM2. These shall use either the S=2 or S=8 coding scheme as defined in Section 3.3, depending on the value of the CI field.

The entire packet is transmitted with 1 Msym/s modulation.

Table 2.1 captures the size and duration of the data packet fields.

	Fields						
	Preamble	**Access Address**	**CI**	**TERM1**	**PDU**	**CRC**	**TERM2**
Number of Bits	Uncoded	32	2	3	16 – 2056	24	3
Duration when using S=8 coding (µs)	80	256	16	24	128 – 16448	192	24
Duration when using S=2 coding (µs)	80	256	16	24	32 – 4112	48	6

Table 2.1: LE Coded PHY field sizes and durations in microseconds

Packets take between 462 and 17040 µs to transmit.

2.2.1 Preamble

The Preamble is 80 symbols in length and consists of 10 repetitions of the symbol pattern '00111100' (in transmission order).

2.2.2 Access Address

The Access Address is specified in Section 2.1.2.

2.2.3 Coding Indication

The CI field consists of two bits as defined in Table 2.2.

CI Field	Meaning
00b	FEC Block 2 coded using S=8
01b	FEC Block 2 coded using S=2
All other values	Reserved for future use

Table 2.2: Meaning of CI field

2.2.4 PDU

When a packet is transmitted on either the primary or secondary advertising channel, the PDU shall be the Advertising Channel PDU as defined in Section 2.3. When a packet is transmitted on the data physical channel, the PDU shall be the Data Channel PDU as defined in Section 2.4.

2.2.5 CRC

The CRC is 24 bits in length and the value is calculated over all the PDU bits. The CRC generator polynomial is defined in Section 3.1.1.

2.2.6 TERM1 and TERM2

There is a termination field at the end of each FEC block referred to as TERM1 and TERM2. Each termination field is 3 bits long and forms the termination sequence defined in Section 3.3.1.

2.3 ADVERTISING CHANNEL PDU

The advertising channel PDU has a 16-bit header and a variable size payload. Its format is as shown in Figure 2.4. The 16-bit Header field of the advertising channel PDU is as shown in Figure 2.5.

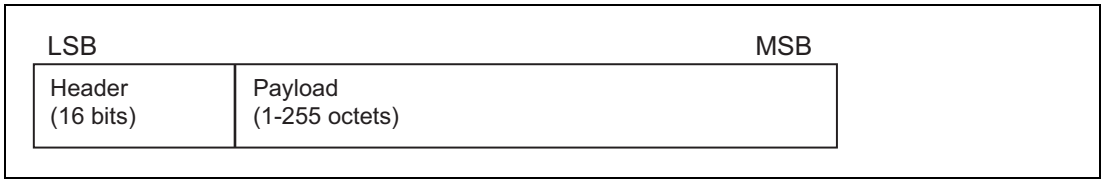

Figure 2.4: Advertising channel PDU

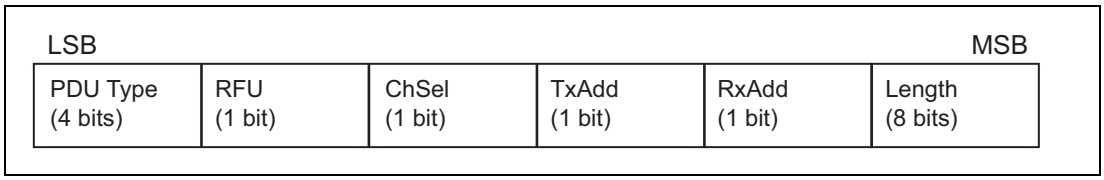

Figure 2.5: Advertising channel PDU Header

The PDU Type field of the advertising channel PDU that is contained in the header indicates the PDU type as defined in Table 2.3. This table also shows which channel and which PHYs the packet may appear on.

PDU Type	PDU Name	Channel	Permitted PHYs		
			LE 1M	LE 2M	LE Coded
0000b	ADV_IND	Primary Advertising	•		
0001b	ADV_DIRECT_IND	Primary Advertising	•		
0010b	ADV_NONCONN_IND	Primary Advertising	•		
0011b	SCAN_REQ	Primary Advertising	•		
	AUX_SCAN_REQ	Secondary Advertising	•	•	•
0100b	SCAN_RSP	Primary Advertising	•		
0101b	CONNECT_IND	Primary Advertising	•		
	AUX_CONNECT_REQ	Secondary Advertising	•	•	•
0110b	ADV_SCAN_IND	Primary Advertising	•		

Table 2.3: Advertising channel PDU Header's PDU Type field encoding

PDU Type	PDU Name	Channel	Permitted PHYs		
			LE 1M	LE 2M	LE Coded
0111b	ADV_EXT_IND	Primary Advertising	•		•
	AUX_ADV_IND	Secondary Advertising	•	•	•
	AUX_SCAN_RSP	Secondary Advertising	•	•	•
	AUX_SYNC_IND	Secondary Advertising	•	•	•
	AUX_CHAIN_IND	Secondary Advertising	•	•	•
1000b	AUX_CONNECT_RSP	Secondary Advertising	•	•	•
All other values	Reserved for Future Use				

Table 2.3: Advertising channel PDU Header's PDU Type field encoding

Each PDU shall only appear on those PHYs indicated with a bullet '•' and on the Advertising Channel shown in Table 2.3.

The ChSel, TxAdd and RxAdd fields of the advertising channel PDU that are contained in the header contain information specific to the PDU type defined for each advertising channel PDU separately. If the ChSel, TxAdd or RxAdd fields are not defined as used in a given PDU then they shall be considered Reserved for Future Use.

The Length field of the advertising channel PDU header indicates the payload field length in octets. The valid range of the Length field shall be 1 to 255 octets.

The Payload fields in the advertising channel PDUs are specific to the PDU Type and are defined in Section 2.3.1 through Section 2.3.4. The PDU Types marked as Reserved for future use shall not be sent and shall be ignored upon receipt.

Within advertising channel PDUs, advertising data or scan response data from the Host may be included in the Payload in some PDU Types. The format of this data is defined in [Vol 3] Part C, Section 11.

Some advertising channel PDUs contain an AuxPtr field (see Section 2.3.4.5) which points to a packet containing another advertising channel PDU. In this case, the second packet and PDU are the *auxiliary packet* and *auxiliary PDU* of the original PDU, which in turn is the *superior packet* and *superior PDU* of the second one. Note that a PDU can only have one auxiliary PDU but more than one superior PDU.

Given a packet, its *subordinate set* consists of its auxiliary packet, if any, and the subordinate set of the auxiliary packet. A packet without an AuxPtr field has an empty subordinate set.

2.3.1 Advertising PDUs

The following advertising channel PDU Types are called advertising PDUs:

- ADV_IND
- ADV_DIRECT_IND
- ADV_NONCONN_IND
- ADV_SCAN_IND
- ADV_EXT_IND
- AUX_ADV_IND
- AUX_SYNC_IND
- AUX_CHAIN_IND

These PDUs are sent by the Link Layer in the Advertising State and received by a Link Layer in the Scanning State or Initiating State. The ADV_IND, ADV_DIRECT_IND, ADV_NONCONN_IND, and ADV_SCAN_IND PDUs are called “legacy advertising PDUs”. The ADV_EXT_IND, AUX_ADV_IND, AUX_SYNC_IND, and AUX_CHAIN_IND PDUs are called “extended advertising PDUs”. Advertising events using legacy advertising PDUs are called “legacy advertising events”.

2.3.1.1 ADV_IND

The ADV_IND PDU has the Payload as shown in Figure 2.6. The PDU shall be used in connectable and scannable undirected advertising events. The TxAdd in the advertising channel PDU header indicates whether the advertiser’s address in the AdvA field is public (TxAdd = 0) or random (TxAdd = 1). The ChSel field in the advertising channel PDU header shall be set to 1 if the advertiser supports the LE Channel Selection Algorithm #2 feature (see Section 4.5.8.3).

Payload	
AdvA (6 octets)	AdvData (0-31 octets)

Figure 2.6: ADV_IND PDU Payload

The Payload field consists of AdvA and AdvData fields. The AdvA field shall contain the advertiser’s public or random device address as indicated by TxAdd. The AdvData field may contain Advertising Data from the advertiser’s Host.

2.3.1.2 ADV_DIRECT_IND

The ADV_DIRECT_IND PDU has the Payload as shown in Figure 2.7. The PDU shall be used in connectable directed advertising events. The TxAdd in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public (TxAdd = 0) or random (TxAdd = 1). The RxAdd in the advertising channel PDU header indicates whether the target's address in the TargetA field is public (RxAdd = 0) or random (RxAdd = 1). The ChSel field in the advertising channel PDU header shall be set to 1 if the advertiser supports the LE Channel Selection Algorithm #2 feature (see Section 4.5.8.3).

Payload	
AdvA (6 octets)	TargetA (6 octets)

Figure 2.7: ADV_DIRECT_IND PDU Payload

The Payload field consists of AdvA and TargetA fields. The AdvA field shall contain the advertiser's public or random device address as indicated by TxAdd. The TargetA field is the address of the device to which this PDU is addressed. The TargetA field shall contain the target's public or random device address as indicated by RxAdd.

Note: This packet does not contain any Host data.

2.3.1.3 ADV_NONCONN_IND

The ADV_NONCONN_IND PDU has the Payload as shown in Figure 2.8. The PDU shall be used in non-connectable and non-scannable undirected advertising events. The TxAdd in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public (TxAdd = 0) or random (TxAdd = 1).

Payload	
AdvA (6 octets)	AdvData (0-31 octets)

Figure 2.8: ADV_NONCONN_IND PDU Payload

The Payload field consists of AdvA and AdvData fields. The AdvA field shall contain the advertiser's public or random device address as indicated by TxAdd. The AdvData field may contain Advertising Data from the advertiser's Host.

2.3.1.4 ADV_SCAN_IND

The ADV_SCAN_IND PDU has the Payload as shown in Figure 2.9. The PDU shall be used in scannable undirected advertising events. The TxAdd in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public (TxAdd = 0) or random (TxAdd = 1).

Payload	
AdvA (6 octets)	AdvData (0-31 octets)

Figure 2.9: ADV_SCAN_IND PDU Payload

The Payload field consists of AdvA and AdvData fields. The AdvA field shall contain the advertiser's public or random device address as indicated by TxAdd. The AdvData field may contain Advertising Data from the advertiser's Host.

2.3.1.5 ADV_EXT_IND

The ADV_EXT_IND PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4. The PDU may be used in all advertising events (except connectable and scannable undirected) as indicated by the AdvMode field value. An advertising event using an ADV_EXT_IND PDU is directed if, and only if, either the TargetA field is present or the AuxPtr field is present and points to a PDU where the TargetA field is present.

The Common Extended Advertising Payload Format fields permitted in the ADV_EXT_IND PDU are shown in Table 2.4.

		Common Extended Advertising Payload Format fields							
Event Type	**Adv Mode**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
Non-Connectable and Non-Scannable Undirected without auxiliary packet	00b	M	X	X	X	X	O	X	X
Non-Connectable and Non-Scannable Undirected with auxiliary packet	00b	C1	X	M	M	X	C1	X	X

Table 2.4: Common Extended Advertising Payload Format fields permitted in the ADV_EXT_IND PDU

		Common Extended Advertising Payload Format fields							
Event Type	**Adv Mode**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
Non-Connectable and Non-Scannable Directed without auxiliary packet	00b	M	M	X	X	X	O	X	X
Non-Connectable and Non-Scannable Directed with auxiliary packet	00b	C1	C1	M	M	X	C1	X	X
Connectable Undirected	01b	X	X	M	M	X	C1	X	X
Connectable Directed	01b	X	X	M	M	X	C1	X	X
Scannable Undirected	10b	X	X	M	M	X	C1	X	X
Scannable Directed	10b	X	X	M	M	X	C1	X	X
RFU	11b								

Table 2.4: Common Extended Advertising Payload Format fields permitted in the ADV_EXT_IND PDU

For the non-connectable and non-scannable directed and non-connectable and non-scannable undirected event types without ACAD or AdvData, the Controller can choose whether or not to use an auxiliary packet. See Sections 4.4.2.6 and 4.4.2.9.

In all tables (including subsequent sections) describing permitted Common Extended Advertising Payload Format Fields:

M This field is mandatory.

O This field is optional.

X This field is reserved for future use.

C1 This field is optional on the LE 1M PHY and reserved for future use on the LE Coded PHY.

C2 This field is mandatory if the corresponding field in the ADV_EXT_IND PDU is not present, otherwise it is reserved for future use.

C3 This field is mandatory if the corresponding field in the PDU pointing to this PDU is present, otherwise it is reserved for future use.

C4 This field is optional if the corresponding field in the ADV_EXT_IND PDU is not present, otherwise it is reserved for future use.

Fields reserved for future use shall not be present when the packet is sent and shall be ignored when received.

Any auxiliary packet shall be an AUX_ADV_IND packet with the same AdvMode as the ADV_EXT_IND packet.

2.3.1.6 AUX_ADV_IND

The AUX_ADV_IND PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4. The PDU may be used in all advertising events (except connectable and scannable undirected) as indicated by the AdvMode field value.

The AdvMode field indicates the type of advertising event the AUX_ADV_IND packet is being used for.

The Common Extended Advertising Payload Format fields permitted in the AUX_ADV_IND PDU are shown in Table 2.5.

The PHY used for the AUX_ADV_IND shall be specified in the AuxPtr field of the superior PDU. The PHY specified in any AuxPtr field in an AUX_ADV_IND PDU shall be the same as the PHY the PDU was sent on.

The ADI field shall have the same value as the field in the PDU pointing to this PDU. Note: The ADI field can be used to detect collisions.

Any auxiliary PDU shall be an AUX_CHAIN_IND PDU.

The SyncInfo field, when present, shall point to an AUX_SYNC_IND PDU.

		Common Extended Advertising Payload Format fields							
Adv Mode	**Event Type**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
00b	Non-Connectable and Non-Scannable Undirected	C4	X	M	O	O	O	O	O
00b	Non-Connectable and Non-Scannable Directed	C4	C2	M	O	O	O	O	O
01b	Connectable Undirected	M	X	M	X	X	O	O	O
01b	Connectable Directed	M	M	M	X	X	O	O	O
10b	Scannable Undirected	M	X	M	X	X	O	O	X
10b	Scannable Directed	M	M	M	X	X	O	O	X
11b	RFU								

Table 2.5: Common Extended Advertising Payload Format fields permitted in the AUX_ADV_IND PDU

2.3.1.7 AUX_SYNC_IND

The AUX_SYNC_IND PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4. The PDU is used in periodic advertising.

The AdvMode field shall be set to 00b.

The Common Extended Advertising Payload Format fields permitted in the AUX_SYNC_IND PDU are shown in Table 2.6.

The PHY used for the AUX_SYNC_IND PDU shall be that specified in Section 4.4.2.12.

Any auxiliary PDU shall be an AUX_CHAIN_IND PDU.

		Common Extended Advertising Payload Format fields							
Adv Mode	**Event Type**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
00b	Non-Connectable and Non-Scannable Undirected or Directed	X	X	X	O	X	O	O	O
01b – 11b	RFU								

Table 2.6: Common Extended Advertising Payload Format fields permitted in the AUX_SYNC_IND PDU

2.3.1.8 AUX_CHAIN_IND

The AUX_CHAIN_IND PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4. The PDU is used to hold additional AdvData. Its superior PDU is an AUX_ADV_IND, AUX_SYNC_IND, AUX_SCAN_RSP or another AUX_CHAIN_IND PDU.

The AdvMode field shall be set to 00b.

The Common Extended Advertising Payload Format fields permitted in the AUX_CHAIN_IND PDU are shown in Table 2.7.

The PHY used for the AUX_CHAIN_IND PDU shall be the same as the PHY used for its superior PDU.

The ADI field, when present, shall have the same value as the field in the superior PDU. Note: The ADI field can be used to detect collisions.

Any auxiliary PDU shall be another AUX_CHAIN_IND PDU.

		Common Extended Advertising Payload Format fields							
Adv Mode	**Event Type**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
00b	Chained data	X	X	C3	O	X	O	X	O
01b – 11b	RFU								

Table 2.7: Common Extended Advertising Payload Format fields permitted in the AUX_CHAIN_IND PDU

2.3.2 Scanning PDUs

The following advertising channel PDU types are called scanning PDUs.

- SCAN_REQ
- SCAN_RSP
- AUX_SCAN_REQ
- AUX_SCAN_RSP

The SCAN_REQ and AUX_SCAN_REQ PDUs are called scan request PDUs. The SCAN_RSP and AUX_SCAN_RSP PDUs are called scan response PDUs.

Where these PDUs are used to reply to a scannable advertisement, the PHY used for them shall be the same as the PHY used for the PDU that they reply to.

2.3.2.1 SCAN_REQ and AUX_SCAN_REQ

The SCAN_REQ and AUX_SCAN_REQ PDUs have the Payload as shown in Figure 2.10. The TxAdd in the advertising channel PDU header indicates whether the scanner's address in the ScanA field is public (TxAdd = 0) or random (TxAdd = 1). The RxAdd in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public (RxAdd = 0) or random (RxAdd = 1).

Payload	
ScanA (6 octets)	AdvA (6 octets)

Figure 2.10: SCAN_REQ and AUX_SCAN_REQ PDU Payload

The Payload field consists of ScanA and AdvA fields. The ScanA field shall contain the scanner's public or random device address as indicated by TxAdd. The AdvA field is the address of the device to which this PDU is addressed.

The AdvA field shall contain the advertiser's public or random device address as indicated by RxAdd.

Note: These PDUs do not contain any Host Data.

2.3.2.2 SCAN_RSP

The SCAN_RSP PDU has a format as shown in Figure 2.11. The TxAdd in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public (TxAdd = 0) or random (TxAdd = 1). The Length field indicates the size of the payload (AdvA and ScanRspData) in octets.

Payload	
AdvA (6 octets)	ScanRspData (0-31 octets)

Figure 2.11: SCAN_RSP PDU payload

The Payload field consists of AdvA and ScanRspData fields. The AdvA field shall contain the advertiser's public or random device address as indicated by TxAdd. The ScanRspData field may contain any data from the advertiser's Host.

2.3.2.3 AUX_SCAN_RSP

The AUX_SCAN_RSP PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4.

The AdvMode field shall be set to 00b.

The Common Extended Advertising Payload Format fields permitted in the AUX_SCAN_RSP PDU are shown in Table 2.8.

Any auxiliary PDU shall be an AUX_CHAIN_IND PDU.

		Common Extended Advertising Payload Format fields							
Adv Mode	**Event Type**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
00b	Scan response	M	X	X	O	X	O	O	M
01b – 11b	RFU								

Table 2.8: Common Extended Advertising Payload Format fields permitted in the AUX_SCAN_RSP PDU

2.3.3 Initiating PDUs

The following advertising channel PDU Types are called initiating PDUs:

- CONNECT_IND
- AUX_CONNECT_REQ
- AUX_CONNECT_RSP

The CONNECT_IND and the AUX_CONNECT_REQ PDUs are sent by the Link Layer in the Initiating State and received by the Link Layer in the Advertising State.
The AUX_CONNECT_RSP PDU is sent by the Link Layer in the Advertising State and received by the Link Layer in the Initiating State.

The PHY used for these PDUs shall be the same as the PHY used for the PDU that they reply to.

2.3.3.1 CONNECT_IND and AUX_CONNECT_REQ

The CONNECT_IND and AUX_CONNECT_REQ PDUs have the Payload as shown in Figure 2.12. TxAdd in the advertising channel PDU header indicates whether the initiator's device address in the InitA field is public (TxAdd = 0) or random (TxAdd = 1). The RxAdd in the advertising channel PDU header indicates whether the advertiser's device address in the AdvA field is public (RxAdd = 0) or random (RxAdd = 1).

The ChSel field in the CONNECT_IND PDU header shall be set to 1 if the initiator supports the LE Channel Selection Algorithm #2 feature (see Section 4.5.8.3).The ChSel field in the AUX_CONNECT_REQ PDU header is Reserved for Future Use.

Payload		
InitA (6 octets)	AdvA (6 octets)	LLData (22 octets)

Figure 2.12: CONNECT_IND and AUX_CONNECT_REQ PDU payload

The format of the LLData field is shown in Figure 2.13.

LLData									
AA (4 octets)	CRCInit (3 octets)	WinSize (1 octet)	WinOffset (2 octets)	Interval (2 octets)	Latency (2 octets)	Timeout (2 octets)	ChM (5 octets)	Hop (5 bits)	SCA (3 bits)

Figure 2.13: LLData field structure in CONNECT_IND and AUX_CONNECT_REQ PDU's payload

The Payload field consists of InitA, AdvA and LLData fields. The InitA field shall contain the Initiator's public or random device address as indicated by TxAdd. The AdvA field shall contain the advertiser's public or random device address as indicated by RxAdd.

The LLData consists of 10 fields:

- The AA field shall contain the Link Layer connection's Access Address determined by the Link Layer following the rules specified in Section 2.1.2.
- The CRCInit field shall contain the initialization value for the CRC calculation for the Link Layer connection, as defined in Section 3.1.1. It shall be a random value, generated by the Link Layer. The seed for the random number generator shall be from a physical source of entropy and should have at least 20 bits of entropy.
- The WinSize field shall be set to indicate the *transmitWindowSize* value, as defined in Section 4.5.3 in the following manner: *transmitWindowSize* = WinSize * 1.25 ms.
- The WinOffset field shall be set to indicate the *transmitWindowOffset* value, as defined in Section 4.5.3 in the following manner: *transmitWindowOffset* = WinOffset * 1.25 ms.
- The Interval field shall be set to indicate the *connInterval* as defined in Section 4.5.1 in the following manner: *connInterval* = Interval * 1.25 ms.
- The Latency field shall be set to indicate the *connSlaveLatency* value, as defined in Section 4.5.1 in the following manner: *connSlaveLatency* = Latency.
- The Timeout field shall be set to indicate the *connSupervisionTimeout* value, as defined in Section 4.5.2, in the following manner: *connSupervisionTimeout* = Timeout * 10 ms.
- The ChM field shall contain the channel map indicating *Used* and *Unused* data channels. Every channel is represented with a bit positioned as per the data channel index as defined in Section 1.4.1. The LSB represents data channel index 0 and the bit in position 36 represents data channel index 36. A bit value of 0 indicates that the channel is *Unused*. A bit value of 1 indicates that the channel is *Used*. The bits in positions 37, 38 and 39 are Reserved for Future Use. Note: When mapping from RF channels to data channel index, care should be taken to remember that there is a gap where advertising channel 38 is placed.
- The Hop field shall be set to indicate the *hopIncrement* used in the data channel selection algorithm as defined in Section 4.5.8.2. It shall have a random value in the range of 5 to 16.
- The SCA field shall be set to indicate the *masterSCA* used to determine the worst case Master's sleep clock accuracy as defined in Section 4.2.2. The value of the SCA field shall be set as defined in Table 2.9.

SCA	*masterSCA*
0	251 ppm to 500 ppm
1	151 ppm to 250 ppm

Table 2.9: SCA field encoding

SCA	*masterSCA*
2	101 ppm to 150 ppm
3	76 ppm to 100 ppm
4	51 ppm to 75 ppm
5	31 ppm to 50 ppm
6	21 ppm to 30 ppm
7	0 ppm to 20 ppm

Table 2.9: SCA field encoding

2.3.3.2 AUX_CONNECT_RSP

The AUX_CONNECT_RSP PDU uses the Common Extended Advertising Payload Format described in Section 2.3.4.

The AdvMode field shall be set to 00b.

The Common Extended Advertising Payload Format fields permitted in the AUX_CONNECT_RSP PDU are shown in Table 2.10.

		Common Extended Advertising Payload Format fields							
Adv Mode	**Event Type**	**AdvA**	**TargetA**	**ADI**	**Aux Ptr**	**Sync Info**	**Tx Power**	**ACAD**	**Adv Data**
00b	Connection response	M	M	X	X	X	X	X	X
01b – 11b	RFU								

Table 2.10: Common Extended Advertising Payload Format fields permitted in the AUX_CONNECT_RSP PDU

2.3.4 Common Extended Advertising Payload Format

The following extended Advertising Channel PDUs share the same Advertising Channel PDU payload format, referred to in this specification as the “Common Extended Advertising Payload Format”:

- ADV_EXT_IND
- AUX_ADV_IND
- AUX_SCAN_RSP
- AUX_SYNC_IND
- AUX_CHAIN_IND
- AUX_CONNECT_RSP

The common extended advertising payload format is shown in Figure 2.14.

Payload			
Extended Header Length (6 bits)	AdvMode (2 bits)	Extended Header (0 - 63 octets)	AdvData (0 - 254 octets)

Figure 2.14: Common Extended Advertising Payload Format

The Extended Header Length is a value between 0 and 63 and indicates the size of the variable length Extended Header field.

The AdvMode field indicates the mode of the advertisement. The value of the AdvMode field shall be set as defined in Table 2.11.

Value	Mode	
00b	Non-connectable	Non-scannable
01b	Connectable	Non-scannable
10b	Non-connectable	Scannable
11b	Reserved for future use	

Table 2.11: AdvMode field encoding

AdvData may contain advertising data from the advertiser's Host. The maximum size of AdvData depends on the size of the Extended Header. The size of the AdvData can be calculated by subtracting the length of the Extended Header plus one octet from the Length specified in the Advertising channel PDU Header.

The Extended Header field is a variable length header that is present if, and only if, the Extended Header Length field is non-zero. The format of the Extended Header is shown in Figure 2.15.

Extended Header								
Extended Header Flags (1 octet)	AdvA (6 octets)	TargetA (6 octets)	RFU (1 octet)	AdvData Info (ADI) (2 octets)	AuxPtr (3 octets)	SyncInfo (18 octets)	TxPower (1 octet)	ACAD (varies)

Figure 2.15: Extended Header

The Extended Header Flags bit field definitions are shown in Table 2.12.

Bit	Extended Header
0	AdvA
1	TargetA
2	Reserved for future use

Table 2.12: Extended Header Flags

Bit	Extended Header
3	AdvDataInfo (ADI)
4	AuxPtr
5	SyncInfo
6	TxPower
7	Reserved for future use

Table 2.12: Extended Header Flags

If a flag bit is set to 1, the corresponding Extended Header field is present; otherwise, the corresponding Extended Header field is not present. The Extended Header fields that are present are always in the same order as the flags in the Extended Header flags (i.e., the AdvA field is first if present, then the TargetA field if present, etc.).

Whether an Extended Header flag and corresponding Extended Header field is mandatory, optional, or reserved for future use is dependent on the Advertising Channel PDU in which the extended header is used.

2.3.4.1 AdvA field

When present, the AdvA field is six octets with the format shown in Figure 2.16.

AdvA
Advertising Address (6 octets)

Figure 2.16: AdvA field

The Advertising Address field contains the advertiser's device address. The TxAdd field of the Advertising Channel PDU Header applies to this value.

2.3.4.2 TargetA field

When present, the TargetA field is six octets with the format shown in Figure 2.17.

TargetA
Target Address (6 octets)

Figure 2.17: TargetA field

The Target Address field contains the scanner's or initiator's device address to which the advertisement is directed. The RxAdd field of the Advertising Channel PDU Header applies to this value.

2.3.4.3 RFU

<Field and section reserved for a future feature>

2.3.4.4 AdvDataInfo field

When present, the AdvDataInfo (ADI) field is two octets with the format shown in Figure 2.18.

AdvDataInfo	
Advertising Data ID (DID) (12 bits)	Advertising Set ID (SID) (4 bits)

Figure 2.18: AdvDataInfo field

The Advertising Set ID (SID) is set by the advertiser to distinguish between different advertising sets transmitted by this device.

The Advertising Data ID (DID) is set by the advertiser to indicate to the scanner whether it can assume that the data contents in the AdvData are a duplicate of the previous AdvData sent in an earlier packet.

2.3.4.5 AuxPtr field

When present, the AuxPtr field is three octets with the format shown in Figure 2.19.

AuxPtr				
Channel Index (6 bits)	CA (1 bits)	Offset Units (1 bits)	AUX Offset (13 bits)	AUX PHY (3 bits)

Figure 2.19: AuxPtr Field

The presence of the AuxPtr field indicates that some or all of the advertisement data is in a subsequent auxiliary packet. The contents of the AuxPtr field describe this packet.

The Channel Index field contains the secondary advertising channel index (see Section 1.4.1) used to transmit the auxiliary packet.

The Offset Units field indicates the units used by the Aux Offset Field. The value of the Offset Units field shall be set as defined in Table 2.13.

Value	Units
0	30 µs

Table 2.13: Offset Units field encoding

Value	Units
1	300 µs

Table 2.13: Offset Units field encoding

The Aux Offset field contains the time from the start of the packet containing the AuxPtr field to the approximate start of the auxiliary packet. The value of the AUX Offset field is in the unit of time indicated by the Offset Units field; the offset is determined by multiplying the value by the unit. The Aux Offset shall be at least the length of the packet plus T_MAFS (see Section 4.1.2). The Offset Units field shall be set to 0 if the Aux Offset is less than 245,700 µs.The auxiliary packet shall not start any earlier than the Aux Offset and shall start no later than the Aux Offset plus one Offset Unit. This allows the LL to round the Aux Offset to the Offset Unit.

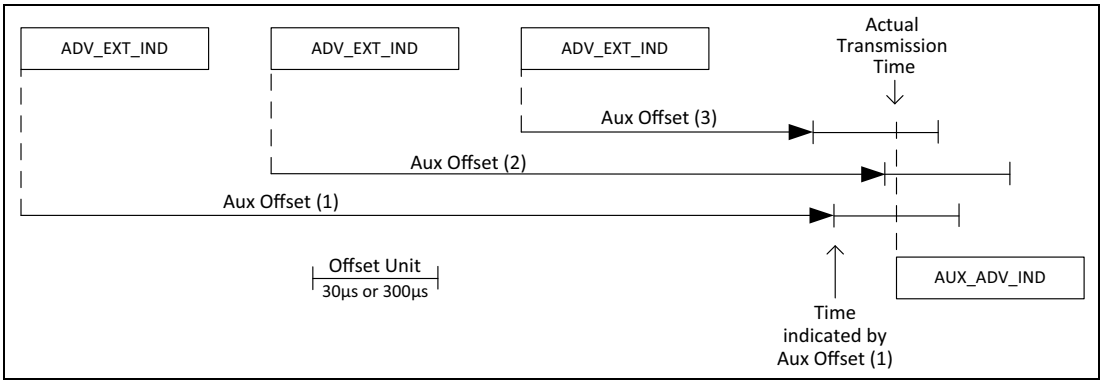

Figure 2.20: Aux Offset Transmission Window

The Aux PHY field indicates the PHY used to transmit the auxiliary packet. The value of the Aux PHY field shall be set as defined in Table 2.14.

Value	PHY used
000b	LE 1M
001b	LE 2M
010b	LE Coded
011b – 111b	Reserved for future use

Table 2.14: Aux PHY field encoding

The CA field contains the clock accuracy of the advertiser that will be used between the packet containing this data and the auxiliary packet. The value of the CA field shall be set as defined in Table 2.15.

CA Value	Advertiser's Clock Accuracy
0	51 ppm to 500 ppm

Table 2.15: Clock Accuracy field encoding

CA Value	Advertiser's Clock Accuracy
1	0 ppm to 50 ppm

Table 2.15: Clock Accuracy field encoding

An AuxPtr field with an Aux Offset of zero is permitted and indicates that no auxiliary packet will be transmitted but the Host advertising data in the current PDU is incomplete (see Section 2.3.4.9); it shall be treated as equivalent to one referring to an AUX_CHAIN_IND PDU that is never received. The remaining fields shall contain valid values.

2.3.4.6 SyncInfo field

When present, the SyncInfo field is 18 octets with the format shown in Figure 2.21.

SyncInfo								
Sync Packet Offset (13 bits)	Offset Units (1 bit)	RFU (2 bits)	Interval (2 octets)	ChM (37 bits)	SCA (3 bits)	AA (4 octets)	CRCInit (3 octets)	Event Counter (2 octets)

Figure 2.21: SyncInfo field

The presence of the SyncInfo field indicates the presence of a periodic advertisement (using AUX_SYNC_IND PDUs). The contents of the SyncInfo field describe this periodic advertisement.

The Offset Units field indicates the units used by the Sync Packet Offset field. The value of the Offset Units field shall be set as defined in Table 2.16.

Value	Units
0	30 µs
1	300 µs

Table 2.16: Offset Units field encoding

The Sync Packet Offset field contains the time from the start of the AUX_ADV_IND packet containing the SyncInfo field to the start of the AUX_SYNC_IND packet. The value of the Sync Packet Offset field is in the unit of time indicated by the Offset Units field; the actual offset is determined by multiplying the value by the unit. The Offset Units field shall be set to 0 if the Sync Packet Offset is less than 245,700 µs. As illustrated in Figure 2.22, the AUX_ADV_IND packet containing the SyncInfo field shall start no later than the Sync Packet Offset and no earlier than the Sync Packet Offset plus one Offset unit prior to the start of the AUX_SYNC_IND.

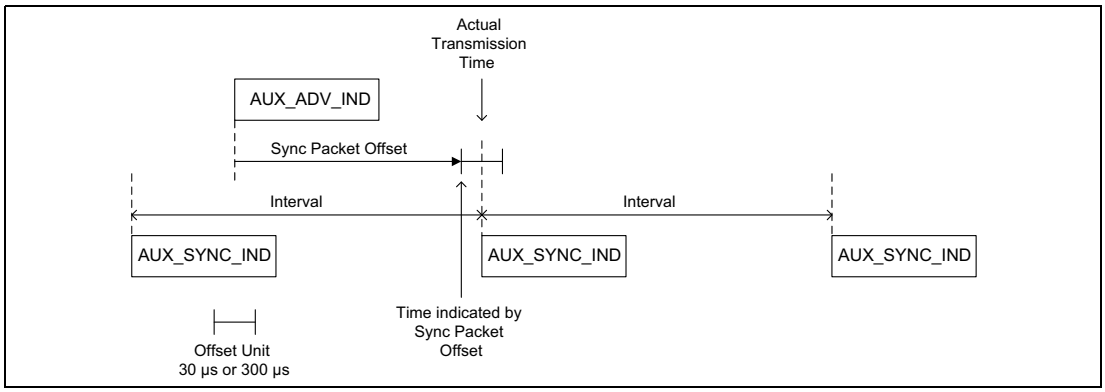

Figure 2.22: Sync Packet Offset Transmission Window

A value of 0 for the Sync Packet Offset indicates that the time to the next AUX_SYNC_IND packet is greater than can be represented.

The Interval field contains the time in 1.25 ms units from the start of one packet of the periodic advertisement to the start of the next packet. The value shall not be less than 6 (7.5 ms).

The ChM field contains the channel map indicating *Used* and *Unused* secondary advertising channels. Every channel is represented with a bit positioned as per the data channel index as defined in Section 1.4.1. The LSB represents channel index 0 and the bit in position 36 represents channel index 36. A bit value of 0 indicates that the channel is *Unused*. A bit value of 1 indicates that the channel is *Used*.

The AA, CRCInit, and SCA fields have the same meaning as the corresponding fields in the CONNECT_IND PDU (see Section 2.3.3.1).

The Event Counter field contains the value of *paEventCounter* (see Section 4.4.2.1) that applies to the AUX_SYNC_IND packet that this SyncInfo field describes.

2.3.4.7 TxPower field

When present, the TxPower is one octet with the format shown in Figure 2.23.

TxPower
Tx Power Level (1 octet)

Figure 2.23: TxPower field

The Tx Power Level field is the same value defined for the Tx Power Advertising Data type defined in Bluetooth Core Specification Supplement (CSS).

2.3.4.8 ACAD field

The remainder of the extended header forms the Additional Controller Advertising Data (ACAD) field. The length of this field is the Extended Header length minus the sum of the size of the extended header flags (1 octet) and those fields indicated by the flags as present. ACAD cannot be fragmented across multiple advertising data PDUs; it shall always fit inside a single advertising data PDU.

The ACAD field holds data from the advertiser's Controller or intended to be used by the recipient's Controller. It uses the same format as the AdvData field in various Advertising Channel PDUs. This format is described in [Vol 3] Part C, Section 11.

The ACAD type formats and meanings are defined in [CSS], Part A, Section 1. The ACAD type identifier values are defined in the Assigned Numbers document.

2.3.4.9 Host Advertising Data

The portion of the PDU after the extended header forms the AdvData field. The length of this field is specified in Section 2.3.4.

The AdvData field holds data from the advertiser's Host. The format of this data is described in [Vol 3] Part C, Section 11. If the Host does not provide any data, the AdvData field shall be omitted but, for all other purposes in this Part, this shall be treated as if the Host had provided data.

The Controller may support fragmentation of Host Advertising Data. The total amount of Host Advertising Data before fragmentation shall not exceed 1650 octets. When the Link Layer fragments the Host advertising data, the number of fragments and the size of each fragment are chosen by the Controller. The Controller should minimize the number of fragments to ensure more reliability in delivering the entire Host advertising data. The Host may indicate a preference whether the Controller should fragment the Host advertising data, but the Controller may ignore the preference. If the amount of advertising or scan response data to be sent in an extended advertising or scanning PDU plus the Extended Header Length, AdvMode, and Extended Header exceed the maximum Advertising Channel PDU payload (255 octets), the Link Layer shall fragment the Host advertising data.

The Link Layer shall place the multiple fragments in the AdvData field of different PDUs. When Host advertising data is fragmented the first fragment shall be placed in the AUX_ADV_IND, AUX_SYNC_IND or AUX_SCAN_RSP PDU while subsequent fragments shall be placed in AUX_CHAIN_IND PDUs. Each AUX_CHAIN_IND PDU is the auxiliary PDU of the PDU containing the previous fragment; the AUX_CHAIN_IND PDU holding the last fragment shall not have an auxiliary PDU.

If the Link Layer has fragmented the Host advertising data but is subsequently unable to transmit all the fragments, the last fragment that it is able to transmit should contain an AuxPtr field with an Aux Offset of zero so that scanners are aware that the data has been truncated.

2.4 DATA CHANNEL PDU

The Data Channel PDU has a 16 bit header, a variable size payload, and may include a Message Integrity Check (MIC) field.

The Data Channel PDU is as shown in Figure 2.24.

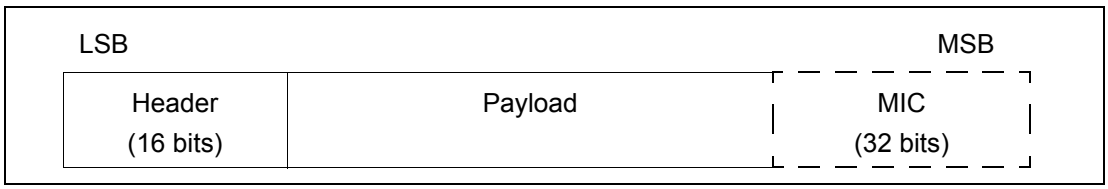

Figure 2.24: Data Channel PDU

The Header field of the Data Channel PDU is as shown in Figure 2.25.

Header					
LLID (2 bits)	NESN (1 bit)	SN (1 bit)	MD (1 bit)	RFU (3 bits)	Length (8 bits)

Figure 2.25: Data channel PDU header

The 16 bit Header field consists of 5 fields that are specified in Table 2.17.

The MIC field shall not be included in an un-encrypted Link Layer connection, or in an encrypted Link Layer connection with a data channel PDU with a zero length Payload.

The MIC field shall be included in an encrypted Link Layer connection, with a data channel PDU with a non-zero length Payload and shall be calculated as specified in [Vol 6] Part E, Section 1.

The payload format depends on the LLID field of the Header. If the LLID field is 01b or 10b, the Data Channel PDU Payload field contains an LL Data PDU as defined in Section 2.4.1. If the LLID field is 11b then the Data Channel PDU Payload field contains an LL Control PDU as defined in Section 2.4.2.

The NESN bit of the Header is defined in Section 4.5.9.

The SN bit of the Header is defined in Section 4.5.9.

The MD bit of the Header is defined in Section 4.5.6.

The Length field of the Header indicates the length of the Payload and MIC if included. The length field has the range of 0 to 255 octets. The Payload field shall be less than or equal to 251 octets in length. The MIC is 4 octets in length.

Field name	Description
LLID	The LLID indicates whether the packet is an LL Data PDU or an LL Control PDU. 00b = Reserved for future use 01b = LL Data PDU: Continuation fragment of an L2CAP message, or an Empty PDU. 10b = LL Data PDU: Start of an L2CAP message or a complete L2CAP message with no fragmentation. 11b = LL Control PDU
NESN	Next Expected Sequence Number
SN	Sequence Number
MD	More Data
Length	The Length field indicates the size, in octets, of the Payload and MIC, if included.

Table 2.17: Data channel PDU Header field

2.4.1 LL Data PDU

An LL Data PDU is a data channel PDU that is used to send L2CAP data. The LLID field in the Header shall be set to either 01b or 10b.

An LL Data PDU with the LLID field in the Header set to 01b, and the Length field set to 00000000b, is known as an Empty PDU. The master's Link Layer may send an Empty PDU to the slave to allow the slave to respond with any Data Channel PDU, including an Empty PDU.

An LL Data PDU with the LLID field in the Header set to 10b shall not have the Length field set to 00000000b.

2.4.2 LL Control PDU

An LL Control PDU is a Data Channel PDU that is used to control the Link Layer connection.

The LL Control PDU Payload is as shown in Figure 2.26.

Payload	
Opcode (1 octet)	CtrData (0 – 26 octets)

Figure 2.26: LL control PDU payload

An LL Control PDU shall not have the Length field set to 00000000b. All LL Control PDUs have a fixed length, depending on the Opcode.

The Payload field consists of Opcode and CtrData fields.

The Opcode field identifies different types of LL Control PDU, as defined in Table 2.18.

The CtrData field in the LL Control PDU is specified by the Opcode field and is defined in the following subsections.

Except where explicitly stated otherwise, all fields within the CtrData field in an LL Control PDU that hold an integer shall be interpreted as unsigned.

Opcode	Control PDU Name
0x00	LL_CONNECTION_UPDATE_IND
0x01	LL_CHANNEL_MAP_IND
0x02	LL_TERMINATE_IND
0x03	LL_ENC_REQ
0x04	LL_ENC_RSP
0x05	LL_START_ENC_REQ
0x06	LL_START_ENC_RSP
0x07	LL_UNKNOWN_RSP
0x08	LL_FEATURE_REQ
0x09	LL_FEATURE_RSP
0x0A	LL_PAUSE_ENC_REQ
0x0B	LL_PAUSE_ENC_RSP
0x0C	LL_VERSION_IND

Table 2.18: LL Control PDU Opcodes

Opcode	Control PDU Name
0x0D	LL_REJECT_IND
0x0E	LL_SLAVE_FEATURE_REQ
0x0F	LL_CONNECTION_PARAM_REQ
0x10	LL_CONNECTION_PARAM_RSP
0x11	LL_REJECT_EXT_IND
0x12	LL_PING_REQ
0x13	LL_PING_RSP
0x14	LL_LENGTH_REQ
0x15	LL_LENGTH_RSP
0x16	LL_PHY_REQ
0x17	LL_PHY_RSP
0x18	LL_PHY_UPDATE_IND
0x19	LL_MIN_USED_CHANNELS_IND
All other values	Reserved for Future Use

Table 2.18: LL Control PDU Opcodes

If an LL Control PDU is received that is not used or not supported, the Link Layer shall respond with an LL_UNKNOWN_RSP PDU. The UnknownType field of the LL_UNKNOWN_RSP PDU shall be set to the value of the not used or not supported Opcode.

If an LL Control PDU is received with an invalid Opcode, i.e. the Opcode field is set to a value that is Reserved for Future Use, or with invalid CtrData fields, the Link Layer shall respond with an LL_UNKNOWN_RSP PDU. The UnknownType field of the LL_UNKNOWN_RSP PDU shall be set to the value of the invalid Opcode.

2.4.2.1 LL_CONNECTION_UPDATE_IND

The format of the CtrData field is as shown in Figure 2.27.

CtrData					
WinSize (1 octet)	WinOffset (2 octets)	Interval (2 octets)	Latency (2 octets)	Timeout (2 octets)	Instant (2 octets)

Figure 2.27: CtrData field of the LL_CONNECTION_UPDATE_IND PDU

The LL_CONNECTION_UPDATE_IND CtrData consists of six fields:

- The WinSize field shall be set to indicate the *transmitWindowSize* value, as defined in Section 4.5.3 in the following manner: *transmitWindowSize* = WinSize * 1.25 ms.
- The WinOffset field shall be set to indicate the *transmitWindowOffset value,* as defined in Section 4.5.3, in the following manner: *transmitWindowOffset* = WinOffset * 1.25 ms.
- The Interval field shall be set to indicate the *connInterval* value, as defined in Section 4.5.1, in the following manner: *connInterval* = Interval * 1.25 ms.
- The Latency field shall be set to indicate the *connSlaveLatency* value, as defined by Section 4.5.1, in the following manner: *connSlaveLatency* = Latency.
- The Timeout field shall be set to indicate the *connSupervisionTimeout* value, as defined by Section 4.5.2, in the following manner: *connSupervisionTimeout* = Timeout * 10 ms.
- The Instant field shall be set to indicate the instant described in Section 5.1.1.

2.4.2.2 LL_CHANNEL_MAP_IND

The format of the CtrData field is shown in Figure 2.28.

CtrData	
ChM (5 octets)	Instant (2 octets)

Figure 2.28: CtrData field of the LL_CHANNEL_MAP_IND PDU

The LL_CHANNEL_MAP_IND CtrData consists of two fields:

- The ChM field shall contain the channel map indicating *Used* and *Unused* data channels. Every channel is represented with a bit positioned as per the data channel index defined by Section 4.5.8. The format of this field is identical to the ChM field in the CONNECT_IND PDU (see Section 2.3.3.1).
- The Instant field shall be set to indicate the instant described in Section 5.1.2.

2.4.2.3 LL_TERMINATE_IND

The format of the CtrData field is shown in Figure 2.29.

CtrData
ErrorCode (1 octet)

Figure 2.29: CtrData field of the LL_TERMINATE_IND PDU

The LL_TERMINATE_IND CtrData consists of one field:

- The ErrorCode field shall be set to inform the remote device why the connection is about to be terminated. See [Vol 2] Part D, Error Codes for details.

2.4.2.4 LL_ENC_REQ

The format of the CtrData field is shown in Figure 2.30.

CtrData			
Rand (8 octets)	EDIV (2 octets)	SKDm (8 octets)	IVm (4 octets)

Figure 2.30: CtrData field of the LL_ENC_REQ PDU

The LL_ENC_REQ CtrData consists of four fields:

- The Rand field contains a random number that is provided by the Host and used with EDIV (see [Vol 3] Part H, Section 2.4.4).
- The EDIV field contains the encrypted diversifier.
- The SKDm field contains the master's portion of the session key diversifier.
- The IVm field contains the master's portion of the initialization vector.

2.4.2.5 LL_ENC_RSP

The format of the CtrData field is shown in Figure 2.31.

CtrData	
SKDs (8 octets)	IVs (4 octets)

Figure 2.31: CtrData field of the LL_ENC_ RSP PDU

The LL_ENC_RSP CtrData consists of two fields.

- The SKDs field shall contain the slave's portion of the session key diversifier.
- The IVs field shall contain the slave's portion of the initialization vector.

2.4.2.6 LL_START_ENC_REQ

The LL_START_ENC_REQ PDU does not have a CtrData field.

2.4.2.7 LL_START_ENC_RSP

The LL_START_ENC_RSP PDU does not have a CtrData field.

2.4.2.8 LL_UNKNOWN_RSP

The format of the CtrData field is shown in Figure 2.32.

CtrData
UnknownType (1 octet)

Figure 2.32: CtrData field of the LL_UNKNOWN_RSP PDU

The LL_UNKNOWN_RSP CtrData consists of one field:

- UnknownType shall contain the Opcode field value of the received LL Control PDU.

2.4.2.9 LL_FEATURE_REQ

The format of the CtrData field is shown in Figure 2.33.

CtrData
FeatureSet (8 octets)

Figure 2.33: CtrData field of the LL_FEATURE_REQ PDU

The LL_FEATURE_REQ CtrData consists of one field:

- FeatureSet shall contain the set of features supported by the master's Link Layer.

2.4.2.10 LL_FEATURE_RSP

The format of the CtrData field is shown in Figure 2.34.

CtrData
FeatureSet (8 octets)

Figure 2.34: CtrData field of the LL_FEATURE_RSP PDU

The LL_FEATURE_RSP CtrData consists of one field:

- FeatureSet[0] shall contain a set of features supported by the Link Layers of both the master and slave.
- FeatureSet[1-7] shall contain a set of features supported by the Link Layer that transmits this PDU.

2.4.2.11 LL_PAUSE_ENC_REQ

The LL_PAUSE_ENC_REQ packet does not have a CtrData field.

2.4.2.12 LL_PAUSE_ENC_RSP

The LL_PAUSE_ENC_RSP packet does not have a CtrData field.

2.4.2.13 LL_VERSION_IND

The format of the CtrData field is shown in Figure 2.35.

CtrData		
VersNr (1 octet)	CompId (2 octets)	SubVersNr (2 octets)

Figure 2.35: CtrData field of the LL_VERSION_IND PDU

The LL_VERSION_IND CtrData consists of three fields:

- VersNr field shall contain the version of the Bluetooth Link Layer specification (see Bluetooth Assigned Numbers).
- CompId field shall contain the company identifier of the manufacturer of the Bluetooth Controller (see Bluetooth Assigned Numbers).
- SubVersNr field shall contain a unique value for each implementation or revision of an implementation of the Bluetooth Controller.

2.4.2.14 LL_REJECT_IND

The format of the CtrData field is shown in Figure 2.36.

CtrData
ErrorCode (1 octet)

Figure 2.36: CtrData field of the LL_ REJECT_IND

ErrorCode shall contain the reason a request was rejected; see [Vol 2] Part D, Error Codes.

2.4.2.15 LL_SLAVE_FEATURE_REQ

The format of the CtrData field is shown in Figure 2.37.

CtrData
FeatureSet (8 octets)

Figure 2.37: CtrData field of the LL_SLAVE_FEATURE_REQ PDU

The LL_SLAVE_FEATURE_REQ CtrData consists of one field:

- FeatureSet shall contain the set of features supported by the slave's Link Layer.

2.4.2.16 LL_CONNECTION_PARAM_REQ

The format of the CtrData field is shown in Figure 2.38.

CtrData											
Interval_Min (2 octets)	Interval_Max (2 octets)	Latency (2 octets)	Timeout (2 octets)	PreferredPeriodicity (1 octet)	ReferenceConnEventCount (2 octets)	Offset0 (2 octets)	Offset1 (2 octets)	Offset2 (2 octets)	Offset3 (2 octets)	Offset4 (2 octets)	Offset5 (2 octets)

Figure 2.38: CtrData field of the LL_CONNECTION_PARAM_REQ PDU

The LL_CONNECTION_PARAM_REQ CtrData consists of 12 fields:

- The Interval_Min field shall be set to indicate the minimum value of *connInterval*, as defined in Section 4.5.1, in the following manner: *connInterval* = Interval_Min * 1.25 ms.
- The Interval_Max field shall be set to indicate the maximum value of *connInterval*, as defined in Section 4.5.1, in the following manner: *connInterval* = Interval_Max * 1.25 ms.
- The Latency field shall be set to indicate the *connSlaveLatency* value, as defined by Section 4.5.1, in the following manner: *connSlaveLatency* = Latency. Latency is in units of number of connection events.
- The Timeout field shall be set to indicate the *connSupervisionTimeout* value, as defined by Section 4.5.2, in the following manner: *connSupervisionTimeout* = Timeout * 10 ms.
- The PreferredPeriodicity field shall be set to indicate a value the *connInterval* is preferred to be a multiple of. PreferredPeriodicity is in units of 1.25 ms. E.g. if the PreferredPeriodicity is set to 100, it implies that *connInterval* is preferred to be any multiple of 125 ms. A value of zero means not valid. The PreferredPeriodicity shall be less than or equal to Interval_Max.
- The ReferenceConnEventCount field shall be set to indicate the value of the *connEventCounter* relative to which all the valid Offset0 to Offset5 fields have been calculated. The ReferenceConnEventCount field shall have a value in the range of 0 to 65535. Note: The ReferenceConnEventCount field is independent of the Instant field in the LL_CONNECTION_UPDATE_IND PDU.
- The Offset0, Offset1, Offset2, Offset3, Offset4, and Offset5 fields shall be set to indicate the possible values of the position of the anchor points of the LE connection with the updated connection parameters relative to the

ReferenceConnEventCount. The Offset0 to Offset5 fields are in units of 1.25 ms and are in decreasing order of preference; that is, Offset0 is the most preferred value, followed by Offset1, and so on. Offset0 to Offset5 shall be less than Interval_Max. A value of 0xFFFF means not valid. Valid Offset0 to Offset5 fields shall contain unique values. Valid fields shall always be before invalid fields.

2.4.2.17 LL_CONNECTION_PARAM_RSP

The format of the LL_CONNECTION_PARAM_RSP PDU is identical to the format of the LL_CONNECTION_PARAM_REQ PDU (see Section 2.4.2.16).

2.4.2.18 LL_REJECT_EXT_IND

The format of the CtrData field is shown in Figure 2.39.

CtrData	
RejectOpcode (1 octet)	ErrorCode (1 octet)

Figure 2.39: CtrData field of the LL_REJECT_EXT_IND PDU

The LL_REJECT_EXT_IND CtrData consists of two fields:

- RejectOpcode shall contain the Opcode field value of the LL Control PDU being rejected.
- ErrorCode shall contain the reason the LL Control PDU was being rejected. See [Vol 2] Part D, Error Codes for a list of error codes and descriptions.

This PDU shall be issued only when the remote Link Layer supports the Extended Reject Indication Link Layer feature (Section 4.6). Otherwise, the LL_REJECT_IND PDU (Section 2.4.2.14) shall be issued instead.

2.4.2.19 LL_PING_REQ

The LL_PING_REQ PDU does not have a CtrData field.

2.4.2.20 LL_PING_RSP

The LL_PING_RSP PDU does not have a CtrData field.

2.4.2.21 LL_LENGTH_REQ and LL_LENGTH_RSP

The format of the CtrData field for both the LL_LENGTH_REQ and LL_LENGTH_RSP PDUs is shown in Figure 2.40.

CtrData			
MaxRxOctets (2 octets)	MaxRxTime (2 octets)	MaxTxOctets (2 octets)	MaxTxTime (2 octets)

Figure 2.40: CtrData field of the LL_LENGTH_REQ and LL_LENGTH_RSP PDUs

The LL_LENGTH_REQ and LL_LENGTH_RSP CtrData consists of four fields:

- MaxRxOctets shall be set to the sender's *connMaxRxOctets* value, as defined in Section 4.5.10. The MaxRxOctets field shall have a value not less than 27 octets.
- MaxRxTime shall be set to the sender's *connMaxRxTime* value, as defined in Section 4.5.10. The MaxRxTime field shall have a value not less than 328 microseconds.
- MaxTxOctets shall be set to the sender's *connMaxTxOctets* value, as defined in Section 4.5.10. The MaxTxOctets field shall have a value not less than 27 octets.
- MaxTxTime shall be set to the sender's *connMaxTxTime* value, as defined in Section 4.5.10. The MaxTxTime field shall have a value not less than 328 microseconds.

2.4.2.22 LL_PHY_REQ and LL_PHY_RSP

The format of the CtrData field for both the LL_PHY_REQ and LL_PHY_RSP PDUs is shown in Figure 2.41.

CtrData	
TX_PHYS (1 octet)	RX_PHYS (1 octet)

Figure 2.41: CtrData field of the LL_PHY_REQ and LL_PHY_RSP PDUs

The LL_PHY_REQ and LL_PHY_RSP CtrData consists of two fields:

- TX_PHYS shall be set to indicate the transmitter PHYs that the sender prefers to use.
- RX_PHYS shall be set to indicate the receiver PHYs that the sender prefers to use.

These fields each consist of 8 bits as specified in Table 2.19. At least one bit in each field shall be set to 1.

Bit number	Meaning
0	Sender prefers to use the LE 1M PHY (possibly among others)
1	Sender prefers to use the LE 2M PHY (possibly among others)
2	Sender prefers to use the LE Coded PHY (possibly among others)
3–7	Reserved for future use

Table 2.19: PHY field bit meanings

2.4.2.23 LL_PHY_UPDATE_IND

The format of the CtrData field is shown in Figure 2.42.

CtrlData		
M_TO_S_PHY (1 octet)	S_TO_M_PHY (1 octet)	Instant (2 octets)

Figure 2.42: CtrData field of the LL_PHY_UPDATE_IND PDU

The LL_PHY_UPDATE_IND CtrData consists of three fields:

- M_TO_S_PHY shall be set to indicate the PHY that shall be used for packets sent from the master to the slave. S_TO_M_PHY shall be set to indicate the PHY that shall be used for packets sent from the slave to the master. These fields each consist of 8 bits as specified in Table 2.20. If a PHY is changing, exactly one bit shall be set to the value 1 in the corresponding field; if a PHY is remaining unchanged, then the corresponding field shall be set to the value 0.
- Instant shall be set to indicate the instant described in Section 5.1.10.

If both the M_TO_S_PHY and S_TO_M_PHY fields are zero then there is no Instant and the Instant field is reserved for future use.

Bit Number	Meaning
0	The LE 1M PHY shall be used
1	The LE 2M PHY shall be used
2	The LE Coded PHY shall be used
3–7	Reserved for future use

Table 2.20: PHY field bit meanings

2.4.2.24 LL_MIN_USED_CHANNELS_IND

The format of the CtrData field is as shown in Figure 2.43.

CtrData	
PHYS (1 octet)	MinUsedChannels (1 octet)

Figure 2.43: CtrData field of the LL_MIN_USED_CHANNELS_IND PDU

The LL_MIN_USED_CHANNELS_IND consists of two fields:

- The PHYS field shall be set to the PHY(s) for which the slave has a minimum number of used channels requirement. The PHYS field consists of 8 bits as specified in Table 2.21. At least one bit in the field shall be set to 1.
- The MinUsedChannels field contains the minimum number of channels to be used on the specified PHY. The MinUsedChannels field shall have a value in the range of 2 to 37 channels.

Bit Number	Meaning
0	LE 1M PHY
1	LE 2M PHY
2	LE Coded PHY
3-7	Reserved for Future Use

Table 2.21: PHY field bit meanings

3 BIT STREAM PROCESSING

Bluetooth devices shall use the bit stream processing schemes as defined in the following sections.

Figure 3.1 shows the bit stream processing for PDUs on the LE Uncoded PHYs.

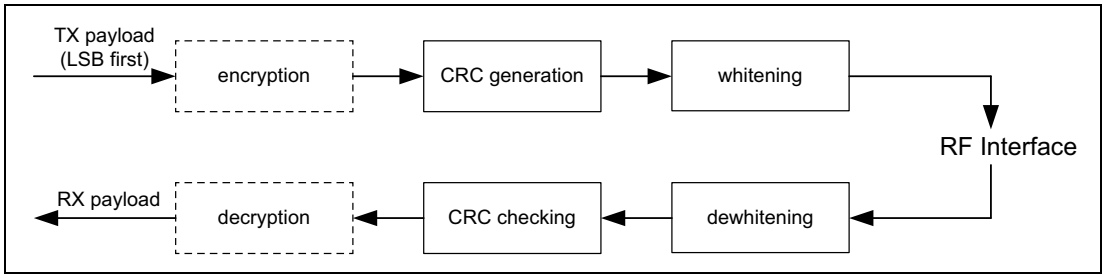

Figure 3.1: Payload bit processes for the LE Uncoded PHYs

Figure 3.2 shows the bit stream processing for PDUs on the LE Coded PHYs.

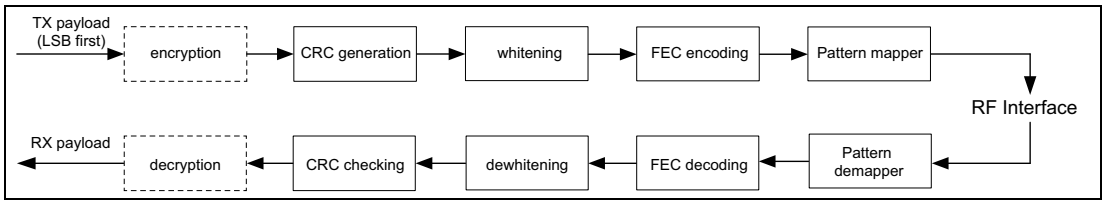

Figure 3.2: Bit stream processing for the LE Coded PHYs

3.1 ERROR CHECKING

At packet reception, the Access Address shall be checked first. If the Access Address is incorrect, the packet shall be rejected, otherwise the packet shall be considered received. If the CRC is incorrect, the packet shall be rejected, otherwise the packet shall be considered valid. A packet shall only be processed if the packet is considered valid. A packet with an incorrect CRC may cause a connection event to continue, as specified in Section 4.5.1.

3.1.1 CRC Generation

The CRC shall be calculated on the PDU field in all Link Layer packets. If the PDU is encrypted, then the CRC shall be calculated after encryption of the PDU has been performed.

The CRC polynomial is a 24-bit CRC and all bits in the PDU shall be processed in transmitted order starting from the least significant bit. The polynomial has the form of $x^{24} + x^{10} + x^9 + x^6 + x^4 + x^3 + x + 1$. For every Data Channel PDU, the shift register shall be preset with the CRC initialization value set for the Link Layer connection and communicated in the CONNECT_IND PDU. For the

AUX_SYNC_IND PDU and its subordinate set, the shift register shall be preset with the CRCInit value set in the SyncInfo field (see Section 2.3.4.6) contained in the AUX_ADV_IND PDU that describes the periodic advertising. For all other Advertising Channel PDUs, the shift register shall be preset with 0x555555.

Position 0 shall be set as the least significant bit and position 23 shall be set as the most significant bit of the initialization value. The CRC is transmitted most significant bit first, i.e. from position 23 to position 0 (see Section 1.2).

Figure 3.3 shows an example linear feedback shift register (LFSR) to generate the CRC.

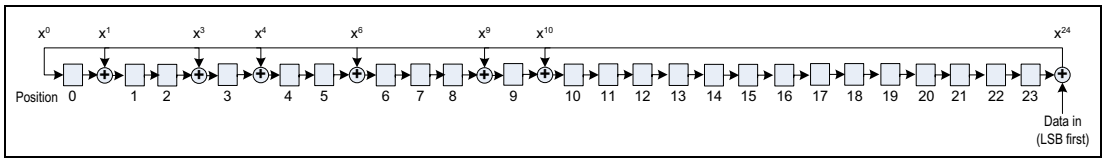

Figure 3.3: The LFSR circuit generating the CRC

3.2 DATA WHITENING

Data whitening is used to avoid long sequences of zeros or ones, e.g. 0000000b or 1111111b, in the data bit stream. Whitening shall be applied on the PDU and CRC fields of all Link Layer packets and is performed after the CRC in the transmitter. De-whitening is performed before the CRC in the receiver (see Figure 3.1).

The whitener and de-whitener are defined the same way, using a 7-bit linear feedback shift register with the polynomial $x^7 + x^4 + 1$. Before whitening or de-whitening, the shift register is initialized with a sequence that is derived from the channel index (data channel index or advertising channel index) in which the packet is transmitted in the following manner:

- Position 0 is set to one.
- Positions 1 to 6 are set to the channel index of the channel used when transmitting or receiving, from the most significant bit in position 1 to the least significant bit in position 6.

For example, if the channel index = 23 (0x17), the positions would be set as follows:

Position 0 = 1
Position 1 = 0
Position 2 = 1
Position 3 = 0
Position 4 = 1
Position 5 = 1
Position 6 = 1

Figure 3.4 shows an example linear feedback shift register (LFSR) to generate data whitening.

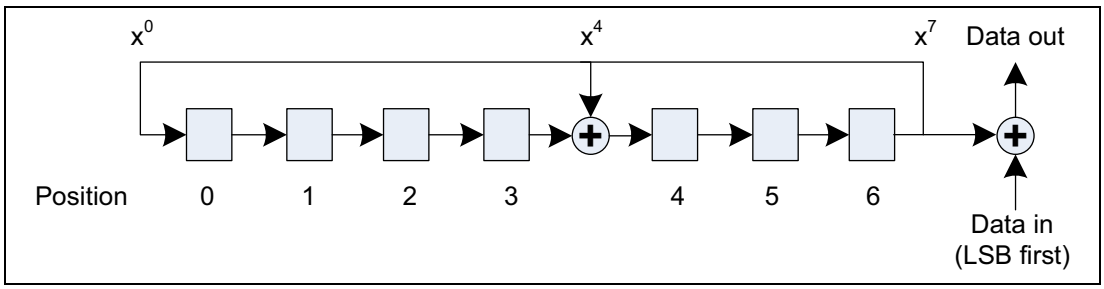

Figure 3.4: The LFSR circuit to generate data whitening

3.3 CODING

Coding only applies to the LE Coded PHY.

Coding consists of two processes. Data is first coded by the Forward Error Correction (FEC) convolutional encoder as defined in Section 3.3.1 and then spread by the pattern mapper as defined in Section 3.3.2.

3.3.1 Forward Error Correction Encoder

The convolutional FEC encoder uses a non-systematic, non-recursive rate ½ code with constraint length K=4. The generator polynomials are:

$G_0(x) = 1 + x + x^2 + x^3$

$G_1(x) = 1 + x^2 + x^3$

The bit coming from generator polynomial G_0 (a_0) is transmitted first; the bit coming from generator polynomial G_1 (a_1) is transmitted second.

The initial state of the convolutional FEC encoder is set to all zeros. An input sequence of three consecutive zeros always brings the convolutional FEC encoder back to its original state. This sequence is known as the termination sequence.

Figure 3.5 illustrates operation of the convolutional FEC encoder. Squares represent bit storage operations and circles represent mod 2 binary additions.

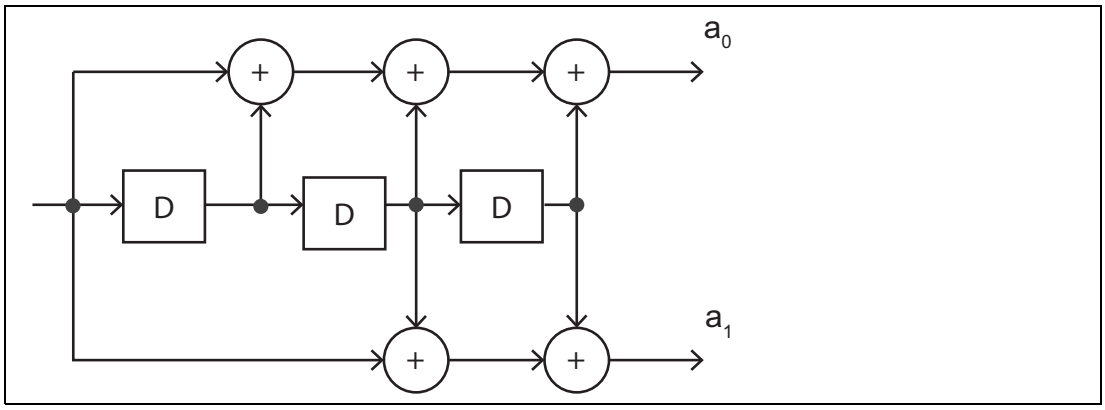

Figure 3.5: Convolutional Forward Error Correction Encoder

3.3.2 Pattern Mapper

The pattern mapper converts each bit from the convolutional FEC encoder into P symbols, where the value of P depends on the coding scheme in use, according to Table 3.1 (the entries in the table are in transmission order):

Input bit from the convolutional FEC encoder	Output sequence when P=1 (used by S=2)	Output sequence when P=4 (used by S=8)
0	0	0011
1	1	1100

Table 3.1: Pattern Mapper inputs and outputs

4 AIR INTERFACE PROTOCOL

The air interface protocol consists of the multiple access scheme, device discovery and link layer connection methods.

4.1 FRAME SPACE

4.1.1 Inter Frame Space

The time interval between two consecutive packets on the same channel index is called the Inter Frame Space. It is defined as the time from the end of the last bit of the previous packet to the start of the first bit of the subsequent packet. The Inter Frame Space is designated “T_IFS” and shall be 150 µs.

4.1.2 Minimum AUX Frame Space

The minimum time interval between a packet containing an AuxPtr and the auxiliary packet it indicates is called the Minimum AUX Frame Space. It is defined as the minimum time from the end of the last bit of the packet containing the AuxPtr to the start of the auxiliary packet. The Minimum AUX Frame Space is designated “T_MAFS” and shall be 300 µs.

Figure 4.1 illustrates an example where the Minimum AUX Frame Space applies.

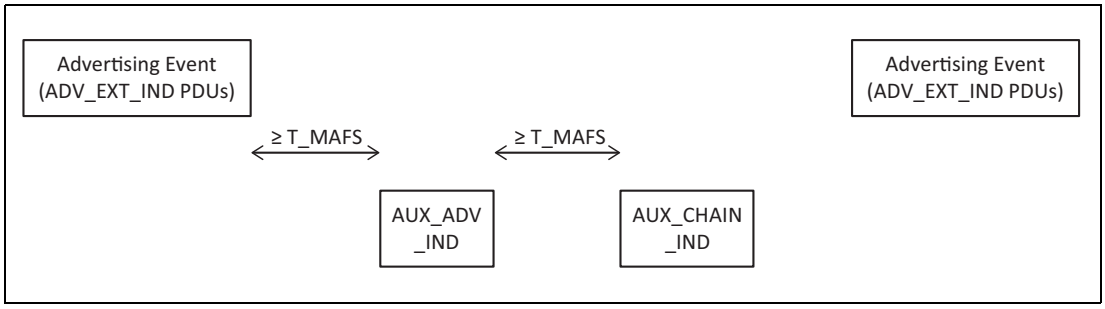

Figure 4.1: Example where the Minimum AUX Frame Space applies

4.2 TIMING REQUIREMENTS

The Link Layer shall use one of two possible clock accuracies. During a connection event or advertising event the Link Layer shall use the active clock accuracy; otherwise it shall use the sleep clock accuracy.

4.2.1 Active Clock Accuracy

The average timing of packet transmission during a connection event is determined using the active clock accuracy, with a drift less than or equal to ±50 ppm. All instantaneous timings shall not deviate more than 2 µs from the average timing.

Note: This means that the start of a packet shall be transmitted 150±2 µs after the end of the previous packet.

4.2.2 Sleep Clock Accuracy

The timing of advertising events (see Section 4.4.2.2) and connection events (see Section 4.5.7) is determined using the sleep clock accuracy, with a drift less than or equal to ±500 ppm.

The instantaneous timing of the anchor point (see Section 4.5.7) shall not deviate more than 16 µs from the average timing.

Note: This means that a 1 s connection interval with a total ±1000ppm sleep clock accuracy will give a window widening either side of the anchor point of 1ms plus 16us, assuming that the slave Controller was using its sleep clock for almost the complete connection interval.

4.2.3 Range Delay

Where two devices are more than a few meters apart the time taken for a signal to propagate between them will be significant compared with the Active Clock Accuracy defined in Section 4.2.1. When a device is listening for a packet that might be up to D meters away, it should listen for an extra 2D * 4 ns after the nominal latest time (e.g. T_IFS + 2 µs) that the packet would have been transmitted.

(1/c ~= 3.3 * refractive index ns/m, so 4 ns gives a conservative allowance.)

Figure 4.2 shows the range delays relative to a master packet transmission.

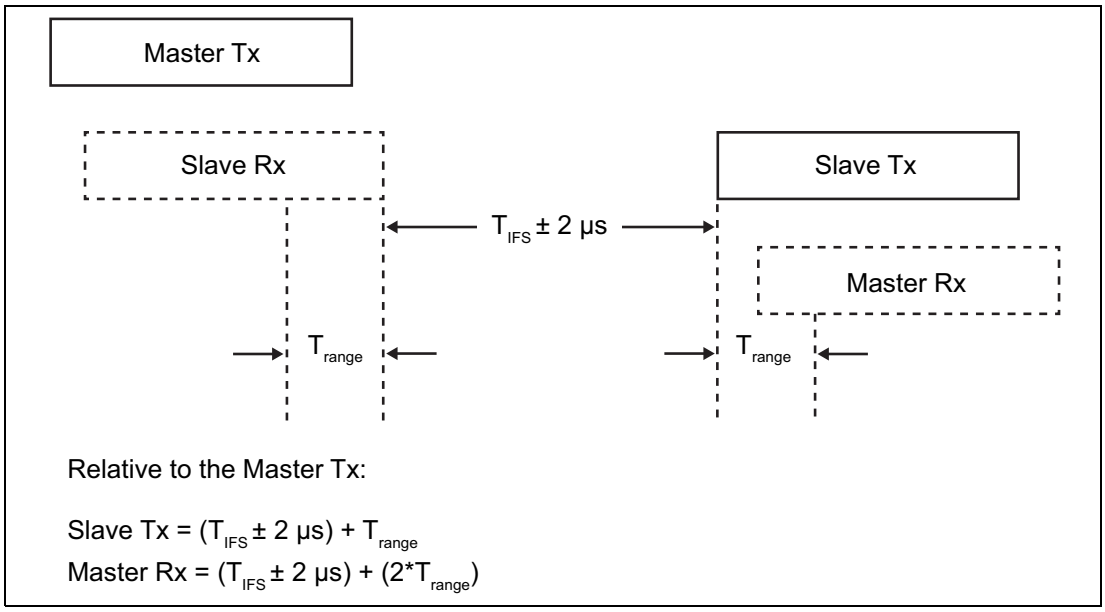

Figure 4.2: Range delays relative to a master packet transmission

4.3 LINK LAYER DEVICE FILTERING

The Link Layer may perform device filtering based on the device address of the peer device. Link Layer Device Filtering is used by the Link Layer to minimize the number of devices to which it responds.

A Link Layer shall support Link Layer Device Filtering unless it only supports non-connectable advertising.

The filter policies for the Advertising State, Scanning State and Initiating State are independent of each other. When the Link Layer is in the Advertising State, the advertising filter policy shall be used. When the Link Layer is in the Scanning State, the scanning filter policy shall be used. When the Link Layer is in the Initiating State, the initiator filter policy shall be used. If the Link Layer does not support the Advertising State, Scanning State, or Initiating State, the corresponding filter policy is not required to be supported.

4.3.1 White List

The set of devices that the Link Layer uses for device filtering is called the White List.

A White List contains a set of White List Records used for Link Layer Device Filtering. A White List Record contains both the device address and the device address type (public or random). There is also a special device address type "anonymous"; an entry with this type matches all advertisements sent with no address. All Link Layers supporting Link Layer Device Filtering shall support a White List capable of storing at least one White List Record.

On reset, the White List shall be empty.

The White List is configured by the Host and is used by the Link Layer to filter advertisers, scanners or initiators. This allows the Host to configure the Link Layer to act on a request without awakening the Host.

All the device filter policies shall use the same White List.

4.3.2 Advertising Filter Policy

The advertising filter policy determines how the advertiser’s Link Layer processes scan and/or connection requests.

When the Link Layer is using non-connectable and non-scannable directed advertising events, scannable directed advertising events, and connectable directed advertising events the advertising filter policy shall be ignored. Otherwise the Link Layer shall use one of the following advertising filter policy modes which are configured by the Host:

- The Link Layer shall process scan and connection requests only from devices in the White List.

- The Link Layer shall process scan and connection requests from all devices (i.e. the White List is not in use). This is the default on reset.
- The Link Layer shall process scan requests from all devices and shall only process connection requests from devices that are in the White List.
- The Link Layer shall process connection requests from all devices and shall only process scan requests from devices that are in the White List.

Only one advertising filter policy mode per advertising set shall be supported at a time.

4.3.3 Scanner Filter Policy

The scanner filter policy determines how the scanner's Link Layer processes advertising packets. The Link Layer shall use one of the following scanner filter policy modes which are configured by the Host:

- The Link Layer shall process advertising packets only from devices in the White List. A connectable directed advertising packet not containing the scanner's device address shall be ignored.
- The Link Layer shall process all advertising packets (i.e., the White List is not used). A connectable directed advertising packet not containing the scanner's device address shall be ignored. This is the default on reset.

If the Link Layer supports the Extended Scanner Filter policies, then the following modes shall also be supported:

- The Link Layer shall process advertising packets only from devices in the White List. A connectable directed advertising packet shall not be ignored if the TargetA is the scanner's device address or a resolvable private address.
- The Link Layer shall process all advertising packets (i.e., the White List is not used). A connectable directed advertising packet shall not be ignored if the TargetA is the scanner's device address or a resolvable private address.

Only one scanner filter policy mode shall be supported at a time.

4.3.4 Initiator Filter Policy

The initiator filter policy determines how an initiator's Link Layer processes advertising packets. The Link Layer shall use one of the following initiator filter policy modes which are configured by the Host:

- The Link Layer shall process connectable advertising packets from all devices in the White List.
- The Link Layer shall ignore the White List and process connectable advertising packets from a specific single device specified by the Host.

If the Link Layer receives a connectable directed advertising packet from an advertiser that is not contained in the White List or the single address specified by the Host, the connectable directed advertising packet shall be ignored.

Only one initiator filter policy mode shall be supported at a time.

4.4 NON-CONNECTED STATES

4.4.1 Standby State

The Standby State is the default state in the Link Layer. The Link Layer shall not send or receive packets in the Standby State. The Link Layer may leave the Standby State to enter the Advertising State, Scanning State or Initiator State.

4.4.2 Advertising State

The Link Layer shall enter the Advertising State when directed by the Host. When placed in the Advertising State, the Link Layer shall send advertising PDUs (see Section 2.3.1) in advertising events.

Each advertising event is composed of one or more advertising PDUs sent on used primary advertising channel indices. The advertising event shall be closed after one advertising PDU has been sent on each of the used primary advertising channel indices (see Section 4.4.2.1) or the advertiser may close an advertising event earlier to accommodate other functionality.

The time between two consecutive advertising events is defined in Section 4.4.2.2.

An advertising event can be one of the following types:

- a connectable and scannable undirected event
- a connectable undirected event
- a connectable directed event
- a non-connectable and non-scannable undirected event
- a non-connectable and non-scannable directed event
- a scannable undirected event
- a scannable directed event

The first PDU of each advertising event shall be transmitted in the used primary advertising channel with the lowest advertising channel index.

The advertising event type determines the allowable response PDUs. Table 4.1 specifies the allowable responses for each advertising event.

Connectable and scannable undirected, connectable undirected, and connectable directed events are collectively referred to as connectable events;

the remaining events (non-connectable and non-scannable undirected, non-connectable and non-scannable directed, scannable undirected, and scannable directed) are collectively referred to as non-connectable events. Connectable and scannable undirected, scannable undirected, and scannable directed events are collectively referred to as scannable events; the remaining events (non-connectable and non-scannable undirected, non-connectable and non-scannable directed, connectable undirected, and connectable directed) are collectively referred to as non-scannable events.

		Allowable response PDUs			
Advertising Event Type	**Type of PDU being responded to**	**SCAN_REQ[1]**	**CONNECT_IND[1]**	**AUX_SCAN_REQ**	**AUX_CONNECT_REQ**
Connectable and Scannable Undirected Event	ADV_IND	YES	YES	NO	NO
Connectable Undirected Event	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	NO	YES
Connectable Directed Event	ADV_DIRECT_IND	NO	YES[2]	NO	NO
	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	NO	YES[2]
Non-Connectable and Non-Scannable Undirected Event	ADV_NONCONN_IND	NO	NO	NO	NO
	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	NO	NO
Non-Connectable and Non-Scannable Directed Event	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	NO	NO
Scannable Undirected Event	ADV_SCAN_IND	YES	NO	NO	NO
	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	YES	NO
Scannable Directed Event	ADV_EXT_IND	NO	NO	NO	NO
	AUX_ADV_IND	NO	NO	YES[3]	NO

Table 4.1: Advertising event types, PDUs used and allowable response PDUs

1. Not permitted on the LE Coded PHY.
2. Initiators other than the correctly addressed initiator shall not respond.
3. Scanners other than the correctly addressed scanner shall not respond.

If the advertiser receives a PDU for the advertising event that is not explicitly allowed it shall be ignored. If no PDU is received or the received PDU was

ignored, the advertiser shall either send an advertising PDU on the next used primary advertising channel index or close the advertising event.

4.4.2.1 Advertising Channel Index Selection

Advertising events use three predefined primary advertising channels. Primary advertising channel indices are either used or unused.

For AUX_ADV_IND and AUX_CHAIN_IND PDUs, the secondary advertising channel index used in the Channel Index subfield of the AuxPtr field is implementation specific. It is recommended that sufficient channel diversity is used to avoid collisions.

Each periodic advertisement shall have a 16-bit event counter (*paEventCounter*). The initial value of this counter is implementation specific. The counter shall be incremented by one for each AUX_SYNC_IND PDU; the *paEventCounter* shall wrap from 0xFFFF to 0x0000. AUX_SYNC_IND PDUs shall use the Channel Selection Algorithm #2 (see Section 4.5.8.3) with this event counter.

The Link Layer shall use the primary and secondary advertising channel indices as specified by the Host, and the used primary and secondary advertising channel indices shall take effect when the Advertising State is entered. The Link Layer need not use all the secondary channels that the Host has marked as "unknown".

4.4.2.2 Advertising Events

Advertising events are defined as one or more advertising PDUs sent on the primary advertising channel beginning with the first used advertising channel index and ending with the last used advertising channel index. The advertising event can be closed early after a CONNECT_IND is received or when a SCAN_RSP is sent. The time between advertising events is the advertising interval.

Advertising packets sent on the secondary advertising channel are not part of the advertising event. Advertising events that use the ADV_EXT_IND PDU may also be part of an extended advertising event. All ADV_EXT_IND PDUs containing an AuxPtr field in the same advertising event shall point to the same AUX_ADV_IND packet.

4.4.2.2.1 Advertising Interval

For all undirected advertising events or connectable directed advertising events used in a low duty cycle mode, the time between the start of two consecutive advertising events (*T_advEvent*) for the same advertising data set (see Section 4.4.2.10) is computed as follows for each advertising event:

T_advEvent = advInterval + advDelay

The *advInterval* shall be an integer multiple of 0.625 ms in the range of 20 ms to 10,485.759375 s.

The *advDelay* is a pseudo-random value with a range of 0 ms to 10 ms generated by the Link Layer for each advertising event.

As illustrated in Figure 4.3, the advertising events are perturbed in time using the advDelay.

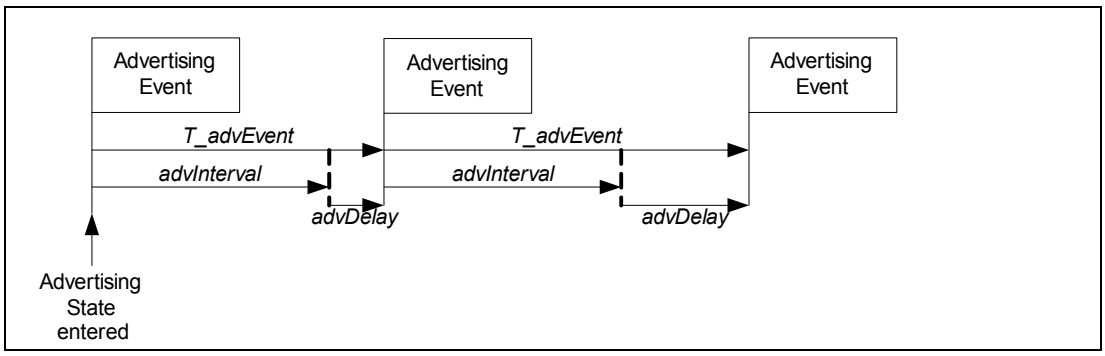

Figure 4.3: Advertising events perturbed in time using advDelay

4.4.2.2.2 Extended Advertising Event

An extended advertising event begins at the start of an advertising event and consists of the PDUs in that advertising event plus their subordinate sets. The extended advertising event ends with the last such PDU.

Multiple extended advertising events may overlap with each other. This can occur when ADV_EXT_IND PDUs containing an AuxPtr field in multiple advertising events point to the same AUX_ADV_IND packet, or when a different advertising event is interposed between the ADV_EXT_IND PDUs and the AUX_ADV_IND PDU.

T_advEvent, advInterval and advDelay have the same meaning as in Section 4.4.2.2.1.

Figure 4.4 illustrates an example of overlapping extended advertising events.

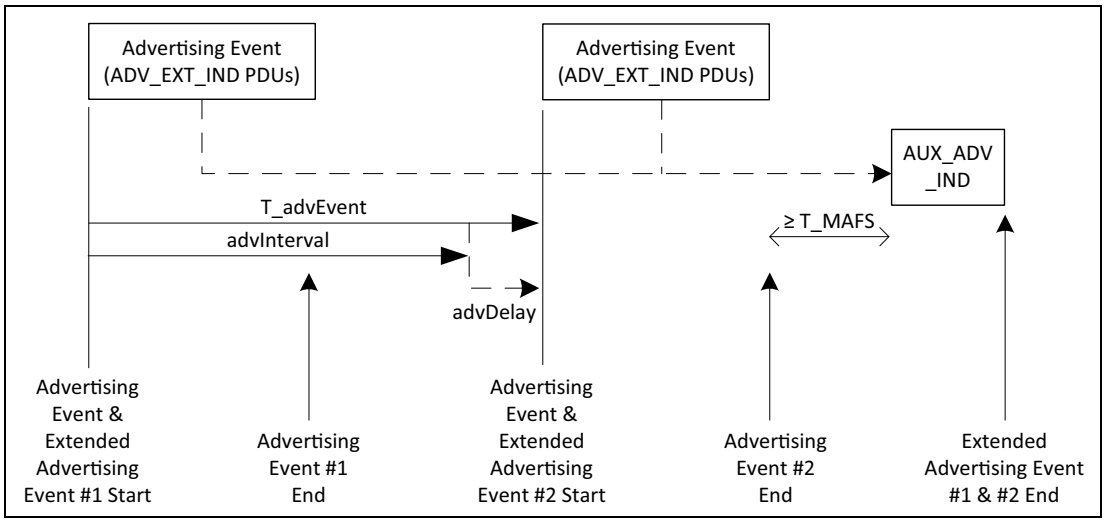

Figure 4.4: Example of overlapping extended advertising events

An auxiliary advertising segment starts with the first AUX_ADV_IND PDU in an extended advertising event and ends at the end of the extended advertising event (an auxiliary advertising segment can belong to more than one extended advertising event). Two auxiliary advertising segments for the same advertising set shall not overlap each other.

Figure 4.5 illustrates an example of auxiliary advertising segments belonging to multiple extended advertising events.

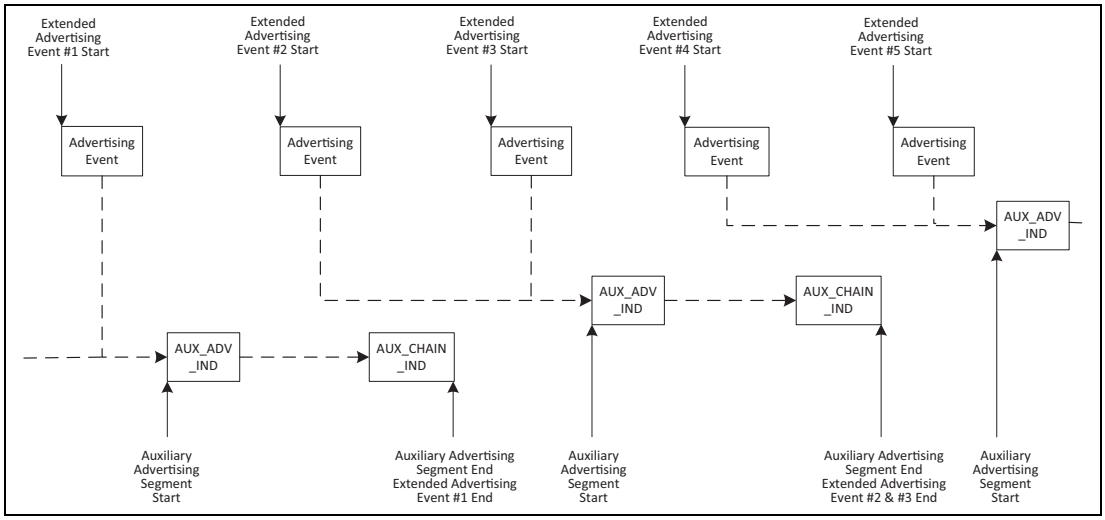

Figure 4.5: Example of Auxiliary Advertising Segments

An advertiser should not space PDUs within the auxiliary advertising set so that two of them would be within the same receive window. If an advertiser transmits a PDU with an AuxPtr field containing an offset of T milliseconds, then it should not start to transmit any other packet on the same RF channel as the auxiliary packet within 2.5*T microseconds of the start of auxiliary packet of the original PDU.

4.4.2.2.3 Periodic Advertising Events

The Periodic Advertising Interval is the interval between the start of two AUX_SYNC_IND PDUs from the same advertising set. The Periodic Advertising Interval shall be an integer multiple of 1.25 ms in the range of 7.5 ms to 81.91875 s.

A periodic advertising event consists of an AUX_SYNC_IND PDU and its subordinate set.

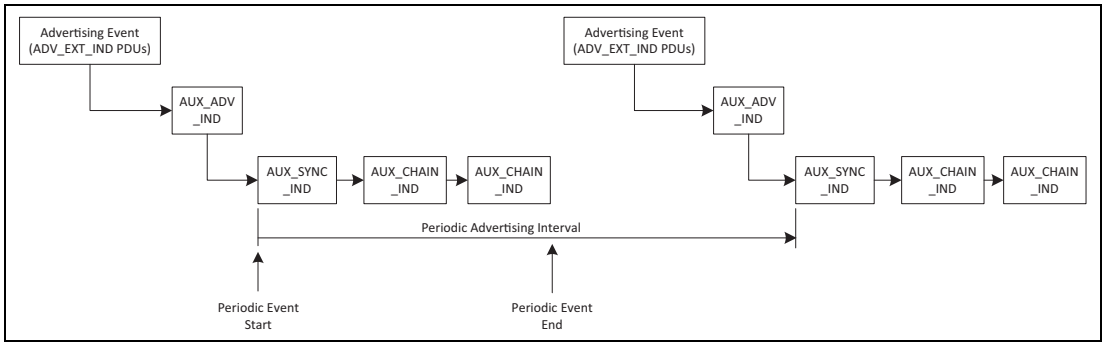

Figure 4.6: Example of Periodic Advertising Events from the same Advertising Set

Two periodic advertising events for the same advertising set shall not overlap each other. The periodic advertising interval shall not change while the periodic advertising is enabled.

4.4.2.3 Connectable and Scannable Undirected Event Type

When the connectable and scannable undirected advertising event type is used, advertising indications (ADV_IND PDUs) are sent by the Link Layer.

The connectable and scannable undirected advertising event type allows a scanner or initiator to respond with either a scan request or connect request. A scanner may send a scan request (SCAN_REQ PDU) to request additional information about the advertiser. An initiator may send a connect request (CONNECT_IND PDU) to request the Link Layer to enter the Connection State.

The Link Layer shall listen on the same primary advertising channel index for requests from scanners or initiators.

If the advertiser receives a SCAN_REQ PDU that contains its device address from a scanner allowed by the advertising filter policy, it shall reply with a SCAN_RSP PDU on the same primary advertising channel index. After the SCAN_RSP PDU is sent, or if the advertising filter policy prohibited processing the SCAN_REQ PDU, the advertiser shall either move to the next used primary advertising channel index to send another ADV_IND PDU, or close the advertising event.

If the advertiser receives a CONNECT_IND PDU that contains its device address, from an initiator allowed by the advertising filter policy, the Link Layer shall exit the Advertising State and transition to the Connection State in the Slave Role as defined in Section 4.5.5. If the advertising filter policy prohibited processing the received CONNECT_IND PDU, the advertiser shall either move to the next used primary advertising channel index to send another ADV_IND PDU, or close the advertising event.

The time between the beginning of two consecutive ADV_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

An illustration of an advertising event using all the primary advertising channel indices and in which no SCAN_REQ or CONNECT_IND PDUs are received is shown in Figure 4.7.

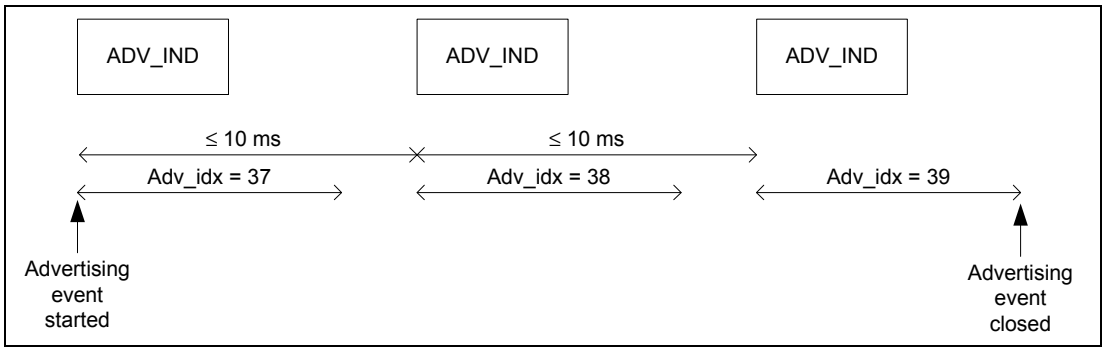

Figure 4.7: Connectable and scannable undirected advertising event with only advertising PDUs

Two illustrations of advertising events using all the primary advertising channel indices during which a SCAN_REQ PDU is received and a SCAN_RSP PDU is sent are shown in Figure 4.8 and in Figure 4.9.

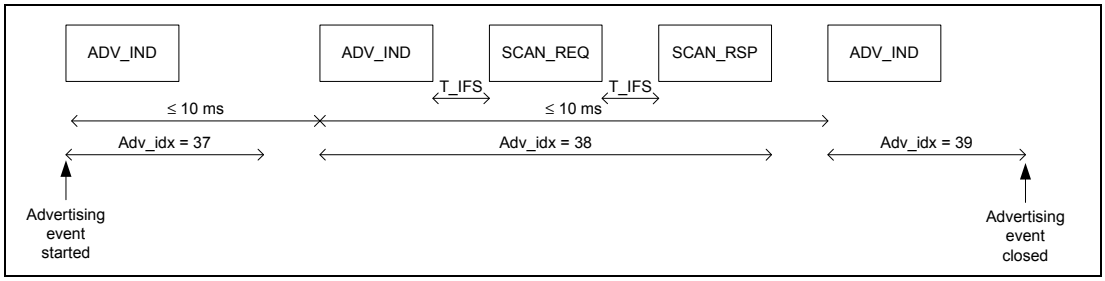

Figure 4.8: Connectable and scannable undirected advertising event with SCAN_REQ and SCAN_RSP PDUs in the middle of an advertising event

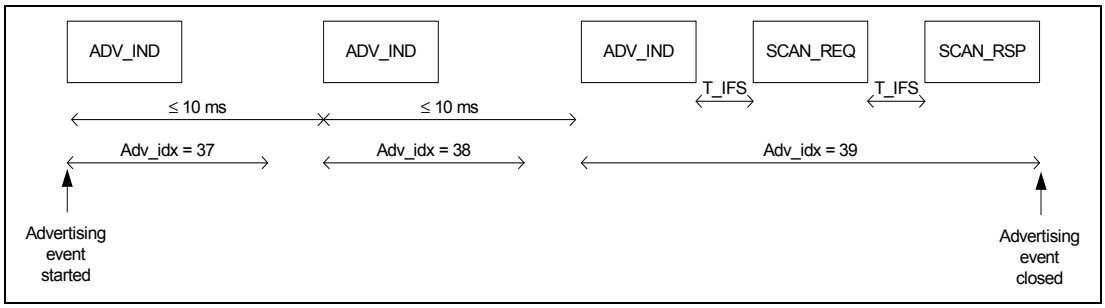

Figure 4.9: Connectable and scannable undirected advertising event with SCAN_REQ and SCAN_RSP PDUs at the end of an advertising event

Figure 4.10 illustrates an advertising event during which a CONNECT_IND PDU is received on the second primary advertising channel index.

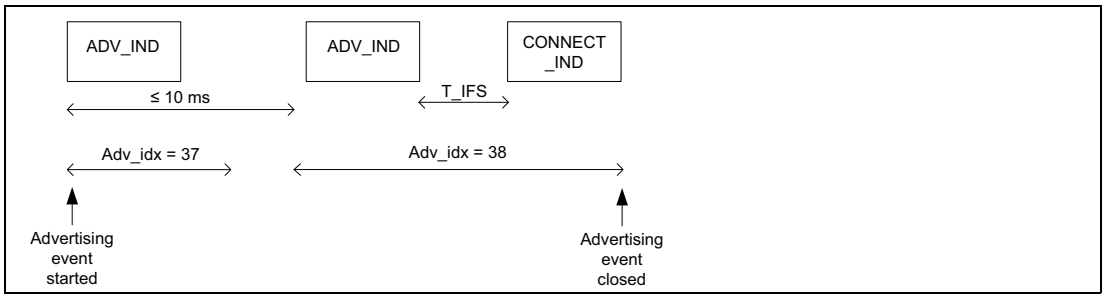

Figure 4.10: Connectable and scannable undirected advertising event when a CONNECT_IND PDU is received

If Link Layer Privacy has been enabled then the requirements in Section 6.2.1 shall also be followed.

4.4.2.4 Connectable Directed Event Type

When the connectable directed advertising event type is used, directed advertising indications are sent by the Link Layer.

The connectable directed advertising event type allows an initiator to respond so that both the advertiser and initiator will enter the Connection State.

The connectable directed advertising event type may use either the ADV_DIRECT_IND PDU (see Sections 4.4.2.4.1 to 4.4.2.4.3) or the ADV_EXT_IND PDU (see Section 4.4.2.4.4). A single connectable directed advertising event shall only use one of these two PDU types.

If Link Layer Privacy has been enabled then the requirements in Section 6.2.2 shall also be followed.

4.4.2.4.1 Connectable Directed Event Type using ADV_DIRECT_IND

This procedure shall not be used when the connectable directed event type is used on the LE Coded PHY.

The connectable directed advertising event type using ADV_DIRECT_IND allows an initiator to respond with a connect request on the primary advertising channel to establish a Link Layer connection.

The ADV_DIRECT_IND PDU contains both the initiator's device address and the advertiser's device address. Only the addressed initiator may initiate a Link Layer connection with the advertiser by sending a CONNECT_IND PDU to the advertiser.

After every ADV_DIRECT_IND PDU sent by the advertiser, the advertiser shall listen for CONNECT_IND PDUs on the same primary advertising channel index. Any SCAN_REQ PDUs received shall be ignored.

If the advertiser receives a CONNECT_IND PDU that contains its device address and the initiator device address is contained in the ADV_DIRECT_IND PDU, the Link Layer shall exit the Advertising State and transition to the Connection State in the Slave Role as defined in Section 4.5.5.

Otherwise, the advertiser shall either move to the next used primary advertising channel index to send another ADV_DIRECT_IND PDU, or close the advertising event.

Connectable directed advertising may be either used in a low duty cycle or high duty cycle mode; these are described in the next two sections. Low duty cycle connectable directed advertising is designed for cases where reconnection with a specific device is required, but time is not of the essence or it is not known if the central device is in range or not. High duty cycle connectable directed advertising is designed for cases in which fast Link Layer connection setup is essential (for example, a reconnection). Note that high duty cycle connectable directed advertising is a power and bandwidth intensive advertising scheme that should only be used when fast connection setup is required.

4.4.2.4.2 Low Duty Cycle Connectable Directed Advertising

In low duty cycle connectable directed advertising, the time between the start of two consecutive ADV_DIRECT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

An illustration of an advertising event using all primary advertising channel indices and in which no CONNECT_IND PDUs are received is shown in Figure 4.11.

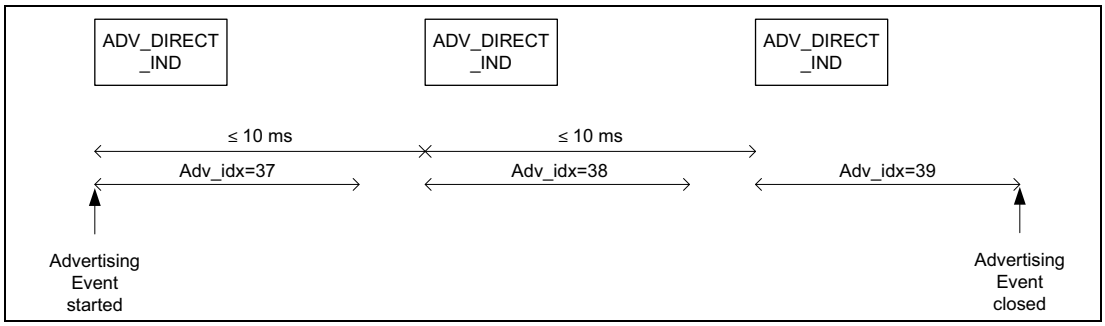

Figure 4.11: Low duty cycle connectable directed advertising event with only advertising PDUs

Figure 4.12 illustrates an advertising event using ADV_DIRECT_IND advertising PDUs during which a CONNECT_IND PDU is received on the second primary advertising channel index.

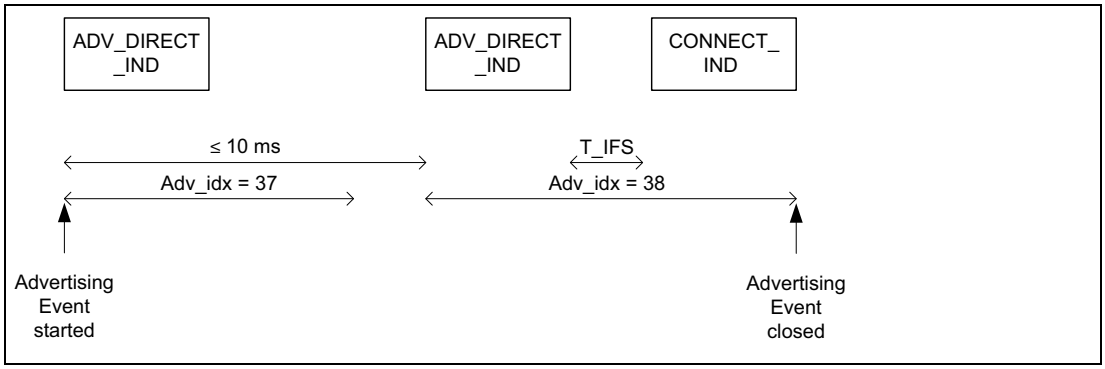

Figure 4.12: Low duty cycle connectable directed advertising event during which a CONNECT_IND PDU is received

4.4.2.4.3 High Duty Cycle Connectable Directed Advertising

In high duty cycle connectable directed advertising mode, the time between the start of two consecutive ADV_DIRECT_IND PDUs sent on the same advertising channel index shall be less than or equal to 3.75 ms.

The Link Layer shall exit the Advertising State no later than 1.28 s after the Advertising State was entered.

A sequence of five ADV_DIRECT_IND PDUs in two advertising events without CONNECT_IND PDUs is shown in Figure 4.13 for the case in which all the primary advertising channels are used.

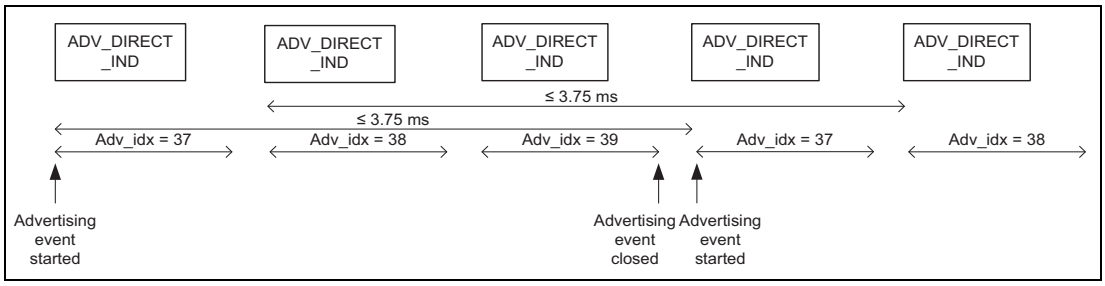

Figure 4.13: High duty cycle connectable directed advertising event with only advertising PDUs

4.4.2.4.4 Connectable Directed Event Type using ADV_EXT_IND

This procedure shall be used when the connectable directed event type is used on the LE Coded PHY.

The connectable directed advertising event type using ADV_EXT_IND allows an initiator to respond with a connect request on the secondary advertising channel to establish a Link Layer connection.

In the ADV_EXT_IND PDU, the AdvMode field shall be set to connectable, the ADI field shall be present, and the PDU shall not contain the AdvA and TargetA fields. The ADV_EXT_IND PDU's AuxPtr field shall point to an AUX_ADV_IND PDU with the AdvMode field set to connectable; the AdvA, TargetA, and ADI fields shall all be present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same.

After every AUX_ADV_IND PDU related to this event it sends, the advertiser shall listen for AUX_CONNECT_REQ PDUs on the same secondary advertising channel index. Any AUX_SCAN_REQ PDUs received shall be ignored.

If the advertiser receives an AUX_CONNECT_REQ PDU that contains its device address and the initiator's device address was contained in the AUX_ADV_IND PDU, it shall reply with an AUX_CONNECT_RSP PDU that contains those addresses on the same secondary advertising channel index. After the AUX_CONNECT_RSP PDU is sent the Link Layer shall exit the Advertising State and transition to the Connection State in the Slave Role as defined in Section 4.5.5. Any AUX_SCAN_REQ PDUs received on the secondary advertising channel shall be ignored.

The time between the start of two consecutive connectable directed ADV_EXT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

The channel index on the secondary channel, SAdv_idx, is contained in the AuxPtr field of the ADV_EXT_IND PDU.

Figure 4.14 shows an advertising event in which no AUX_CONNECT_REQ PDU is received.

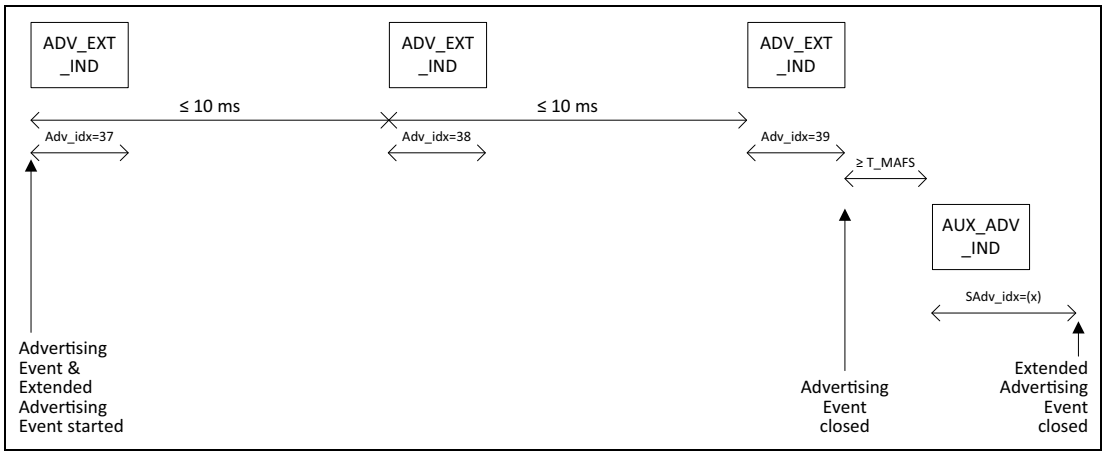

Figure 4.14: Connectable directed advertising event using the ADV_EXT_IND PDUs and AUX_ADV_IND PDU containing advertising data

Figure 4.15 illustrates an advertising event using connectable directed ADV_EXT_IND advertising PDUs during which an AUX_CONNECT_REQ PDU is received on the second secondary advertising channel index.

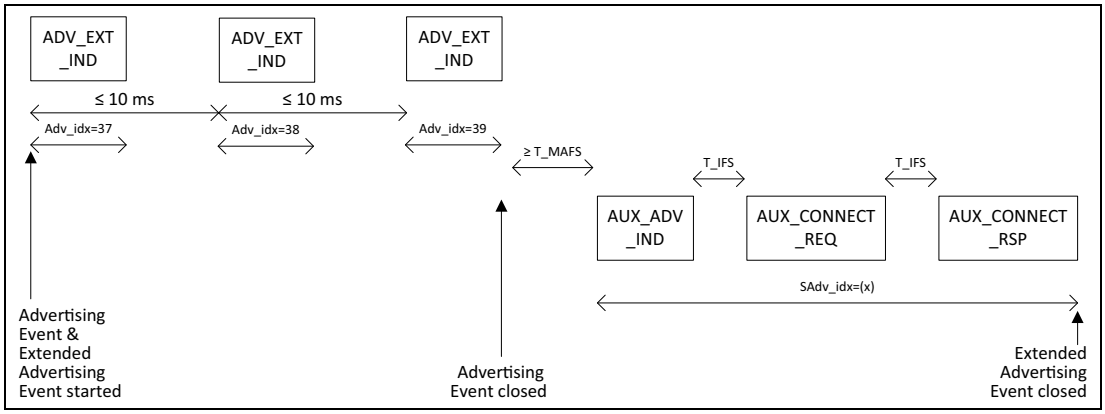

Figure 4.15: Connectable directed advertising event using ADV_EXT_IND PDUs and AUX_ADV_IND PDUs containing advertising data with an AUX_CONNECT_REQ PDU

4.4.2.5 Scannable Undirected Event Type

When the scannable undirected advertising event type is used, scannable undirected advertising indications (ADV_SCAN_IND or scannable undirected ADV_EXT_IND PDUs) are sent by the Link Layer.

A scannable undirected advertising event shall use either ADV_SCAN_IND or scannable undirected ADV_EXT_IND PDUs but not both.

If Link Layer Privacy has been enabled then the requirements in Section 6.2.3 shall also be followed.

4.4.2.5.1 Scannable Undirected Event Type using ADV_SCAN_IND

The scannable undirected event type allows a scanner to respond with a scan request (SCAN_REQ PDU) to request additional information about the advertiser.

The Link Layer shall listen on the same primary advertising channel index for requests from scanners. Any CONNECT_IND PDUs received shall be ignored.

If the advertiser receives a SCAN_REQ PDU that contains its device address from a scanner allowed by the advertising filter policy it shall reply with a SCAN_RSP PDU on the same advertising channel index. After the SCAN_RSP PDU is sent or if the advertising filter policy prohibited processing the SCAN_REQ PDU the advertiser shall either move to the next used primary advertising channel index to send another ADV_SCAN_IND PDU, or close the advertising event.

The time between the beginning of two consecutive ADV_SCAN_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

The structure of an advertising event in which no SCAN_REQ PDU was received is shown in Figure 4.16 for the case in which all the primary advertising channels are used.

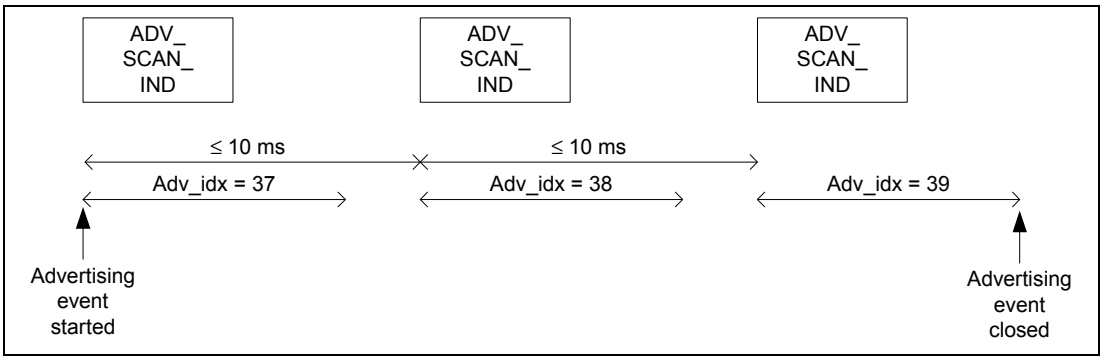

Figure 4.16: Scannable undirected advertising event with only advertising PDUs

Two example advertising events during which a SCAN_REQ PDU is received and a SCAN_RSP PDU is sent are shown in Figure 4.17 and in Figure 4.18 for the case in which all the primary advertising channels are used.

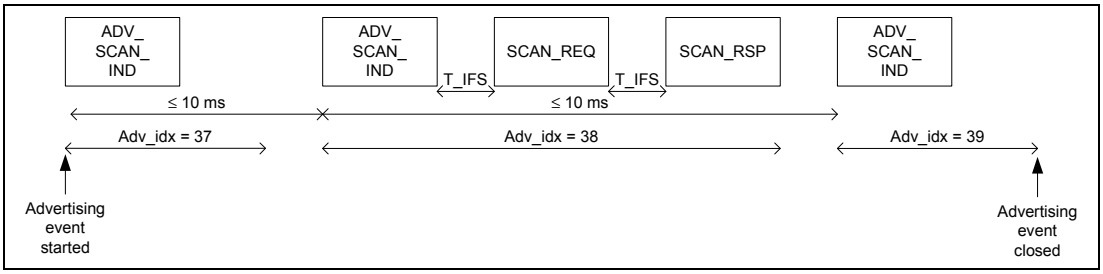

Figure 4.17: Scannable undirected advertising event with SCAN_REQ and SCAN_RSP PDUs in the middle of an advertising event

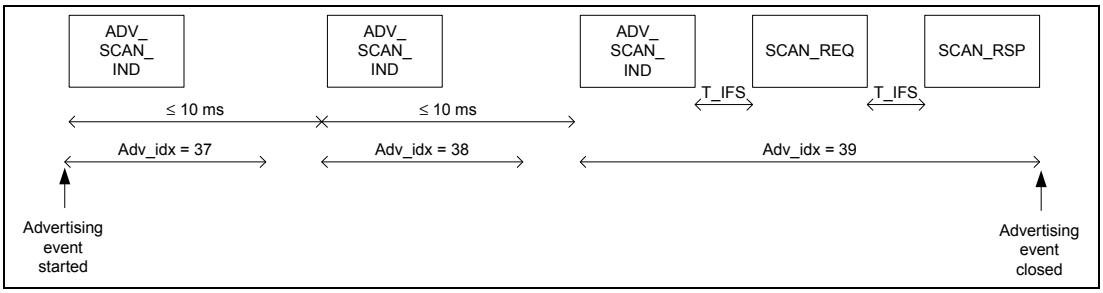

Figure 4.18: Scannable undirected advertising event with SCAN_REQ and SCAN_RSP PDUs at the end of an advertising event

4.4.2.5.2 Scannable Undirected Event Type using ADV_EXT_IND

The scannable undirected event type using the ADV_EXT_IND PDU allows any scanner to respond with a scan request to receive scan response data on the secondary advertising channel.

In the ADV_EXT_IND PDU the AdvMode field shall be set to scannable, the ADI field shall be present, and the PDU shall not contain the AdvA field. The ADV_EXT_IND PDU's AuxPtr field shall point to an AUX_ADV_IND PDU with the AdvMode field set to scannable; the AdvA and ADI fields shall be present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same. A scanner may send a scan request using the AUX_SCAN_REQ PDU on the same secondary advertising channel index as the received AUX_ADV_IND PDU pointed to by the ADV_EXT_IND PDU.

After every AUX_ADV_IND PDU sent by the advertiser, the advertiser shall listen for AUX_SCAN_REQ PDUs on the same secondary advertising channel index from scanners. Any AUX_CONNECT_REQ PDUs received shall be ignored.

If the advertiser receives an AUX_SCAN_REQ PDU that contains its device address from a scanner allowed by the advertising filter policy, it shall reply with an AUX_SCAN_RSP PDU on the same secondary advertising channel

index prior to the start of the next advertising event. After the AUX_SCAN_RSP PDU is sent, or if the advertising filter policy prohibits processing the AUX_SCAN_REQ PDU, the advertising event shall be closed. Any AUX_CONNECT_REQ PDUs on the secondary advertising channel shall be ignored.

The time between the beginning of two consecutive ADV_EXT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

Figure 4.19 shows an advertising event in which no AUX_SCAN_REQ PDU is received.

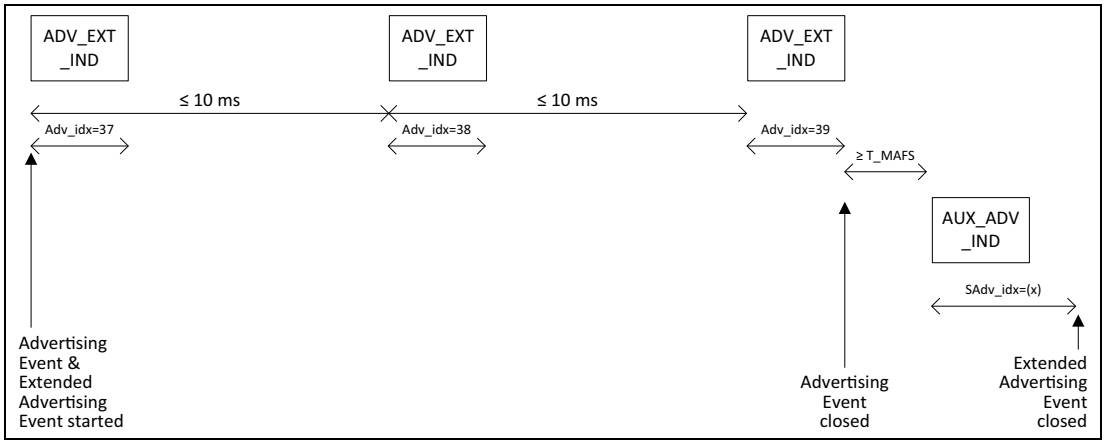

Figure 4.19: Scannable undirected advertising event using the ADV_EXT_IND PDUs and AUX_ADV_IND PDU containing advertising data

An example advertising event during which an AUX_SCAN_REQ PDU is received and an AUX_SCAN_RSP PDU is sent on the secondary advertising channel is shown in Figure 4.20.

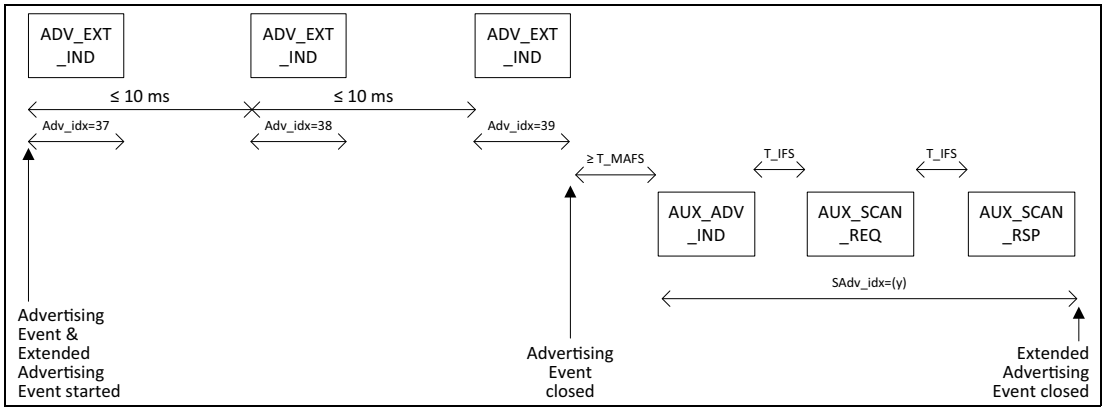

Figure 4.20: Scannable undirected advertising event with ADV_EXT_IND and AUX_ADV_IND PDUs with AUX_SCAN_REQ and AUX_SCAN_RSP PDUs on the secondary advertising channel

4.4.2.6 Non-Connectable and Non-Scannable Undirected Event Type

When the non-connectable and non-scannable undirected advertising event type is used, non-connectable and non-scannable undirected advertising indications (ADV_NONCONN_IND or non-connectable and non-scannable undirected ADV_EXT_IND PDUs) are sent by the Link Layer. The non-connectable and non-scannable undirected advertising event shall use either ADV_NONCONN_IND or non-connectable and non-scannable undirected ADV_EXT_IND PDUs but not both. The ADV_NONCONN_IND PDU shall not be used on the LE Coded PHY.

The non-connectable and non-scannable undirected event type allows a scanner to receive information from the advertiser. This information is contained either in the ADV_NONCONN_IND PDU or in an AUX_ADV_IND PDU pointed to by the AuxPtr field of the ADV_EXT_IND PDU.

The advertiser shall either move to the next used primary advertising channel index or close the advertising event after each ADV_NONCONN_IND or ADV_EXT_IND PDU that is sent. The Link Layer does not listen, and therefore cannot receive any requests from scanners or initiators.

The time between the beginning of two consecutive ADV_NONCONN_IND or ADV_EXT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

If an ADV_EXT_IND PDU is used, the AdvMode shall be set to non-connectable and non-scannable.

If an ADV_EXT_IND PDU is used, the Controller may use an auxiliary packet. It shall use an auxiliary packet if the advertisement includes ACAD or AdvData.

If an ADV_EXT_IND PDU is used without an auxiliary packet, it shall not contain an AuxPtr field and shall contain an AdvA field.

If an ADV_EXT_IND PDU is used with an auxiliary packet, it shall contain an AuxPtr field and an ADI field. Either the ADV_EXT_IND PDU or the AUX_ADV_IND that it points to, but not both, may contain the AdvA field (the AdvA field may be omitted entirely, in which case the advertising is anonymous). In the AUX_ADV_IND PDU the AdvMode shall be set to non-connectable and non-scannable and the ADI field shall be present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same. On the LE Coded PHY, the ADV_EXT_IND PDU shall not contain an AdvA field.

Note: The Controller can decide which PDU contains the AdvA field and should make this choice based on overall efficient use of the medium.

The TargetA field shall not be present in any PDU.

An illustration of a non-connectable and non-scannable undirected advertising event is shown in Figure 4.21 for the case in which all the primary advertising channels are used.

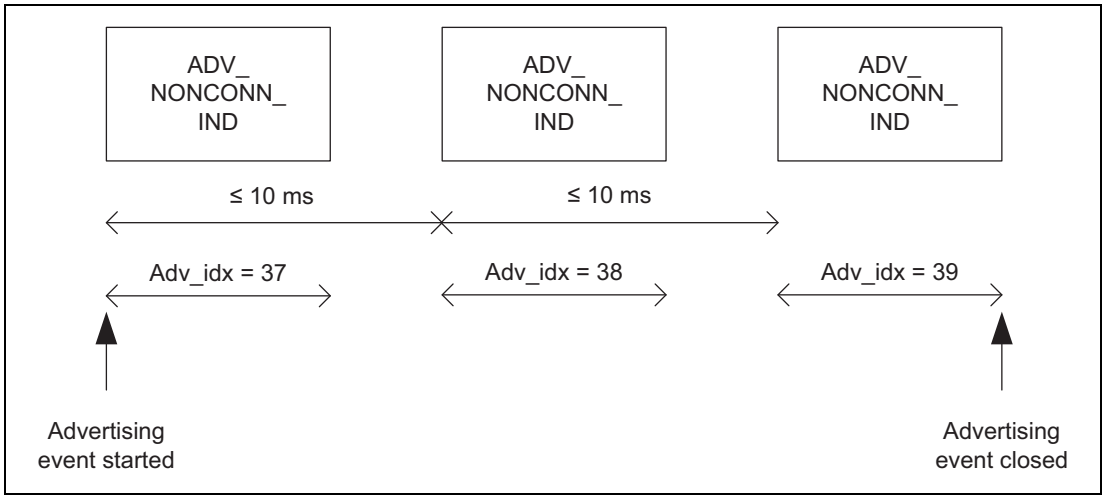

Figure 4.21: Non-connectable and non-scannable undirected advertising event using ADV_NONCONN_IND PDUs

Figure 4.22 shows an example of a non-connectable and non-scannable undirected ADV_EXT_IND PDU.

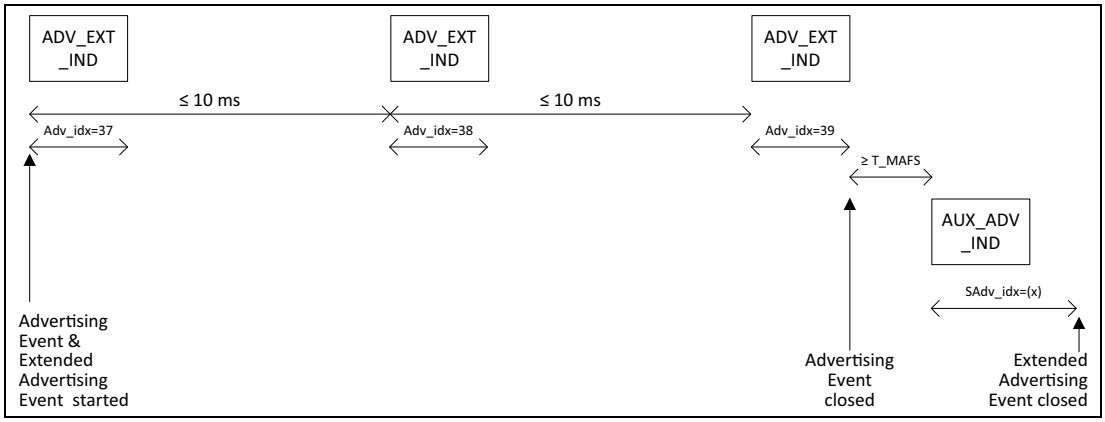

Figure 4.22: Non-connectable and non-scannable undirected advertising event using the ADV_EXT_IND PDU

Figure 4.23 shows an example of a non-connectable and non-scannable undirected ADV_EXT_IND PDU where the Host advertising data is fragmented using the AUX_CHAIN_IND PDU.

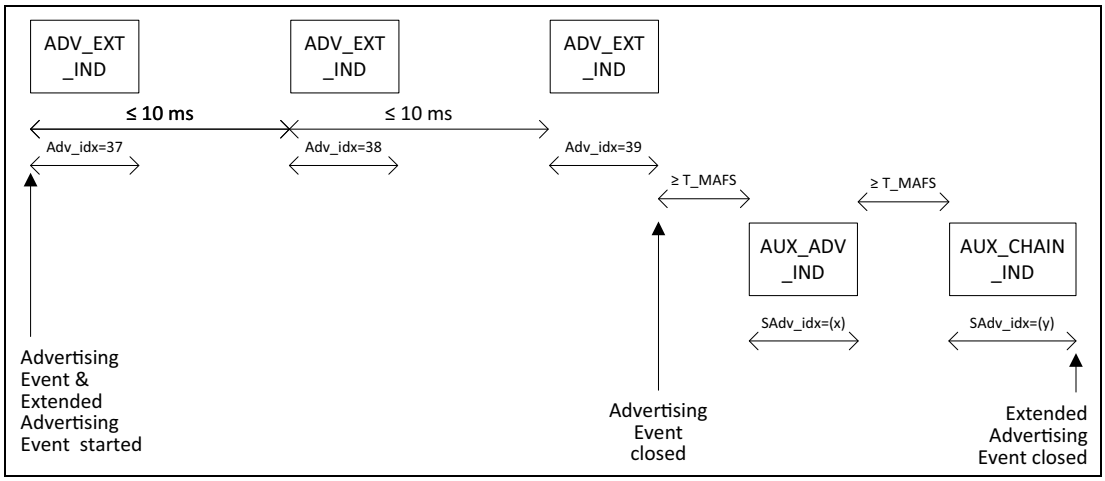

Figure 4.23: Non-connectable and non-scannable undirected advertising event using the ADV_EXT_IND PDU with fragmented Host advertising data

If Link Layer Privacy has been enabled then the requirements in Section 6.2.3 shall also be followed.

4.4.2.7 Connectable Undirected Event Type

The connectable undirected advertising event type using the ADV_EXT_IND PDU allows an initiator to respond with a connect request to establish a link layer connection on the secondary advertising channel.

In the ADV_EXT_IND PDU, the AdvMode field shall be set to connectable, the ADI field shall be present, and the PDU shall not contain the AdvA and TargetA fields. The AuxPtr field shall point to an AUX_ADV_IND PDU with the AdvMode field set to connectable and the AdvA and ADI fields present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same.

An initiator may send a connect request using the AUX_CONNECT_REQ PDU on the same secondary advertising channel as the AUX_ADV_IND PDU to request the Link Layer to enter the Connection State.

After every AUX_ADV_IND PDU sent related to this event by the advertiser, the advertiser shall listen for AUX_CONNECT_REQ PDUs on the same secondary advertising channel index. Any AUX_SCAN_REQ PDUs received shall be ignored.

If the advertiser receives an AUX_CONNECT_REQ PDU that contains its device address from an initiator allowed by the advertising filter policy it shall reply with an AUX_CONNECT_RSP PDU on the same secondary advertising channel index. After the AUX_CONNECT_RSP PDU is sent the Link Layer shall exit the Advertising State and transition to the Connection State in the Slave Role as defined in Section 4.5.5.

The time between the beginning of two consecutive ADV_EXT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

Figure 4.24 shows an advertising event in which no AUX_CONNECT_REQ PDU is received.

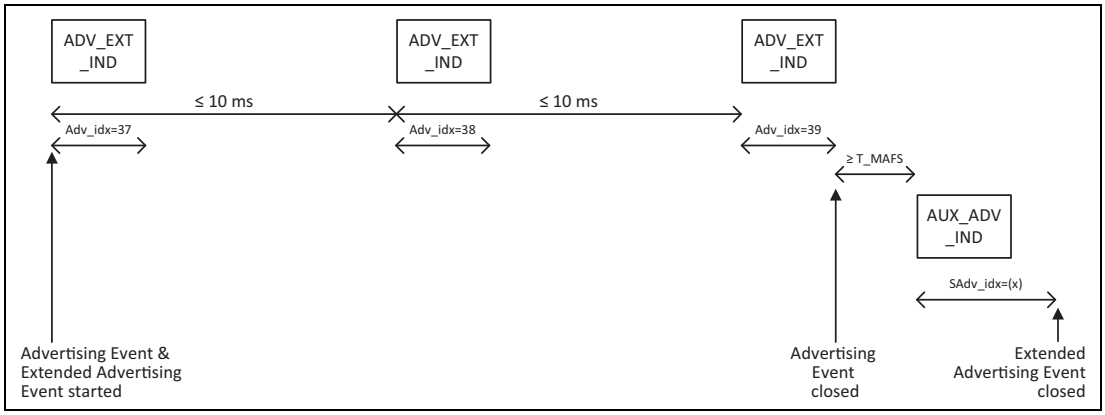

Figure 4.24: Connectable undirected advertising event using the ADV_EXT_IND PDUs and AUX_ADV_IND PDU containing advertising data

Figure 4.25 illustrates an advertising event during which an AUX_CONNECT_REQ PDU is received and an AUX_CONNECT_RSP PDU is sent on the secondary advertising channel index.

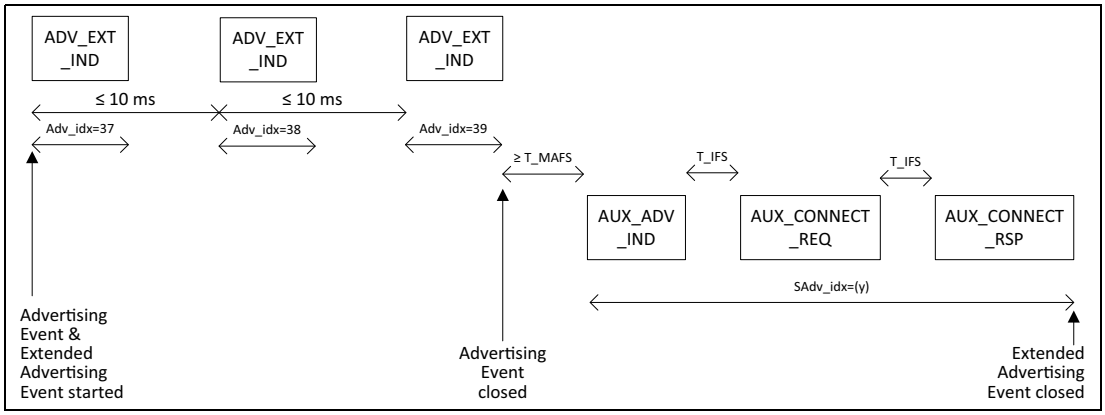

Figure 4.25: Connectable undirected advertising using ADV_EXT_IND PDUs when an AUX_CONNECT_REQ PDU is received

If Link Layer Privacy has been enabled then the requirements in Section 6.2.4 shall also be followed.

4.4.2.8 Scannable Directed Event Type

The scannable directed advertising event type using the ADV_EXT_IND PDU allows a specific scanner to respond with a scan request to receive scan response data on the secondary advertising channel.

In the ADV_EXT_IND PDU the AdvMode field shall be set to scannable, the ADI field shall be present, and the PDU shall not contain the AdvA and TargetA fields. The ADV_EXT_IND PDU's AuxPtr field shall point to an AUX_ADV_IND PDU with the AdvA, TargetA, and ADI fields all present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same.

After every AUX_ADV_IND PDU sent, the advertiser shall listen for an AUX_SCAN_REQ PDU on the same secondary advertising channel index from the targeted scanner.

If the advertiser receives an AUX_SCAN_REQ PDU that contains its device address and the scanner's device address is contained in the AUX_ADV_IND PDU, it shall reply with an AUX_SCAN_RSP PDU on the same secondary advertising channel index prior to the next advertising event. The AUX_SCAN_RSP PDU shall contain the scan response data. AUX_SCAN_REQ PDUs from any other scanner or any AUX_CONNECT_REQ PDUs received shall be ignored.

The time between the beginning of two consecutive ADV_EXT_IND PDUs within an advertising event shall be less than or equal to 10 ms. The advertising event shall be closed within the advertising interval.

See Section 4.4.2.5.2 for a description on how the AUX_SCAN_REQ packet is used in conjunction with the AUX_SCAN_RSP packets on the secondary advertising channel.

If Link Layer Privacy has been enabled then the requirements in Section 6.2.5 shall also be followed.

4.4.2.9 Non-Connectable and Non-Scannable Directed Event Type

The non-connectable and non-scannable directed advertising event type using the ADV_EXT_IND PDU allows an advertiser to send non-connectable and non-scannable directed ADV_EXT_IND PDUs on the primary advertising channel with any advertising data sent on the secondary advertising channel targeted for a specific scanner.

The AdvMode field in the ADV_EXT_IND PDU shall be set to non-connectable and non-scannable.

The Controller shall use an auxiliary packet if the advertisement includes ACAD or AdvData. Otherwise the Controller may use an auxiliary packet.

If an auxiliary packet is not used, the ADV_EXT_IND PDU shall not contain an AuxPtr field and shall contain the AdvA and TargetA fields.

If an auxiliary packet is used, the ADV_EXT_IND PDU shall contain an AuxPtr field and an ADI field. Either the ADV_EXT_IND PDU or the AUX_ADV_IND PDU it points to, but not both, may contain the AdvA field (the AdvA field may be omitted entirely, in which case the advertising is anonymous). The TargetA field shall be present in either PDU but not both. In the AUX_ADV_IND PDU the AdvMode shall be set to non-connectable and non-scannable and the ADI field shall be present. The ADI fields in the ADV_EXT_IND PDU and the AUX_ADV_IND PDU shall be the same. On the LE Coded PHY, the ADV_EXT_IND PDU shall not contain an AdvA or TargetA field.

Note: The Host cannot specify which PDU contains the AdvA or TargetA field; the Controller should make this choice based on overall efficient use of the medium.

The Link Layer does not listen, and therefore cannot receive any requests from scanners or initiators.

If Link Layer Privacy has been enabled then the requirements in Section 6.2.5 shall also be followed.

4.4.2.10 Advertising Data Sets

The advertiser's Host may instruct the Link Layer to interleave advertising events. Advertising data belonging together is called an advertising data set. The Link Layer may support multiple advertising data sets, with each set having different advertising parameters such as advertising PDU type, advertising interval, and PHY.

When advertising with the ADV_EXT_IND, AUX_ADV_IND, or AUX_SYNC_IND PDUs, the advertising data set is identified by the Advertising SID subfield of the ADI field. The Link Layer shall set the Advertising SID subfield as directed by the Host.

The scanner may filter advertisements based on the Advertising SID.

The advertising events for each Advertising Data Set are considered a separate instance of the Advertising State and each have their own Advertising Interval (see Section 4.4.2.2.1).

Figure 4.26 illustrates an example of advertising using multiple advertising sets.

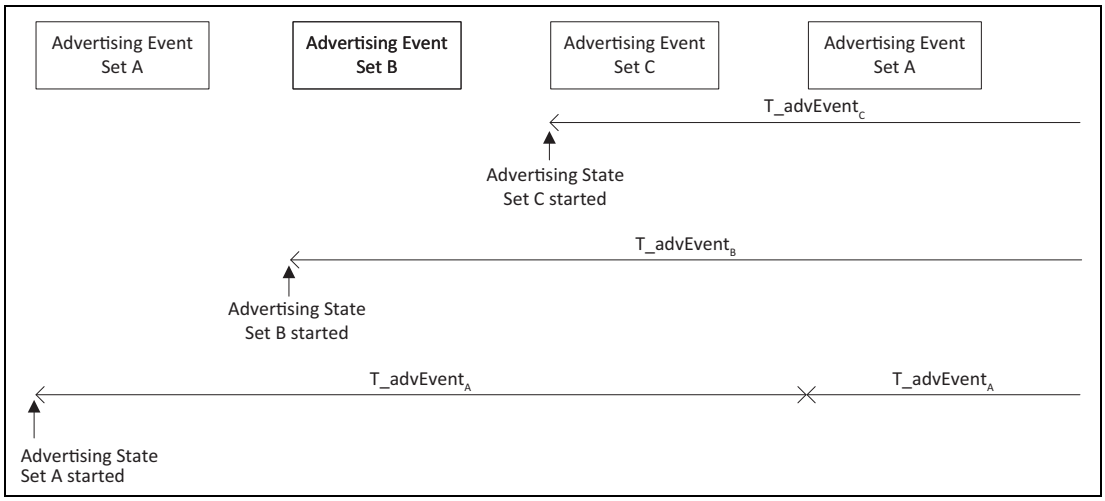

Figure 4.26: Multiple advertising data sets example

On reset, all advertising sets are destroyed.

When an advertising set is created that includes advertising data, the Controller shall guarantee that the set can contain at least 31 octets of advertising data. The guarantee shall no longer apply after the Host first specifies advertising data for that set or creates another advertising set.

When an advertising set is created that is scannable, the Controller shall guarantee that the set can contain at least 31 octets of scan response data. The guarantee shall no longer apply if the set is made non-scannable or after the Host first specifies scan response data for that set or creates another advertising set.

4.4.2.11 Using AdvDataInfo (ADI)

The AdvDataInfo (ADI) field is used to identify advertising sets and duplicate AdvData in either the AUX_ADV_IND or AUX_SCAN_RSP PDUs. For scannable advertising events using the ADV_EXT_IND PDU, AdvData is not permitted in the AUX_ADV_IND PDU so the ADI only refers to the AdvData contained in the AUX_SCAN_RSP PDU.

The Advertising DID for a given advertising set shall be initialized with a randomly chosen value. Whenever the Host provides new advertising data or scan response data for a given advertising set (whether it is the same as the previous data or not), the Advertising DID shall be updated. The new value shall be a randomly chosen value that is not the same as the previously used value.

Note: Choosing Advertising DID field values randomly reduces the possibility of PDUs from different advertisers containing the same ADI field value.

4.4.2.12 Periodic Advertising

When advertising data is required to be sent regularly at a fixed interval, periodic advertising is used. Periodic advertising consists of advertisements sent at a fixed interval with the advertisement data changing from time to time.

When periodic advertising takes place, the advertiser shall send AUX_SYNC_IND PDUs at regular intervals (the periodic advertising interval - see Section 4.4.2.2.3), which are described in the SyncInfo field of AUX_ADV_IND PDUs. The Periodic Advertising is identified by the AdvDataInfo field of ADV_EXT_IND PDUs that point to AUX_ADV_IND PDUs containing the SyncInfo field. The AUX_SYNC_IND PDUs and the PDUs that point to them shall always be sent on the same PHY. The PHY used shall not change while the periodic advertising is enabled. Advertising pointing to a periodic advertisement shall not be anonymous. Each time that periodic advertising is enabled, the Controller shall transmit at least one AUX_IND_PDU pointing to the first AUX_SYNC_IND PDU of that periodic advertising; after this, there is no requirement whether or when to transmit advertising PDUs pointing to the periodic advertisements.

The Host may send periodic advertising data to the Link Layer. This advertising data is placed by the Link Layer in the periodic AUX_SYNC_IND PDUs and their subordinate sets. The Link Layer shall repeat the last advertising data sent by the Host until it receives new advertising data. The AUX_SYNC_IND PDUs are continuously sent out until the Host directs the Link Layer to terminate the periodic advertising.

When an advertising set is first configured for periodic advertising, the Controller shall guarantee that the set can contain at least 31 octets of advertising data or else shall not allow periodic advertising on that advertising set. The guarantee shall no longer apply after the Host first specifies periodic advertising data for that set or creates another advertising set.

Figure 4.27 illustrates an example of periodic advertising.

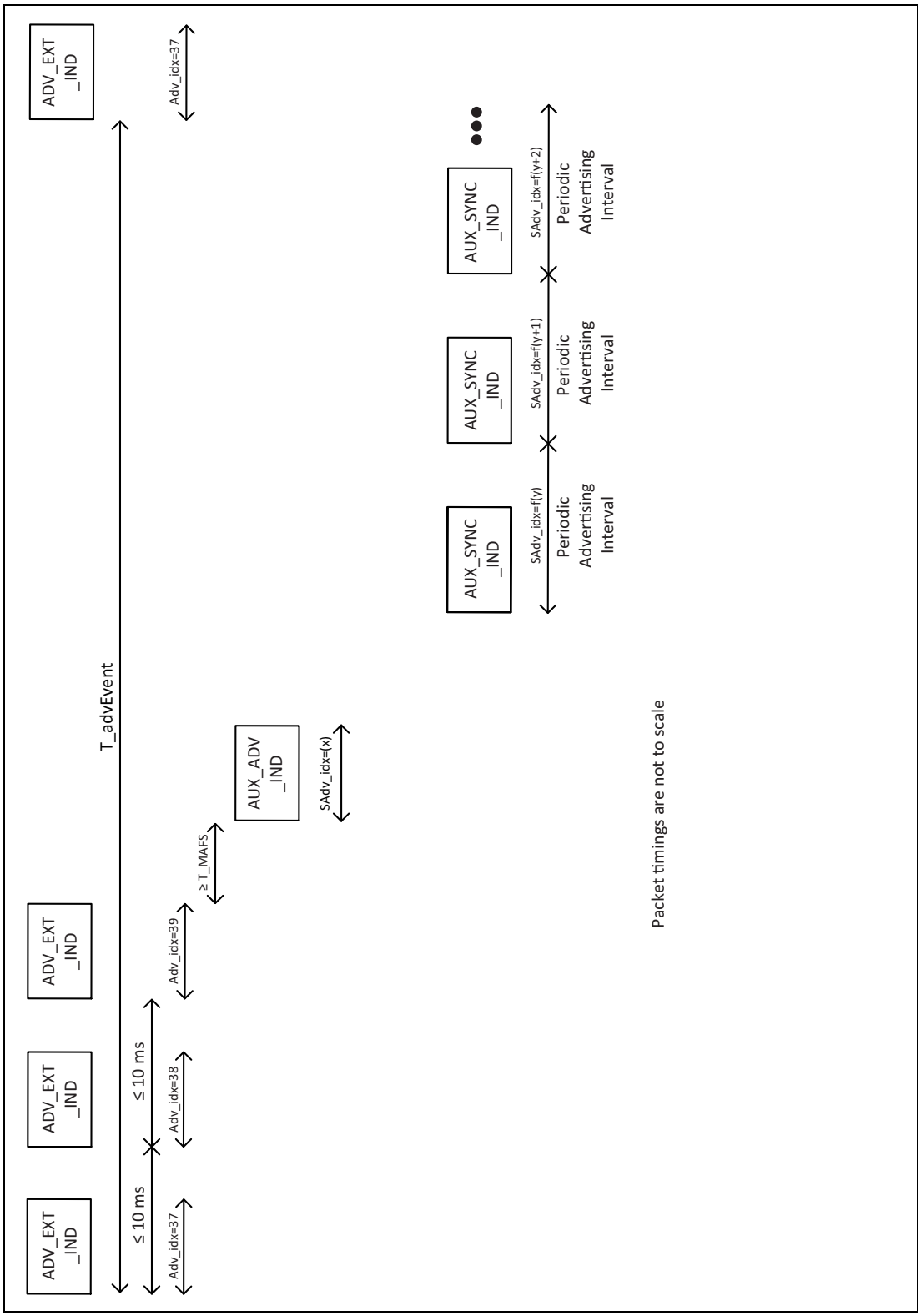

Figure 4.27: Example of periodic advertising

4.4.3 Scanning State

The Link Layer shall enter the Scanning State when directed by the Host. When scanning, the Link Layer shall listen on the primary advertising channel. There are two types of scanning, determined by the Host: passive and active.

There are no strict timing or advertising channel index selection rules for scanning.

During scanning, the Link Layer listens on a primary advertising channel index for the duration of the scan window, *scanWindow*. The scan interval, *scanInterval*, is defined as the interval between the start of two consecutive scan windows.

The Link Layer should listen for the complete *scanWindow* every *scanInterval* as directed by the Host unless there is a scheduling conflict. In each scan window, the Link Layer should scan on a different primary advertising channel index. The Link Layer shall use all the primary advertising channel indices.

The *scanWindow* and *scanInterval* parameters shall be less than 40.96 s. The *scanWindow* shall be less than or equal to the *scanInterval*. If the *scanWindow* and the *scanInterval* parameters are set to the same value by the Host, the Link Layer should scan continuously.

The scanner filter policy shall apply when receiving an advertising PDU or scanning PDU when scanning.

On receiving a PDU with the AuxPtr field present, the scanner should also listen for the auxiliary PDU it points to (provided that it supports the PHY specified in the AuxPtr field).

When a scanner receives ADV_EXT_IND PDUs that contain an AuxPtr field, it may either always listen for the auxiliary packet or may sometimes skip listening. In the latter case, the following requirements shall apply.

For each Advertising SID value received:

- The Controller shall keep a cache of one or more recent Advertising DID values used by each advertising device (for this purpose, all anonymous advertising is treated as being from a single device different to all real devices) and shall update them whenever a PDU containing an ADI field is received. The Controller may delete any cache entry at any time. The Controller should delete the cache entry relating to an ADV_EXT_IND PDU if it fails to receive that PDU's entire subordinate set.
- The Controller may only skip listening for the auxiliary packet if the cache has an entry specifying the Advertising DID value in the ADI field being used by a device; if the ADV_EXT_IND PDU contains an AdvA field, the entry shall be for that device. Otherwise, the Controller shall not skip listening for the auxiliary packet. The Controller should sometimes listen for the

AUX_ADV_IND PDU in case another advertiser has started using the same Advertising DID value.

If Link Layer Privacy has been enabled then the requirements in Section 6.3 shall also be followed.

4.4.3.1 Passive Scanning

When in passive scanning, the Link Layer will only receive packets; it shall not send any packets.

4.4.3.2 Active Scanning

In active scanning, the Link Layer shall listen for advertising PDUs and, depending on the advertising PDU type, it may request an advertiser to send additional information.

After entering the Scanning State, if the Link Layer receives a scannable PDU (i.e. an ADV_IND, ADV_SCAN_IND, or scannable AUX_ADV_IND PDU) from an advertiser allowed by the scanner filter policy, it shall respond with a scan request PDU and then listen for the scan response PDU. It shall continue to respond to the same advertiser until it has successfully received the scan response PDU. It may then either respond to or ignore subsequent scannable PDUs from the same advertiser. It should ignore them if either they are legacy PDUs or if the Advertising DID field has not changed since the last advertisement from the same advertiser with the same Advertising SID field; it should not ignore them otherwise.

The Link Layer shall only send a SCAN_REQ PDU to an advertiser from which an ADV_IND PDU or ADV_SCAN_IND PDU is received. The Link Layer shall only send an AUX_SCAN_REQ PDU to an advertiser from which a scannable AUX_ADV_IND is received. The Link Layer shall ignore a scannable ADV_EXT_IND or AUX_ADV_IND PDU if the TargetA field is present and it does not match the Link Layer's device address.

The scanner shall run a backoff procedure to minimize collisions of scan request PDUs from multiple scanners. An example of such a procedure is given in the following paragraphs.

The backoff procedure uses two parameters, *backoffCount* and *upperLimit,* to restrict the number of scan request PDUs sent when collisions occur on scan response PDUs. Upon entering the Scanning State, the *upperLimit* and *backoffCount* are set to one.

On every received ADV_IND, ADV_SCAN_IND, or scannable AUX_ADV_IND PDU that is allowed by the scanner filter policy and for which a scan request PDU is to be sent, the *backoffCount* is decremented by one until it reaches the value of zero. The scan request PDU is only sent when *backoffCount* becomes zero.

After sending a scan request PDU the Link Layer listens for a scan response PDU from that advertiser. If the scan response PDU was not received from that advertiser, it is considered a failure; otherwise it is considered a success. On every two consecutive failures, the *upperLimit* is doubled until it reaches the value of 256. On every two consecutive successes, the *upperLimit* is halved until it reaches the value of one. After success or failure of receiving the scan response PDU, the Link Layer sets *backoffCount* to a new pseudo-random integer between one and *upperLimit* inclusive.

If a device uses a different backoff algorithm it shall share the medium responsibly.

Two illustrations of advertising events using all the advertising channel indices during which a SCAN_REQ PDU is received and a SCAN_RSP PDU is sent are shown in Figure 4.8 and in Figure 4.9.

4.4.3.3 Advertising Data Sets

The ADV_EXT_IND PDU may contain an ADI field. When the ADI field is present, it can be used to identify advertisement data that belong to the same set. This is specified in the Advertising SID subfield in the ADI. The Advertising SID is set by the Host of the advertiser.

4.4.3.4 Periodic Advertisements

For an AUX_ADV_IND PDU where the SyncInfo field is present the scanner should, when instructed by the Host, listen for the AUX_SYNC_IND PDU specified in the SyncInfo field. The scanner should then continue to listen for AUX_SYNC_IND PDUs on the secondary advertising channel indices specified in Section 4.4.2.1.

Because of sleep clock accuracies (see Section 4.2.2), the scanner should perform the window widening specified in Section 4.5.7, with connection events replaced by packets containing AUX_SYNC_IND PDUs.

If the Sync Packet Offset of the SyncInfo is zero, the scanner should listen for a subsequent advertisement to be able to locate the periodic advertisement.

The Link Layer on the scanner shall report the advertising data received in the periodic advertisements to the Host.

A scanner shall not attempt to synchronize to a periodic advertising set that it is already synchronized to.

4.4.3.5 Advertising Reports

For each non-duplicate advertising or scan response PDU from an advertiser, the Link Layer shall send an advertising report to the Host. However, if the Controller receives an ADV_EXT_IND PDU with an AuxPtr field, it shall delay

the report until after the corresponding AUX_ADV_IND PDU has been received and the report shall combine the information in the PDUs; if the Controller does not listen for or does not receive the AUX_ADV_IND PDU, no report shall be generated. The advertising report shall contain at least the advertiser's device address and advertising data or scan response data if present. The Host may request that duplicate advertising reports are filtered.

Where a received ADV_EXT_IND PDU contains an ADI field, a duplicate advertising report is an advertising report for the same device address where the previous report that contained an ADI value with the same Advertising SID also had the same Advertising DID. For this purpose, all anonymous advertising is treated as being from a single device different to all non-anonymous devices.

Where the ADV_EXT_IND PDU does not contain an ADI field or a legacy PDU was received, a duplicate advertising report is an advertising report for the same device address while the Link Layer stays in the Scanning State.

In either case the actual data may change; advertising data or scan response data is not considered significant when determining duplicate advertising reports.

4.4.4 Initiating State

The Link Layer shall enter the Initiating State when directed by the Host. When initiating, the Link Layer shall listen on the primary advertising channel.

There are no strict timing or advertising channel index selection rules for initiators.

During initiating, the Link Layer listens on a primary advertising channel index for the duration of the scan window, *scanWindow*. The scan interval, *scanInterval*, is defined as the interval between the start of two consecutive scan windows.

The Link Layer should listen for the complete *scanWindow* every *scanInterval* as directed by the Host unless there is a scheduling conflict. In each scan window, the Link Layer should listen on a different primary advertising channel index. The Link Layer shall use all the primary advertising channel indices.

The *scanWindow* and *scanInterval* parameters shall be less than or equal to 40.96 s. The *scanWindow* shall be less than or equal to the *scanInterval*. If the *scanWindow* and the *scanInterval* parameters are set to the same value by the Host, the Link Layer should listen continuously.

Connection indications or requests in response to a connectable advertisement shall be sent on either the primary or secondary advertising channel depending on which advertising PDU contains an AdvA field. The following sub-sections describe the two procedures.

If Link Layer Privacy has been enabled then the requirements in Section 6.4 shall also be followed.

4.4.4.1 Connect Requests on the Primary Advertising Channel

This procedure shall not be used when establishing a connection on the LE Coded PHY.

If an ADV_IND PDU is received that is allowed by the initiator filter policy, the initiator shall send a CONNECT_IND PDU to the advertiser. If an ADV_DIRECT_IND PDU containing the initiator's Link Layer device address and allowed by the initiator filter policy is received, the initiator shall send a CONNECT_IND PDU to the advertiser; otherwise it shall be ignored.

After sending the CONNECT_IND PDU, the Link Layer shall exit the Initiating State, and shall transition to the Connection State in the Master Role as defined in Section 4.5.4.

4.4.4.2 Connect Requests on the Secondary Advertising Channel

This procedure shall be used when establishing a connection on the LE Coded PHY.

If a connectable ADV_EXT_IND PDU is received, the initiator shall listen for the connectable AUX_ADV_IND on the secondary advertising channel. If a connectable undirected AUX_ADV_IND PDU, or a connectable directed AUX_ADV_IND PDU containing the initiator's Link Layer device address, is received and is allowed by the initiator filter policy, the initiator shall send an AUX_CONNECT_REQ PDU to the advertiser; otherwise, it shall be ignored.

After sending the AUX_CONNECT_REQ PDU, the initiator shall wait for the advertiser to send an AUX_CONNECT_RSP PDU. Once an AUX_CONNECT_RSP PDU is received, the Link Layer shall exit the Initiating State and shall transition to the Connection State in the Master Role as defined in Section 4.5.4. If the initiator does not receive an AUX_CONNECT_RSP PDU from the advertiser, it shall use the back-off algorithm described for SCAN_REQ in Section 4.4.3.2 before responding to the next connectable AUX_ADV_IND PDU.

4.5 CONNECTION STATE

The Link Layer enters the Connection State when an initiator sends a CONNECT_IND PDU on the primary advertising channel to an advertiser, an advertiser receives a CONNECT_IND PDU on the primary advertising channel from an initiator, an advertiser sends an AUX_CONNECT_RSP PDU on the secondary advertising channel to an initiator, or an initiator receives an AUX_CONNECT_RSP PDU on the secondary advertising channel from an advertiser.

After entering the Connection State, the connection is considered to be created. The connection is not considered to be established at this point. A connection is only considered to be established once a data channel packet has been received from the peer device. The only difference between a connection that is created and a connection that is established is the Link Layer connection supervision timeout value that is used (see Section 4.5.2).

If the connection is first created using the CONNECT_IND PDU on the primary advertising channel, it shall use the LE 1M PHY in both directions. If the connection is first created on the secondary channel using the AUX_CONNECT_REQ and AUX_CONNECT_RSP PDUs, it shall use the same PHY in both directions as was used for the AUX_CONNECT_REQ and AUX_CONNECT RSP PDU. Either PHY may be changed subsequently using the PHY Update Procedure (Section 5.1.10). When the LE Coded PHY is in use, the coding of each packet is determined by the CI field as defined in Section 2.2.3 and may be different in each direction and in adjacent packets in a given direction.

When two devices are in a connection, the two devices act in different roles. A Link Layer in the Master Role is called a master. A Link Layer in the Slave Role is called a slave. The master controls the timing of a connection event. A connection event is a point of synchronization between the master and the slave. There shall be only one connection, whether or not established, between two LE device addresses. An initiator shall not send a connection request to an advertiser it is already connected to.

If an advertiser receives a connection request from an initiator it is already connected to, it shall ignore that request.

If the initiator sent a CONNECT_IND PDU in response to an ADV_IND or ADV_DIRECT_IND PDU and either or both device's PDU had the ChSel field set to 0, then Channel Selection Algorithm #1 (see Section 4.5.8.2) shall be used on the connection. Otherwise, Channel Selection Algorithm #2 (see Section 4.5.8.3) shall be used.

4.5.1 Connection Events

The Link Layer in the Connection State shall only transmit Data Channel PDUs (see Section 2.4) in connection events. The master and slave shall determine the data channel index for each connection event as defined in Section 4.5.8. The same data channel index shall be used for all packets in the connection event. Each connection event contains at least one packet sent by the master.

During a connection event, the master and slave alternate sending and receiving packets. The connection event is considered open while both devices continue to send packets. The slave shall always send a packet if it receives a packet from the master regardless of a valid CRC match, except after multiple consecutive invalid CRC matches as specified in Section 4.5.6. The master may send a packet if it receives a packet from the slave regardless of a valid CRC match. The Length field of the Header is assumed to be correct even if the CRC match was invalid. If the master does not receive a packet from the slave, the master shall close the connection event.

The connection event can be closed by either device, as defined in Section 4.5.6.

The timing of connection events is determined by two parameters: connection interval (*connInterval*), and slave latency (*connSlaveLatency*).

The start of a connection event is called an anchor point. At the anchor point, a master shall start to transmit a Data Channel PDU to the slave. The start of connection events are spaced regularly with an interval of *connInterval* and shall not overlap. The master shall ensure that a connection event closes at least T_IFS before the anchor point of the next connection event. The slave listens for the packet sent by its master at the anchor point.

The *connInterval* shall be a multiple of 1.25 ms in the range of 7.5 ms to 4.0 s. The *connInterval* is set by the Initiator's Link Layer in the CONNECT_IND PDU from the range given by the Host.

Slave latency allows a slave to use a reduced number of connection events. The *connSlaveLatency* parameter defines the number of consecutive connection events that the slave device is not required to listen for the master. The value of *connSlaveLatency* should not cause a Supervision Timeout (see Section 4.5.2). *connSlaveLatency* shall be an integer in the range of 0 to ((*connSupervisionTimeout* / (*connInterval**2)) - 1). The *connSlaveLatency* parameter shall also be less than 500. When *connSlaveLatency* is set to zero the slave device shall listen at every anchor point. If the slave does not receive a packet from the master after applying slave latency, it should listen at each anchor point and not apply slave latency until it receives a packet from the master.

Both the master and the slave shall have a 16-bit connection event counter (*connEventCounter*), containing the value connEventCount, for each Link Layer connection. It shall be set to zero on the first connection event sent by

the master of the connection. It shall be incremented by one for each new connection event sent by the master; the *connEventCounter* shall wrap from 0xFFFF to 0x0000. This counter is used to synchronize Link Layer control procedures.

The slave shall increment *connEventCounter* for all connection events, even if it is not listening to the master due to slave latency in those events.

4.5.2 Supervision Timeout

A connection can break down due to various reasons such as a device moving out of range, encountering severe interference or a power failure condition. Since this may happen without any prior warning, it is important for both the master and the slave to monitor the status of the connection.

To be able to detect link loss, both the master and the slave shall use a Link Layer connection supervision timer, $T_{LLconnSupervision}$. Upon reception of a valid packet, the timer shall be reset.

If the Link Layer connection supervision timer reaches 6 * *connInterval* before the connection is established (see Section 4.5), the connection shall be considered lost. This enables fast termination of connections that fail to establish.

Connection supervision timeout (*connSupervisionTimeout*) is a parameter that defines the maximum time between two received Data Packet PDUs before the connection is considered lost. The *connSupervisionTimeout* shall be a multiple of 10 ms in the range of 100 ms to 32.0 s and it shall be larger than (1 + *connSlaveLatency*) * *connInterval* * *2*.

If at any time in Connection State after the connection has been established and the timer reaches the *connSupervisionTimeout* value, the connection shall be considered lost.

If the connection is considered lost, the Link Layer shall not send any further packets. The Link Layer exits the Connection State and shall transition to the Standby State. The Host shall be notified of the loss of connection.

4.5.3 Connection Event Transmit Window

To allow the master to efficiently schedule connection events for multiple connections or other activities it may be involved in, the master has the flexibility to schedule the first connection event anchor point at a time of its choosing. The CONNECT_IND and AUX_CONNECT_REQ PDUs include parameters to determine when the master can send its first packet in the Connection State to set the anchor point and when the slave must listen.

The CONNECT_IND and AUX_CONNECT_REQ PDUs include three parameters used to determine the transmit window. The transmit window starts

at *transmitWindowDelay* + *transmitWindowOffset* after the end of the packet containing the CONNECT_IND PDU or AUX_CONNECT_REQ PDU, and the *transmitWindowSize* parameter shall define the size of the transmit window. The *connInterval* is used in the calculation of the maximum offset and size of the transmit window. The *transmitWindowOffset* and *transmitWindowSize* parameters are determined by the Link Layer.

The *transmitWindowOffset* shall be a multiple of 1.25 ms in the range of 0 ms to *connInterval*. The *transmitWindowSize* shall be a multiple of 1.25 ms in the range of 1.25 ms to the lesser of 10 ms and (*connInterval* - 1.25 ms).

Therefore the start of the first packet will be no earlier than *transmitWindowDelay* + *transmitWindowOffset* and no later than *transmitWindowDelay* + *transmitWindowOffset* + *transmitWindowSize* after the end of the packet containing the CONNECT_IND PDU or AUX_CONNECT_REQ PDU.

The value of *transmitWindowDelay* shall be 1.25 ms when a CONNECT_IND PDU is used, 2.5 ms when an AUX_CONNECT_REQ PDU is used on an LE Uncoded PHY, and 3.75 ms when an AUX_CONNECT_REQ PDU is used on the LE Coded PHY.

4.5.4 Connection Setup – Master Role

After the initiator sends a CONNECT_IND PDU on the primary advertising channel or receives an AUX_CONNECT_RSP PDU on the secondary advertising channel, the Link Layer is in the Connection State in the Master Role. The master shall reset the Link Layer connection supervision timer $T_{LLconnSupervision}$. The Link Layer shall notify the Host that the connection has been created. The first connection event shall use the data channel index as specified in Section 1.4.1.

The master shall start to send the first packet within the transmit window as defined in Section 4.5.3. It is permitted that the master's first packet can extend beyond the transmit window.

The first packet sent in the Connection State by the master determines the anchor point for the first connection event, and therefore the timings of all future connection events in this connection.

The second connection event anchor point shall be *connInterval* after the first connection event anchor point. All the normal connection event transmission rules specified in Section 4.5.1 shall apply.

Two examples of the LL connection setup procedure timing from the master's perspective are shown in Figure 4.28 and in Figure 4.29.

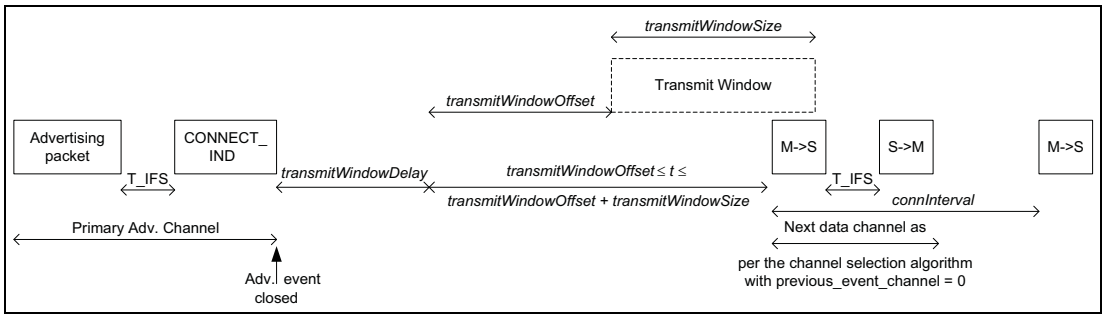

Figure 4.28: Master's view of LL connection setup with CONNECT_IND

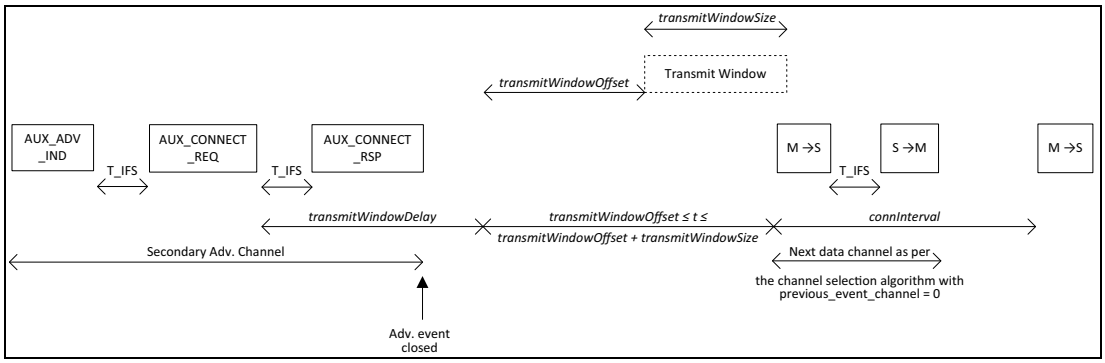

Figure 4.29: Master's view of LL connection setup with AUX_CONNECT_REQ

4.5.5 Connection Setup – Slave Role

After the advertiser receives a CONNECT_IND PDU on the primary advertising channel or sends an AUX_CONNECT_RSP PDU on the secondary advertising channel, the Link Layer is in the Connection State in the Slave Role. The slave shall reset the Link Layer connection supervision timer $T_{LLconnSupervision}$. The Link Layer shall notify the Host that the connection has been created. The first connection event shall use the data channel index as specified in Section 1.4.1.

The slave shall start to listen for the first packet within the transmit window as defined in Section 4.5.3. It is permitted that the master's first packet can extend beyond the transmit window, and therefore the slave must take this into account.

The first packet received, regardless of a valid CRC match (i.e., only the access code matches), in the Connection State by the slave determines the anchor point for the first connection event, and therefore the timings of all future connection events in this connection.

If a packet is not received in a transmit window, the slave shall attempt to receive a packet in a subsequent transmit window. A subsequent transmit window shall start *connInterval* after the start of the previous transmit window, with the same *transmitWindowSize*. The data channel index shall be the next

data channel index as specified in Section 1.4.1. The *connEventCount* shall also be incremented by one.

Two examples of the procedure from the slave's perspective are shown in Figure 4.30 and in Figure 4.31. In these examples the slave fails to receive any part of the first packet (i.e., connEventCount = 0) from the master and acquires anchor point timing from the second packet (i.e., connEventCount = 1).

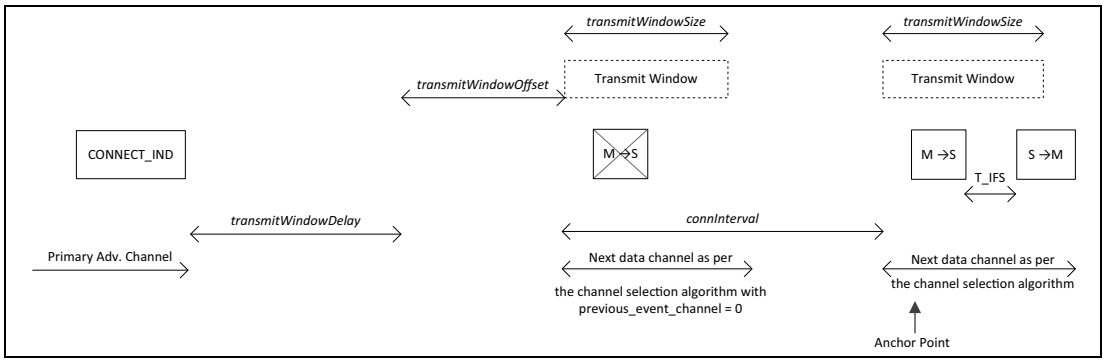

Figure 4.30: Slave closing LL connection setup in the second LL connection event with CONNECT_IND

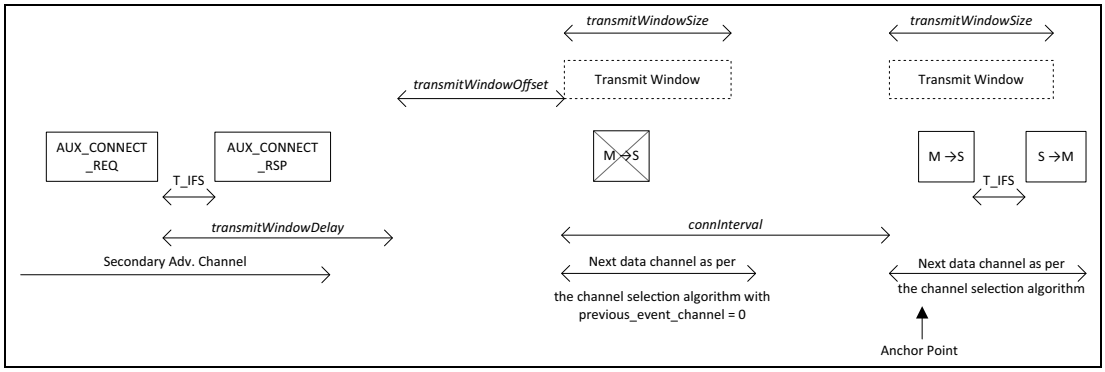

Figure 4.31: Slave closing LL connection setup in the second LL connection event with AUX_CONNECT_REQ

The slave shall be active in every connection event until it receives a packet from the master with the NESN set to one. From then on it may use slave latency as defined in Section 4.5.1.

4.5.6 Closing Connection Events

The MD bit of the Header of the Data Channel PDU is used to indicate that the device has more data to send. If neither device has set the MD bit in their packets, the packet from the slave closes the connection event. If either or both of the devices have set the MD bit, the master may continue the connection event by sending another packet, and the slave should listen after sending its packet. If a packet is not received from the slave by the master, the master will

close the connection event. If a packet is not received from the master by the slave, the slave will close the connection event.

Two consecutive packets received with an invalid CRC match within a connection event shall close the event.

MD bit usage is summarized in Table 4.2.

		Master	
		MD = 0	**MD = 1**
Slave	**MD = 0**	Master shall not send another packet, closing the connection event. Slave does not need to listen after sending its packet.	Master may continue the connection event. Slave should listen after sending its packet.
	MD = 1	Master may continue the connection event. Slave should listen after sending its packet.	Master may continue the connection event. Slave should listen after sending its packet.

Table 4.2: MD bit usage for closing connection events

4.5.7 Window Widening

Because of sleep clock accuracies (see Section 4.2.2), there is uncertainty in the slave of the exact timing of the master's anchor point. Therefore the slave is required to re-synchronize to the master's anchor point at each connection event where it listens for the master. If the slave receives a packet from the master regardless of a CRC match, the slave shall update its anchor point.

The slave calculates the time when the master will send the first packet of a connection event (*slaveExpectedAnchorPoint*) taking clock jittering, and in the case of connection setup or a connection parameter update the transmit window, into account. In the absence of more accurate information about the master's clock, the slave shall also use the master's sleep clock accuracy (*masterSCA*) from the CONNECT_IND PDU, together with its own sleep clock accuracy (*slaveSCA*) and the anchor point of the last connection event where it received a packet from the master (*timeSinceLastAnchor*) to calculate the time it needs to receive.

The increase in listening time is called the window widening. Assuming the clock inaccuracies are purely given in parts per million (ppm), it is calculated as follows:

windowWidening = ((*masterSCA* + *slaveSCA*) / 1000000) * *timeSinceLastAnchor*

If the slave has more accurate information about the master's clock, it may select a smaller value for *windowWidening*.

During connection setup or during a connection parameter update, the slave should listen for *windowWidening* before the start of the transmit window and until *windowWidening* after the end of the transmit window for the master's anchor point.

At each subsequent connection event, the slave should listen for *windowWidening* before the start of the *slaveExpectedAnchorPoint* and until *windowWidening* after *slaveExpectedAnchorPoint* for the master's anchor point.

The *windowWidening* shall be smaller than ((*connInterval*/2) - T_IFS us). If the *windowWidening* reaches ((*connInterval*/2) - T_IFS us) in magnitude, the connection should be considered lost.

4.5.8 Data Channel Index Selection

4.5.8.1 Channel Classification

The master's Link Layer shall classify data channels into *used channels* (used for the connection) and *unused channels* (not used for the connection). This is called the channel map. The minimum number of used channels shall be 2.

The Host may provide channel classification information to the Link Layer. The Link Layer may use the information provided by the Host. The slave shall receive the channel map from the master in the CONNECT_IND PDU. If the master changes the channel map it shall notify the slave as specified in Section 5.1.2.

4.5.8.2 Channel Selection Algorithm #1

Channel Selection Algorithm #1 only supports channel selection for connection events.

Channel Selection Algorithm #1 consists of two stages: calculation of the unmapped channel index followed by mapping this index to a data channel index from the set of *used channels*.

The *unmappedChannel* and *lastUnmappedChannel* are the unmapped channel indices of two consecutive connection events. The *unmappedChannel* is the unmapped channel index for the current connection event. The *lastUnmappedChannel* is the unmapped channel index of the previous connection event. The *lastUnmappedChannel* shall be 0 for the first connection event of a connection.

At the start of a connection event, *unmappedChannel* shall be calculated using the following basic algorithm:

unmappedChannel = (*lastUnmappedChannel* + *hopIncrement*) mod 37

When a connection event closes, the *lastUnmappedChannel* shall be set to the value of the *unmappedChannel*.

If the *unmappedChannel* is a *used channel* according to the channel map, Channel Selection Algorithm #1 shall use the *unmappedChannel* as the data channel index for the connection event.

If the *unmappedChannel* is an *unused channel* according to the channel map, the *unmappedChannel* shall be re-mapped to one of the used channels in the channel map using the following algorithm:

remappingIndex = *unmappedChannel* mod *numUsedChannels*

where *numUsedChannels* is the number of used channels in the channel map.

A remapping table is built that contains all the *used channels* in ascending order, indexed from zero. The *remappingIndex* is then used to select the data channel index for the connection event from the remapping table.

The complete procedure is as shown in Figure 4.32.

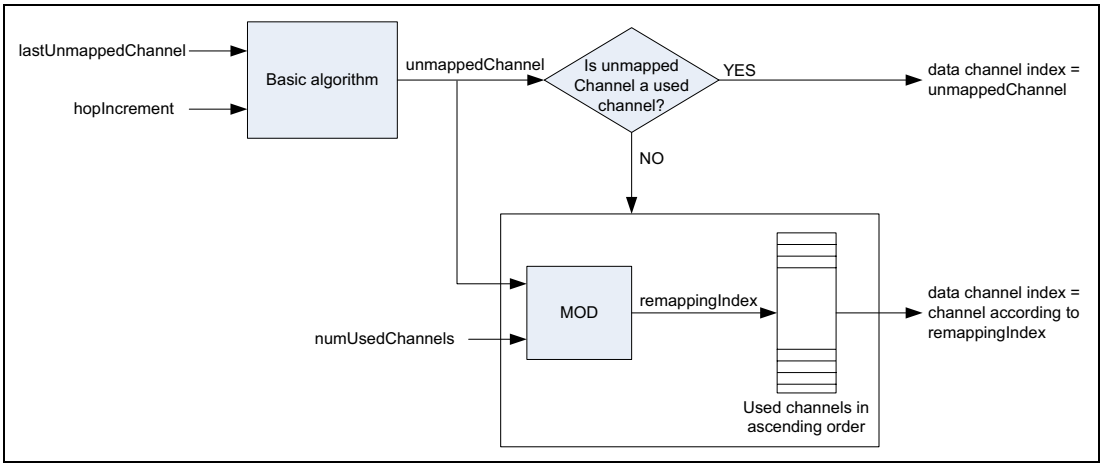

Figure 4.32: Block diagram of data Channel Selection Algorithm #1

4.5.8.3 Channel Selection Algorithm #2

4.5.8.3.1 Overview

Channel Selection Algorithm #2 supports channel selection for connection events and periodic advertising packets.

At the start of an event, which can be a connection event or a periodic advertising packet, the algorithm described here generates an event channel index (which is a data channel index or secondary advertising channel index, as appropriate).

A block diagram of the overall algorithm is shown in Figure 4.33.

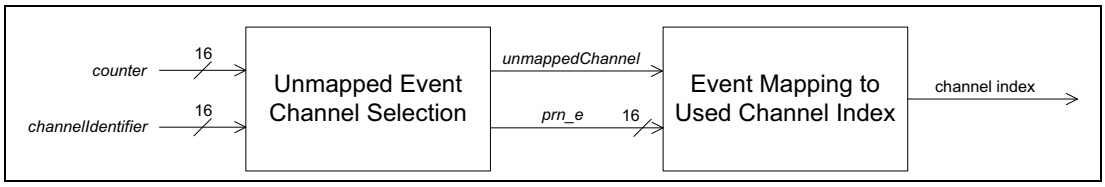

Figure 4.33: General block diagram of Channel Selection Algorithm #2

4.5.8.3.2 Inputs and Basic Components

The algorithm makes use of the following inputs and basic components:

- The 6-bit input *N* is the number of channels classified as *Used* channels.
- The 16-bit input *channelIdentifier* is fixed for any given connection or periodic advertising; it is calculated from the Access Address by:
  channelIdentifier = (Access Address$_{31\text{-}16}$) XOR (Access Address$_{15\text{-}0}$)
- The 16-bit input *counter* changes for each event. For data connections it is the connection event counter *connEventCounter* defined in Section 4.5.1. For periodic advertising it is the event counter *paEventCounter* defined in Section 4.4.3.4.

The “XOR” operation always refers to a 16-bit bit-wise XOR.

The symbol $\lfloor \ \rfloor$ is used to represent the floor function (the greatest integer less than or equal to the argument).

The permutation operation consists of separately bit-reversing the lower 8 input bits and upper 8 input bits, as illustrated in Figure 4.34.

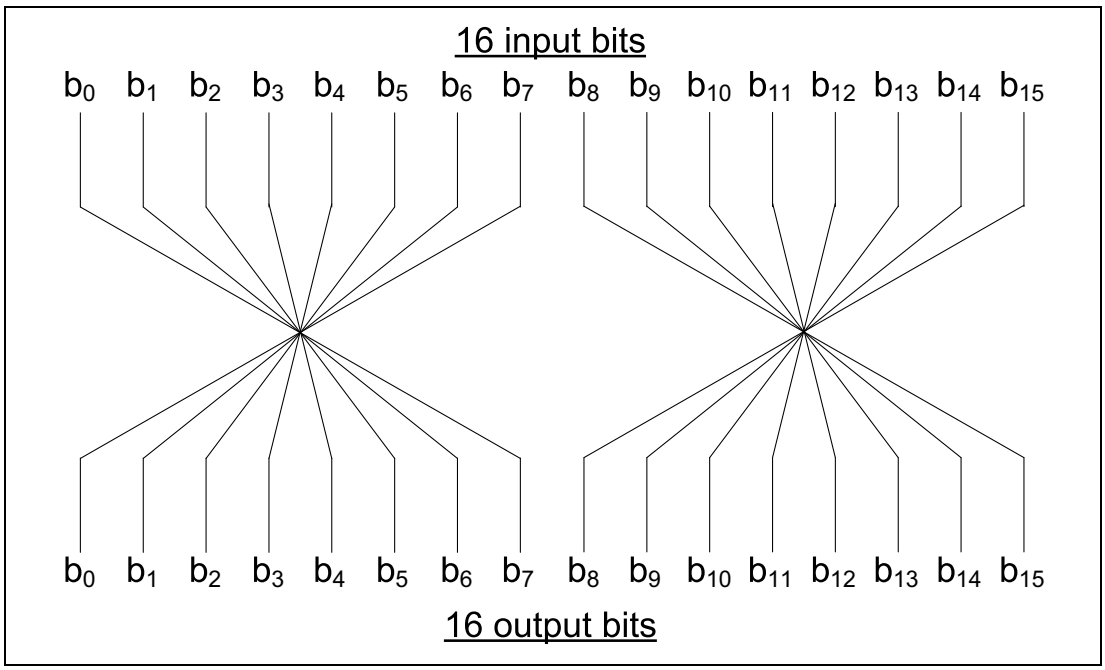

Figure 4.34: Permutation operation

The Multiply, Add, and Modulo (MAM) block performs a multiplication operation, an addition operation, and a modulo operation, as illustrated in Figure 4.35.

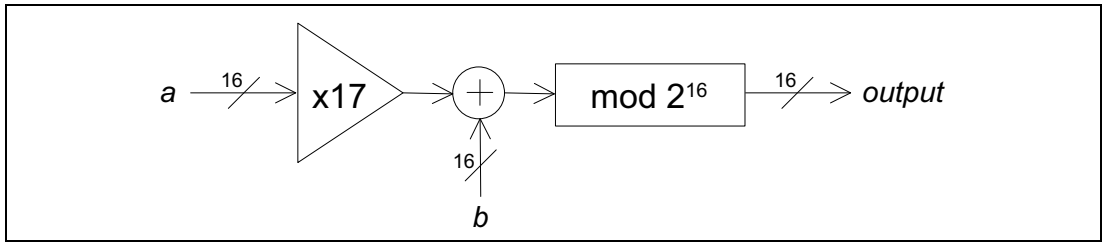

Figure 4.35: Multiply, Add, and Modulo block operation

The output of the MAM operation, given inputs *a* and *b*, is:

$$output = (17 \times a + b) \bmod 2^{16}$$

A *remapping table* is built that contains all the *used channels* in ascending order, indexed from zero.

4.5.8.3.3 Unmapped Event Channel Selection

The unmapped event channel selection process consists of two stages. First, the unsigned pseudo-random number *prn_e* is generated, after which the unmapped channel index *unmappedChannel* is derived from *prn_e*.

The first stage shall be as shown in Figure 4.36.

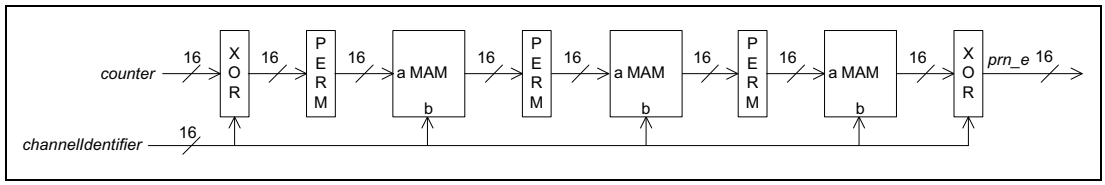

Figure 4.36: Event pseudo-random number generation

unmappedChannel is then calculated as *prn_e* modulo 37. A block diagram of the overall process is shown in Figure 4.37.

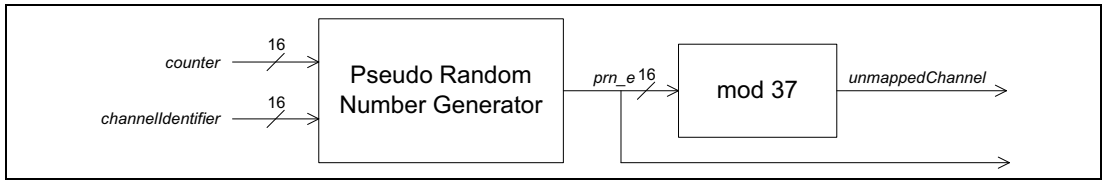

Figure 4.37: Unmapped channel selection process

4.5.8.3.4 Event Mapping to Used Channel Index

If *unmappedChannel* is the channel index of a *used channel* according to the channel map, it is used as the channel index for the event. If *unmappedChannel* is the index of an *unused channel* according to the channel map, then the channel index for the event is calculated from *prn_e* and *N* (the number of used channels) by first calculating the value *remappingIndex* as:

$$remappingindex = \left\lfloor \left(\frac{N * prn\_e}{2^{16}} \right) \right\rfloor$$

and then using *remappingIndex* as an index into the remapping table to obtain the channel index for the event.

The overall process is illustrated in Figure 4.38.

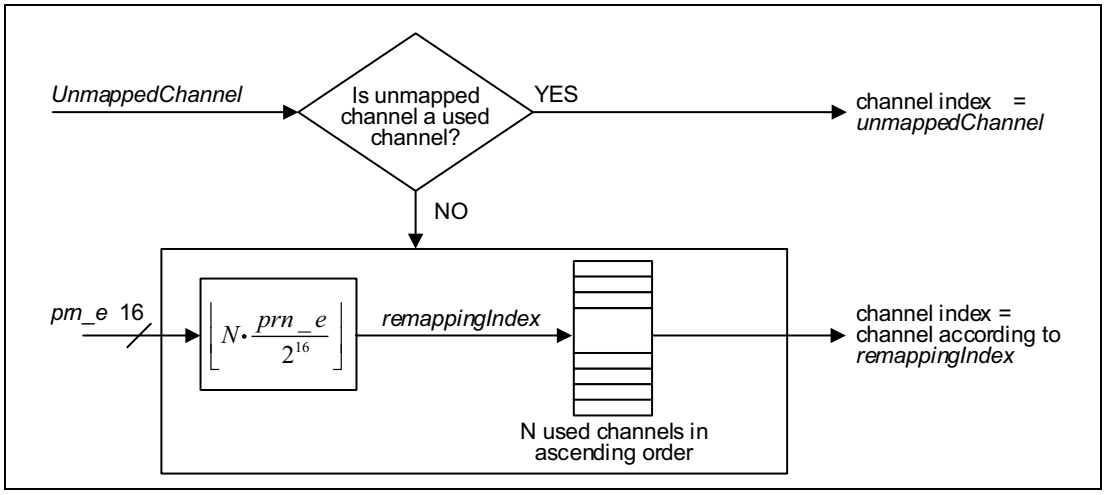

Figure 4.38: Event mapping to used channel index process

4.5.9 Acknowledgment and Flow Control

The Link Layer acknowledgment and flow control scheme shall be used in all Link Layer connections.

For each connection the Link Layer has two parameters, *transmitSeqNum* and *nextExpectedSeqNum*, each one bit in size. The *transmitSeqNum* parameter is used to identify packets sent by the Link Layer. The *nextExpectedSeqNum* parameter is used by the peer to either acknowledge the last Data Channel PDU sent, or to request resending of the last Data Channel PDU sent.

The *transmitSeqNum* and *nextExpectedSeqNum* parameters shall be set to zero upon entering the Connection State.

If the last Data Channel PDU was sent on the LE Coded PHY, the coding scheme (see Section 2.2.3) used when resending may be the same as or different from that used in the last Data Channel PDU. If the instant of a PHY

Update procedure (see Section 5.1.10) occurs while a Data Channel PDU is waiting to be resent, the new PHY shall be used when resending.

A new Data Channel PDU is a Data Channel PDU sent for the first time by the Link Layer. A last Data Channel PDU is a Data Channel PDU that is resent by the Link Layer. When resending a Data Channel PDU, the LLID field, the SN field and the payload of the sent Data Channel PDU shall be equal to those of the last Data Channel PDU sent by the Link Layer.

For each new Data Channel PDU that is sent, the SN bit of the Header shall be set to *transmitSeqNum*. If a Data Channel PDU is resent, then the SN bit shall not be changed.

Upon reception of a Data Channel PDU, the SN bit shall be compared to *nextExpectedSeqNum*. If the bits are different, then this is a resent Data Channel PDU, and *nextExpectedSeqNum* shall not be changed. If the bits are the same, then this is a new Data Channel PDU, and *nextExpectedSeqNum* may be incremented by one (see Section 4.5.9.1).

When a Data Channel PDU is sent, the NESN bit of the Header shall be set to *nextExpectedSeqNum*.

Upon receiving a Data Channel PDU, if the NESN bit of that Data Channel PDU is the same as *transmitSeqNum*, then the last sent Data Channel PDU has not been acknowledged and shall be resent. If the NESN bit of the Data Channel PDU is different from *transmitSeqNum*, then the last sent Data Channel PDU has been acknowledged, *transmitSeqNum* shall be incremented by one, and a new Data Channel PDU may be sent.

The above process is illustrated in Figure 4.39.

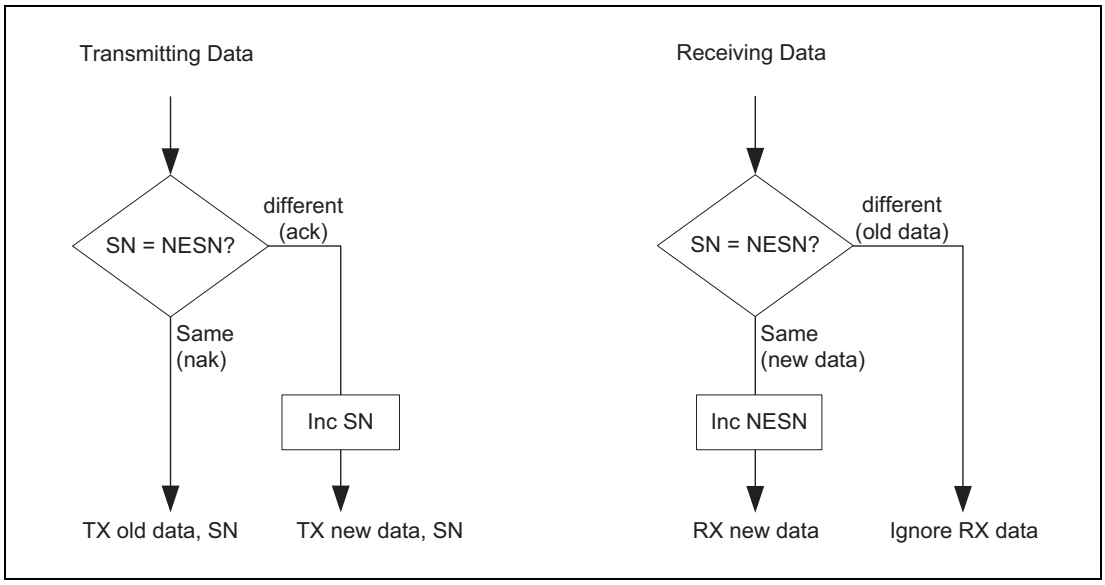

Figure 4.39: Transmit and Receive SN and NESN flow diagram

If a Data Channel PDU is received with an invalid CRC match, *nextExpectedSeqNum* shall not be changed; this means that the Data Channel PDU will not be acknowledged, causing the peer to resend the Data Channel PDU. Since the received Data Channel PDU has been rejected, the *nextExpectedSeqNum* from the peer device cannot be trusted, and therefore the last sent Data Channel PDU from this device was not acknowledged and must be retransmitted.

SN, NESN and MD bits shall be used from every received Data Channel PDU which has passed the CRC check. The Data Channel PDU payload shall be ignored on every received Data Channel PDU that has the same SN value as the previously received Data Channel PDU.

4.5.9.1 Flow Control

A Link Layer may fail to update *nextExpectedSeqNum* for reasons, including, but not limited to, lack of receive buffer space. This will cause the peer to resend the Data Channel PDU at a later time, thus enabling flow control.

4.5.10 Data PDU Length Management

The Controller shall maintain the following global parameters:

- *connInitialMaxTxOctets* - the value of *connMaxTxOctets* that the Controller will use for a new connection.
- *connInitialMaxTxTime* - a value that the Controller will use to determine the value of *connMaxTxTime* that it will use for a new connection.
- *connInitialMaxTxTimeUncoded* - the value of *connMaxTxTime* that the Controller will use for a new connection on an LE Uncoded PHY. The value of *connInitialMaxTxTimeUncoded* shall be the greater of 328 and the value of *connInitialMaxTxTime*.
- *connInitialMaxTxTimeCoded* - the value of *connMaxTxTime* that the Controller will use for a new connection on the LE Coded PHY. The value of *connInitialMaxTxTimeCoded* shall be the greater of 2704 and the value of *connInitialMaxTxTime*.
- *supportedMaxTxOctets* - the maximum value of *connMaxTxOctets* that the Controller supports.
- *supportedMaxTxTime* - the maximum value of *connMaxTxTime* that the Controller supports.
- *supportedMaxRxOctets* - the maximum value of *connMaxRxOctets* that the Controller supports.
- *supportedMaxRxTime* - the maximum value of *connMaxRxTime* that the Controller supports.

Note: 2704 µs is derived from the duration of a packet with a 27 octet payload when sent on the LE Coded PHY using S=8 coding.

The Controller shall maintain the following parameters for each connection:

- *connMaxTxOctets* - the maximum number of octets in the Payload field that the local device will send to the remote device.
- *connMaxRxOctets* - the maximum number of octets in the Payload field that the local device is able to receive from the remote device.
- *connRemoteMaxTxOctets* - the maximum number of octets in the Payload field that the remote device will send to the local device.
- *connRemoteMaxRxOctets* - the maximum number of octets in the Payload field that the remote device is able to receive from the local device.
- *connMaxTxTime* - the maximum number of microseconds that the local device will take to transmit a PDU to the remote device.
- *connMaxRxTime* - the maximum number of microseconds that the local device can take to receive a PDU from the remote device.
- *connRemoteMaxTxTime* - the maximum number of microseconds that the remote device will take to transmit a PDU to the local device.
- *connRemoteMaxRxTime* - the maximum number of microseconds that the remote device can take to receive a PDU from the local device.

The values of these parameters shall each be within the range given in Table 4.3:

LE Data Packet Length Extension feature supported	LE Coded PHY feature supported	Parameters with names ending in "Octets"		Parameters with names ending in "Time"	
		Minimum	Maximum	Minimum	Maximum
No	No	27	27	328	328
Yes	No	27	251	328	2120
No	Yes	27	27	328	2704
Yes	Yes	27	251	328	17040

Table 4.3: Valid ranges for data PDU length management parameters

The following values are derived from the parameters maintained by the Controller:

- *connEffectiveMaxTxOctets* - the lesser of *connMaxTxOctets* and *connRemoteMaxRxOctets*.
- *connEffectiveMaxRxOctets* - the lesser of *connMaxRxOctets* and *connRemoteMaxTxOctets*.
- *connEffectiveMaxTxTimeUncoded* - the lesser of *connMaxTxTime* and *connRemoteMaxRxTime*.
- *connIntervalPortionAvailable* - the current *connInterval* for the connection minus C, where:
  C = (2*T_IFS) + min (*connEffectiveMaxRxTime*, ((*connEffectiveMaxRxOctets* * 64) + 976))

Note: 976 µs is the duration of a packet with a zero octet payload when sent on the LE Coded PHY using S=8 coding.

- *connEffectiveMaxTxTimeAvailable* - the lesser of *connEffectiveMaxTxTimeUncoded* and *connIntervalPortionAvailable*.
- *connEffectiveMaxTxTimeCoded* - the greater of 2704 and *connEffectiveMaxTxTimeAvailable*.
- *connEffectiveMaxTxTime* - equal to *connEffectiveMaxTxTimeUncoded* while the connection is on an LE Uncoded PHY and equal to *connEffectiveMaxTxTimeCoded* while the connection is on the LE Coded PHY.
- *connEffectiveMaxRxTimeUncoded* - the lesser of *connMaxRxTime* and *connRemoteMaxTxTime*.
- *connEffectiveMaxRxTimeCoded* - the greater of 2704 and *connEffectiveMaxRxTimeUncoded*.
- *connEffectiveMaxRxTime* - equal to *connEffectiveMaxRxTimeUncoded* while the connection is on an LE Uncoded PHY and equal to *connEffectiveMaxRxTimeCoded* while the connection is on the LE Coded PHY.

Note: Corresponding octet and time parameters do not have to be mutually consistent. For example, it is permissible for a time parameter to be 2120 µs even though, on some PHYs, the maximum possible time is less.

The Controller shall not change the values of *supportedMaxTxOctets*, *supportedMaxTxTime*, *supportedMaxRxOctets*, and *supportedMaxRxTime*.

For a new connection:

- *connMaxTxOctets* shall be set to *connInitialMaxTxOctets* and *connMaxRxOctets* shall be chosen by the Controller. If either value is not 27 then the Controller should initiate the Data Length Update Procedure (Section 5.1.9) at the earliest practical opportunity.
- *connRemoteMaxTxOctets* and *connRemoteMaxRxOctets* shall be 27.

For a new connection on an LE Uncoded PHY:

- *connMaxTxTime* shall be set to *connInitialMaxTxTimeUncoded* and *connMaxRxTime* shall be chosen by the Controller. If either value is not 328, then the Controller should initiate the Data Length Update Procedure (Section 5.1.9) at the earliest practical opportunity.
- *connRemoteMaxTxTime* and *connRemoteMaxRxTime* shall be 328.

For a new connection on the LE Coded PHY:

- *connMaxTxTime* shall be set to *connInitialMaxTxTimeCoded* and *connMaxRxTime* shall be chosen by the Controller. If either value is not

2704, then the Controller should initiate the Data Length Update Procedure (Section 5.1.9) at the earliest practical opportunity.

- *connRemoteMaxTxTime* and *connRemoteMaxRxTime* shall be 2704.

The Controller may change the values of *connMaxTxOctets, connMaxRxOctets, connMaxTxTime,* and *connMaxRxTime* at any time after entering the Connection State. Whenever it does so, it shall communicate these values to the peer device using the Data Length Update Procedure. The values shall not exceed the values of *supportedMaxTxOctets*, *supportedMaxTxTime*, *supportedMaxRxOctets*, and *supportedMaxRxTime* respectively.

The Controller shall not transmit packets as part of a connection that have a maximum Payload Length greater than *connEffectiveMaxTxOctets* or that take more than *connEffectiveMaxTxTime* microseconds to transmit except during the period where the values of either *connEffectiveMaxTxOctets* or *connEffectiveMaxTxTime* are being modified. During that period, the Controller may still have Data Channel PDUs queued for transmission that conformed to the old parameters but violate the new ones. These PDUs remain valid; only PDUs queued after the Data Length Update Procedure is completed are required to conform to the changed parameters. However, a Controller should ensure that it has no Data Channel PDUs queued for transmission when it transmits an LL_LENGTH_REQ or LL_LENGTH_RSP PDU.

If the Controller decreases the value of *connMaxRxOctets* or *connMaxRxTime*, it shall not apply the new values until a Data Length Update Procedure (Section 5.1.9) that sends the new value has completed.

The Controller shall notify its Host if any of the parameters *connEffectiveMaxTxOctets*, *connEffectiveMaxRxOctets*, *connEffectiveMaxTxTime*, or *connEffectiveMaxRxTime* have changed.

4.6 FEATURE SUPPORT

The set of features supported by a Link Layer is represented by a bit mask called FeatureSet. The value of FeatureSet shall not change while the Controller has a connection to another device. A peer device may cache information about features that the device supports. The Link Layer may cache information about features that a peer supports during a connection.

Within FeatureSet, a bit set to 0 indicates that the Link Layer Feature is not supported in this Controller; a bit set to 1 indicates that the Link Layer Feature is supported in this Controller.

A Link Layer shall not use a procedure that is not supported by the peer's Link Layer. A Link Layer shall not transmit a PDU listed in the following subsections unless it supports at least one of the features that requires support for that PDU.

The bit positions for each Link Layer Feature shall be as shown in Table 4.4. This table also shows if these bits are valid between Controllers. If a bit is shown as not valid, using 'N', then this bit shall be ignored upon receipt by the peer Controller.

Bit position	Link Layer Feature	Valid from Controller to Controller
0	LE Encryption	Y
1	Connection Parameters Request Procedure	Y
2	Extended Reject Indication	Y
3	Slave-initiated Features Exchange	Y
4	LE Ping	N
5	LE Data Packet Length Extension	Y
6	LL Privacy	N
7	Extended Scanner Filter Policies	N
8	LE 2M PHY	Y
9	Stable Modulation Index - Transmitter	Y
10	Stable Modulation Index - Receiver	Y
11	LE Coded PHY	Y
12	LE Extended Advertising	N
13	LE Periodic Advertising	N
14	Channel Selection Algorithm #2	Y
15	LE Power Class 1	Y
16	Minimum Number of Used Channels Procedure	
All other values	Reserved for Future Use	

Table 4.4: FeatureSet field's bit mapping to Controller features

4.6.1 LE Encryption

A Controller that supports LE Encryption shall support the following sections within this document:

- LL_ENC_REQ (Section 2.4.2.4)
- LL_ENC_RSP (Section 2.4.2.5)
- LL_START_ENC_REQ (Section 2.4.2.6)
- LL_START_ENC_RSP (Section 2.4.2.7)
- LL_PAUSE_ENC_REQ (Section 2.4.2.11)
- LL_PAUSE_ENC_RSP (Section 2.4.2.12)
- Encryption Start Procedure (Section 5.1.3.1)
- Encryption Pause Procedure (Section 5.1.3.2)

4.6.2 Connection Parameters Request Procedure

A Controller that supports Connection Parameters Request Procedure shall support the following sections within this document:

- LL_REJECT_EXT_IND (Section 2.4.2.18)
- LL_CONNECTION_PARAM_REQ (Section 2.4.2.16)
- LL_CONNECTION_PARAM_RSP (Section 2.4.2.17)
- Connection Parameters Request Procedure (Section 5.1.7)

4.6.3 Extended Reject Indication

A Controller that supports Extended Reject Indication shall support the following sections within this document:

- LL_REJECT_EXT_IND (Section 2.4.2.18)

4.6.4 Slave-initiated Features Exchange

A Controller that supports Slave-initiated Features Exchange shall support the following sections within this document:

- LL_SLAVE_FEATURE_REQ (Section 2.4.2.15)
- LL_FEATURE_RSP (Section 2.4.2.10)

4.6.5 LE Ping

A Controller that supports LE Ping shall support the following sections of this document.

- LL_PING_REQ (Section 2.4.2.19)
- LL_PING_RSP (Section 2.4.2.20)
- LE Ping Procedure (Section 5.1.8)
- LE Authenticated Payload Timeout (Section 5.4)

4.6.6 LE Data Packet Length Extension

A Controller that supports LE Data Packet Length Extension shall support the following sections of this document.

- LL_LENGTH_REQ and LL_LENGTH_RSP (Section 2.4.2.21)
- Data Length Update Procedure (Section 5.1.9)

4.6.7 LL Privacy

A Controller that supports LL Privacy shall support the following sections of this document.

- LL Privacy (Section 6)

4.6.8 Extended Scanner Filter Policies

A Controller that supports Directed Advertising Report shall support the following sections of this document.

- Scanner Filter Policy (Section 4.3.3)

4.6.9 Multiple PHYs

A Controller that supports any PHY other than LE 1M PHY shall support the following sections within this document:

- Transmission and reception using the supported modulation schemes ([Vol 6] Part A, Section 1)
- LL_REJECT_EXT_IND Section 2.4.2.18)
- LL_PHY_REQ (Section 2.4.2.22)
- LL_PHY_RSP (Section 2.4.2.22)
- LL_PHY_UPDATE_IND (Section 2.4.2.23)
- PHY Update Procedure (Section 5.1.10)

4.6.9.1 Symmetric and Asymmetric Connections

A Controller shall support connections using the same PHY in each direction (“symmetric connections”) and may support connections using different PHYs in each direction (“asymmetric connections”).

If a Controller cannot support asymmetric connections then, in the PHY Update Procedure:

- Any LL_PHY_REQ or LL_PHY_RSP PDUs sent shall indicate that it wants a symmetric connection.
- Any LL_PHY_UPDATE_IND PDU sent shall not specify an asymmetric connection.

4.6.10 Stable Modulation Index - Transmitter

A Controller that supports Stable Modulation Index - Transmitter shall support the following section within this document:

- Stable Modulation Index ([Vol 6] Part A, Section 3.1.1)

4.6.11 Stable Modulation Index - Receiver

A Controller that supports Stable Modulation Index - Receiver shall support the following section within this document:

- Stable Modulation Index ([Vol 6] Part A, Section 4.7)

4.6.12 LE Extended Advertising

A Controller that supports LE Extended Advertising shall support reception of an Advertising Channel PDU payload of 255 octets and support the following sections of this document.

- ADV_EXT_IND (Section 2.3.1.5)
- AUX_ADV_IND (Section 2.3.1.6)
- AUX_CHAIN_IND (Section 2.3.1.8)
- AUX_SCAN_REQ (Section 2.3.2.1)
- AUX_SCAN_RSP (Section 2.3.2.3)
- AUX_CONNECT_REQ (Section 2.3.3.1)
- AUX_CONNECT_RSP (Section 2.3.3.2)
- Common Extended Advertising Payload Format (Section 2.3.4)
- Connectable Directed Event Type using ADV_EXT_IND (Section 4.4.2.4.4)
- Scannable Undirected Event Type using ADV_EXT_IND (Section 4.4.2.5.2)
- Connectable Undirected Event Type (Section 4.4.2.7)

- Scannable Directed Event Type (Section 4.4.2.8)
- Non-Connectable and Non-Scannable Directed Event Type (Section 4.4.2.9)
- Advertising Data Sets (Section 4.4.2.10)
- Using AdvDataInfo (ADI) (Section 4.4.2.11)
- Advertising Data Sets (Section 4.4.3.3)
- Connect Requests on the Secondary Advertising Channel (Section 4.4.4.2)

A Controller that supports connections shall also support the Channel Selection Algorithm #2 feature.

4.6.13 LE Periodic Advertising

A Controller that supports LE Periodic Advertising shall support the LE Extended Advertising feature, Channel Selection Algorithm #2 feature, and the following sections of this document.

- AUX_SYNC_IND (Section 2.3.1.7)
- Periodic Advertising (Section 4.4.2.12 and Section 4.4.3.4)

4.6.14 Channel Selection Algorithm #2

A Controller that supports Channel Selection Algorithm #2 shall support the following sections within this document:

- ChSel bit set to 1 (Sections 2.3, 2.3.1.1, 2.3.1.2, and 2.3.3.1)
- Channel Selection Algorithm #2 (Section 4.5.8.3).

4.6.15 Minimum Number of Used Channels Procedure

A Controller that supports the Minimum Number of Used Channels Procedure shall support the following sections of this document:

- LL_MIN_USED_CHANNELS_IND (Section 2.4.2.24)
- Minimum Number Of Used Channels Procedure (Section 5.1.11)

4.7 RESOLVING LIST

All Link Layers supporting Link Layer Privacy (see Section 6) shall contain a set of records for local and peer IRK value pairs. These values are known as the Local IRK and the Peer IRK. The Resolving List IRK pairs shall be associated with a public or static device address known as the Identity Address. The Identity Address may be in the White List. All Link Layers supporting Link Layer Privacy shall support a Resolving List capable of storing at least one Resolving List Record.

On reset, the Resolving List shall be empty.

The Resolving List is configured by the Host and is used by the Link Layer to resolve Resolvable Private Addresses used by advertisers, scanners or initiators. This allows the Host to configure the Link Layer to act on a request without awakening the Host.

The White List and filter policies set by the Host are applied to the associated Identity Address once the Resolvable Private Address has been resolved.

If the Host, when populating the resolving list, sets a peer IRK to all zeros, then the peer address used within an advertising channel PDU shall use the peer's Identity Address, which is provided by the Host.

The Host specifies the privacy mode to be used with each peer identity on the resolving list. If it specifies that device privacy mode is to be used, then the Controller shall accept both the peer's device identity address and a resolvable private address generated by the peer device using its distributed IRK. Otherwise, network privacy mode is used: the Controller shall only accept resolvable private addresses generated by the peer device using its distributed IRK. If the Host has added the peer device to the resolving list with an all-zero peer IRK, the Controller shall only accept the peer's identity address, as defined in Section 6.5.

If the Host, when populating the resolving list, sets a local IRK to all zeros, then any local address used within an advertising channel PDU shall use the local Identity Address, which is provided by the Host.

If the Link Layer is using the Resolving List and the peer device has been resolved, the Address returned to the Host is the peer device's Identity Address.

If the Link Layer is using the Resolving List and the peer device has been resolved but the encryption fails then the current Resolvable Private Address(es) shall be immediately discarded and new Resolvable Private Address(es) shall be generated.

Note: Encryption may fail when the address was resolved successfully using an incorrect IRK and, therefore, encryption keys on both sides did not match.

When the Controller address resolution is enabled, both peer and local RPAs received by the Link Layer shall be resolved using the Resolving List.

5 LINK LAYER CONTROL

The Link Layer Control Protocol (LLCP) is used to control and negotiate aspects of the operation of a connection between two Link Layers. This includes procedures for control of the connection, starting and pausing encryption and other link procedures.

Procedures have specific timeout rules as defined in Section 5.2. The Termination Procedure may be initiated at any time, even if any other Link Layer Control Procedure is currently active. For all other Link Layer Control Procedures, only one Link Layer Control Procedure shall be initiated in the Link Layer at a time per connection per device. A new Link Layer Control Procedure can be initiated only after a previous Link Layer Control Procedure has completed. However, except where prohibited elsewhere in this section, a Link Layer may initiate an LL Control Procedure while responding to a procedure initiated by its peer device.

There are no restrictions on the order that Link Layer Control Procedures are carried out except that no procedure can be started until after entering the Connection State; i.e., no procedure requires a different procedure to be carried out previously.

The prioritization of LL Control PDUs and LL Data PDUs is implementation specific. For example, a Host cannot assume that pending data will be sent when a termination of the link is requested without waiting for those data PDUs to be completed and indicated to the Host.

5.1 LINK LAYER CONTROL PROCEDURES

5.1.1 Connection Update Procedure

The Link Layer parameters for a connection (*connInterval*, *connSlaveLatency* and *connSupervisionTimeout*) may be updated after entering the Connection State. The master may initiate the update of the connection parameters by sending an LL_CONNECTION_UPDATE_IND PDU if either the master or slave or both do not support the Connection Parameters Request procedure (Section 5.1.7). The slave shall not send this PDU. The slave may request a change to the connection parameters using the L2CAP LE signaling channel if either the master or the slave or both do not support the Connection Parameters Request procedure (Section 5.1.7). The slave may request a change to the connection parameters using the Connection Parameters Request Procedure if both the master and slave support the Connection Parameters Request procedure.

In order to request a change to the connection parameters, the master shall use the Connection Parameters Request Procedure if both the master and slave support that procedure. If the slave rejects the Connection Parameters

Request Procedure, then the master may update the connection parameters using the Connection Update Procedure.

The Link Layer of the master shall determine the *connInterval* from the interval range given by the Host (*connInterval*$_{min}$ and *connInterval*$_{max}$). However, if the current PHY is the LE Coded PHY and the Controller supports the LE Data Packet Length Extension feature, then the new connection interval shall be at least C µs, where:

C = (2*T_IFS) + min (*connEffectiveMaxRxTime*, ((*connEffectiveMaxRxOctets* * 64) + 976)) + 2704

Note: 976 µs and 2704 µs are derived from the durations of packets with a zero octet payload and with a 27 octet payload when sent on the LE Coded PHY using S=8 coding.

The Link Layer shall indicate to the Host the selected interval value.

Section 5.5 shall apply to the LL_CONNECTION_UPDATE_IND PDU. When the slave receives such a PDU with the instant in the future, it shall listen to the connection event where connEventCount equals Instant and the connection event before it.

The connection interval used before the instant is known as *connInterval*$_{OLD}$. The connection interval contained in the LL_CONNECTION_UPDATE_IND PDU and used at the instant and after, is known as *connInterval*$_{NEW}$.

The connection slave latency used before the instant is known as *connSlaveLatency*$_{OLD}$. The connection slave latency contained in the LL_CONNECTION_UPDATE_IND PDU and used at the instant and after, is known as *connSlaveLatency*$_{NEW}$.

The connection supervision timeout used before the instant is known as *connSupervisionTimeout*$_{OLD}$. The connection supervision timeout contained in the LL_CONNECTION_UPDATE_IND PDU and used at the instant and after, is known as *connSupervisionTimeout*$_{NEW}$. The connection supervision timer shall be reset at the instant.

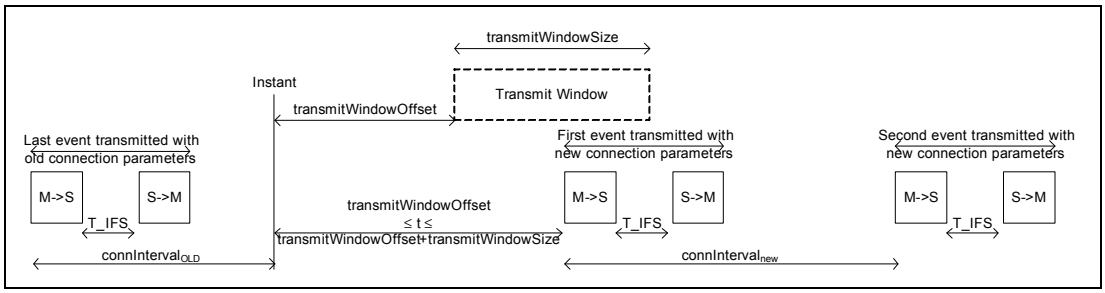

Figure 5.1: Connection event timing in the case of connection parameter update

For example, the interval between the preceding connection event before the instant and the instant will be $connInterval_{OLD}$. The interval between the connection event after the instant and the following connection event will be $connInterval_{NEW}$.

The master may adjust the anchor point when deciding the timing of the first packet transmitted with new connection parameters. A transmit window is used, as defined in Section 4.5.3. The transmit window starts at $connInterval_{OLD}$ + *transmitWindowOffset* after the anchor point of the connection event before the instant. The *transmitWindowOffset* shall be a multiple of 1.25 ms in the range of 0 ms to $connInterval_{NEW}$. The *transmitWindowSize* shall be a multiple of 1.25 ms in the range of 1.25 ms to the lesser of 10 ms and ($connInterval_{NEW}$ - 1.25 ms).

The master shall start to send the first packet within the transmit window as defined in Section 4.5.3. It is permitted that the master's first packet can extend beyond the transmit window.

The first packet sent after the instant by the master determines the new anchor point for the connection events, and therefore the timings of all future connection events in this connection.

The instant occurs after $connInterval_{OLD}$ and before *transmitWindowOffset*. All the normal connection event transmission rules specified in Section 4.5.1, shall apply.

At the start of the transmit window, the Link Layer shall reset $T_{LLconnSupervision}$.

If the Link Layer of the master transmits an LL_CONNECTION_UPDATE_IND PDU autonomously, for example without being requested to by the Host, the Latency and Timeout parameters shall not be changed and shall remain the same as in the last LL_CONNECTION_UPDATE_IND or CONNECT_IND PDU, any of the other parameters (*transmitWindowSize*, *transmitWindowOffset*, *connInterval*, Instant) may be changed within the restrictions given above. Note: Autonomous updates can be used to change the anchor points to allow the master to change the scheduling of the connection due to other activities.

The Link Layer shall notify its Host if any of the three connection parameters have changed. If no connection parameters are changed, the Host would not be notified; this is called an anchor point move.

The procedure is complete when the instant has passed, and the new connection event parameters have been applied.

5.1.2 Channel Map Update Procedure

The Link Layer parameter for channel map (*channelMap*) may be updated after entering the Connection State. The master can update the channel map by

sending an LL_CHANNEL_MAP_IND PDU. The slave shall not send this PDU. The master Controller can update the channel map without being requested to by the Host.

Section 5.5 shall apply to the LL_CHANNEL_MAP_IND PDU.

The channel map used before the instant is known as $channelMap_{OLD}$. The channel map contained in the LL_CHANNEL_MAP_IND PDU and used at the instant and after, is known as $channelMap_{NEW}$.

When *connEventCount* is equal to the Instant field, the $channelMap_{NEW}$ shall be the current *channelMap*. The *lastUnmappedChannel* shall not be reset. If the *unmappedChannel* is an unused channel, then the $channelMap_{NEW}$ will be used when remapping. The only parameter that changes is the *channelMap*.

For example:

At connection set-up:

- initial $channelMap_{OLD}$: 0x1FFFFFFFFF (i.e., all channels enabled)
- initial *hopIncrement*: 10 (decimal)

An LL_CHANNEL_MAP_IND PDU with the following parameters is then issued:

- Instant: 100 (decimal). Assume that no connection event count wrap-around occurred since the start of the connection.
- $channelMap_{NEW}$: 0x1FFFFFF7FF (i.e. all channels enabled except channel 11)

Channels used:

- *connEventCount* 99 --> data channel index 1 ($channelMap_{OLD}$)
- *connEventCount* 100 --> data channel index 12 (remapped from 11) ($channelMap_{NEW}$)
- *connEventCount* 101 --> data channel index 21 ($channelMap_{NEW}$)

The procedure is complete when the instant has passed, and the new channel map has been applied.

5.1.3 Encryption Procedure

The Link Layer, upon request from the Host, can enable the encryption of packets after entering the Connection State.

If the connection is not encrypted, the Link Layer shall only use the encryption start procedure.

If the connection is encrypted, the Link Layer shall first use the encryption pause procedure followed by the encryption start procedure.

5.1.3.1 Encryption Start Procedure

To enable encryption, two parameters must be exchanged, IV and SKD. Both are composed of two parts, a master part and a slave part, and exchanged in LL_ENC_REQ and LL_ENC_RSP PDUs. After these are exchanged, and the Host has notified the Link Layer of the Long Term Key to be used on this connection, encryption can be started using a three way handshake, using LL_START_ENC_REQ and LL_START_ENC_RSP PDUs.

To start encryption, the Link Layer of the master shall generate the master's part of the initialization vector (IVm) and the master's part of the session key diversifier (SKDm). IVm shall be a 32 bit random number generated by the Link Layer of the master. SKDm shall be a 64 bit random number generated by the Link Layer of the master. Both IVm and SKDm shall be generated using the requirements for random number generation defined in [Vol 2] Part H, Section 2.

The Link Layer of the master shall finalize the sending of the current Data Channel PDU and may finalize the sending of additional Data Channel PDUs queued in the Controller. After these Data Channel PDUs are acknowledged, the Link Layer of the master shall only send Empty PDUs or LL_ENC_REQ, LL_START_ENC_RSP, LL_TERMINATE_IND, LL_REJECT_IND or LL_REJECT_EXT_IND PDUs.

The Link Layer of the master shall then send an LL_ENC_REQ PDU; the Rand and EDIV fields are provided by the Host.

If encryption is not supported by the Link Layer of the slave, the Link Layer of the slave shall send an LL_REJECT_IND or LL_REJECT_EXT_IND PDU with the ErrorCode set to *Unsupported Remote Feature / Unsupported LMP Feature* (0x1A). The Link Layer of the master receiving the LL_REJECT_IND or LL_REJECT_EXT_IND PDU shall notify the Host. The Link Layer of the master can now send LL Data Packets and LL Control Packets; these packets will not be encrypted. This procedure is complete in the master when the master receives the LL_REJECT_IND or LL_REJECT_EXT_IND PDU from the slave. The procedure is complete in the slave when the acknowledgment for the LL_REJECT_IND or LL_REJECT_EXT_IND PDU is received from the master.

Otherwise, when the Link Layer of the slave receives an LL_ENC_REQ PDU it shall generate the slave's part of the initialization vector (IVs) and the slave's part of the session key diversifier (SKDs). IVs shall be a 32 bit random number generated by the Link Layer of the slave. SKDs shall be a 64 bit random number generated by the Link Layer of the slave. Both IVs and SKDs shall be generated using the requirements for random number generation defined in [Vol 2] Part H, Section 2.

The Link Layer of the slave shall finalize the sending of the current Data Channel PDU and may finalize the sending of additional Data Channel PDUs queued in the Controller. After these Data Channel PDUs are acknowledged,

the Link Layer of the slave is only allowed to send Empty PDUs or LL_ENC_RSP, LL_START_ENC_REQ, LL_START_ENC_RSP, LL_TERMINATE_IND, LL_REJECT_IND or LL_REJECT_EXT_IND PDUs.

The Link Layer of the slave shall then send an LL_ENC_RSP PDU. The Link Layer of the slave shall then notify the Host with the Rand and EDIV fields. After having sent the LL_ENC_RSP PDU, the Link Layer of the slave can receive an LL_UNKNOWN_RSP PDU corresponding to a LL Control PDU sent by the slave. The slave should not disconnect the link in this case.

Each Link Layer shall combine the initialization vector parts and session key diversifier parts in the following manner:

SKD = SKDm || SKDs

IV = IVm || IVs

The SKDm is concatenated with the SKDs. The least significant octet of SKDm becomes the least significant octet of SKD. The most significant octet of SKDs becomes the most significant octet of SKD.

The IVm is concatenated with the IVs. The least significant octet of IVm becomes the least significant octet of IV. The most significant octet of IVs becomes the most significant octet of IV.

The Long Term Key is provided by the Host to the Link Layer in the master and slave, and one of the following three actions shall occur:

- If this procedure is being performed after a Pause Encryption Procedure, and the Host does not provide a Long Term Key, the slave shall perform the Termination Procedure with the error code *PIN or key Missing* (0x06).
- If the Host does not provide a Long Term Key, either because the event to the Host was masked out or if the Host indicates that a key is not available, the slave shall either send an LL_REJECT_IND with the ErrorCode set to *PIN or key Missing* (0x06) or an LL_REJECT_EXT_IND PDU with the RejectOpcode set to "LL_ENC_REQ" and the ErrorCode set to *PIN or key Missing* (0x06). Upon receiving an LL_REJECT_IND or LL_REJECT_EXT_IND PDU, the Link Layer shall notify the Host. The Link Layer can now send LL Data PDUs and LL Control PDUs; these packets will not be encrypted. This procedure is complete in the master when the master receives the LL_REJECT_IND or LL_REJECT_EXT_IND PDU from the slave. The procedure is completed in the slave when the acknowledgment has been received for the LL_REJECT_IND or LL_REJECT_EXT_IND PDU from the master.
- If the Host does provide a Long Term Key, the Link Layer of the slave shall calculate *sessionKey* using the encryption engine with LTK as the key, and SKD as the plain text input. The *sessionKey* parameter shall be set to the output of the encryption engine.

The *sessionKey* shall be used as the key for the encryption engine for all encrypted packets.

After *sessionKey* has been calculated, the Link Layer of the slave shall send an LL_START_ENC_REQ PDU. This packet shall be sent unencrypted, and the Link Layer shall be set up to receive an encrypted packet in response.

When the Link Layer of the master receives an LL_START_ENC_REQ PDU it shall send an LL_START_ENC_RSP PDU. This PDU shall be sent encrypted and set up to receive encrypted.

When the Link Layer of the slave receives an LL_START_ENC_RSP PDU it shall transmit an LL_START_ENC_RSP PDU. This packet shall be sent encrypted.

When the Link Layer of the master receives the LL_START_ENC_RSP PDU, the connection is encrypted. The Link Layer can now send LL Data PDUs and LL Control PDUs; these PDUs will be encrypted.

The Link Layers shall notify the Hosts that the connection is encrypted.

The procedure is complete in the master when the master receives the LL_START_ENC_RSP PDU from the slave. The procedure is complete in the slave when the slave receives the LL_START_ENC_RSP PDU from the master.

If at any time during the encryption start procedure, the Link Layer of the master or the slave receives an unexpected Data Channel PDU from the peer Link Layer, it shall immediately exit the Connection State, and shall transition to the Standby State. The Host shall be notified that the link has been disconnected with the error code *Connection Terminated Due to MIC Failure* (0x3D).

5.1.3.2 Encryption Pause Procedure

To enable a new encryption key to be used without disconnecting the link, encryption must be disabled and then enabled again. During the pause, data PDUs shall not be sent unencrypted to protect the data.

The Link Layer of the master shall finalize the sending of the current Data Channel PDU and may finalize the sending of additional Data Channel PDUs queued in the Controller. After these Data Channel PDUs are acknowledged, the Link Layer of the master shall only send Empty PDUs or LL_PAUSE_ENC_REQ or LL_TERMINATE_IND PDUs.

The Link Layer of the master shall then send an LL_PAUSE_ENC_REQ PDU.

When the Link Layer of the slave receives an LL_PAUSE_ENC_REQ PDU it shall finalize the sending of the current Data Channel PDU and may finalize the sending of additional Data Channel PDUs queued in the Controller. After these

Data Channel PDUs are acknowledged, the Link Layer of the slave is only allowed to send Empty PDUs or LL_PAUSE_ENC_RSP or LL_TERMINATE_IND PDUs.

The Link Layer of the slave shall then send an LL_PAUSE_ENC_RSP PDU. This packet shall be sent encrypted, and Link Layer shall be set up to receive unencrypted.

When the Link Layer of the master receives an LL_PAUSE_ENC_RSP PDU it shall set up to send and receive unencrypted. It shall then send an LL_PAUSE_ENC_RSP PDU to the slave unencrypted.

When the Link Layer of the slave receives an LL_PAUSE_ENC_RSP PDU it shall set up to also send unencrypted.

The encryption start procedure shall now be used to re-enable encryption using a new session key.

If at any time during the encryption pause procedure, the Link Layer of the master or the slave receives an unexpected Data Channel PDU from the peer Link layer, it shall immediately exit the Connection State, and shall transition to the Standby State. The Host shall be notified that the link has been disconnected with the error code *Connection Terminated Due to MIC Failure* (0x3D).

5.1.4 Feature Exchange Procedure

The Link Layer parameter for the current supported feature set (FeatureSet) may be exchanged after entering the Connection State. Both the master and slave can initiate this procedure.

The FeatureSet information may be cached either during a connection or between connections. A Link Layer should not request this information on every connection if the information has been cached for this device. Cached information for a device from a previous connection is not authoritative and, therefore, an implementation must be able to accept the LL_UNKNOWN_RSP PDU if use of a feature is attempted that is not currently supported or used by the peer.

The $FeatureSet_M$ parameter is the feature capabilities of the Link Layer of the master.

The $FeatureSet_S$ parameter is the feature capabilities of the Link Layer of the Slave.

The $FeatureSet_{USED}$ parameter is one octet long and is the logical AND of $FeatureSet_M[0]$ and $FeatureSet_S[0]$.

5.1.4.1 Master-initiated Feature Exchange Procedure

The master initiates this procedure with an LL_FEATURE_REQ PDU, and the slave responds with an LL_FEATURE_RSP PDU.

When the Link Layer of the master sends an LL_FEATURE_REQ PDU, the FeatureSet field shall be set to $FeatureSet_M$.

When the Link Layer of the slave sends an LL_ FEATURE_RSP PDU, octet 0 of the FeatureSet field shall be set to $FeatureSet_{USED}$ and the remaining octets shall be set to the corresponding octets of $FeatureSet_S$.

The Link Layer of the master sends an LL_FEATURE_REQ PDU. This can be sent on request from the Host or autonomously.

When the Link Layer of the slave receives an LL_FEATURE_REQ PDU it shall send an LL_FEATURE_RSP PDU.

The procedure is complete when the master receives the LL_FEATURE_RSP PDU from the slave.

5.1.4.2 Slave-initiated Feature Exchange Procedure

The slave initiates this procedure with an LL_SLAVE_FEATURE_REQ PDU, and the master responds with an LL_FEATURE_RSP PDU.

When the Link Layer of the slave sends an LL_SLAVE_FEATURE_REQ PDU, the FeatureSet field shall be set to $FeatureSet_S$.

When the Link Layer of the master sends an LL_FEATURE_RSP PDU, octet 0 of the FeatureSet field shall be set to $FeatureSet_{USED}$ and the remaining octets shall be set to the corresponding octets of $FeatureSet_M$.

The Link Layer of the slave sends an LL_SLAVE_FEATURE_REQ PDU. This can be sent on request from the Host or autonomously.

When the Link Layer of the master receives an LL_SLAVE_FEATURE_REQ PDU, it shall send an LL_FEATURE_RSP PDU.

If the Link Layer of the slave sends the LL_SLAVE_FEATURE_REQ PDU to a master that does not understand that PDU, then the slave should expect an LL_UNKNOWN_RSP PDU in response. If the LL_SLAVE_FEATURE_REQ PDU was issued as a result of a Host-initiated read remote features procedure (see [Vol 2] Part E, Section 7.8.21), then the Host shall be notified that the read remote features procedure has completed with the ErrorCode set to *Unsupported Remote Feature / Unsupported LMP Feature* (0x1A).

The procedure is complete when the slave receives the LL_FEATURE_RSP or LL_UNKNOWN_RSP PDU from the master.

5.1.5 Version Exchange

The Link Layer parameters for version information (*companyID*, *subVerNum*, *linkLayerVer*, as defined in Section 2.4.2.13) may be exchanged after entering the Connection State. Either the Link Layer of the master or slave can initiate this procedure by sending an LL_VERSION_IND PDU. This procedure should be used when requested by the Host. This procedure may be initiated autonomously by the Link Layer.

The Link Layer shall only queue for transmission a maximum of one LL_VERSION_IND PDU during a connection.

If the Link Layer receives an LL_VERSION_IND PDU and has not already sent an LL_VERSION_IND then the Link Layer shall send an LL_VERSION_IND PDU to the peer device.

If the Link Layer receives an LL_VERSION_IND PDU and has already sent an LL_VERSION_IND PDU then the Link Layer shall not send another LL_VERSION_IND PDU to the peer device.

The procedure has completed when an LL_VERSION_IND PDU has been received from the peer device.

5.1.6 Termination Procedure

This procedure is used for voluntary termination of a connection while in the Connection State. Voluntary termination occurs when the Host requests the Link Layer to terminate the connection. Either the Link Layer of the master or slave can initiate this procedure by sending an LL_TERMINATE_IND PDU. The termination procedure is not used in the event of the loss of the connection, for example after link supervision timeout or after a procedure timeout.

The Link Layer shall start a timer, $T_{terminate}$, when the LL_TERMINATE_IND PDU has been queued for transmission. The initiating Link Layer shall send LL_TERMINATE_IND PDUs until an acknowledgment is received or until the timer, $T_{terminate}$, expires, after which it shall exit the Connection State and transition to the Standby State. The initial value for $T_{terminate}$ shall be set to value of the *connSupervisionTimeout*.

When the Link Layer receives an LL_TERMINATE_IND PDU it shall send the acknowledgment, exit the Connection State and shall transition to the Standby State.

The procedure has completed when the acknowledgment has been received or the timer, $T_{terminate}$, expires.

5.1.7 Connection Parameters Request Procedure

The master or slave may initiate a Connection Parameters Request procedure to request the remote device to have the Link Layer parameters for the connection (*connInterval*, *connSlaveLatency* and *connSupervisionTimeout*) updated any time after entering the Connection State.

5.1.7.1 Issuing an LL_CONNECTION_PARAM_REQ PDU

The Connection Parameters Request procedure is initiated by issuing an LL_CONNECTION_PARAM_REQ PDU. The procedure can be initiated as a result of a Host initiated connection update procedure (see [Vol 2] Part E, Section 7.8.18) or autonomously by the Link Layer (that is, without being requested by the Host).

If the Link Layer of the master or slave sends the LL_CONNECTION_PARAM_REQ PDU to a device that does not understand that PDU, then the device should expect an LL_UNKNOWN_RSP PDU in response. If the LL_CONNECTION_PARAM_REQ PDU was issued by the Link Layer of the slave as a result of a Host initiated connection update procedure, then the Host shall be notified that the connection update procedure has completed with the ErrorCode set to *Unsupported Remote Feature / Unsupported LMP Feature* (0x1A).

If the Link Layer initiates this procedure as a result of a Host initiated connection update procedure, then the Link Layer:

- Should set the Interval_Min, Interval_Max, Timeout, and Latency fields to the values received from the Host. Note: The Link Layer may modify the values of these fields, for example, because the values received from the Host would prevent the Link Layer from meeting commitments in another piconet.
- May indicate the preferred periodicity by setting the PreferredPeriodicity field to a value other than zero, as described in Section 2.4.2.16.
- May set the Offset0 to Offset5 fields to a value other than 0xFFFF as described in Section 2.4.2.16. If one or more of the Offset0 to Offset5 fields have been set, then:
  - The ReferenceConnEventCount field shall be set to indicate that at least one of the Offset0 to Offset5 fields is valid. If the ReferenceConnEvent-Count field is set, then it shall always be set to the connEventCount of a connection event that is less than 32767 connection events in the future from the first transmission of the PDU. Note: Retransmissions of the PDU can result in the ReferenceConnEventCount to be up to 32767 events in the past when the PDU is successfully received by the remote device. See Section 5.1.7.3.2 for examples on how to set the ReferenceConnE-ventCount field.
  - If Interval_Min is not equal to Interval_Max then the PerferredPeriodicity field shall be set to a value other than zero. If Interval_Min is equal to

Interval_Max then the PreferredPeriodicity field may be set to any value and shall be ignored by the recipient.

If the Link Layer initiates this procedure autonomously, then the Latency field shall be set to the current value of *connSlaveLatency* and the Timeout field (in milliseconds) shall be set to the current value of *connSupervisionTimeout*. Any of the other fields (Interval_Min, Interval_Max, PreferredPeriodicity, ReferenceConnEventCount and Offset0 to Offset5) may be changed within the restrictions given above.

The Link Layer shall ensure that the parameters in the LL_CONNECTION_PARAM_REQ shall not cause supervision timeout. That is, the Link Layer shall ensure that the Timeout (in milliseconds) is greater than 2* Interval_Max * (Latency + 1).

5.1.7.2 Responding to LL_CONNECTION_PARAM_REQ and LL_CONNECTION_PARAM_RSP PDUs

Upon receiving an LL_CONNECTION_PARAM_REQ PDU:

- The slave shall respond with either an LL_CONNECTION_PARAM_RSP PDU or an LL_REJECT_EXT_IND PDU.
- The master shall respond with either an LL_CONNECTION_UPDATE_IND PDU or an LL_REJECT_EXT_IND PDU.

Upon receiving an LL_CONNECTION_PARAM_RSP PDU, the master shall respond with either an LL_CONNECTION_UPDATE_IND PDU or an LL_REJECT_EXT_IND PDU.

The master shall not send the LL_CONNECTION_PARAM_RSP PDU. The slave shall send an LL_CONNECTION_PARAM_RSP PDU only in response to an LL_CONNECTION_PARAM_REQ PDU.

If the received LL_CONNECTION_PARAM_REQ PDU contains parameters that are not acceptable to the Link Layer, then the Link Layer of the device shall respond to the LL_CONNECTION_PARAM_REQ PDU with one of the following:

- An LL_CONNECTION_PARAM_RSP PDU (if the Link Layer is the slave of the connection) or an LL_CONNECTION_UPDATE_IND PDU (if the Link Layer is the master of the connection) containing alternative parameters.
- An LL_REJECT_EXT_IND PDU with the ErrorCode set to *Unsupported LL Parameter Value* (0x20).

If the received LL_CONNECTION_PARAM_REQ PDU contains any fields that are out of valid range, then the Link Layer shall reject the LL_CONNECTION_PARAM_REQ PDU by issuing an LL_REJECT_EXT_IND PDU with the ErrorCode set to *Invalid LL Parameters* (0x1E).

If an LL_REJECT_EXT_IND PDU is sent during the Connection Parameters Request procedure, then the procedure is complete on a device when it receives the LL_REJECT_EXT_IND PDU, and is complete on the device that issued the LL_REJECT_EXT_IND PDU when it receives the acknowledgment for the LL_REJECT_EXT_IND PDU.

If the received LL_CONNECTION_PARAM_REQ PDU requests only a change in the anchor points of the LE connection, then the Link Layer shall not indicate this request to its Host.

If the received LL_CONNECTION_PARAM_REQ PDU requests a change to one or more of *connInterval*, *connSlaveLatency*, and *connSupervisionTimeout* and if the values selected by the Link Layer are, respectively, within the range of the *connInterval*, the value of *connSlaveLatency* and the value of *connSupervisionTimeout* provided by the local Host, then the Link Layer may choose to not indicate this request to its Host and proceed as if the Host has accepted the remote device's request. Otherwise, if the event to the Host is not masked, then the Link Layer shall first indicate this request to its Host.

If the local Host has not provided the range of *connInterval*, the value of *connSlaveLatency* and the value of *connSupervisionTimeout* to the Link Layer of the slave, then the Link Layer of the slave may indicate the received request to its Host if the event to the Host is not masked.

If the request is being indicated to the Host and the event to the Host is masked, then the Link Layer shall issue an LL_REJECT_EXT_IND PDU with the ErrorCode set to *Unsupported Remote Feature / Unsupported LMP Feature* (0x1A). Note: The device could have issued the LL_REJECT_EXT_IND PDU temporarily. The initiating device may retry. Note: If the request is not being indicated to the Host, then the event mask is ignored.

If the Host is indicated of the request, it shall either accept or reject this request. If the Host rejects this request, then the device shall issue an LL_REJECT_EXT_IND PDU with the ErrorCode set to a value provided by the Host. The Host shall only use the error code *Unacceptable Connection Parameters* (0x3B) in order to reject the request.

If the Host accepts this request or if the request was not indicated to the Host, then:

- The slave shall respond to an LL_CONNECTION_PARAM_REQ PDU with an LL_CONNECTION_PARAM_RSP PDU. The rules for filling in various fields of the LL_CONNECTION_PARAM_RSP PDU are the same as those for filling in various fields of the LL_CONNECTION_PARAM_REQ PDU, as described in Section 5.1.7.1. The rules for handling a received LL_CONNECTION_PARAM_RSP PDU on the Link Layer of the master are identical to the rules for handling a received LL_CONNECTION_PARAM_REQ PDU that are described earlier in this section.

- The master shall respond to an LL_CONNECTION_PARAM_REQ PDU or an LL_CONNECTION_PARAM_RSP PDU with an LL_CONNECTION_UPDATE_IND PDU. The master should try to choose a value of Interval that is a multiple of PreferredPeriodicity if the slave has set the PreferredPeriodicity field of the LL_CONNECTION_PARAM_REQ or LL_CONNECTION_PARAM_RSP PDU. The master should try to pick the values of WinOffset and WinSize such that the timing of the new connection events matches one of the Offset0 to Offset5 fields of the LL_CONNECTION_PARAM_REQ PDU or the LL_CONNECTION_PARAM_RSP PDU sent by the slave. The Instant field of the LL_CONNECTION_UPDATE_IND PDU is set as described in Section 5.1.1.

Once the master issues the LL_CONNECTION_UPDATE_IND PDU, the connection parameters get updated as described in Section 5.1.1.

The procedure is complete when the instant has passed and the new connection event parameters have been applied.

5.1.7.3 Examples

5.1.7.3.1 Slave initiated anchor point move

The following example shows the Link Layer of the slave requesting a change in the anchor points of the LE connection by 3.75ms.

The Link Layer of the slave issues an LL_CONNECTION_PARAM_REQ PDU with the following parameters:

- Interval_Min: *connInterval*
- Interval_Max: *connInterval*
- Latency: *connSlaveLatency*
- Timeout: *connSupervisionTimeout*
- PreferredPeriodicity: 0
- ReferenceConnEventCount: <any value that is less than 32767 connection events in the future>
- Offset0: 0x0003
- Offset1: 0xFFFF
- Offset2: 0xFFFF
- Offset3: 0xFFFF
- Offset4: 0xFFFF
- Offset5: 0xFFFF

If the Link Layer of the master accepts the slave's request, then it could respond with an LL_CONNECTION_UPDATE_IND PDU that contains any one

of the following set of parameters. In all the sets, Interval is set to *connInterval*, Latency is set to *connSlaveLatency*, Timeout is set to *connSupervisionTimeout* and Instant is set to any value that is less than 32767 connection events in the future.

- Option 1: the first packet sent after the instant by the master is inside the Transmit Window and 3.75ms from the beginning of the Transmit Window.
  - 3 ≤ WinSize ≤ 8
  - WinOffset: 0
- Option 2: the first packet sent after the instant by the master is inside the Transmit Window and 2.5ms from the beginning of the Transmit Window.
  - 2 ≤ WinSize ≤ 8
  - WinOffset: 1
- Option 3: the first packet sent after the instant by the master is inside the Transmit Window and1.25ms from the beginning of the Transmit Window.
  - 1 ≤ WinSize ≤ 8
  - WinOffset: 2
- Option 4: the first packet sent after the instant by the master is inside the Transmit Window and 0ms from the beginning of the Transmit Window.
  - 1 ≤ WinSize ≤ 8
  - WinOffset: 3

5.1.7.3.2 ReferenceConnEventCount

Figure 5.2 and Figure 5.3 show examples of how the ReferenceConnEventCount and the Offset0 to Offset5 fields of the LL_CONNECTION_PARAM_REQ and the LL_CONNECTION_PARAM_RSP PDU can be utilized to indicate the possible position of the anchor points of the connection with the new connection parameters relative to the anchor points of the connection with the old connection parameters. This figure only shows Offset0 (and not Offset1 to Offset5) for simplicity. The figure also shows the Instant where the updated connection parameters are applied. Note that the actual Instant occurs $connInterval_{OLD}$ after the last connection event transmitted with the old connection parameters whereas the Instant field in the LL_CONNECTION_UPDATE_IND PDU is set to the *connEventCount* of the connection event transmitted with the old connection parameters.

The ReferenceConnEventCount is set to the *connEventCount* of the connection event on the old connection parameters such that the start of the very next connection event on the new connection parameters is Offset0 (in milliseconds) away from the start of the ReferenceConnEventCount connection event.

Figure 5.2 shows the case where the Instant is before the ReferenceConnEventCount. Figure 5.3 shows the case where the Instant is after the ReferenceConnEventCount. Imaginary connection events transmitted

with the old connection parameters have been shown beyond the Instant and imaginary connection events transmitted with the new connection parameters have been shown before the Instant.

In Figure 5.2 and Figure 5.3, the time interval, Δt, between the Instant and the start of the first connection event transmitted with the new connection parameters can be calculated using the following equation:

$$\Delta t = (connInterval_{NEW} - ((Instant - ReferenceConnEventCount) * connInterval_{OLD}) \% connInterval_{NEW} + offset0) \% connInterval_{NEW}$$

Note: The case where the ReferenceConnEventCount and Instant are on different sides of the eventCount wraparound point is not shown in the equations above.

Based on the calculated Δt, the WinOffset and WinSize fields in the LL_CONNECTION_UPDATE_IND PDU could be set accordingly. See Section 5.1.7.3.3 for an example.

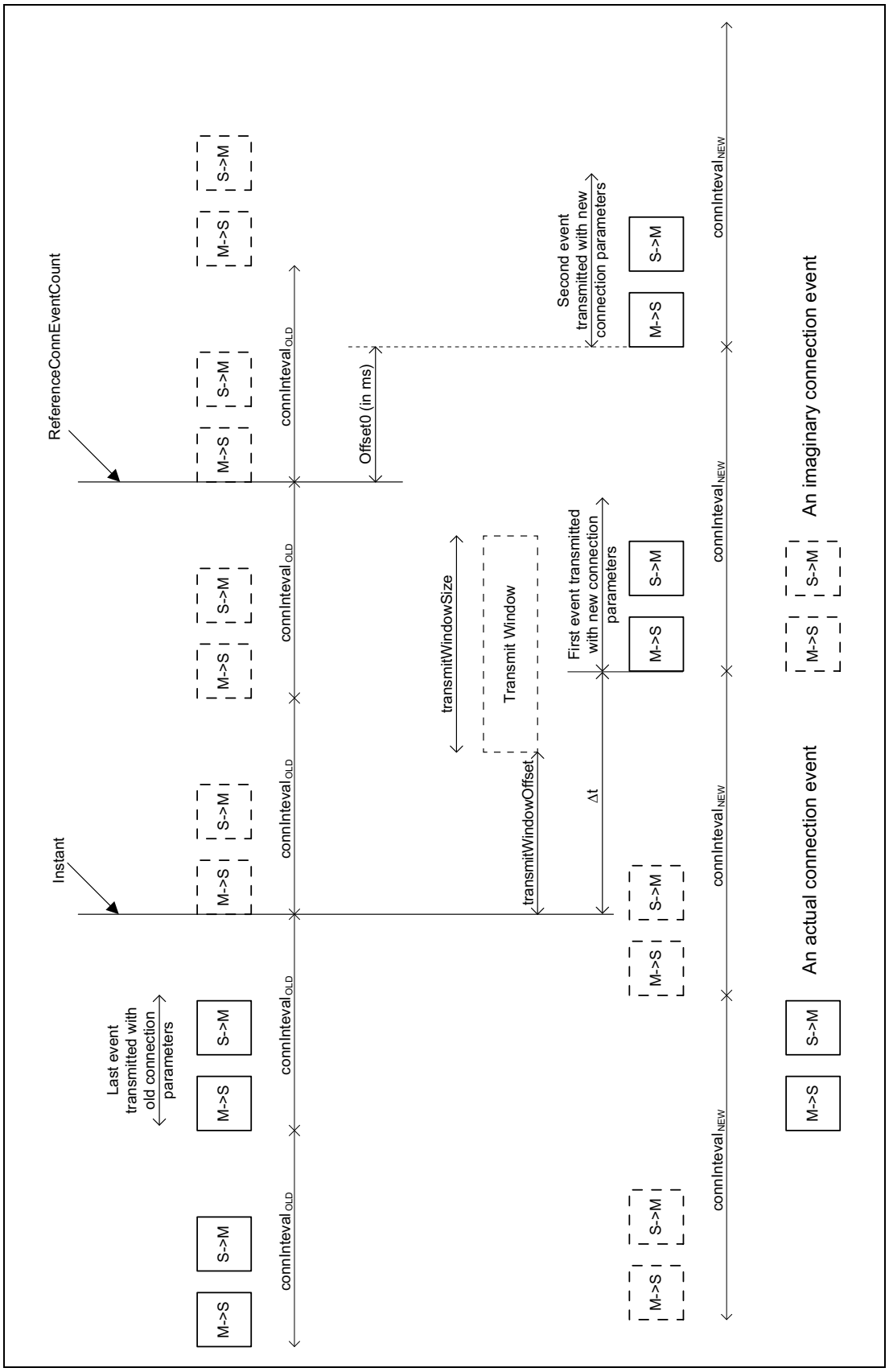

Figure 5.2: Utilizing the ReferenceConnEventCount and Offset0 fields to indicate position of the new anchor points – Instant is before the ReferenceConnEventCount

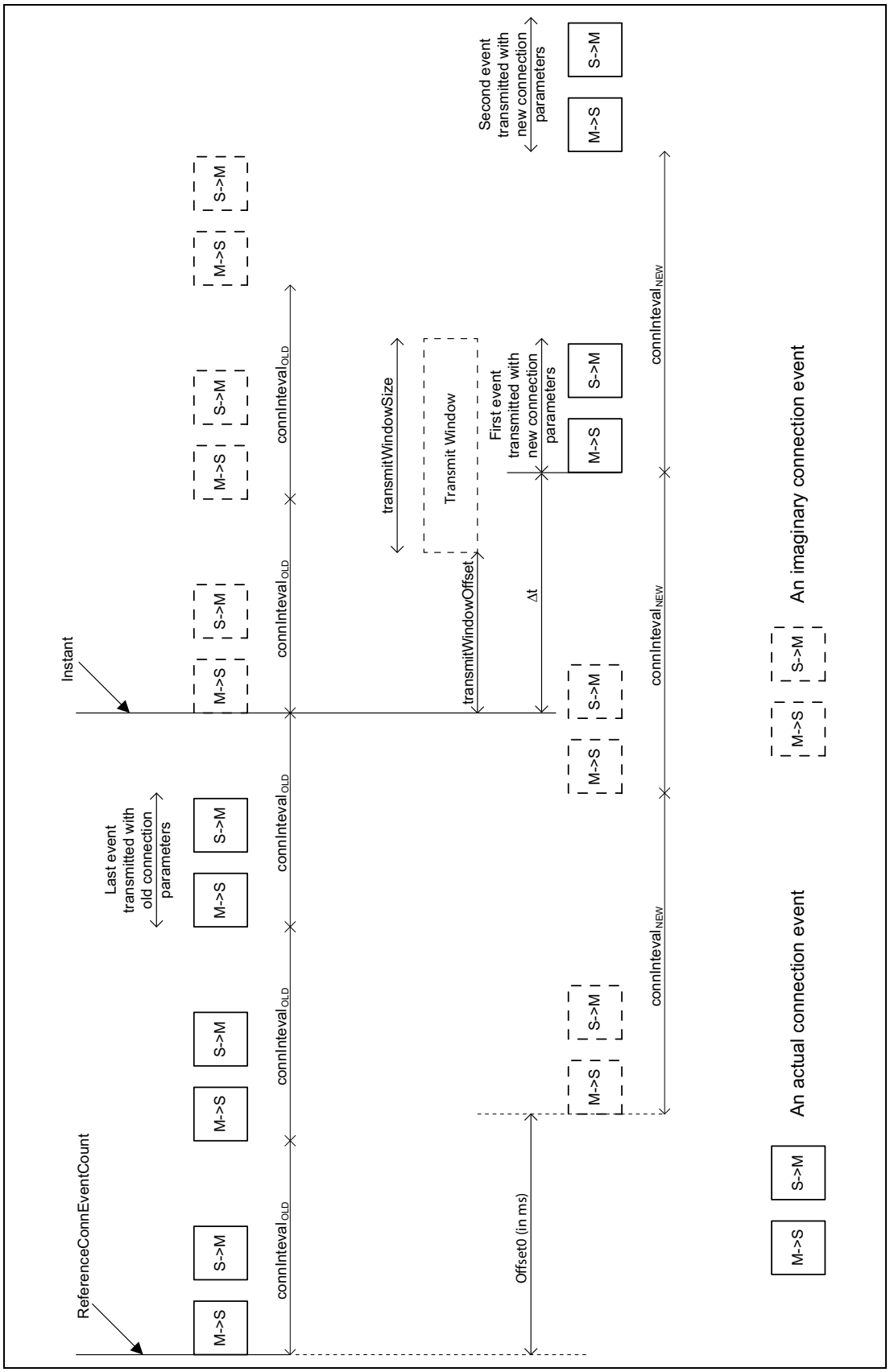

Figure 5.3: Utilizing the ReferenceConnEventCount and Offset0 fields to indicate position of the new anchor points – Instant is after the ReferenceConnEventCount

5.1.7.3.3 Slave initiated interval and anchor point move

The following example shows the Link Layer of the slave requesting a change in both the connection interval (by indicating a PreferredPeriodicity such that PreferredPeriodicity and $connInterval_{OLD}$ are not integral multiples of one another) and a change in anchor points of the LE connection by 3.75ms with respect to the ReferenceConnEventCount.

In this example, $connInterval_{OLD}$ is 0x0C (15 ms). The Link Layer of the slave issues an LL_CONNECTION_PARAM_REQ PDU with the following parameters:

- Interval_Min: 0x16
- Interval_Max: 0x20
- Latency: *connSlaveLatency*
- Timeout: *connSupervisionTimeout*
- PreferredPeriodicity: 0x0A
- ReferenceConnEventCount: 0x1F00
- Offset0: 0x0003
- Offset1: 0xFFFF
- Offset2: 0xFFFF
- Offset3: 0xFFFF
- Offset4: 0xFFFF
- Offset5: 0xFFFF

If the Link Layer of the master accepts the slave's request, then it could respond with an LL_CONNECTION_UPDATE_IND PDU that contains any one of the following set of parameters. In all the sets, the new connection interval $connInterval_{NEW}$ is set to 0x1E (37.5 ms), Latency is set to *connSlaveLatency*, Timeout is set to *connSupervisionTimeout* and Instant is set to 0x1F06.

Δt, as described in Section 5.1.7.3.2 is calculated as 21 (26.25 ms).

The WinSize and WinOffset fields in the LL_CONNECTION_UPDATE_IND PDU can contain any of the following example set of parameters:

- Option 1: the first packet sent after the instant by the master is inside the Transmit Window and 3.75 ms from the beginning of the Transmit Window.
  - 3 ≤ WinSize ≤ 8
  - WinOffset: 18
- Option 2: the first packet sent after the instant by the master is inside the Transmit Window and 2.5 ms from the beginning of the Transmit Window.
  - 2 ≤ WinSize ≤ 8
  - WinOffset: 19

- Option 3: the first packet sent after the instant by the master is inside the Transmit Window and 1.25ms from the beginning of the Transmit Window.
  - 1 ≤ WinSize ≤ 8
  - WinOffset: 20
- Option 4: the first packet sent after the instant by the master is inside the Transmit Window and 0ms from the beginning of the Transmit Window.
  - 1 ≤ WinSize ≤ 8
  - WinOffset: 21

5.1.7.4 Packet Transmit Time Restrictions

This section only applies if the current PHY is the LE Coded PHY and the Controller supports the LE Data Packet Length Extension feature.

After having sent or received an LL_CONNECTION_UPDATE_IND PDU that decreases the connection interval, and until the instant has been reached, the Link Layer shall not transmit a packet that would take longer than *connEffectiveMaxTxTime* microseconds (see Section 4.5.10) to transmit, calculated using the connection interval that will apply after the instant.

After a slave sends an LL_CONNECTION_PARAM_REQ or LL_CONNECTION_PARAM_RSP PDU where *Interval_Min* indicates an interval less than the current connection interval, and until it receives an LL_CONNECTION_UPDATE_IND, LL_UNKNOWN_RSP, or LL_REJECT_EXT_IND PDU in response, its link layer shall not transmit a packet that would take longer than *connEffectiveMaxTxTime* microseconds to transmit, calculated using a connection interval corresponding to the *Interval_Min* value in the transmitted PDU.

If the value of *connEffectiveMaxTxTime* changes during the procedure, the above requirements apply to the value at the moment the Data Channel PDU is queued for transmission.

Note: The requirements of this section are in addition to, and do not override, those in Section 4.5.10.

Note: If a Link Layer has any Data Channel PDUs queued for transmission at the start of the procedure or queues any during the procedure, it may need to re-fragment those PDUs in order to meet these requirements.

5.1.8 LE Ping Procedure

The LE Ping procedure, when supported, can be used at the Link Layer to verify presence of the remote Link Layer. The procedure can also be used to verify message integrity on the LE ACL logical transport by forcing the remote device to send an LE ACL packet that contains a valid MIC.

Either the master or the slave Link Layer may initiate this procedure at any time after entering the Connection State by sending an LL_PING_REQ PDU. The responding Link Layer responds with the LL_PING_RSP PDU.

The Link Layer supporting this feature shall send an LL_PING_REQ PDU when the remote device has not sent a packet containing a payload protected by a MIC within the authenticated payload timeout set by the Host ([Vol 2] Part E, Section 7.3.94).

The procedure is completed when either an LL_PING_RSP is received or, in the case the remote device does not support the LE Ping feature, an LL_UNKNOWN_RSP is received with the Unknown type set to LL_PING_REQ.

5.1.9 Data Length Update Procedure

A Controller uses the Data Length Update Procedure to transmit the latest values of the current maximum Receive Data Channel PDU Payload Length and PDU Time (*connMaxRxOctets* and *connMaxRxTime*) and the current maximum Transmit Data Channel PDU Payload Length and PDU Time (*connMaxTxOctets* and *connMaxTxTime*) to the peer device.

Both the master and slave can initiate this procedure at any time after entering the Connection State by sending an LL_LENGTH_REQ PDU. This procedure shall be initiated by the Link Layer whenever any of these parameters change, whether requested by the Host or autonomously by the Link Layer. However, if this procedure has already been initiated by the remote Controller and the local Controller has not yet responded, it shall use the response to communicate the changes instead of initiating a new procedure.

If the Link Layer receives an LL_LENGTH_REQ, or an LL_LENGTH_RSP PDU that was a response to an LL_LENGTH_REQ PDU, then it shall update its *connRemoteMaxTxOctets*, *connRemoteMaxRxOctets*, *connRemoteMaxTxTime*, and *connRemoteMaxRxTime* parameters for the connection with the values in the PDU. It shall immediately start using the updated values for all new Data Channel PDUs queued for transmission (including any response as specified in the next paragraph). The length of any Data Channel PDUs that have already been queued for transmission or transmitted at least once shall not be changed.

Note: Because Link Layer PDUs are not required to be processed in real time, it is possible for the local Controller to have queued but not yet transmitted an LL_LENGTH_REQ PDU when it receives an LL_LENGTH_REQ PDU from the peer device. In this situation each device responds as normal; the resulting collision is harmless.

Upon receiving an LL_LENGTH_REQ PDU, the Link Layer shall respond with an LL_LENGTH_RSP PDU containing its own *connMaxTxOctets*, *connMaxRxOctets*, *connMaxTxTime*, and *connMaxRxTime* values for the

connection (which it may have updated based on the values received, for example so as to allow the remote device to transmit longer packets).

If the peer device does not support the LE Coded PHY feature, then the MaxRxTime and MaxTxTime fields in the LL_LENGTH_REQ and LL_LENGTH_RSP PDUs shall be set to a value less than or equal to 2120 microseconds.

If the Link Layer of the master or slave sends the LL_LENGTH_REQ PDU to a device that does not understand that PDU, then the device should expect an LL_UNKNOWN_RSP PDU in response.

The procedure is completed when the initiating Controller receives either an LL_LENGTH_RSP PDU or, in the case the remote device does not support the LE Data Packet Length Extension feature, an LL_UNKNOWN_RSP PDU with the Unknown type set to LL_LENGTH_REQ.

5.1.10 PHY Update Procedure

The PHY Update Procedure, when supported, is used to change the transmit or receive PHYs, or both. The procedure can be initiated either on a request by the Host or autonomously by the Link Layer. Either the master or the slave may initiate this procedure at any time after entering the Connection State. Link Layer PHY preferences may change during a connection or between connections and, therefore, they should not be cached by the peer device.

When this procedure is initiated by the master, it sends an LL_PHY_REQ PDU. The slave responds with an LL_PHY_RSP PDU. The master then responds to this with an LL_PHY_UPDATE_IND PDU.

When this procedure is initiated by the slave, it sends an LL_PHY_REQ PDU. The master responds with an LL_PHY_UPDATE_IND PDU.

The TX_PHYS and RX_PHYS fields of the LL_PHY_REQ and LL_PHY_RSP PDUs shall be used to indicate the PHYs that the sending Link Layer prefers to use. If the sender wants a symmetric connection (one where the two PHYs are the same) it should make both fields the same, only specifying a single PHY.

The M_TO_S_PHY and S_TO_M_PHY fields of the LL_PHY_UPDATE_IND PDU shall indicate the PHYs that shall be used after the instant.

If the master initiated the procedure, it shall determine the PHY to use in each direction based on the contents of the LL_PHY_REQ and LL_PHY_RSP PDUs using the following rules:

- the M_TO_S_PHY field of the LL_PHY_UPDATE_IND PDU shall be determined from the master's TX_PHYS field and the slave's RX_PHYS field;

- the S_TO_M_PHY field of the LL_PHY_UPDATE_IND PDU shall be determined from the master's RX_PHYS field and the slave's TX_PHYS field.

In each of those cases the following rules apply:

- if, for at least one PHY, the corresponding bit is set to 1 in both the TX_PHYS and RX_PHYS fields, the master shall select any one of those PHYs for that direction;
- if there is no PHY for which the corresponding bit is set to 1 in both the TX_PHYS and RX_PHYS fields, the master shall not change the PHY for that direction.

If the slave initiated the procedure, the master shall determine the PHY to use in each direction based on the contents of the LL_PHY_REQ PDU sent by the slave using the following rules:

- the M_TO_S_PHY field of the LL_PHY_UPDATE_IND PDU shall be determined from the RX_PHYS field of the slave’s PDU;
- the S_TO_M_PHY field of the LL_PHY_UPDATE_IND PDU shall be determined from the TX_PHYS field of the slave’s PDU.

In each of those cases the following rules apply:

- if, for at least one PHY, the PHY is one that the master prefers to use and the corresponding bit is set to 1 in the relevant field of the slave’s PDU, the master shall select any one of those PHYs for that direction;
- if there is no PHY which the master prefers to use and for which the corresponding bit is set to 1 in the relevant field of the slave’s PDU, the master shall not change the PHY for that direction.

The remainder of this section shall apply irrespective of which device initiated the procedure.

Irrespective of the above rules, the master may leave both directions unchanged. If the slave specified a single PHY in both the TX_PHYS and RX_PHYS fields and both fields are the same, the master shall either select the PHY specified by the slave for both directions or shall leave both directions unchanged.

If either PHY will change, Section 5.5 shall apply to the LL_PHY_UPDATE_IND PDU. Both devices shall use the new PHYs starting at the instant.

If a master or slave sends an LL_PHY_REQ PDU to a device that does not understand that PDU, then the receiving device shall send an LL_UNKNOWN_RSP PDU in response.

The procedure has completed when:

- an LL_UNKNOWN_RSP or LL_REJECT_EXT_IND PDU has been sent or received;
- an LL_PHY_UPDATE_IND PDU indicating that neither PHY will change has been sent or received; or
- the master sends an LL_PHY_UPDATE_IND PDU indicating that at least one PHY will change and the instant has been reached. In this case, the procedure response timeout shall be stopped on the master when it sends that PDU and on the slave when it receives that PDU.

The Controller shall notify the Host of the PHYs now in effect when the PHY Update Procedure completes if either it has resulted in a change of one or both PHYs or if the procedure was initiated by a request from the Host. Otherwise, it shall not notify the Host that the procedure took place.

5.1.10.1 Packet Transmit Time Restrictions

After having sent or received an LL_PHY_UPDATE_IND PDU that changes either PHY, and until the instant has been reached, the Link Layer shall not transmit a packet that would take longer than *connEffectiveMaxTxTime* microseconds (see Section 4.5.10) to transmit on the PHY that will apply after the instant.

After a slave sends an LL_PHY_REQ PDU, and until it receives an LL_PHY_UPDATE_IND, LL_UNKNOWN_RSP, or LL_REJECT_EXT_IND PDU in response, its link layer shall not transmit a packet that would take longer than *connEffectiveMaxTxTime* microseconds to transmit on any PHY that appears in the TX_PHYS field of that LL_PHY_REQ PDU.

If a slave responds to the PHY Update Procedure then, during the period starting when it sends the LL_PHY_RSP PDU and ending when it receives the LL_PHY_UPDATE_IND PDU in response, the slave's Link Layer shall not transmit a packet that would take longer than *connEffectiveMaxTxTime* microseconds to transmit on any PHY that appears in both the TX_PHYS field of its LL_PHY_RSP PDU and the RX_PHYS field of the master's LL_PHY_REQ PDU.

If the value of *connEffectiveMaxTxTime* changes during the procedure, the above requirements apply to the value at the moment the Data Channel PDU is queued for transmission.

Note: The requirements of this section are in addition to, and do not override, those in Section 4.5.10.

Note: If a Link Layer has any Data Channel PDUs queued for transmission at the start of the procedure or queues any during the procedure, it may need to re-fragment those PDUs in order to obey these requirements.

5.1.11 Minimum Number Of Used Channels Procedure

A Controller uses the Minimum Number Of Used Channels Procedure to request that the peer device uses a minimum number of channels on a given PHY.

The slave can initiate this procedure at any time after entering the Connection State by sending an LL_MIN_USED_CHANNELS_IND PDU. The Master shall not send this PDU.

If the Link Layer receives an LL_MIN_USED_CHANNELS_IND PDU, it should ensure that, whenever the slave-to-master PHY is one of those specified, the connection uses at least the number of channels given in the MinUsedChannels field of the PDU.

The procedure has completed when the Link Layer acknowledgment of the LL_MIN_USED_CHANNELS_IND PDU is sent or received.

If the channel map does not include the minimum number of channels the slave requires for regulatory compliance, the slave must take steps to remain regulatory compliant, which can include disconnecting the link or reducing the output power.

5.2 PROCEDURE RESPONSE TIMEOUT

This section specifies procedure timeout rules that shall be applied to all the Link Layer control procedures specified in Section 5.1, except for the Connection Update and Channel Map Update procedures for which there are no timeout rules.

To be able to detect a non-responsive Link Layer Control Procedure, both the master and the slave shall use a procedure response timeout timer, T_{PRT}. Upon the initiation of a procedure, the procedure response timeout timer shall be reset and started.

Each LL Control PDU that is queued for transmission resets the procedure response timeout timer.

When the procedure completes, the procedure response timeout timer shall be stopped.

If the procedure response timeout timer reaches 40 seconds, the connection is considered lost. The Link Layer exits the Connection State and shall transition to the Standby State. The Host shall be notified of the loss of connection.

5.3 PROCEDURE COLLISIONS

Since LL Control PDUs are not interpreted in real time, collisions can occur where the Link Layer of the master and the Link Layer of the slave initiate incompatible procedures. Two procedures are incompatible if they both involve an instant. In this situation, the rules in this section shall be followed:

A device shall not initiate a procedure after responding to a PDU that had initiated an incompatible procedure until that procedure is complete.

If device initiates a procedure A and, while that procedure is not complete, receives a PDU from its peer that initiates an incompatible procedure B, then:

- If the peer has already sent at least one PDU as part of procedure A, the device should immediately exit the Connection State and transition to the Standby State.
- Otherwise, if the device is the master, it shall reject the PDU received from the slave by issuing an LL_REJECT_EXT_IND (if supported by both devices) or LL_REJECT_IND (otherwise) PDU. It shall then proceed with procedure A.
- Otherwise (the device is the slave) it shall proceed to handle the master-initiated procedure B and take no further action in the slave-initiated procedure A except processing the rejection from the master.

The Host shall be notified that the link has been disconnected with, or the rejection PDU shall use (as appropriate):

- the error code *LMP Error Transaction Collision / LL Procedure Collision* (0x23) if procedures A and B are the same procedure;
- the error code *LMP Error Transaction Collision / LL Procedure Collision* (0x23) if procedure A is the Connection Update Procedure and procedure B is the Connection Parameters Update Procedure;
- the error code *Different Transaction Collision* (0x2A) otherwise.

5.4 LE AUTHENTICATED PAYLOAD TIMEOUT

LE Authenticated Payload Timeout (*authenticatedPayloadTO*) is a parameter that defines the maximum amount of time in milliseconds allowed between receiving packets containing a valid MIC. The Host can change the value of *authenticatedPayloadTO* using the HCI_Write_Authenticated_Payload_Timeout Command ([Vol 2] Part E, Section 7.3.94). The default value for *authenticatedPayloadTO* is 30 seconds.

When the connection is encrypted, a device supporting LE Ping feature shall start the LE Authenticated Payload timer $T_{LE\_Authenticated\_Payload}$ to monitor the time since the last reception of a packet containing a valid MIC from the remote device. Each device shall reset the timer $T_{LE\_Authenticated\_Payload}$ upon reception of a packet with a valid MIC.

If at any time in the CONNECTION state the timer $T_{LE\_Authenticated\_Payload}$ reaches the *authenticatedPayloadTO* value, the Host shall be notified using the HCI Authenticated Payload Timeout Expired event ([Vol 2] Part E, Section 7.7.75). The $T_{LE\_Authenticated\_Payload}$ Timer restarts after it is expired.

The timer $T_{LE\_Authenticated\_Payload}$ shall continue to run during encryption pause procedure.

Whenever the Host sets the *authenticatedPayloadTO* while the timer $T_{LE\_Authenticated\_Payload}$ is running, the timer shall be reset.

5.5 PROCEDURES WITH INSTANTS

Where a procedure involves a PDU with an Instant field, then the following rules shall apply.

The Instant field shall be used to indicate the *connEventCount* when the relevant change shall be applied; this is known as the instant for the procedure. The master should allow a minimum of 6 connection events that the slave will be listening for before the instant occurs, considering that the slave may only be listening once every *connSlaveLatency* events.

When a slave receives such a PDU where (Instant – *connEventCount*) modulo 65536 is less than 32767 and Instant is not equal to *connEventCount*, the slave shall listen to all the connection events until it has confirmation that the master has received its acknowledgment of the PDU or *connEventCount* equals Instant.

When a slave receives such a PDU where (Instant – *connEventCount*) modulo 65536 is greater than or equal to 32767 (because the instant is in the past), the Link Layer of the slave shall consider the connection to be lost, shall exit the Connection State and transition to the Standby State, and shall notify the Host using the error code *Instant Passed* (0x28).

Note: The comparison of the *connEventCount* and the received Instant field is performed using modulo 65536 math (only values from 0 to 65535 are allowed), to handle the situation when the *connEventCount* field has wrapped.

6 PRIVACY

The Link Layer provides Privacy by using Private Addresses (see Section 1.3.2).

If a device is using Resolvable Private Addresses Section 1.3.2.2, it shall also have an Identity Address that is either a Public or Random Static address type.

6.1 PRIVATE ADDRESS GENERATION INTERVAL

A private address shall be generated using the Resolvable Private Address Generation (see Section 1.3.2.2).

The Link Layer shall set a timer determined by the Host. A new private address shall be generated when the timer expires. If the Link Layer is reset, a new private address shall be generated and the timer started with any value in the allowed range.

Note: If the private address is generated frequently, connection establishment times may be affected. It is recommended to set the timer to 15 minutes.

6.2 PRIVACY IN THE ADVERTISING STATE

Privacy in the advertising state determines how the Link Layer processes Resolvable Private Addresses for advertising events.

The requirements in the following sub-sections apply in addition to those in Section 4.4.2.

6.2.1 Connectable and Scannable Undirected Event Type

The Link Layer may use resolvable private addresses or non-resolvable private addresses for the advertiser's device address (AdvA field) when entering the Advertising State and using connectable and scannable undirected events.

The AdvA field of the connectable and scannable undirected advertising event PDU is generated using the Local IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2). If the Host has not provided any Resolving List IRK pairs for the peer to the Link Layer, then the AdvA field shall use a Host-provided address.

When an advertiser receives a connection request that contains a resolvable private address for the initiator's address (InitA field), the Link Layer shall resolve the private address (see Section 1.3.2.3). The advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser establishes a connection.

When an advertiser receives a connection request that contains a device identity address for the initiator's address field (InitA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser establishes a connection.

When an advertiser receives a scan request that contains a resolvable private address for the scanner’s device address (ScanA field), the Link Layer shall resolve the private address (see Section 1.3.2.3). The advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser processes the scan request.

When an advertiser receives a scan request that contains a device identity address for the scanner's device address (ScanA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser processes the scan request.

When an advertiser receives a scan or connection request that contains a non-resolvable private address, the advertising filter policy (see Section 4.3.2) shall determine if the advertiser processes the scan or connection request.

If the advertiser processes the scan request, the advertiser’s device address (AdvA field) in the SCAN_RSP PDU shall be the same as the advertiser’s device address (AdvA field) in the SCAN_REQ PDU to which it is responding.

6.2.2 Connectable Directed Event Type

The Link Layer shall use resolvable private addresses for the advertiser’s device address (AdvA field). If an IRK is available in the Link Layer Resolving List for the peer device, then the target’s device address (TargetA field) shall use a resolvable private address. If an IRK is not available in the Link Layer Resolving List or the IRK is set to zero for the peer device, then the target’s device address (TargetA field) shall use the Identity Address when entering the Advertising State and using connectable directed events.

The AdvA field of the connectable directed advertising event PDU is generated using the Local IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2).

The TargetA field of the connectable directed advertising event PDU is generated using the Peer IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2). The TargetA field uses the public or static device address of the peer device if no peer IRK is available.

When an advertiser receives a connection request that contains a resolvable private address for the initiator's address (InitA field), the Link Layer shall resolve the private address (see Section 1.3.2.3).

When an advertiser receives a connection request that contains a device identity address for the initiator's address field (InitA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser establishes a connection.

6.2.3 Non-connectable and Non-scannable Undirected and Scannable Undirected Event Types

The Link Layer may use resolvable private addresses or non-resolvable private addresses for the advertiser's device address (AdvA field) when entering the Advertising State and using the following event types:

- non-connectable and non-scannable undirected event
- scannable undirected event

The AdvA field of the non-connectable and non-scannable undirected advertising event PDU and scannable undirected event PDU are generated using the advertiser's Local IRK value and the Resolvable Private Address Generation Procedure or Non-Resolvable Private Address Generation Procedure (see Section 1.3.2.2).

When an advertiser receives a scan request that contains a resolvable private address for the scanner's device address (ScanA field), the Link Layer shall resolve the private address (see Section 1.3.2.3). The advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser processes the scan request.

When an advertiser receives a scan request that contains a device identity address for the scanner's device address (ScanA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser processes the scan request.

When an advertiser receives a scan request that contains a non-resolvable private address, the advertising filter policy (see Section 4.3.2) shall determine if the advertiser processes the scan request.

If the advertiser processes the scan request, the advertiser's device address (AdvA field) in the scan response PDU shall be the same as the advertiser's device address (AdvA field) in the scan request PDU to which it is responding.

6.2.4 Connectable Undirected Event Type

The Link Layer may use resolvable private addresses or non-resolvable private addresses for the advertiser's device address (AdvA field) when entering the Advertising State and using connectable undirected events.

The AdvA field of the connectable undirected advertising event PDU is generated using the Local IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2). If the Host has not provided any Resolving List IRK pairs for the peer to the Link Layer, then the AdvA field shall use a Host-provided address.

When an advertiser receives a connection request that contains a resolvable private address for the target's address (TargetA field), the Link Layer shall resolve the private address (see Section 1.3.2.3). The advertising filter policy, where the White List is enabled (see Section 4.3.2), shall determine if the advertiser establishes a connection.

The advertising filter policy (see Section 4.3.2) shall determine if the advertiser processes the connect request if an advertiser receives a connect request that contains a non-resolvable private address.

6.2.5 Non-connectable and Non-scannable Directed and Scannable Directed Event Types

The Link Layer may use resolvable private addresses or non-resolvable private addresses for the advertiser's device address (AdvA field) when entering the Advertising State and using the following event types:

- non-connectable and non-scannable directed event
- scannable directed event

If an IRK is available in the Link Layer Resolving List for the peer device, then the target's device address (TargetA field) shall use a resolvable private address. If an IRK is not available in the Link Layer Resolving List or the IRK is set to zero for the peer device, then the target's device address (TargetA field) shall use the Identity Address when entering the Advertising State and using non-connectable and non-scannable directed and scannable directed events.

The AdvA field of the non-connectable and non-scannable directed advertising event PDU and scannable directed event PDU is generated using the advertiser's Local IRK value and the Resolvable Private Address Generation Procedure or Non-Resolvable Private Address Generation Procedure (see Section 1.3.2.2).

The TargetA field of the scannable directed advertising event PDU is generated using the Peer IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2). The TargetA field uses the public or static device address of the peer device if no peer IRK is available.

When an advertiser receives a scan request that contains a resolvable private address for the scanner's device address (ScanA field), the Link Layer shall resolve the private address (see Section 1.3.2.3).

If the advertiser processes the scan request, the advertiser's device address (AdvA field) in the AUX_SCAN_RSP PDU shall be the same as the advertiser's device address (AdvA field) in the AUX_SCAN_REQ PDU to which it is responding.

6.3 PRIVACY IN THE SCANNING STATE

The requirements in this section apply in addition to those in Section 4.4.3.

The Link Layer may use resolvable private addresses or non-resolvable private addresses for the scanner's device address (ScanA field) when entering the Scanning State.

The ScanA field of the scanning PDU is generated using the Resolving List's Local IRK value and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2), or the address is provided by the Host.

The advertiser's device address (AdvA field) in the scan request PDU shall be the same as the advertiser's device address (AdvA field) received in the advertising PDU to which the scanner is responding.

When a scanner receives an advertising event that contains a resolvable private address for the advertiser's device address (AdvA field), the Link Layer shall resolve the private address (see Section 1.3.2.3). The scanner's filter policy, where the White List is enabled (see Section 4.3.3), shall determine if the scanner responds with a scan request.

When a scanner receives an advertising packet that contains a device identity address for the advertiser's device address (AdvA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the scanner's filter policy, where the White List is enabled (see Section 4.3.3), shall determine if the scanner responds with a scan request.

When a scanner receives an advertising event that contains a non-resolvable private address, the scanner's filter policy (see Section 4.3.3) shall determine if the scanner processes the advertising event.

6.4 PRIVACY IN THE INITIATING STATE

The requirements in this section apply in addition to those in Section 4.4.4.

The Link Layer may use resolvable private addresses or an address provided by the Host for the initiator's device address (InitA field) when in the Initiating state.

When an initiator receives a connectable advertising event that contains a resolvable private address for the advertiser's address (AdvA field), the Link Layer shall resolve the private address using the Peer IRK values (see Section 1.3.2.3). The initiator's filter policy (see Section 4.3.4) shall determine if the initiator establishes a connection.

The advertiser's device address (AdvA field) in the initiating PDU shall be the same as the advertiser's device address (AdvA field) received in the advertising event PDU to which the initiator is responding.

When an initiator receives a directed connectable advertising event that contains a resolvable private address for the target's address (TargetA field), the Link Layer shall resolve the private address using the Local IRK values (see Section 1.3.2.3). An initiator that has been instructed by the Host to use Resolvable Private Addresses shall not respond to directed connectable advertising events that contain Public or Static addresses for the target's address (TargetA field).

When an initiator receives a connectable advertising event that contains a device identity address for the advertiser's device address (AdvA field), and if that device is in the Resolving List with a non-zero peer IRK for which the Host has specified device privacy mode, then the initiator's filter policy, where the White List is enabled (see Section 4.3.4), shall determine if the initiator establishes a connection.

The Link Layer shall use resolvable private addresses for the initiator's device address (InitA field) when initiating connection establishment with an associated device that exists in the Resolving List. The initiator's device address (InitA field) in the initiating PDU is generated using the Resolving List Local IRK and the Resolvable Private Address Generation Procedure (see Section 1.3.2.2). The Link Layer should not set the InitA field to the same value as the TargetA field in the received advertising PDU.

The Link Layer shall use the Host-provided address for the initiator's device address (InitA field) when initiating connection establishment with a device that is not in the Resolving List.

6.5 PRIVACY OF THE DEVICE

A private device shall not use its Identity Address in any advertising PDU. The Host may command the Controller to advertise, scan, or initiate a connection using a Resolvable Private Address when the resolving list is enabled. If the local IRK in the resolving list associated with the peer Identity Address is all zeros, the Controller will use the Identity Address. If the peer IRK in the resolving list associated with the peer Identity Address is all zeros, the Controller will accept the Identity Address. If the Host has instructed the Controller to use device privacy mode with a peer Identity Address, the Controller will accept the peer's Identity Address. This implies that the device's network privacy is violated. To maintain a device's network privacy, the Host should only populate entries in the Controller's resolving list with non-zero IRKs and not instruct the Controller to use device privacy mode.

SAMPLE DATA

This part of the specification contains sample data for Bluetooth low energy. All sample data are provided for reference purpose only. They can be used to check the behavior of an implementation and avoid misunderstandings.

CONTENTS

1 ENCRYPTION SAMPLE DATA

This section contains sample data for the Low Energy encryption process.

The following scenario describes the start of encryption, followed by the transfer of an encrypted data channel data packet in each direction. It describes:

- how the derived values are calculated (fixed values are given in red)
- which HCI command and events are exchanged (given in italic)
- which LL messages are exchanged over the air (given in green).

Note: CRCs are not shown because they depend on a random CRC init value. Scrambling is disabled.

The following parameters are set to the fixed values below:

```
LTK = 0x4C68384139F574D836BCF34E9DFB01BF (MSO to LSO)
EDIV = 0x2474 (MSO to LSO)

RAND = 0xABCDEF1234567890 (MSO to LSO)
SKDm = 0xACBDCEDFE0F10213 (MSO to LSO)
SKDs = 0x0213243546576879 (MSO to LSO)
IVm = 0xBADCAB24 (MSO to LSO)
IVs = 0xDEAFBABE (MSO to LSO)
```

HCI_LE_Start_Encryption (length 0x1C) – master HCI command
Pars (LSO to MSO) 00 08 90 78 56 34 12 ef cd ab 74 24 bf 01 fb 9d 4e f3 bc 36 d8 74 f5 39 41 38 68 4c
Handle (2-octet value MSO to LSO) 0x0800
Random (8-octet value MSO to LSO) 0xabcdef1234567890
Encrypted Diversifier (2-octet value MSO to LSO) 0x2474
Long Term Key (16-octet value MSO to LSO) 0x4c68384139f574d836bcf34e9dfb01bf

SKDm (LSO to MSO) :0x13:0x02:0xF1:0xE0:0xDF:0xCE:0xBD:0xAC:

IVm (LSO to MSO) :0x24:0xAB:0xDC:0xBA

LL_ENC_REQ 03 17 03 90 78 56 34 12 ef cd ab 74 24 13 02 f1 e0 df ce bd ac 24 ab dc ba
Length 0x17
Control Type 0x03
Rand 90 78 56 34 12 ef cd ab
EDIV 74 24
SKDm 13 02 f1 e0 df ce bd ac
IVm 24 ab dc ba

SKDs (LSO to MSO) :0x79:0x68:0x57:0x46:0x35:0x24:0x13:0x02:

IVs (LSO to MSO) :0xBE:0xBA:0xAF:0xDE

Sample Data

```
LL_ENC_RSP 0b 0d 04 79 68 57 46 35 24 13 02 be ba af de
  Length 0x0D
  Control Type 0x04
  SKDs 79 68 57 46 35 24 13 02
  IVs be ba af de

IV = IVm || IVs
IV (LSO to MSO)      :0x24:0xAB:0xDC:0xBA:0xBE:0xBA:0xAF:0xDE

HCI_Long_Term_Key_Requested(length 0x0D) – slave event
  Pars (LSO to MSO)05 01 08 90 78 56 34 12 ef cd ab 74 24
    LE_Event_Code 0x05
    Handle (2-octet value MSO to LSO) 0x0801
    Random (8-octet value MSO to LSO) 0xabcdef1234567890
    Encrypted Diversifier (2-octet value MSO to LSO) 0x2474

HCI_LE_Long_Term_Key_Request_Reply (length 0x12) – slave command
  Pars (LSO to MSO)    01 08 bf 01 fb 9d 4e f3 bc 36 d8 74 f5 39 41 38 68 4c
    Handle (2-octet value MSO to LSO) 0x0801
    Key (16-octet value MSO to LSO) 0x4C68384139F574D836BCF34E9DFB01BF


SKD = SKDm || SKDs
SKD (LSO to MSO)
:0x13:0x02:0xF1:0xE0:0xDF:0xCE:0xBD:0xAC:0x79:0x68:0x57:0x46:0x35:0x24:0x13:0x02:

SK = Encrypt(LTK, SKD)
SK (LSO to MSO)
:0x66:0xC6:0xC2:0x27:0x8E:0x3B:0x8E:0x05:0x3E:0x7E:0xA3:0x26:0x52:0x1B:0xAD:0x99:

LL_START_ENC_REQ 07 01 05
  Length 0x01
  Control Type 0x05

LL_START_ENC_RSP1 0f 05 9f cd a7 f4 48
  Length 0x05
  Control Type Encrypted:0x9F Clear:0x06
  MIC (32-bit value MSO to LSO) 0xCDA7F448 (note that MICs are sent MSO first on
the air)

LL_START_ENC_RSP2 07 05 a3 4c 13 a4 15
  Length 0x05
  Control Type Encrypted:0xA3 Clear:0x06
  MIC (32-bit value MSO to LSO) 0x4C13A415

HCI_ACL_Data_Packet Master Host to Controller
  00 08 1b 00 17 00 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 31 32 33 34 35 36
37 38 39 30
    Handle (12-bit value MSO to LSO) 0x0800
    Data Total Length (16-bit value MSO to LSO) 0x001B (27 dec)
    Data (LSO to MSO) 17 00 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 31 32 33
34 35 36 37 38 39 30

LL_DATA1 0e 1f 7a 70 d6 64 15 22 6d f2 6b 17 83 9a 06 04 05 59 6b d6 56 4f 79 6b 5b
9c e6 ff 32 f7 5a 6d 33
  Length 0x1F (i.e. 27 + 4 = 31 dec)
  Data (LSO to MSO)
```

Sample Data

```
    Clear     17 00 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 31 32 33 34 35 36
37 38 39 30
    Encrypted 7a 70 d6 64 15 22 6d f2 6b 17 83 9a 06 04 05 59 6b d6 56 4f 79 6b 5b
9c e6 ff 32
  MIC (32-bit value MSO to LSO)   0xF75A6D33

HCI_ACL_Data_Packet Slave Host to Controller
  01 08 1b 00 17 00 37 36 35 34 33 32 31 30 41 42 43 44 45 46 47 48 49 4a 4b 4c 4d
4e 4f 50 51
    Handle (12-bit value MSO to LSO) 0x0801
    Data Total Length (16-bit value MSO to LSO) 0x001B (27 dec)
    Data (LSO to MSO) 17 00 37 36 35 34 33 32 31 30 41 42 43 44 45 46 47 48 49 4a
4b 4c 4d 4e 4f 50 51


LL_DATA2 06 1f f3 88 81 e7 bd 94 c9 c3 69 b9 a6 68 46 dd 47 86 aa 8c 39 ce 54 0d 0d
ae 3a dc df 89 b9 60 88
  Length 0x1F (i.e. 27 + 4 = 31 dec)
  Data (LSO to MSO)
    Clear     17 00 37 36 35 34 33 32 31 30 41 42 43 44 45 46 47 48 49 4a 4b 4c 4d
4e 4f 50 51
    Encrypted f3 88 81 e7 bd 94 c9 c3 69 b9 a6 68 46 dd 47 86 aa 8c 39 ce 54 0d 0d
ae 3a dc df
  MIC (32-bit value MSO to LSO)   0x89B96088
```

1.1 ENCRYPT COMMAND

```
HCI_LE_Encrypt (length 0x20) – command
  Pars (LSO to MSO) bf 01 fb 9d 4e f3 bc 36 d8 74 f5 39 41 38 68 4c 13 02 f1 e0 df
ce bd ac 79 68 57 46 35 24 13 02
    Key (16-octet value MSO to LSO):            0x4C68384139F574D836BCF34E9DFB01BF
    Plaintext_Data (16-octet value MSO to LSO): 0x0213243546576879acbdcedfe0f10213

HCI_Command_Complete (length 0x14) – event
  Pars (LSO to MSO) 02 17 20 00 66 c6 c2 27 8e 3b 8e 05 3e 7e a3 26 52 1b ad 99
    Num_HCI_Commands_Packets: 0x02
    Command_Opcode (2-octet value MSO to LSO): 0x2017
    Status: 0x00
    Encrypted_Data (16-octet value MSO to LSO): 0x99ad1b5226a37e3e058e3b8e27c2c666
```

1.2 DERIVATION OF THE MIC AND ENCRYPTED DATA

All B/X/A/S values below follow the notation: LSbyte to MSbyte & msbit to lsbit.

```
IV = DEAFBABEBADCAB24
SK = 99AD1B5226A37E3E058E3B8E27C2C666

1.START_ENC_RSP1 (packet 0, M --> S)
----------------

B0 = 49000000008024ABDCBABEBAAFDE0001
B1 = 00010300000000000000000000000000
B2 = 06000000000000000000000000000000
```

Sample Data

```
X1 = 712eaaaae60603521d245e50786eefe4
X2 = debc43782a022675fca0aa6f0854f1ab
X3 = 6399913fede5fa111bdb993bbfb9be06
=> MIC = 6399913f

A0 = 01000000008024ABDCBABEBAAFDE0000
A1 = 01000000008024ABDCBABEBAAFDE0001

S0 = ae3e6577f64a8f25408c9c10d53acf8e
S1 = 99190d88f4aa1b60b97ecfe6f5fee777

So, encrypted packet payload = 9F
    encrypted MIC = CDA7F448

Which results in the following packet:

LL_START_ENC_RSP1 - 0f 05 9f cd a7 f4 48
  Length: 05
  Control Type:
    Clear:     06
    Encrypted: 9f
  MIC: CD A7 F4 48


2.START_ENC_RSP2 (packet 0, S --> M)
----------------

B0 = 49000000000024ABDCBABEBAAFDE0001
B1 = 00010300000000000000000000000000
B2 = 06000000000000000000000000000000

X1 = ddc86e3094f0c29cf341ef4c2c1e0088
X2 = fe960f5c93fba45a53959842ea8a0c0a
X3 = db403db3a32f39156faf6a6b472e1010
=> MIC = db403db3

A0 = 01000000000024ABDCBABEBAAFDE0000
A1 = 01000000000024ABDCBABEBAAFDE0001

S0 = 975399a66acdc39124886930d7bca95f
S1 = a5add4127b2f43788ddc9cd86b0b89d2

So, encrypted packet payload = A3
    encrypted MIC = 4c13a415

Which results in the following packet:

LL_START_ENC_RSP2 07 05 a3 4c 13 a4 15
  Length: 05
  Control Type:
    Clear:     06
```

Sample Data

Encrypted: A3
MIC: 4c 13 a4 15

3. Data packet1 (packet 1, M --> S)

B0 = 49010000008024ABDCBABEBAAFDE001B
B1 = 00010200000000000000000000000000
B2 = 17006364656667686 96A6B6C6D6E6F70
B3 = 71313233343536373839300000000000

X1 = 7c688612996de101f3eacb68b443969c
X2 = e3f1ef5c30161c0a9ec07274a0757fc8
X3 = e7e346f5b7c8a6072890a60dcf4ec20a
X4 = 3db113320b182f9fed635db14cac2df0
=> MIC = 3db11332

A0 = 01010000008024ABDCBABEBAAFDE0000
A1 = 01010000008024ABDCBABEBAAFDE0001
A2 = 01010000008024ABDCBABEBAAFDE0002

S0 = caeb7e017296dd2fa9a2ce789179501a
S1 = 6d70b50070440a9a027de8f66b6a6a29
S2 = 1ae7647c4d5e6dabdec602404c302341

So, encrypted packet payload =

7A70D66415226DF26B17839A060405596BD6564F796B5B9CE6FF32
encrypted MIC = F75A6D33

which results in the following packet:

LL_DATA1 0E 1F 7A 70 D6 64 15 22 6D F2 6B 17 83 9A 06 04 05 59 6B D6
56 4F 79 6B 5B 9C E6 FF 32 F7 5A 6D 33
Length: 1F
Data:
Clear: 17 00 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 31
32 33 34 35 36 37 38 39 30
Encrypted: 7A 70 D6 64 15 22 6D F2 6B 17 83 9A 06 04 05 59 6B D6
56 4F 79 6B 5B 9C E6 FF 32
MIC: F7 5A 6D 33

4. Data packet2 (packet 1, S --> M)

B0 = 49010000000024ABDCBABEBAAFDE001B
B1 = 00010200000000000000000000000000
B2 = 17003736353433323130414243444546
B3 = 4748494A4B4C4D4E4F50510000000000

Sample Data

```
X1 = 714234d50d6f1da5663be3e78460ad87
X2 = 96df1d97959e6176ac215c7baf90c674
X3 = 6cc52c3dcecdc2fa81eb347887960673
X4 = a776a26be617366496c391e36f6374a1 => MIC = a776a26b

A0 = 01010000000024ABDCBABEBAAFDE0000
A1 = 01010000000024ABDCBABEBAAFDE0001
A2 = 01010000000024ABDCBABEBAAFDE0002

S0 = 2ecfc2e31e01875653c0f306fc7bfb96
S1 = e488b6d188a0faf15889e72a059902c0
S2 = edc470841f4140e0758c8e8f708399bd


So, encrypted packet payload =

F38881E7BD94C9C369B9A66846DD4786AA8C39CE540D0DAE3ADCDF
    encrypted MIC = 89B96088


Which results in the following packet:


LL_DATA2 06 1F F3 88 81 E7 BD 94 C9 C3 69 B9 A6 68 46 DD 47 86 AA 8C
39 CE 54 0D 0D AE 3A DC DF 89 B9 60 88
  Length: 1F
  Data:
    Clear:     17 00 37 36 35 34 33 32 31 30 41 42 43 44 45 46 47 48
49 4a 4b 4c 4d 4e 4f 50 51
    Encrypted: F3 88 81 E7 BD 94 C9 C3 69 B9 A6 68 46 DD 47 86 AA 8C
39 CE 54 0D 0D AE 3A DC DF

MIC: 89 B9 60 88
```

2 LE CODED PHY SAMPLE DATA

Whenever bits are specified, they are in transmission order irrespective of spacing.

2.1 REFERENCE INFORMATION PACKET

The reference packet is described as bytes in transmission order (the leftmost byte in a line is transmitted first). Inside a byte, bits are transmitted LSB first.

```
Access address:   D6 BE 89 8E
PDU:              00 03 42 4C 45
CRC:              29 0A CE
```

2.2 FORWARD ERROR CORRECTION ENCODER

This data shows the bits input to and output by the FEC encoder and its internal state.

The encoder state is expressed in octal notation where the LSB represents the rightmost bit store in Figure 3.5 of [Vol 6] Part B, Section 3.3.1. The state specified is that after the bits are output and the shift operations have taken place.

```
Access address
Input:    0   1   1   0   1   0   1   1   0   1   1   1   1   1   0   1
          1   0   0   1   0   0   0   1   0   1   1   1   0   0   0   1
State:    0   4   6   3   5   2   5   6   3   5   6   7   7   7   3   5
          6   3   1   4   2   1   0   4   2   5   6   7   3   1   0   4
Output:   0 0 1 1 0 1 0 1 1 1 0 1 0 0 1 0 0 1 1 1 1 0 1 0 0 1 0 1 1 0 1 1
          1 0 0 1 0 0 0 0 1 0 1 1 1 1 1 1 1 0 0 0 1 0 1 0 1 0 0 0 1 1 1 1
```

Note to reviewers: this spacing makes it more obvious where the bits come from.

```
CI

          If S=2              If S=8
Input:    1   0               0   0
State:    6   3               2   1
Output:   0 1 0 1             1 0 1 1

TERM1
          If S=2              If S=8
Input:    0   0   0           0   0   0
State:    1   0   0           0   0   0
Output:   0 0 1 1 0 0         1 1 0 0 0 0

PDU

Input:    0   0   0   0   0   0   0   0   1   1   0   0   0   0   0   0
          0   1   0   0   0   0   1   0   0   0   1   1   0   0   1   0
          1   0   1   0   0   0   1   0
State:    0   0   0   0   0   0   0   0   4   6   3   1   0   0   0   0
          0   4   2   1   0   0   4   2   1   0   4   6   3   1   4   2
```

Sample Data

```
          5   2   5   2   1   0   4   2
Output:   0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 0 1 0 0 1 1 0 0 0 0 0 0 0
          0 0 1 1 1 0 1 1 1 1 0 0 1 1 1 0 1 1 1 1 1 1 0 1 0 1 0 0 0 0 1 0
          0 0 0 1 0 0 0 1 1 1 1 1 1 1 1 0
CRC
Input:    1   0   0   1   0   1   0   0   0   1   0   1   0   0   0   0
          0   1   1   1   0   0   1   1
State:    5   2   1   4   2   5   2   1   0   4   2   5   2   1   0   0
          0   4   6   7   3   1   4   6
Output:   0 0 0 1 1 1 0 0 1 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 0 0
          0 0 1 1 0 1 1 0 1 0 0 0 0 0 0 1
TERM2
Input:    0   0   0
State:    3   1   0
Output:   0 1 0 0 1 1
```

2.3 TRANSMITTED SYMBOLS (S=2)

```
Preamble
0011 1100 0011 1100 0011 1100 0011 1100 0011 1100 0011 1100
0011 1100 0011 1100 0011 1100 0011 1100

Access Address
0011 0011 1100 1100 0011 1100 0011 1100 1100 1100 0011 1100
0011 0011 1100 0011 0011 1100 1100 1100 1100 0011 1100 0011
0011 1100 0011 1100 1100 0011 1100 1100 1100 0011 0011 1100
0011 0011 0011 0011 1100 0011 1100 1100 1100 1100 1100 1100
1100 0011 0011 0011 1100 0011 1100 0011 1100 0011 0011 0011
1100 1100 1100 1100

CI
0011 1100 0011 1100

TERM1
0011 0011 1100 1100 0011 0011

PDU
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 0 1 0 0 1 1 0 0 0 0 0 0 0 0 1 1 1 0 1
1 1 1 0 0 1 1 1 0 1 1 1 1 1 1 0 1 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 1 1 1 1 1 1
1 0

CRC
0 0 0 1 1 1 0 0 1 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 0 0 0 0 1 1 0 1 1
0 1 0 0 0 0 0 0 1

TERM2
0 1 0 0 1 1
```

Total Packet Duration 510 µs

Note: Groupings of 4 bits show the effects of the P=4 pattern mapper.

2.4 TRANSMITTED SYMBOLS (S=8)

```
Preamble
0011 1100 0011 1100 0011 1100 0011 1100 0011 1100 0011 1100
0011 1100 0011 1100 0011 1100 0011 1100
```

Sample Data

```
Access Address
0011 0011 1100 1100 0011 1100 0011 1100 1100 1100 0011 1100
0011 0011 1100 0011 0011 1100 1100 1100 1100 0011 1100 0011
0011 1100 0011 1100 1100 0011 1100 1100 1100 0011 0011 1100
0011 0011 0011 0011 1100 0011 1100 1100 1100 1100 1100 1100
1100 0011 0011 0011 1100 0011 1100 0011 1100 0011 0011 0011
1100 1100 1100 1100

CI
1100 0011 1100 1100

TERM1
1100 1100 0011 0011 0011 0011

PDU
0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011
0011 0011 0011 0011 1100 1100 0011 1100 0011 1100 0011 0011
1100 1100 0011 0011 0011 0011 0011 0011 0011 0011 1100 1100
1100 0011 1100 1100 1100 1100 0011 0011 1100 1100 1100 0011
1100 1100 1100 1100 1100 1100 0011 1100 0011 1100 0011 0011
0011 0011 1100 0011 0011 0011 0011 1100 0011 0011 0011 1100
1100 1100 1100 1100 1100 1100 1100 0011

CRC
0011 0011 0011 1100 1100 1100 0011 0011 1100 0011 0011 0011
0011 1100 1100 1100 1100 1100 1100 1100 1100 0011 0011 0011
0011 1100 1100 1100 1100 1100 0011 0011 0011 0011 1100 1100
0011 1100 1100 0011 1100 0011 0011 0011 0011 0011 0011 1100

TERM2
0011 1100 0011 0011 1100 1100
```

Total Packet Duration 912 µs

Note: Groupings of 4 bits show the effects of the P=4 pattern mapper.

3 LE CHANNEL SELECTION ALGORITHM #2 SAMPLE DATA

This section contains two sets of sample data with different channel maps for the LE Channel Selection Algorithm #2.

The test access address is 0x8E89BED6, meaning the *channelIdentifier* is 0x305F.

3.1 SAMPLE DATA 1 (37 USED CHANNELS)

Channel map [36:0] = 11111_11111111_11111111_11111111_11111111b.

Counter	1	2	3
prn_e	1685	38301	27475
unmappedChannel	20	6	21
mappedChannel	20	6	21

3.2 SAMPLE DATA 2 (9 USED CHANNELS)

Channel map [36:0] =11110_00000000_11100000_00000110_00000000b.

The remapping table is [9, 10, 21, 22, 23, 33, 34, 35, 36].

Counter	6	7	8
prn_e	10975	5490	46970
unmappedChannel	23	14	17
mappedChannel	23	9	34

MESSAGE SEQUENCE CHARTS

Examples of message sequence charts showing the interactions of the Host Controller Interface with the Link Layer.

CONTENTS

1 INTRODUCTION

This section shows typical interactions between Host Controller Interface (HCI) Commands and Events and the Link Layer (LL). It focuses on the message sequence charts (MSCs) for the procedures specified in “Bluetooth Host Controller Interface Functional Specification” with regard to Link Layer Control Procedures from “Link Layer”. This section illustrates only the most useful scenarios; it does not cover all possible alternatives. Furthermore, the message sequence charts do not consider errors over the air interface or Host interface. In all message sequence charts it is assumed that all events are not masked, so the Host Controller will not filter out any events.

The sequence of messages in these message sequence charts is for illustrative purposes. The messages may be sent in a different order where allowed by the Link Layer or HCI sections. If any of these charts differ with text in the Link Layer or HCI sections, the text in those sections shall be considered normative. This section is informative.

1.1 NOTATION

The notation used in the message sequence charts (MSCs) consists of ovals, elongated hexagons, boxes, lines, and arrows. The vertical lines terminated on the top by a shadow box and at the bottom by solid oval indicate a protocol entity that resides in a device. MSCs describe interactions between these entities and states those entities may be in.

The following symbols represent interactions and states:

Oval	Defines the context for the message sequence chart
Hexagon	Indicates a condition needed to start the transactions below this hexagon. The location and width of the Hexagon indicates which entity or entities make this decision.
Box	Replaces a group of transactions. May indicate a user action, or a procedure in the baseband.
Dashed Box	Optional group of transactions.
Solid Arrow	Represents a message, signal or transaction. Can be used to show Link Layer and HCI traffic. Some baseband packet traffic is also shown. These are prefixed by BB followed by either the type of packet, or an indication that there is an ACK signal in a packet.
Dashed Arrow	Represents an optional message, signal or transaction. Can be used to show Link Layer and HCI traffic.

1.2 CONTROL FLOW

Some message sequences are split into several charts. These charts are marked in sequence with different step numbers with multiple paths through with optional letters after the step numbers. Numbers indicate normal or required ordering. The letters represent alternative paths. For example, Step 4 is after Step 3, and Step 5a could be executed instead of Step 5b.

1.3 EXAMPLE MSC

The protocol entities represented in the example shown in Figure 1.1 illustrate the interactions of two devices named A and B. Note that each device includes a Host and a LL entity in this example. Other MSCs in this section may show the interactions of more than two devices.

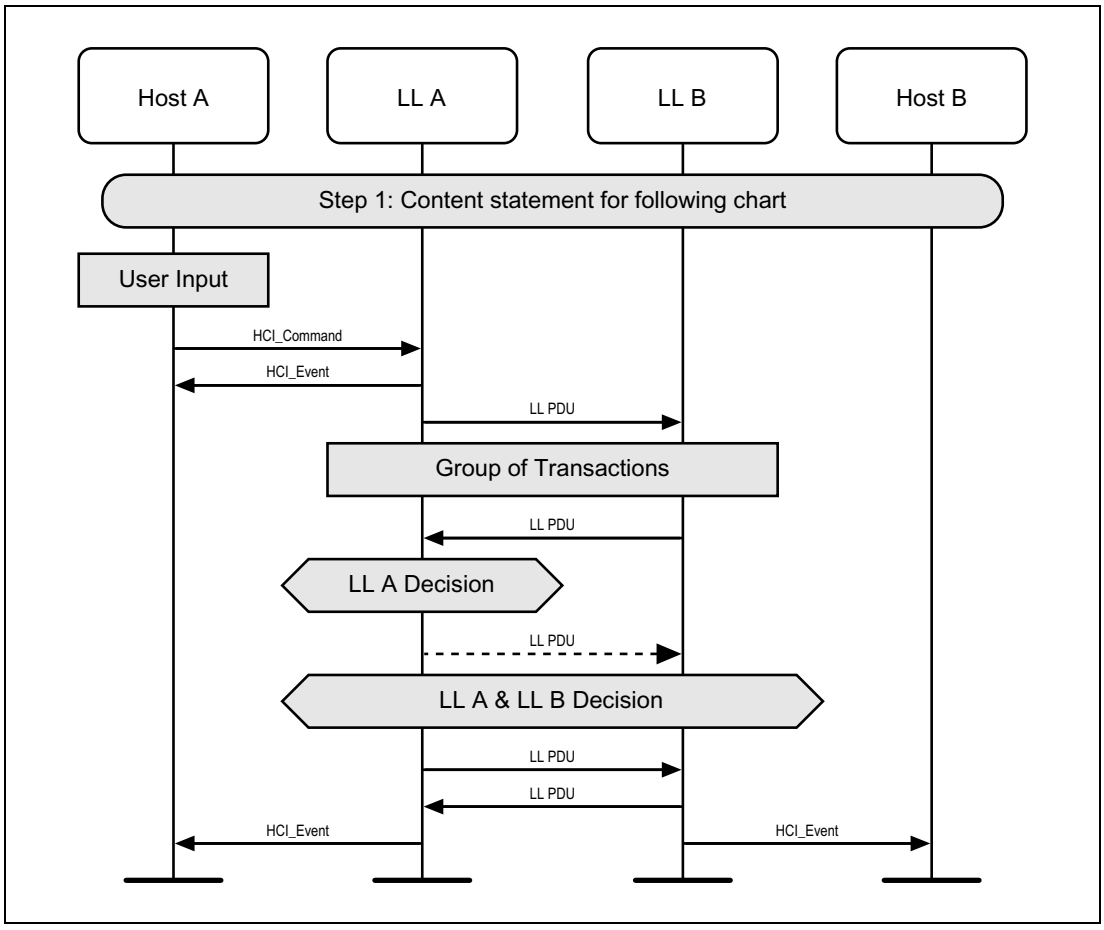

Figure 1.1: Example MSC

2 STANDBY STATE

2.1 INITIAL SETUP

To perform initial setup of a LE Controller, the following sequence of actions may be required.

First, the Host would wait for the Controller to indicate the number of HCI Command Packets the Host is currently allowed to send using a Command Complete event on a No OPeration command opcode. Then it would reset the Controller to a known state. Then it needs to read the local supported features to check that low energy is supported on this Controller. It would then set the event mask and LE event mask to enable the events that it wants the Controller to generate to the Host. Next, it will check the buffers that are available for data flow, using the Read Buffer Size and LE Read Buffer Size commands. Then it would read the locally supported LE features and select the features that it wishes to use. Finally, it will read the public device address if the Controller has one (see Figure 2.1).

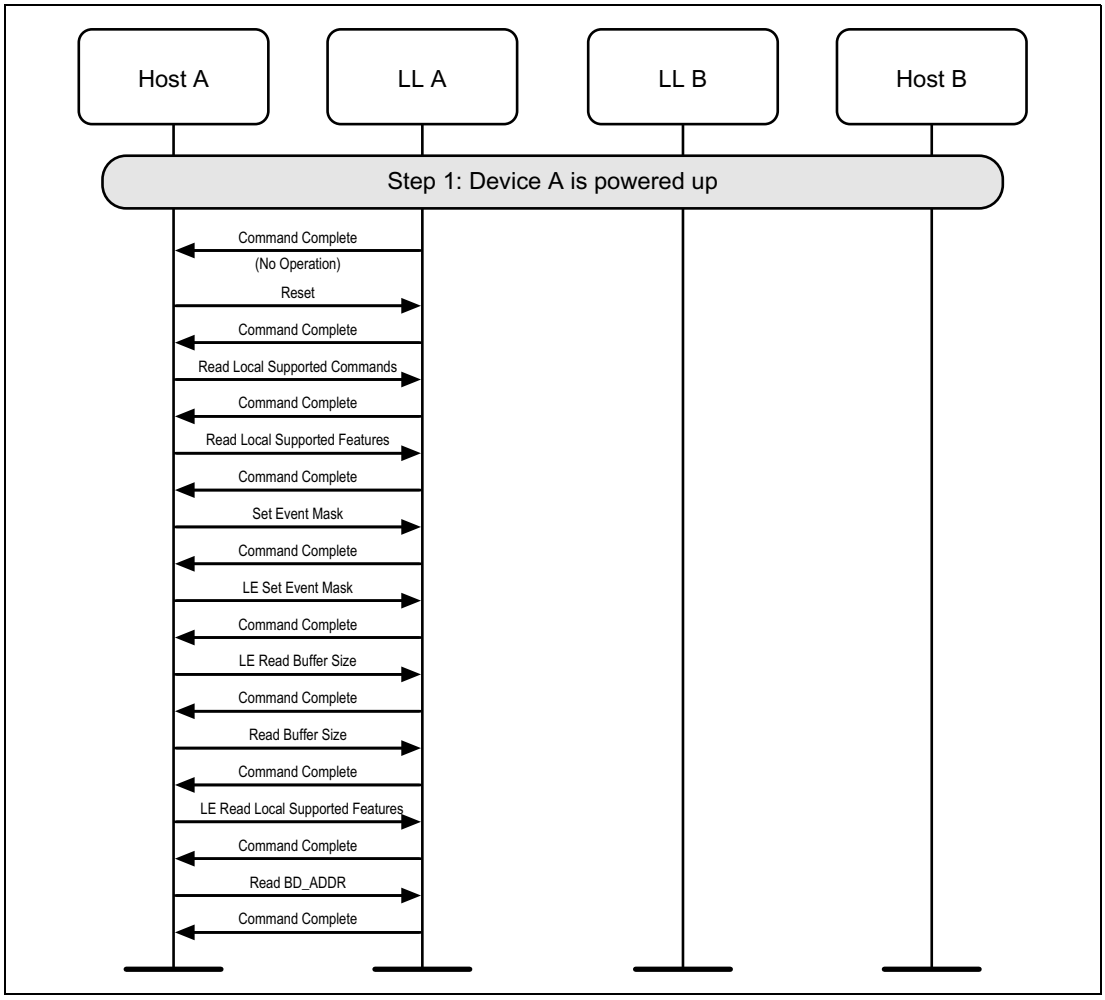

Figure 2.1: Initial Setup

2.2 RANDOM DEVICE ADDRESS

A device may use a random device address, but this address has to be configured before being used during advertising, scanning or initiating (see Figure 2.2).

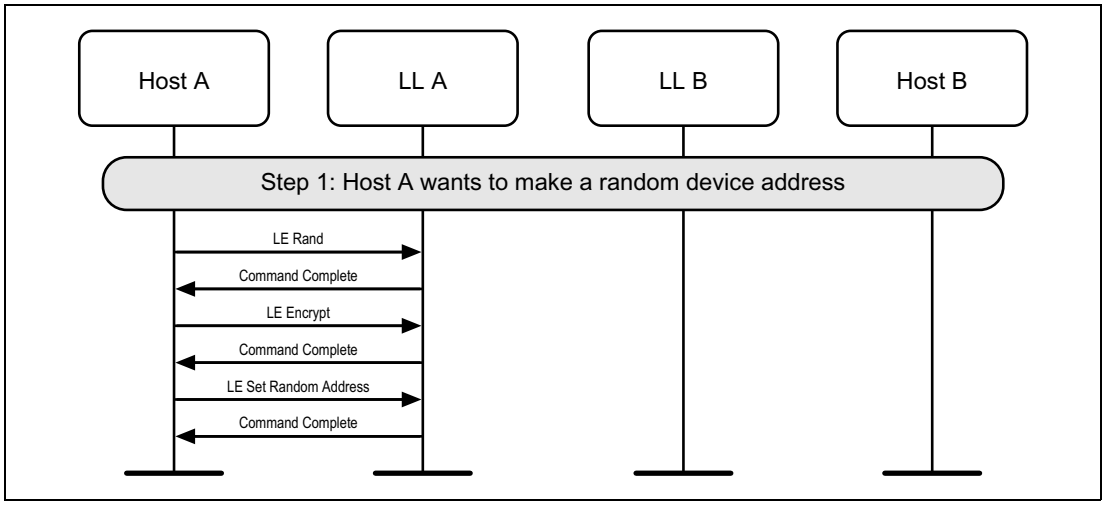

Figure 2.2: Random Device Address

2.3 WHITE LISTS

Before advertising, scanning or initiating can use White Lists, the White List may be cleared and devices added in as required (see Figure 2.3).

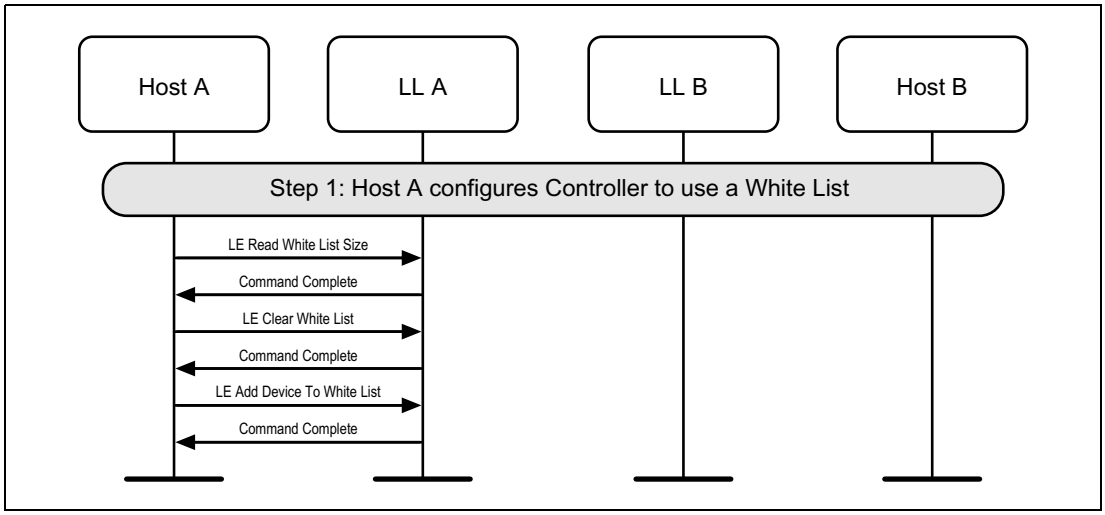

Figure 2.3: White Lists

2.4 ADDING IRK TO RESOLVING LIST

Before advertising, scanning or initiating can use resolving lists, the resolving list may be cleared and devices added in as required (see Figure 2.4).

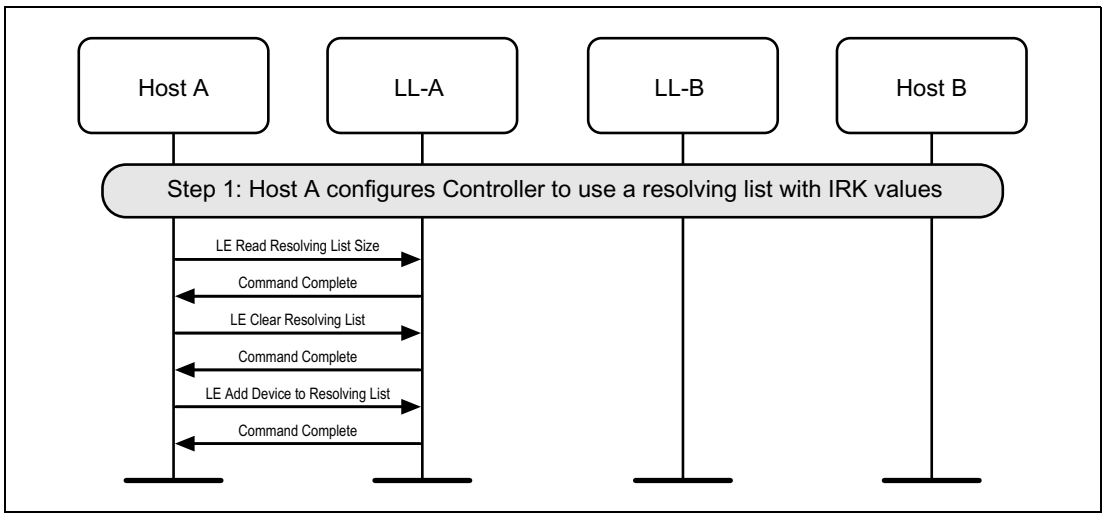

Figure 2.4: Resolving Lists

2.5 DEFAULT DATA LENGTH

Before creating a connection, the Host may specify its preferred values for the Controller's maximum transmission packet size and maximum packet transmission time to be used for new connections. This may be done on either the master or the slave.

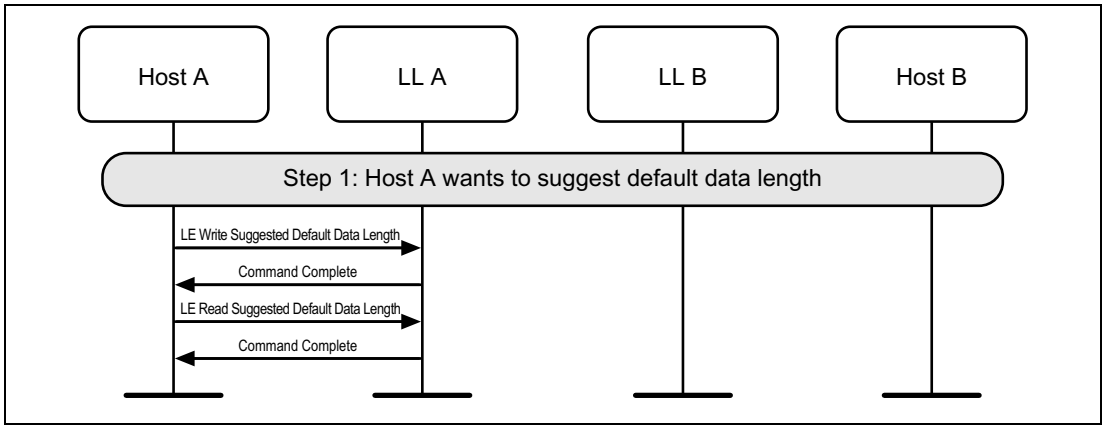

Figure 2.5: Default Data Length

2.6 PERIODIC ADVERTISER LIST

The Periodic Advertiser List may be cleared and devices added in as required, before it is made use of (see Figure 2.6).

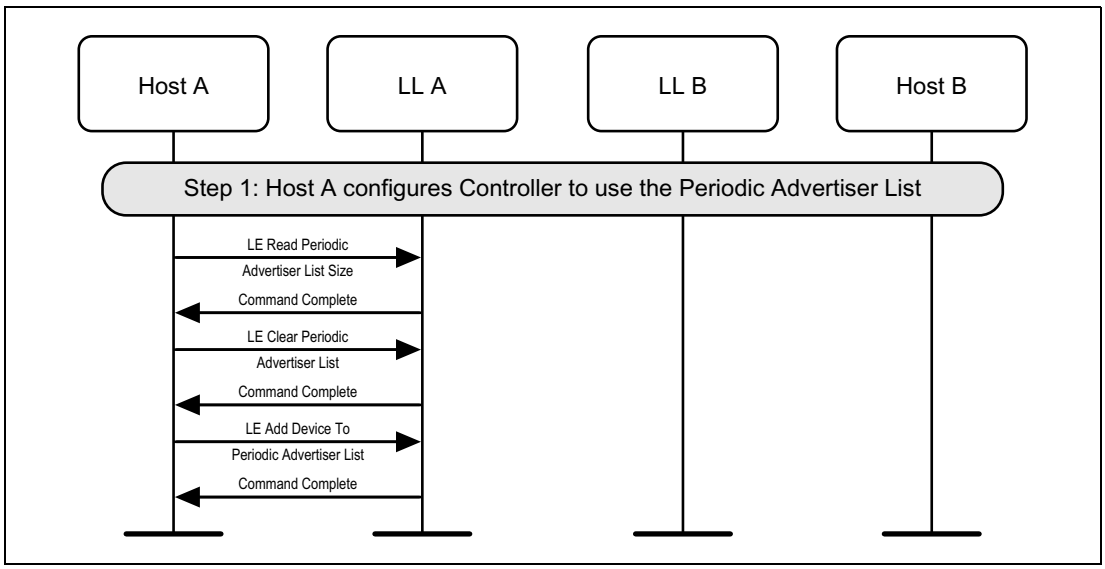

Figure 2.6: Periodic Advertiser List

3 ADVERTISING STATE

3.1 UNDIRECTED ADVERTISING

A device may enter the Advertising State by enabling advertising. It should also configure the advertising parameters before doing this (see Figure 3.1).

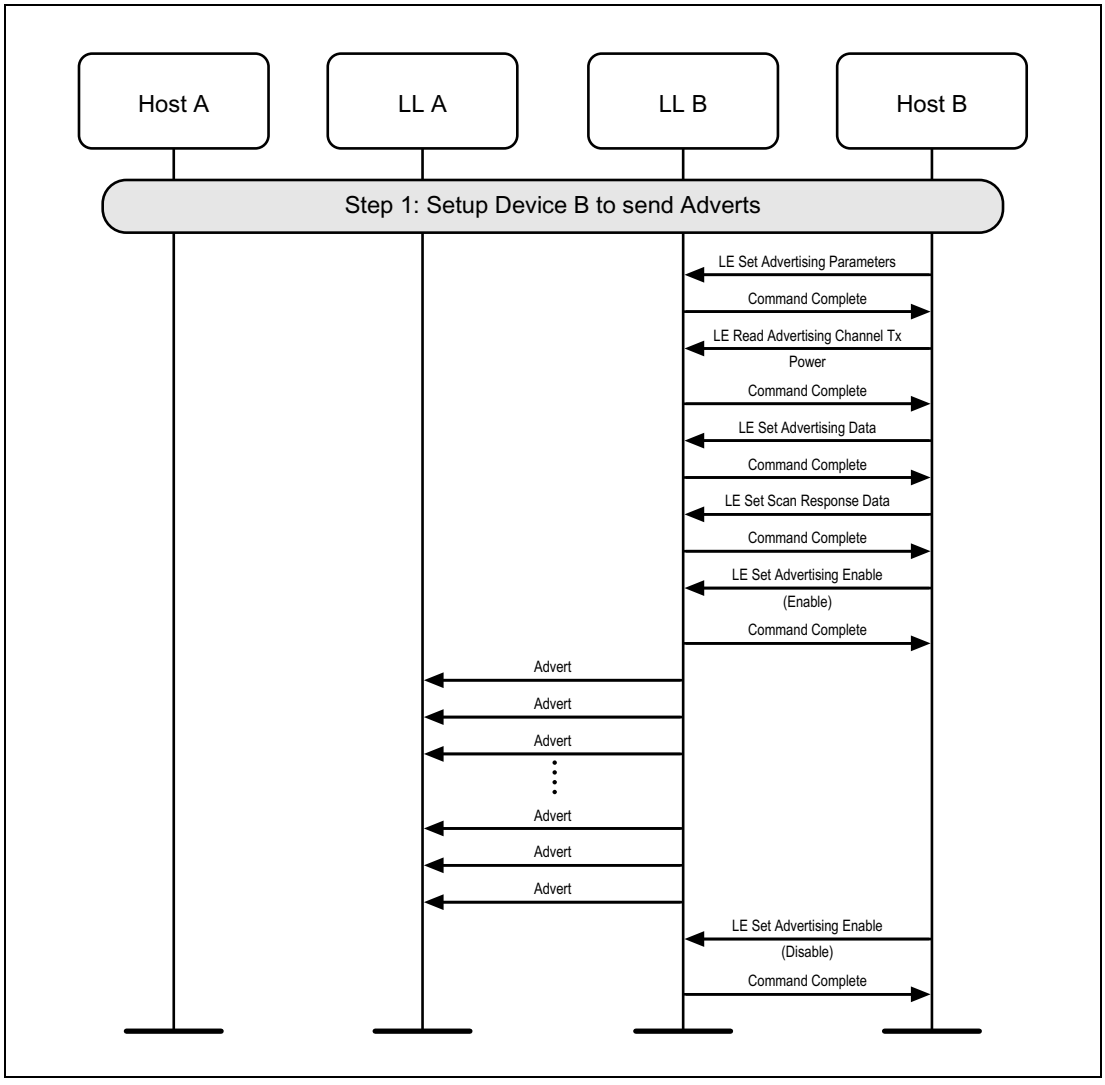

Figure 3.1: Undirected Advertising

3.2 DIRECTED ADVERTISING

A device may use directed advertising to allow an initiator to connect to it. High duty cycle directed advertising is time limited in the Controller and therefore this may fail before a connection is created. This example only shows the failure case (see Figure 3.2).

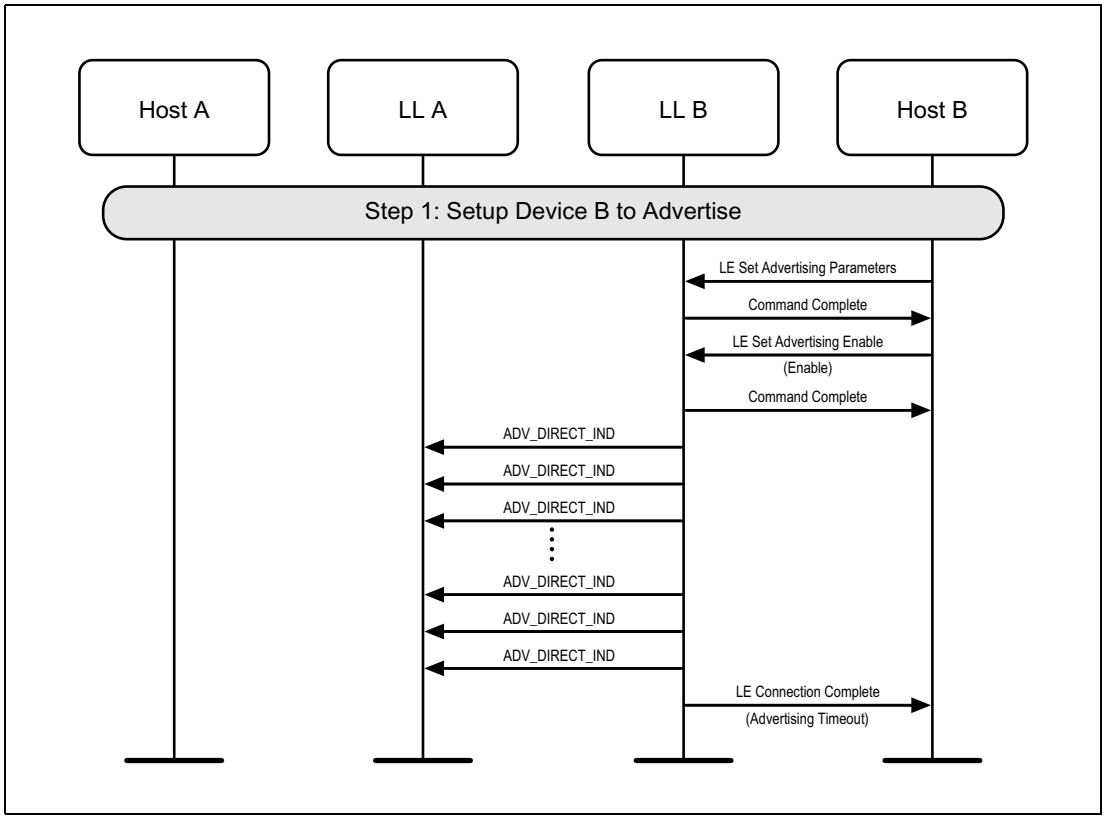

Figure 3.2: High Duty Cycle Directed Advertising showing failure case

Low duty cycle directed advertising must similarly be enabled in order to enter the Advertising State. A device should also configure the advertising parameters before doing this (see Figure 3.3).

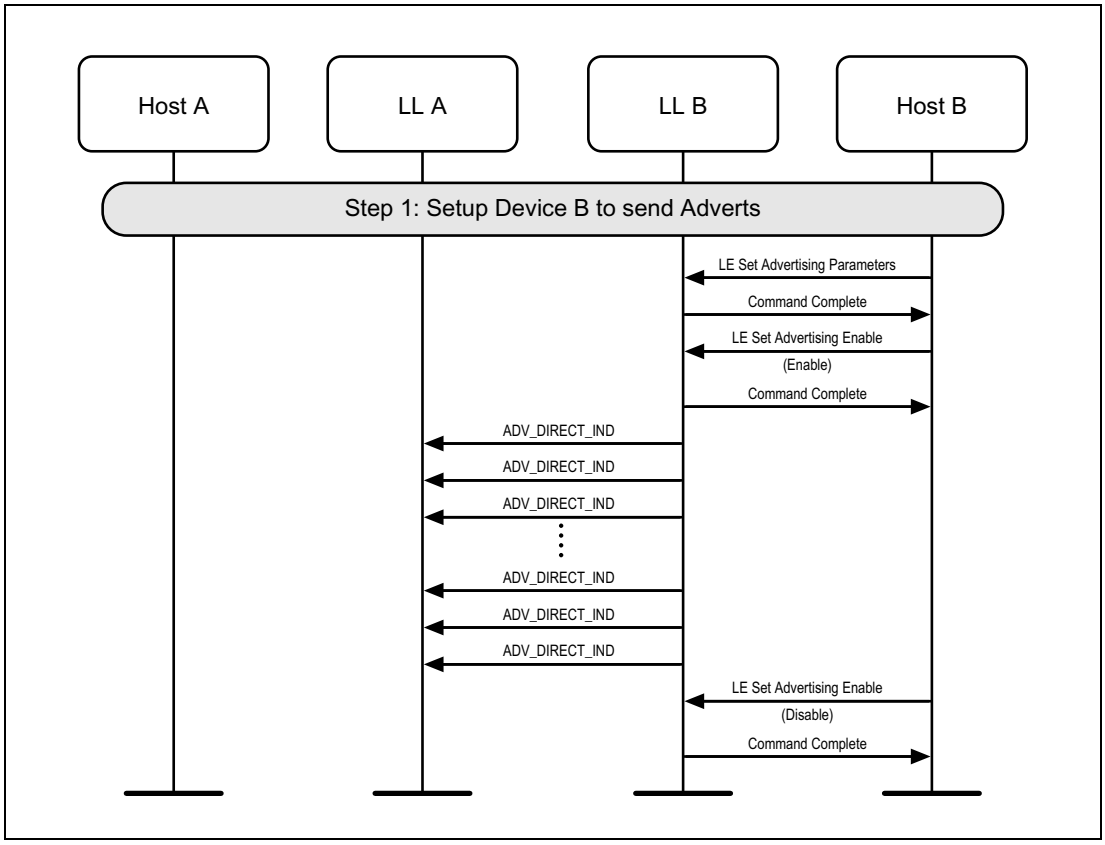

Figure 3.3: Low Duty Cycle Directed Advertising

3.3 ADVERTISING USING ADV_EXT_IND

A device may enter the Advertising State by enabling advertising a set. It should also configure the advertising set parameters before doing this (see Figure 3.4).

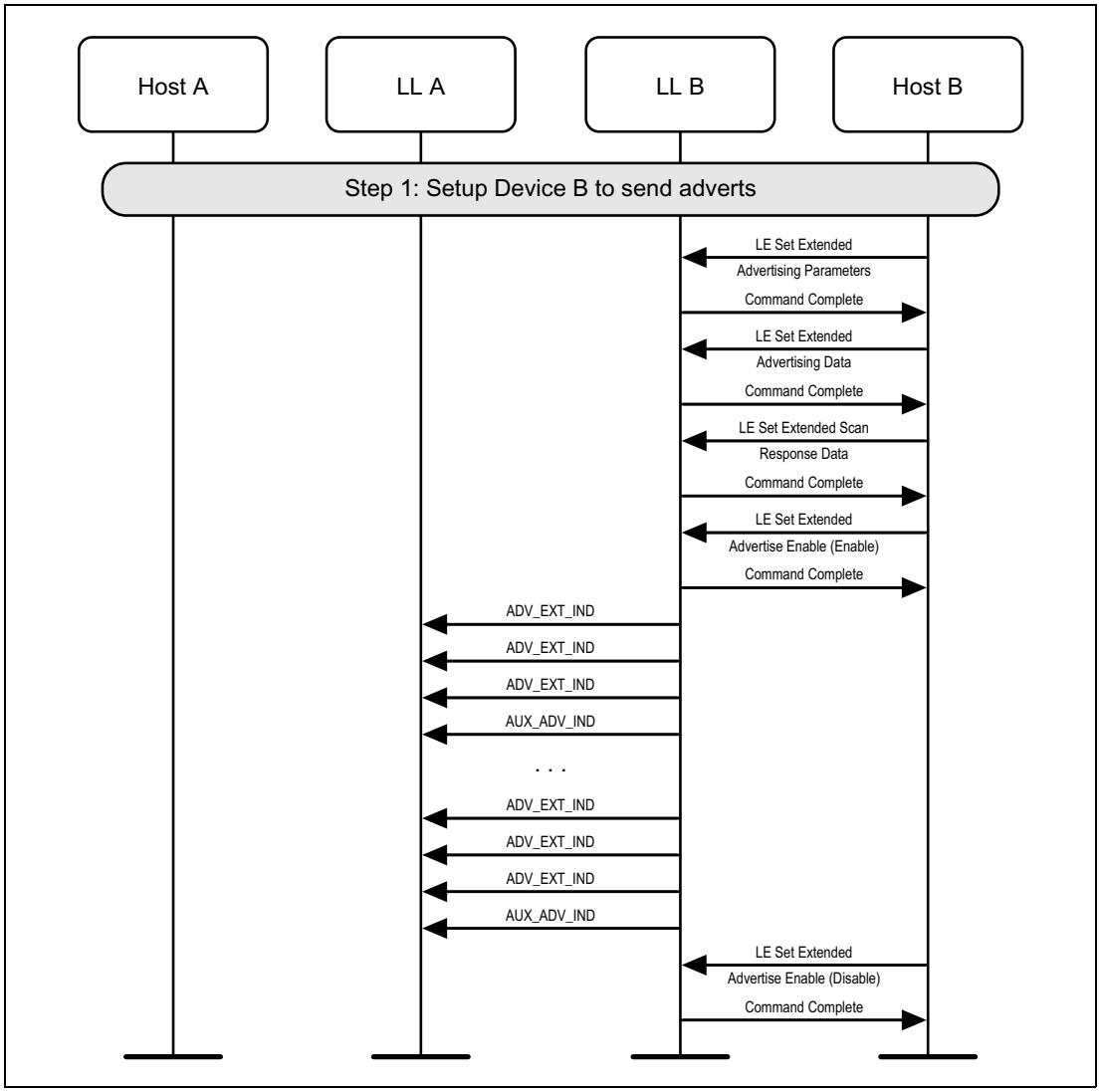

Figure 3.4: Advertising using ADV_EXT_IND

3.4 SCAN REQUEST NOTIFICATIONS

A device may enable scan request notifications in an advertising set (see Figure 3.5).

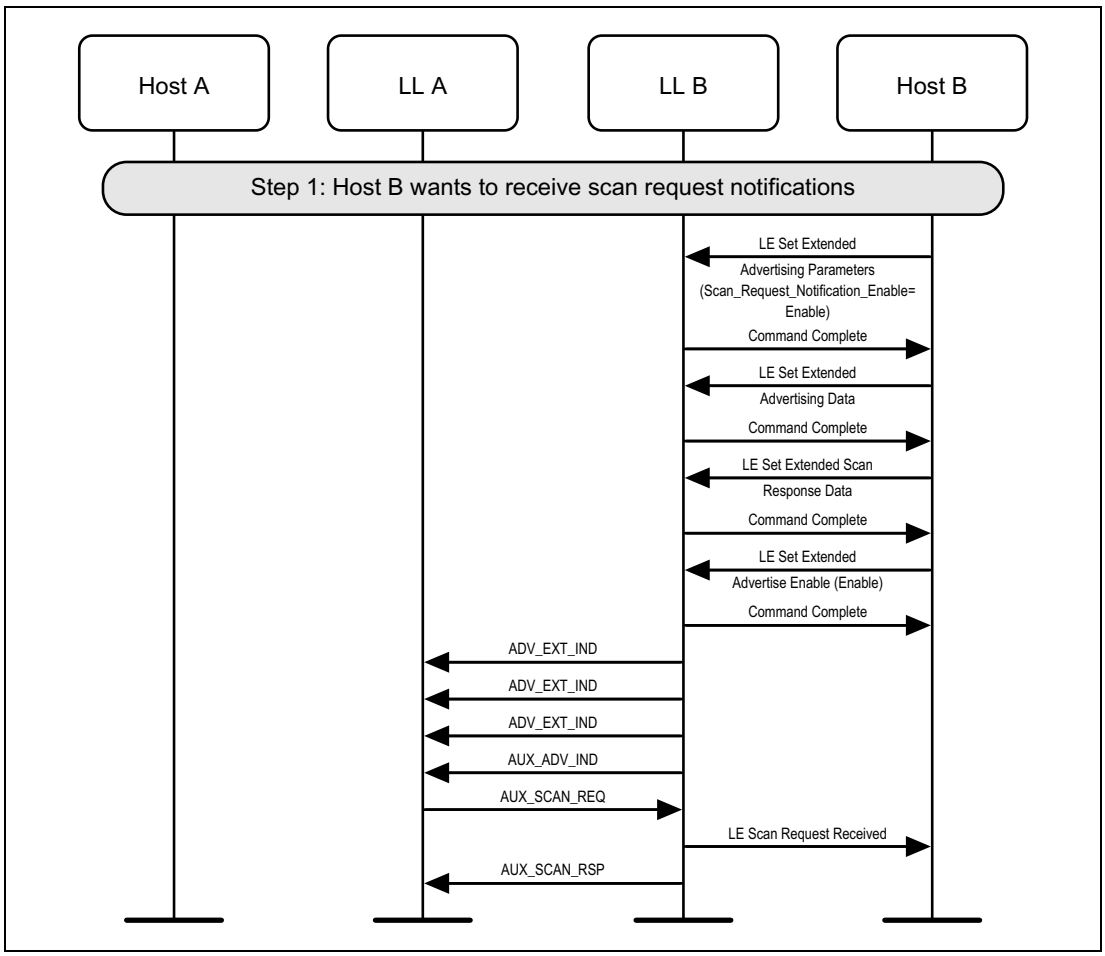

Figure 3.5: Scan Request Notifications

3.5 ADVERTISING DURATION ENDED

A device may enter the Advertising State by enabling advertising a set for a limited duration of time (see Figure 3.6).

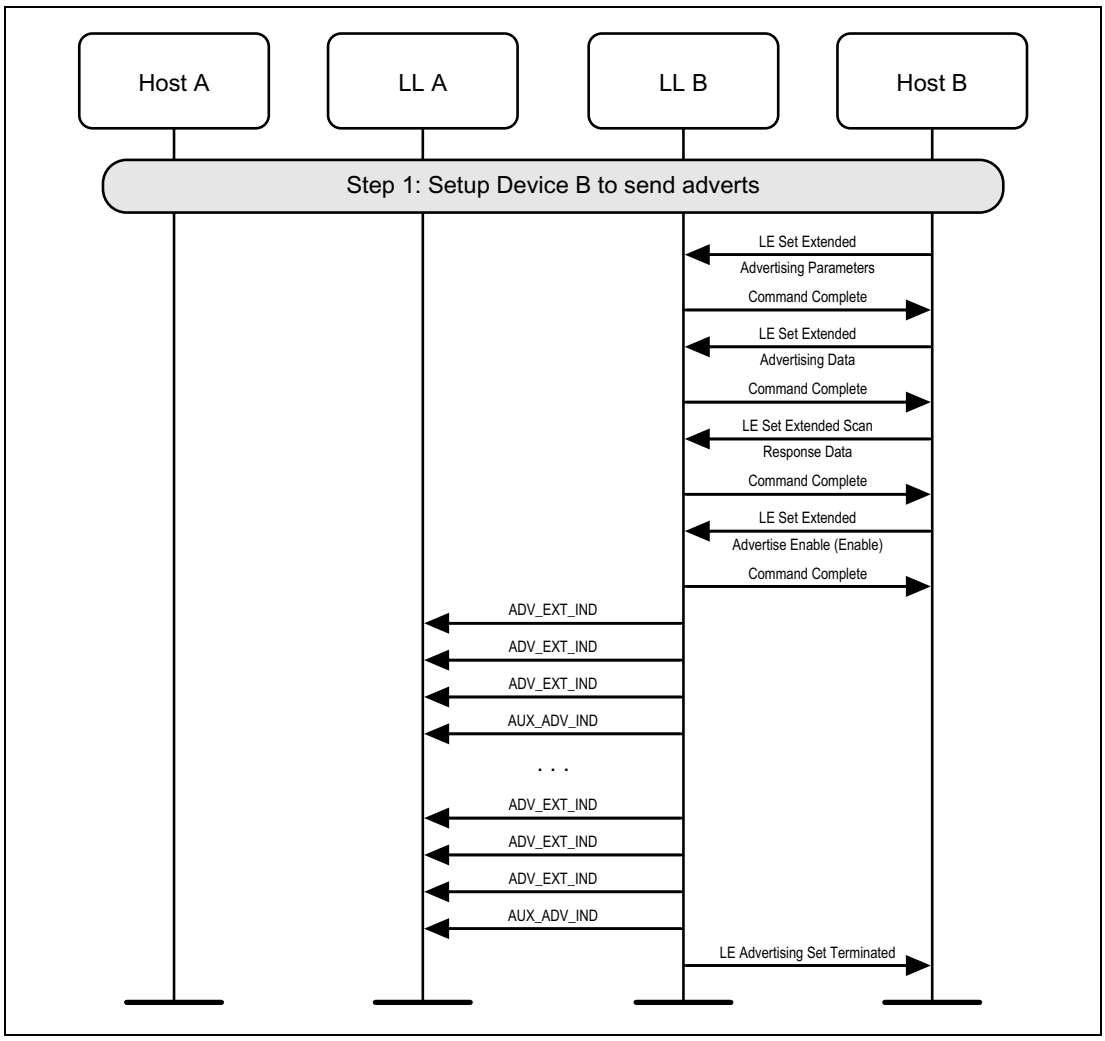

Figure 3.6: Advertising Duration Ended

3.6 PERIODIC ADVERTISING

A device may enter the Advertising State by enabling periodic advertising in a set. It should also configure the advertising set parameters before doing this (see Figure 3.7).

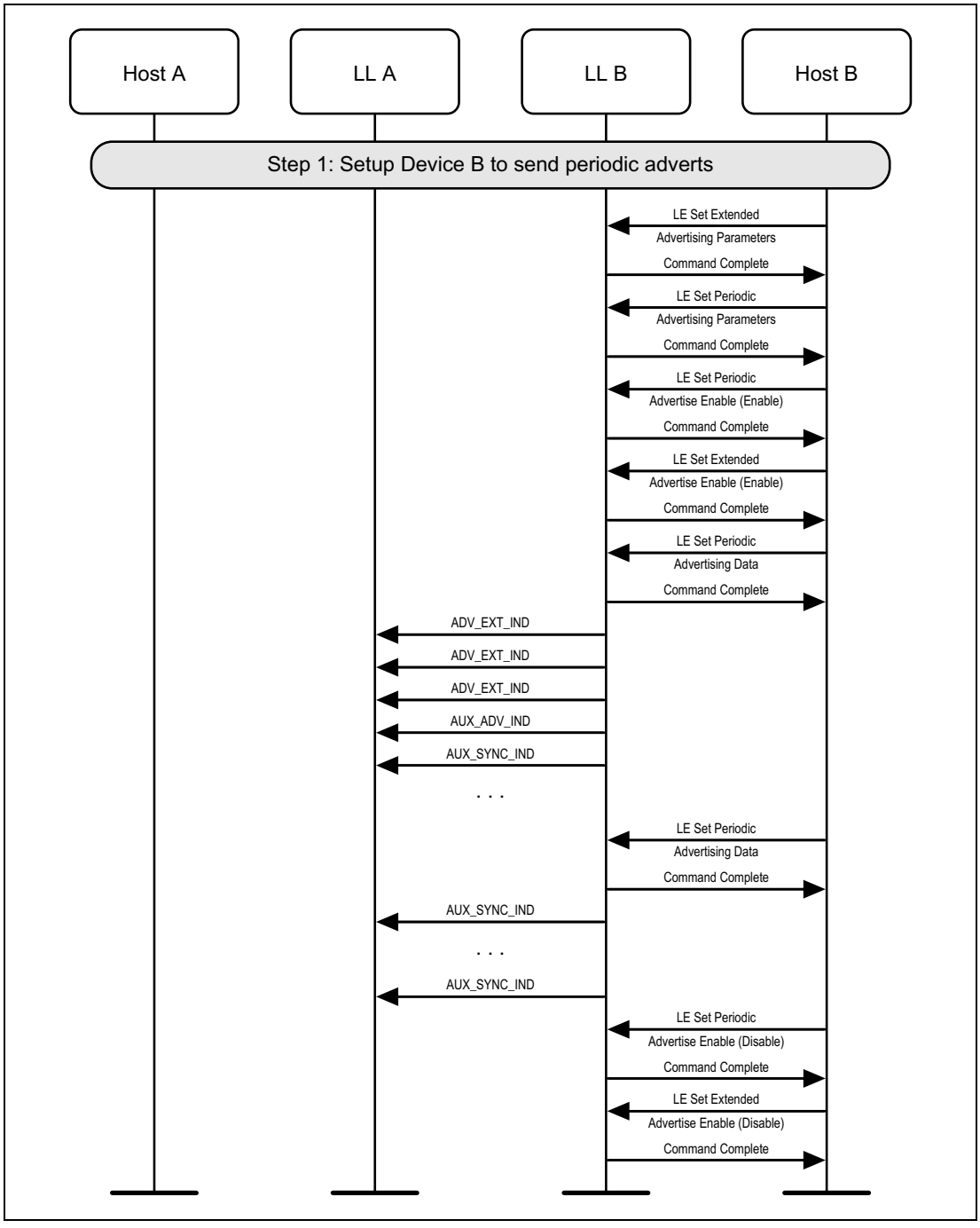

Figure 3.7: Periodic Advertising

4 SCANNING STATE

4.1 PASSIVE SCANNING

A device can use passive scanning to find advertising devices in the area. This would receive advertising packets from peer devices and report these to the Host (see Figure 4.1).

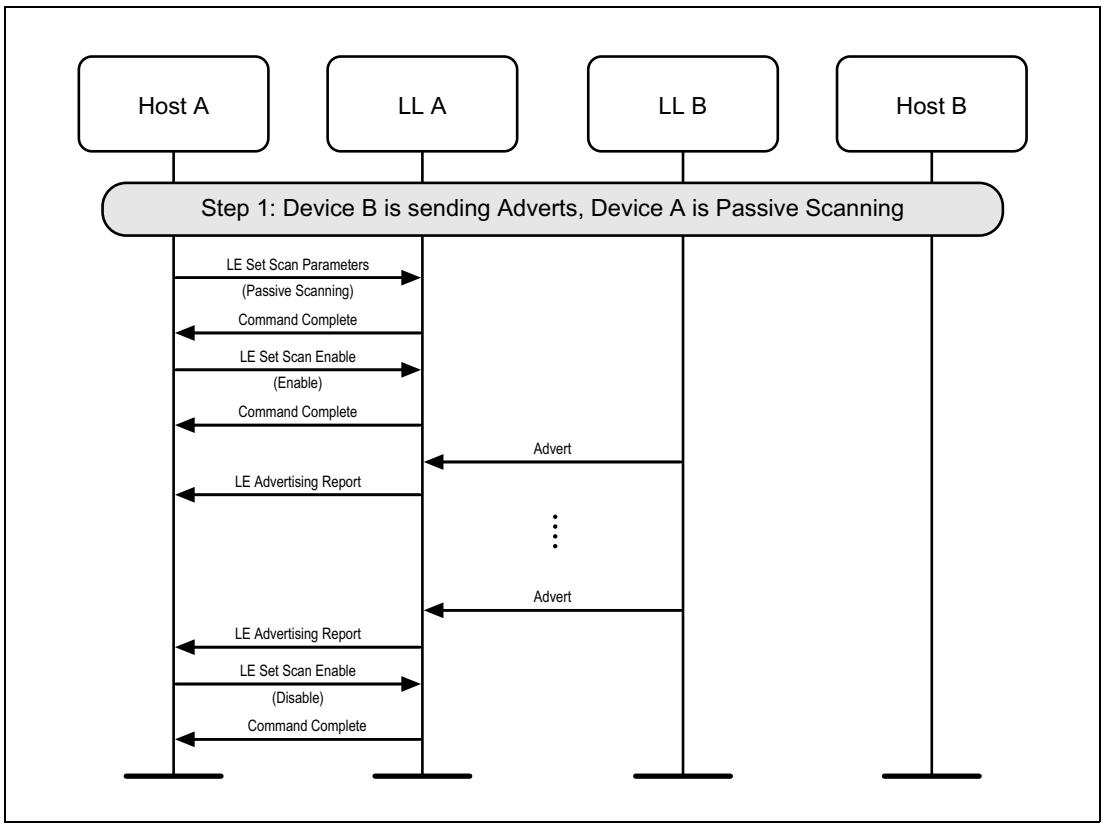

Figure 4.1: Passive Scanning

4.2 ACTIVE SCANNING

A device may use active scanning to obtain more information about devices that may be useful to populate a user interface. Active scanning involves more link layer advertising messages (see Figure 4.2).

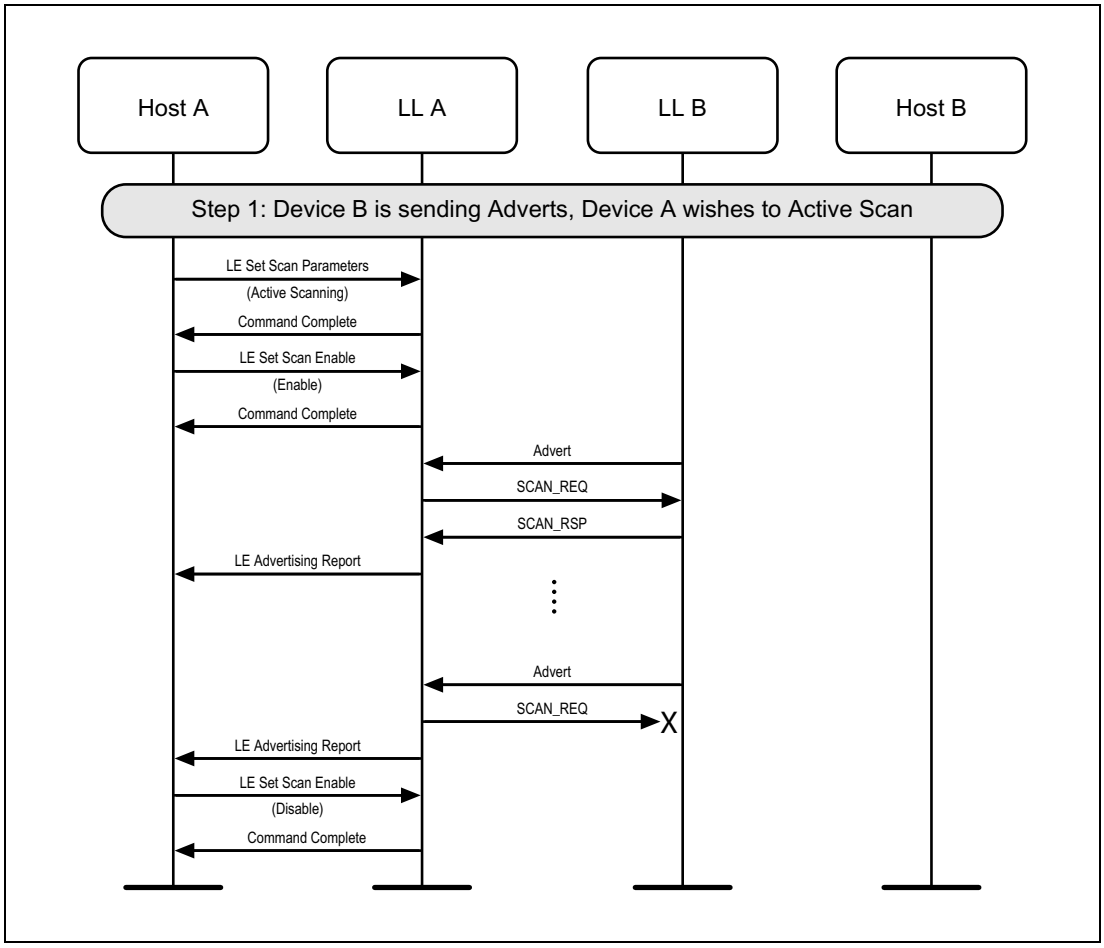

Figure 4.2: Active Scanning

4.3 PASSIVE SCANNING FOR DIRECTED ADVERTISEMENTS WITH PRIVACY

If a device does not support Privacy in the Controller, it may choose to forward LE Directed Advertising Report events from devices supporting Privacy without requiring filtering through the Controller Resolving List.

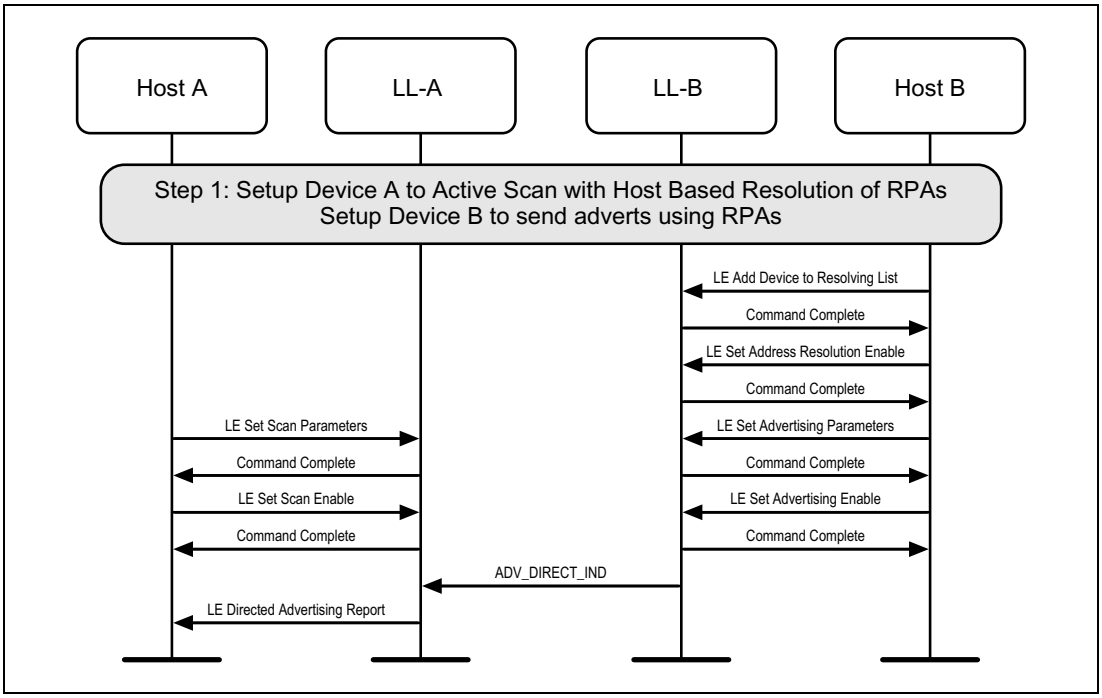

Figure 4.3: Directed Advertising with Privacy

4.4 ACTIVE SCANNING WITH PRIVACY

A device may use active scanning to obtain more information about devices that may be useful

to populate a user interface. Privacy may be used during active scanning to make it more

difficult to track either device during active scanning (see Figure 4.4).

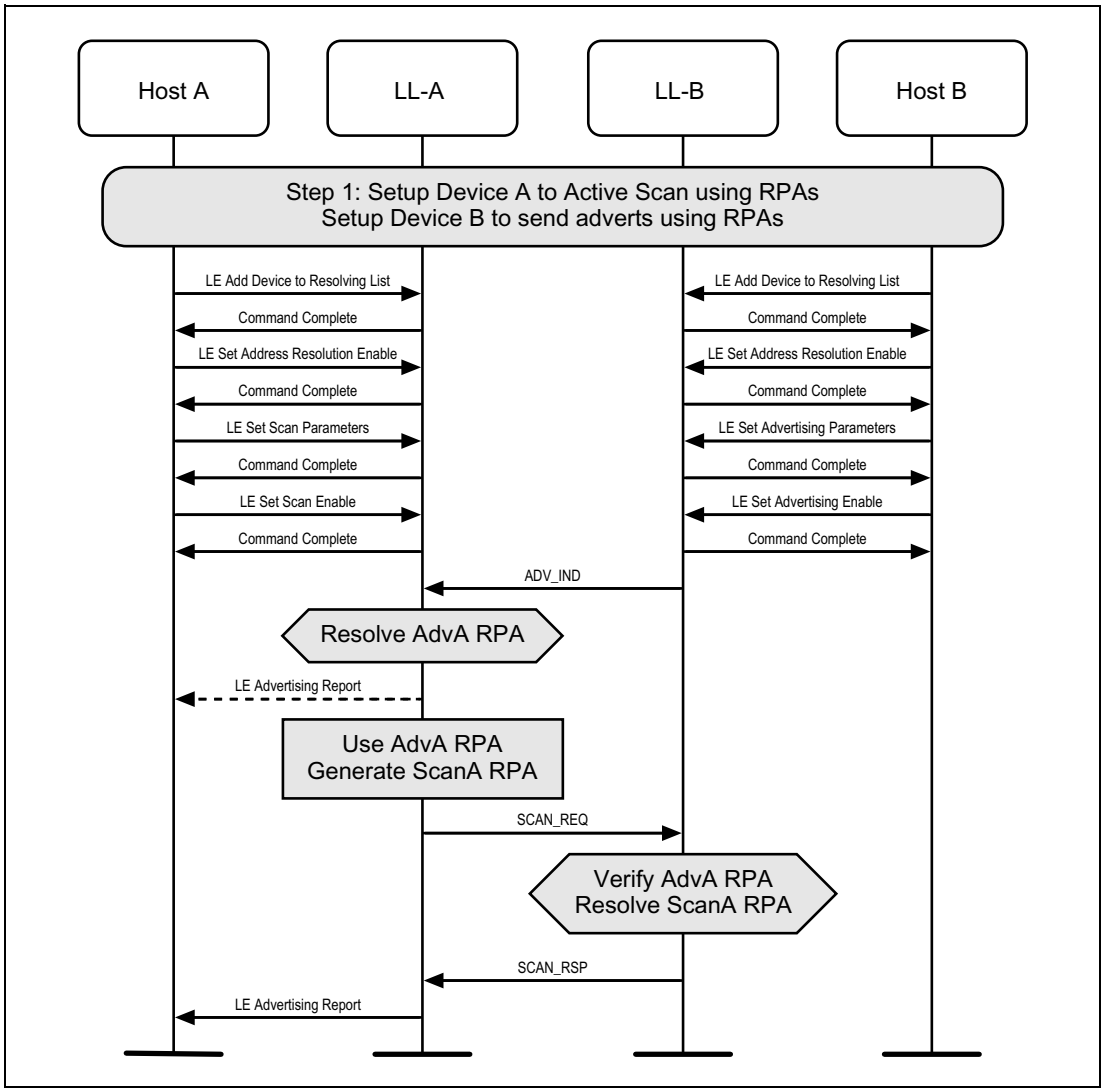

Figure 4.4: Active Scanning with Privacy

4.5 ACTIVE SCANNING WITH PRIVACY AND CONTROLLER BASED RESOLVABLE PRIVATE ADDRESS GENERATION

A Controller will periodically update the resolvable private addresses used on both devices if the devices use active scanning and advertising with Privacy. A Host may at anytime retrieve the read from the Controller the current addresses being used (see Figure 4.5).

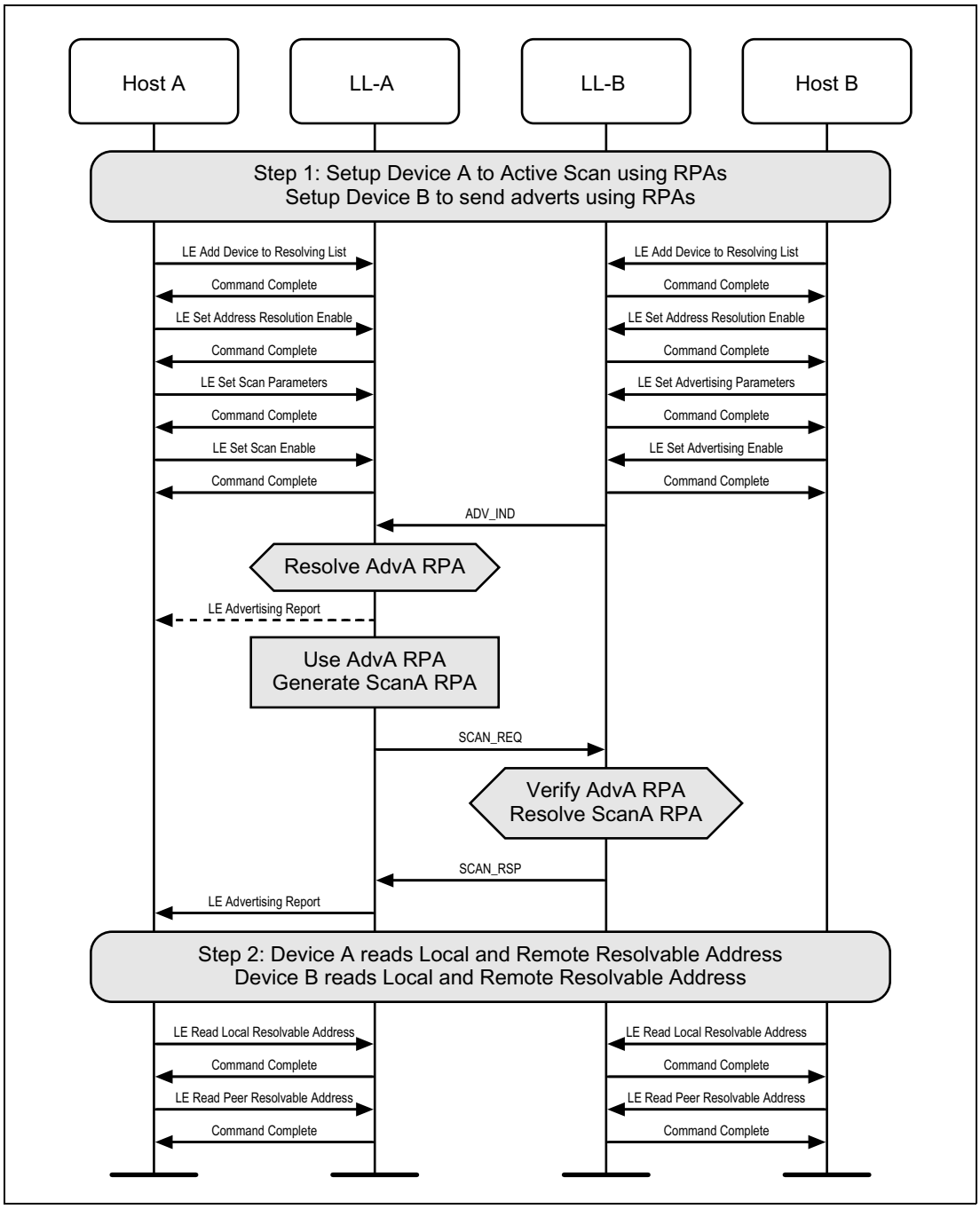

Figure 4.5: Retrieving local and remote resolvable address updates from the Controller

4.6 ACTIVE SCANNING ON THE SECONDARY ADVERTISING CHANNEL

A device may use active scanning on the secondary advertising channel in order to obtain more information about devices that may be useful to populate a user interface (see Figure 4.6).

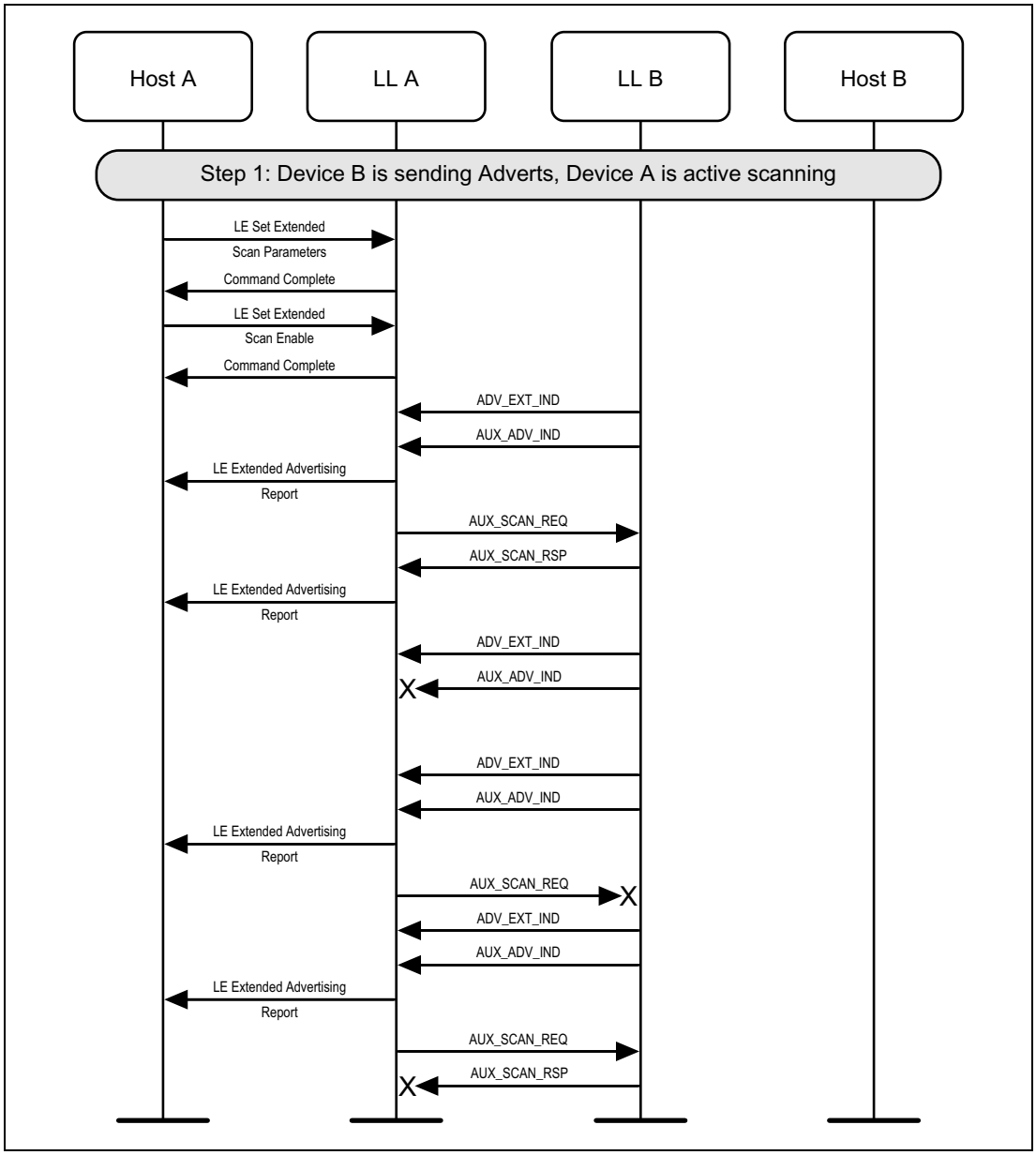

Figure 4.6: Extended active scanning on the secondary advertising channel

4.7 SCAN TIMEOUT

A device may scan for a limited duration of time (see Figure 4.7).

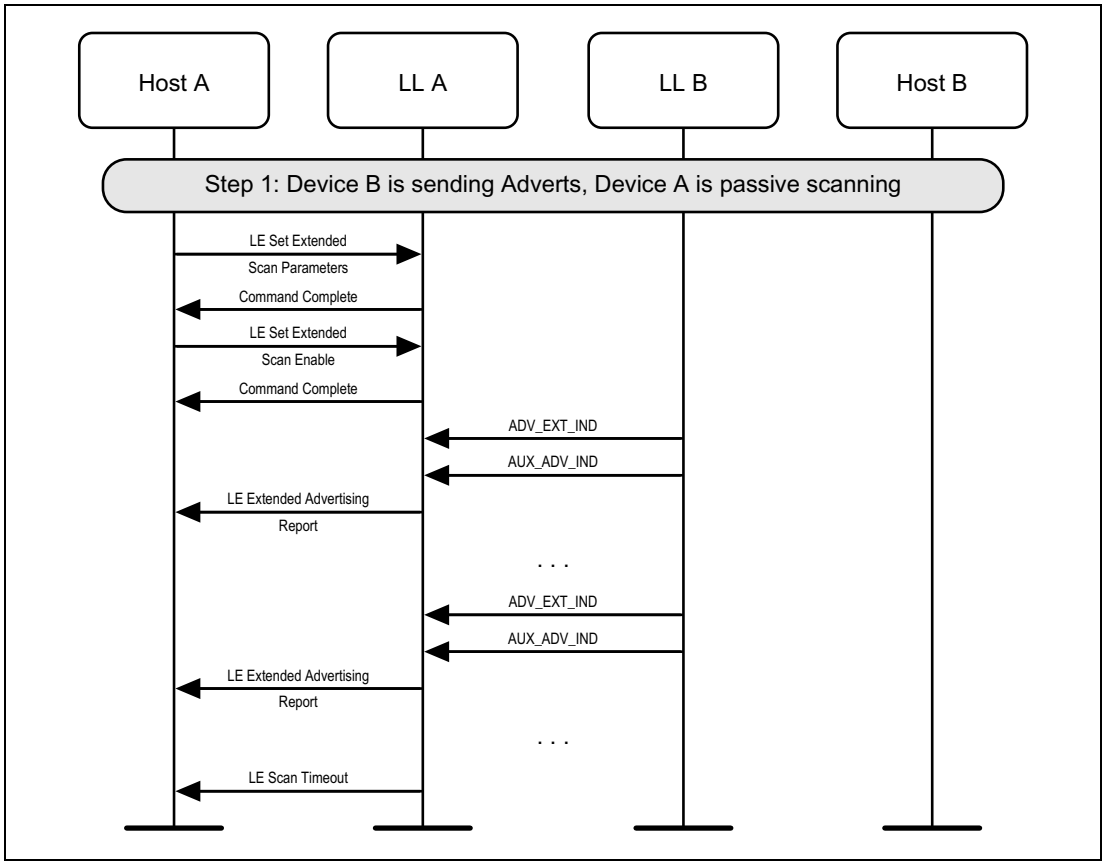

Figure 4.7: Scan Timeout

4.8 PERIODIC SCANNING

A device may establish synchronization with a periodic advertiser and report periodic advertising packets to the Host (see Figure 4.8).

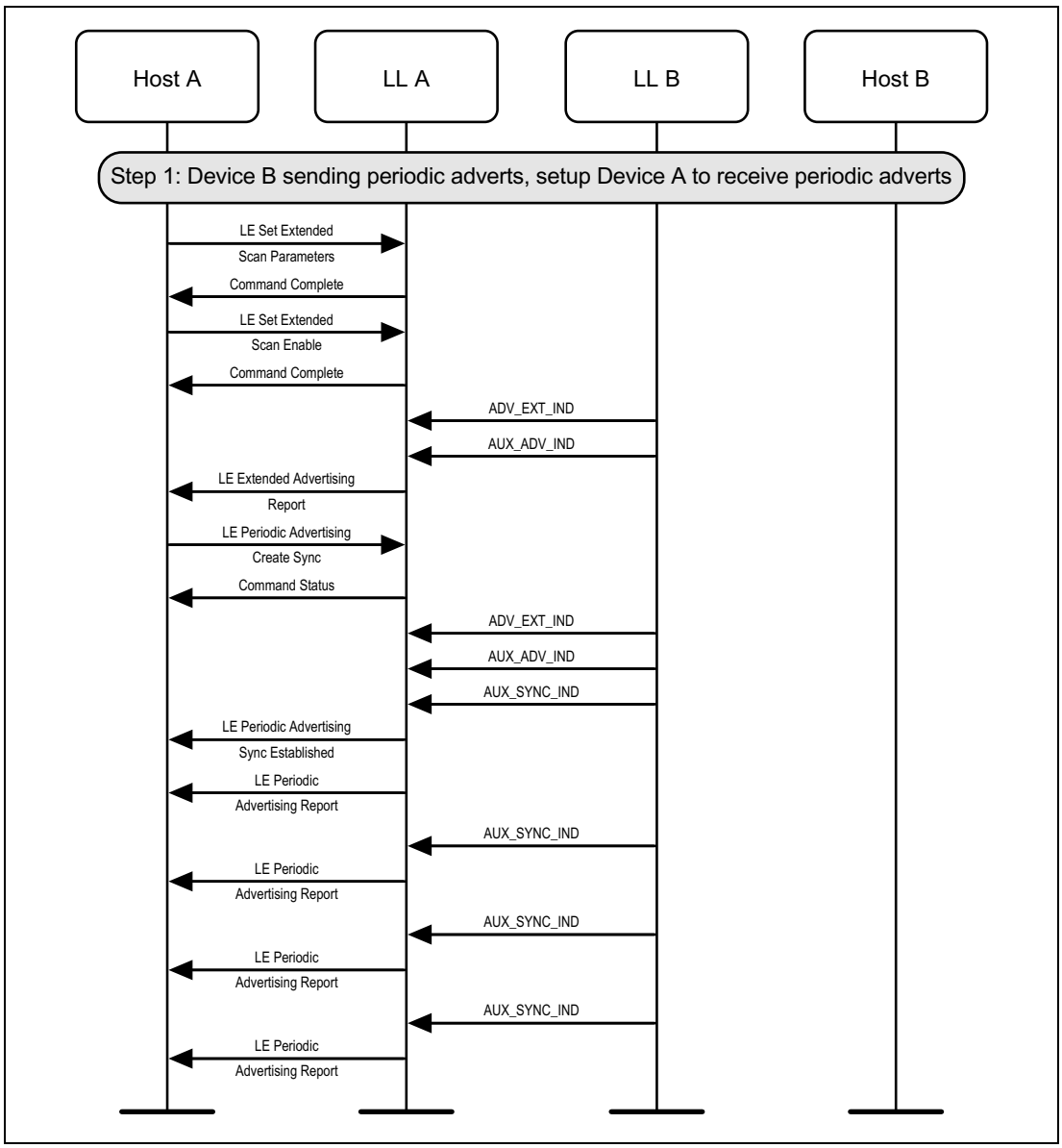

Figure 4.8: Periodic Scanning

4.9 PERIODIC SCANNING CANCEL

A device may cancel a pending request to establish synchronization with a periodic advertiser. This example shows an unsuccessful synchronization, followed by cancellation of the synchronization (see Figure 4.9).

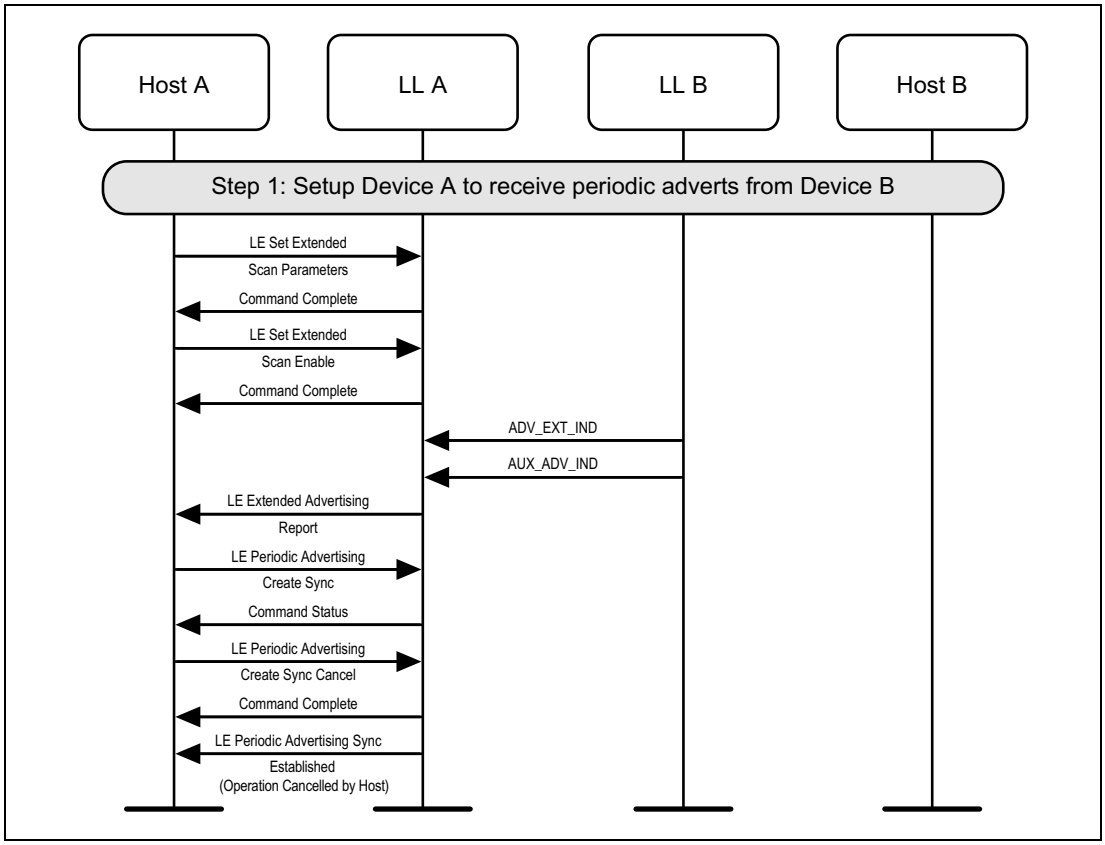

Figure 4.9: Periodic Scanning Cancel

4.10 PERIODIC SCANNING TIMEOUT

A device may lose synchronization with a periodic advertiser (see Figure 4.10).

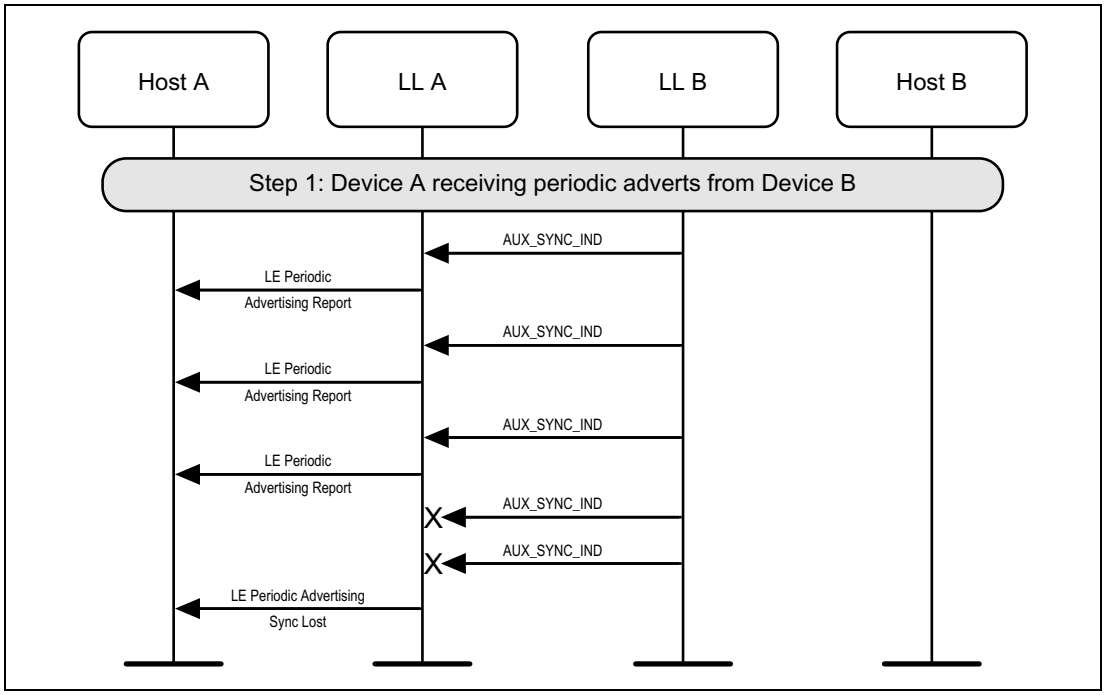

Figure 4.10: Periodic Scanning Timeout

4.11 PERIODIC SCANNING TERMINATE

Once synchronized with a periodic advertiser, the Host can terminate the synchronization (see Figure 4.11).

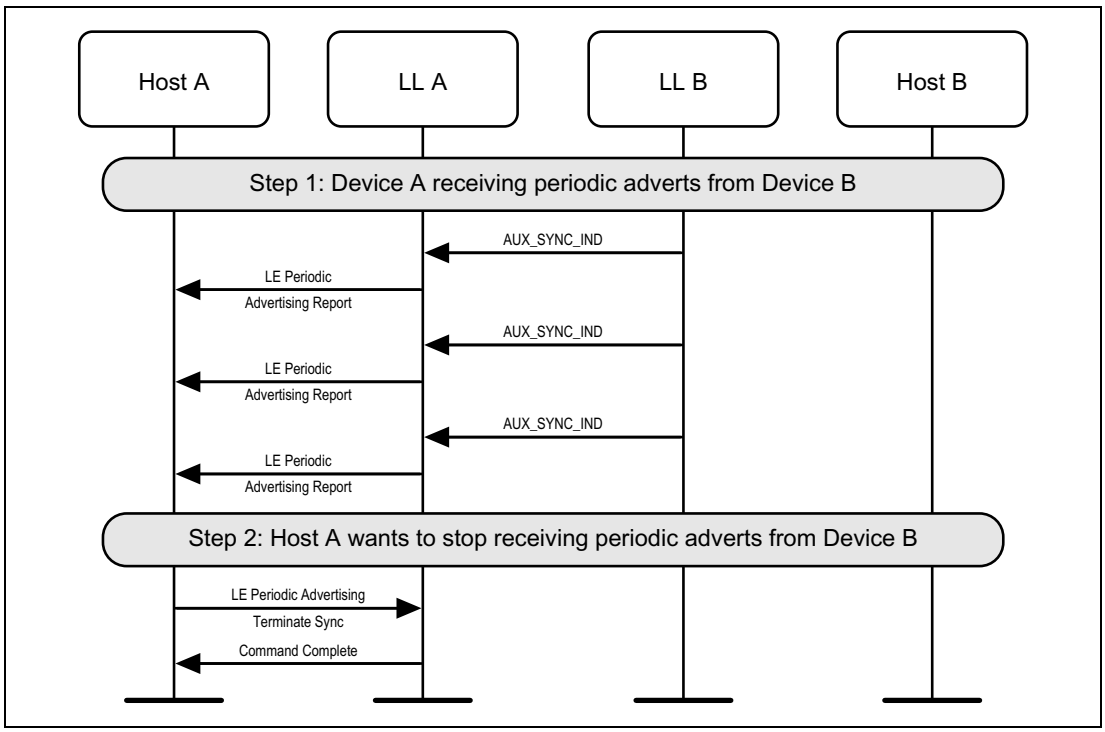

Figure 4.11: Periodic Scanning Terminate

5 INITIATING STATE

5.1 INITIATING A CONNECTION

A device can initiate a connection to an advertiser. This example shows a successful initiation, resulting in both devices able to send application data (see Figure 5.1).

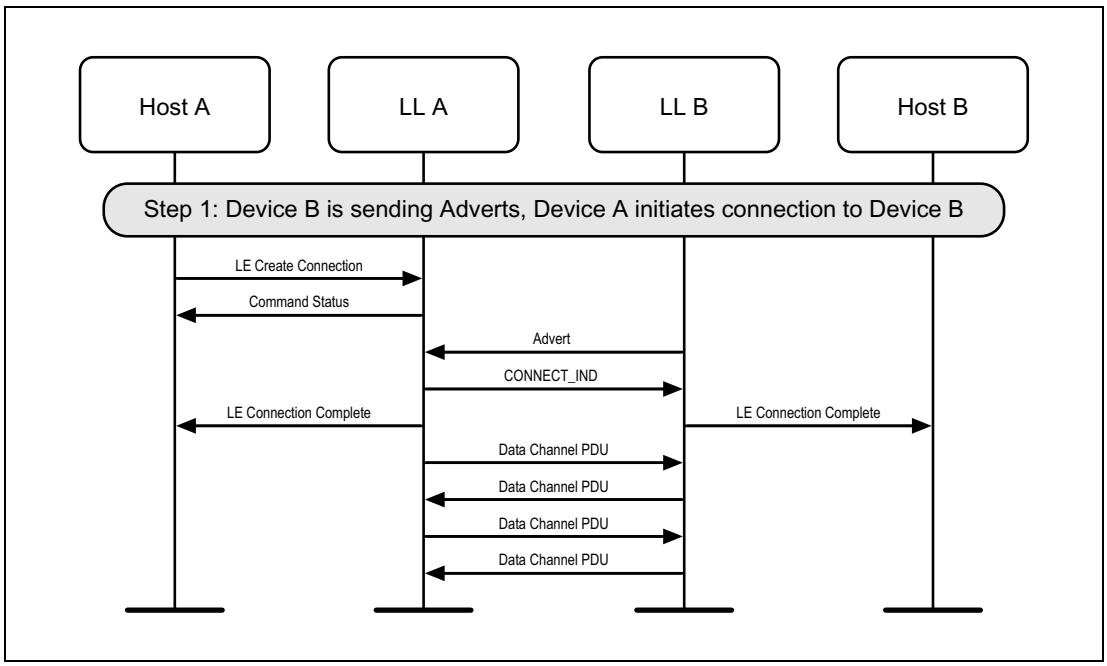

Figure 5.1: Initiating a Connection

5.2 CANCELING AN INITIATION

A device can cancel a pending connection creation. This example shows an unsuccessful initiation, followed by a cancellation of the initiation (see Figure 5.2).

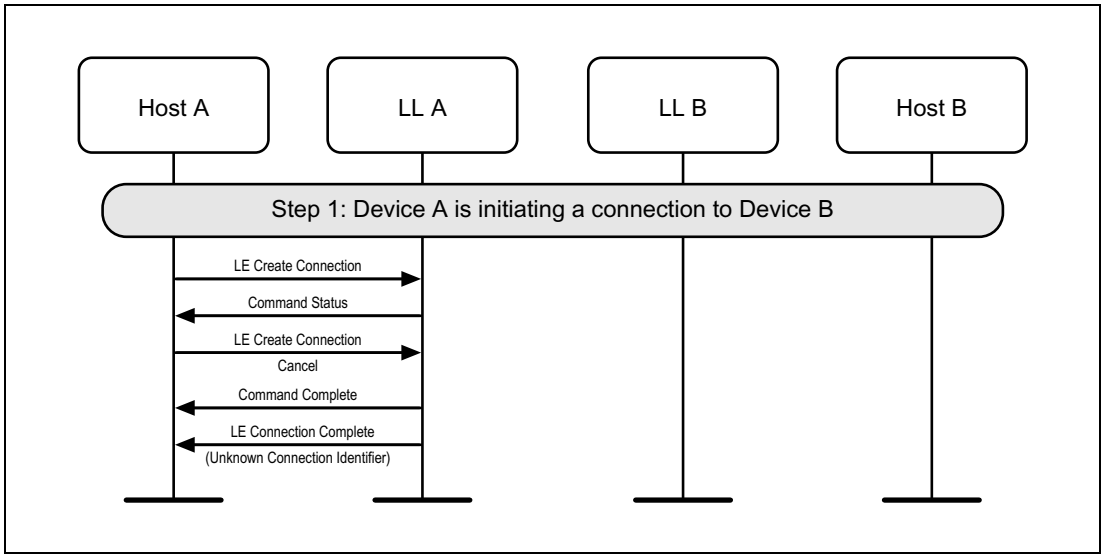

Figure 5.2: Canceling an Initiation

5.3 INITIATING A CONNECTION USING UNDIRECTED ADVERTISING WITH PRIVACY

A device can initiate a connection to an advertiser. Privacy may be used during connection initiation to make it more difficult to track either device during connection setup. The example shows a successful initiation, resulting in both devices able to send application data (see Figure 5.3).

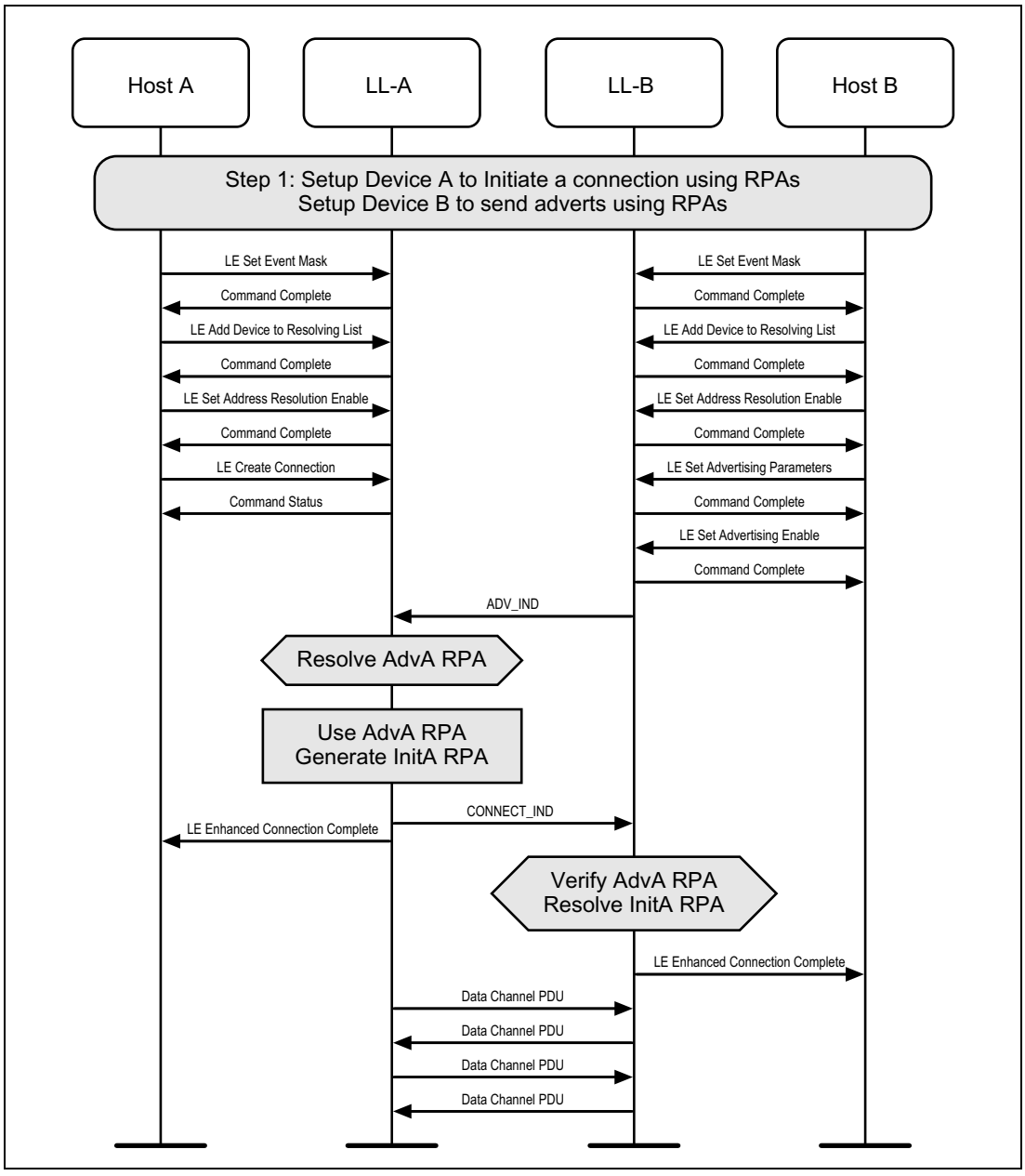

Figure 5.3: Initiating a connection using Undirected Advertising with Privacy

5.4 INITIATING A CONNECTION USING DIRECTED ADVERTISING WITH PRIVACY

A device can initiate a connection to an advertiser who is using Directed Advertising. Privacy may be used during connection initiation to make it more difficult to track either device during connection setup as well as target a single initiator. The example shows a successful initiation, resulting in both devices able to send application data (see Figure 5.4).

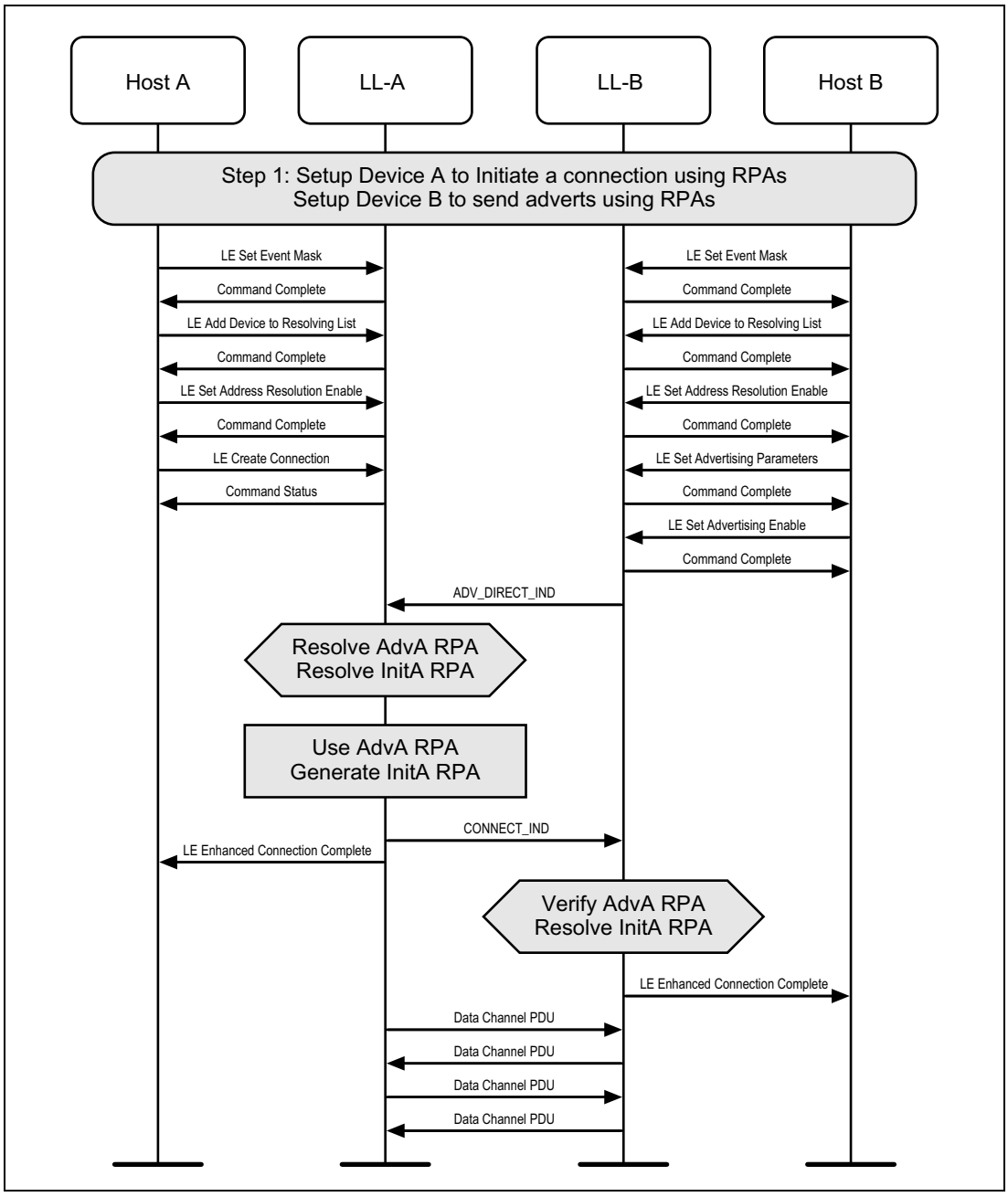

Figure 5.4: Initiating a connection using Directed Advertising with Privacy

5.5 INITIATING A CONNECTION THAT FAILS TO ESTABLISH

This example shows an initiation that fails to establish because Device B (the advertiser) fails to respond to the Data Channel PDUs sent by Device A.

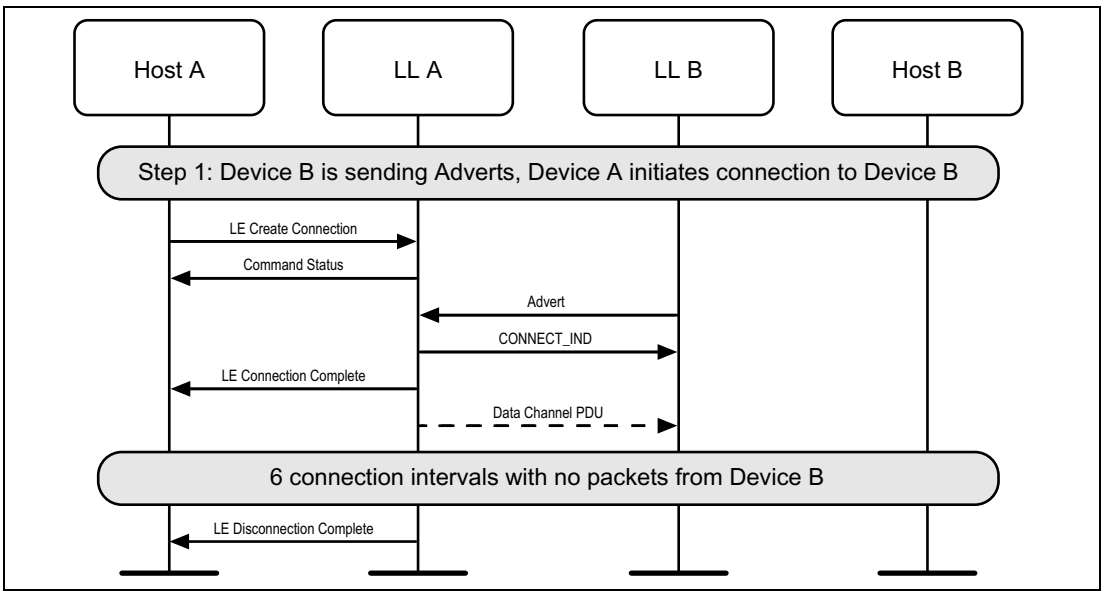

Figure 5.5: Initiating a Connection that fails to establish

Device A may or may not send data channel PDUs in the 6 connection intervals before establishment fails. If it does not do so, Device B is unable to respond.

5.6 INITIATING A CONNECTION ON THE SECONDARY ADVERTISING CHANNEL

A device can initiate a connection to an advertiser on the secondary channel. This example shows a successful initiation, resulting in both devices able to send application data (see Figure 5.6).

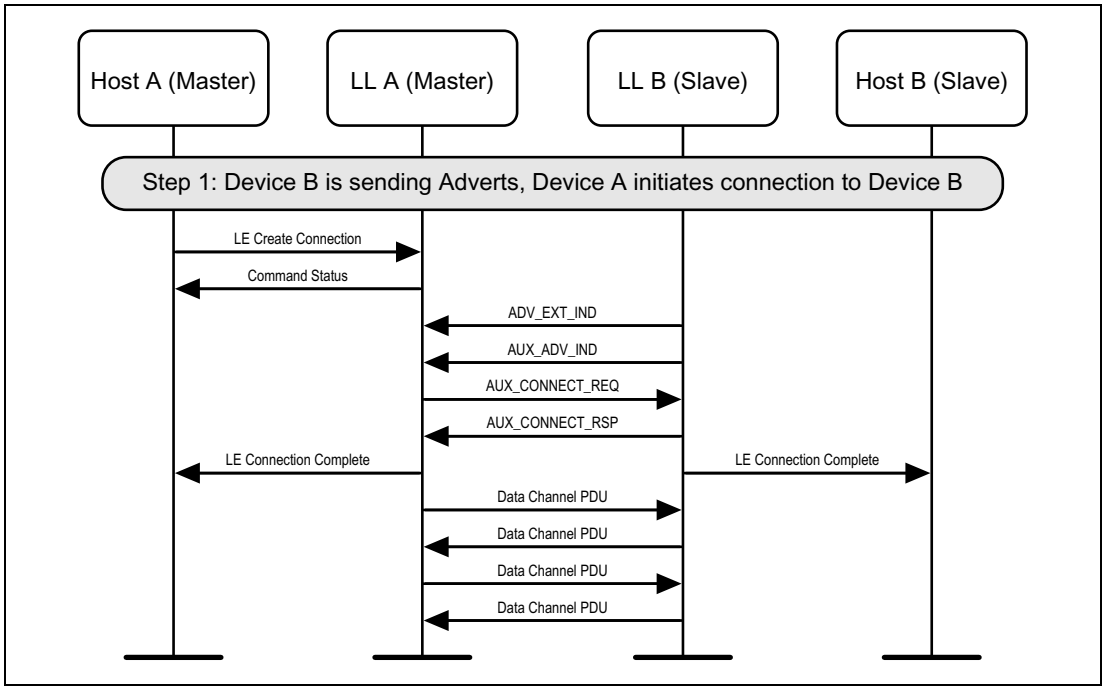

Figure 5.6: Initiating a connection on the secondary advertising channel

5.7 INITIATING A CHANNEL SELECTION ALGORITHM #2 CONNECTION

Where a device supports the Channel Selection Algorithm #2 feature, it can initiate a connection which will use Channel Selection Algorithm #2 to an advertiser who has the ChSel field of the advertising channel PDU set to 1. The example shows a successful initiation, resulting in the connection using Channel Selection Algorithm #2.

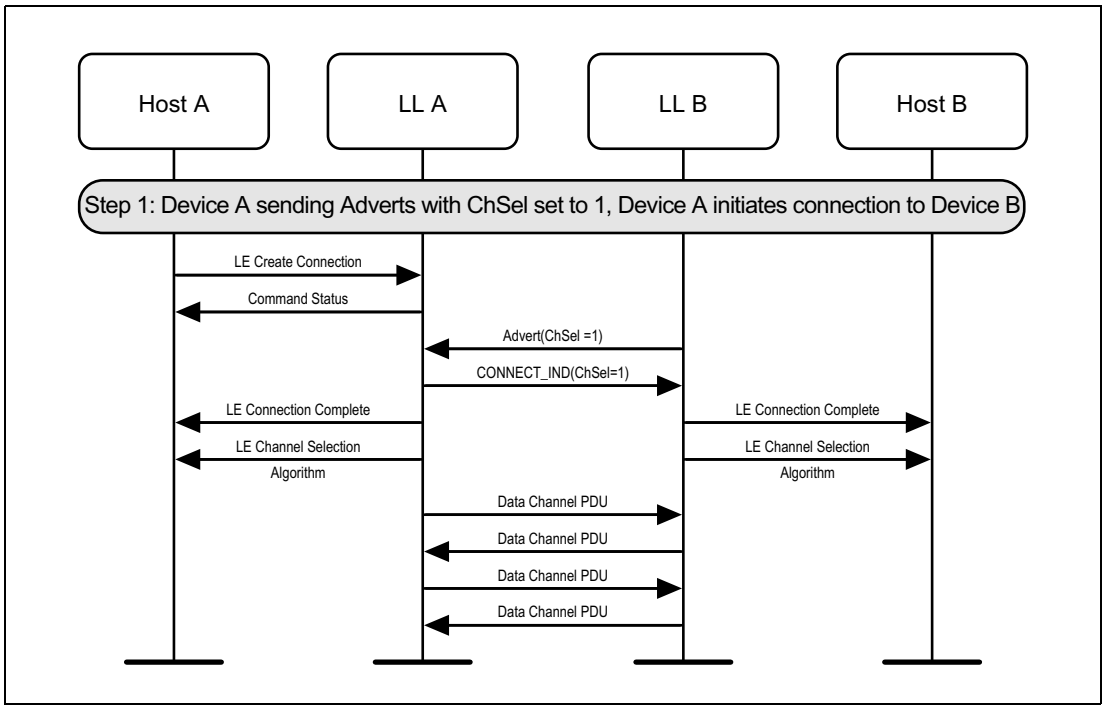

Figure 5.7: Initiating a Channel Selection Algorithm #2 Connection

6 CONNECTION STATE

6.1 SENDING DATA

Once two devices are in a connection, either device can send data. This example shows both devices sending data, for example when the Attribute Protocol does a read request and a read response is returned (see Figure 6.1).

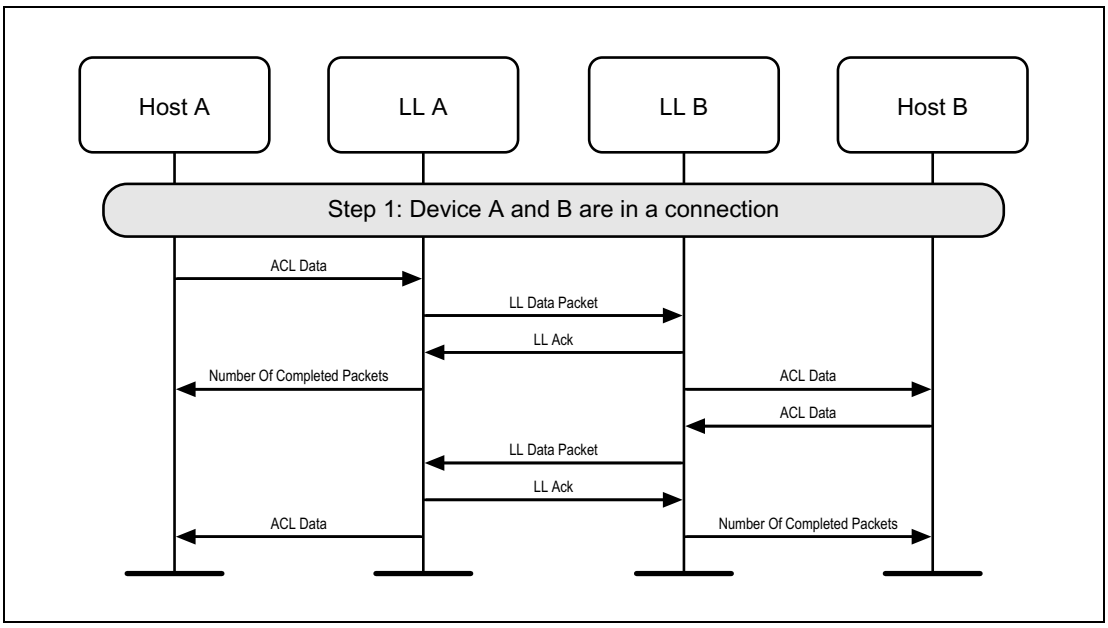

Figure 6.1: Sending Data

6.2 CONNECTION UPDATE

The master of the connection may request a connection update using a Link Layer Control Procedure (see Figure 6.2).

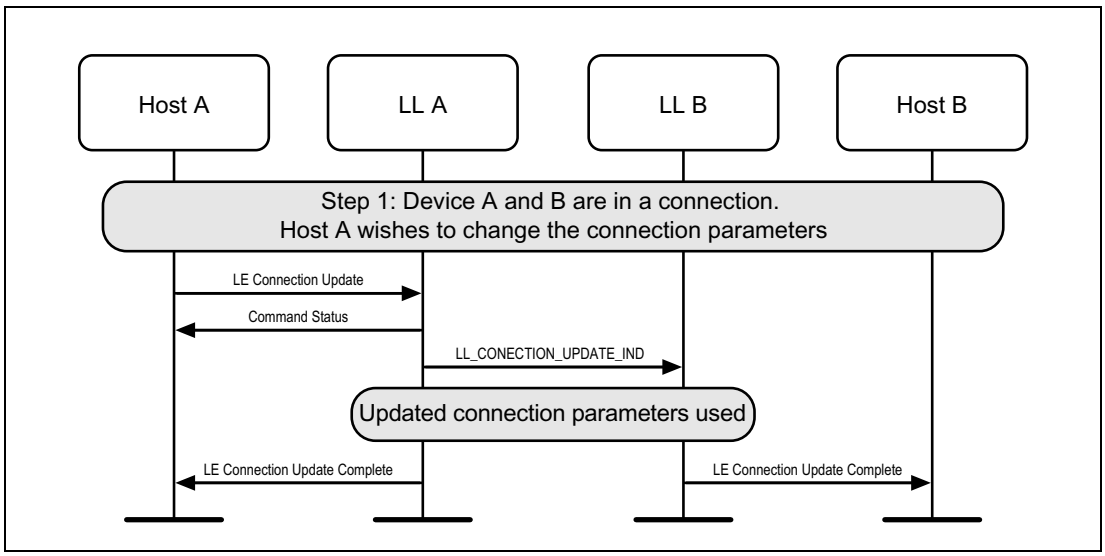

Figure 6.2: Connection Update

6.3 CHANNEL MAP UPDATE

The Controller of the master may receive some channel classification data from the Host and then perform the Channel Update Link Layer Control Procedure (see Figure 6.3).

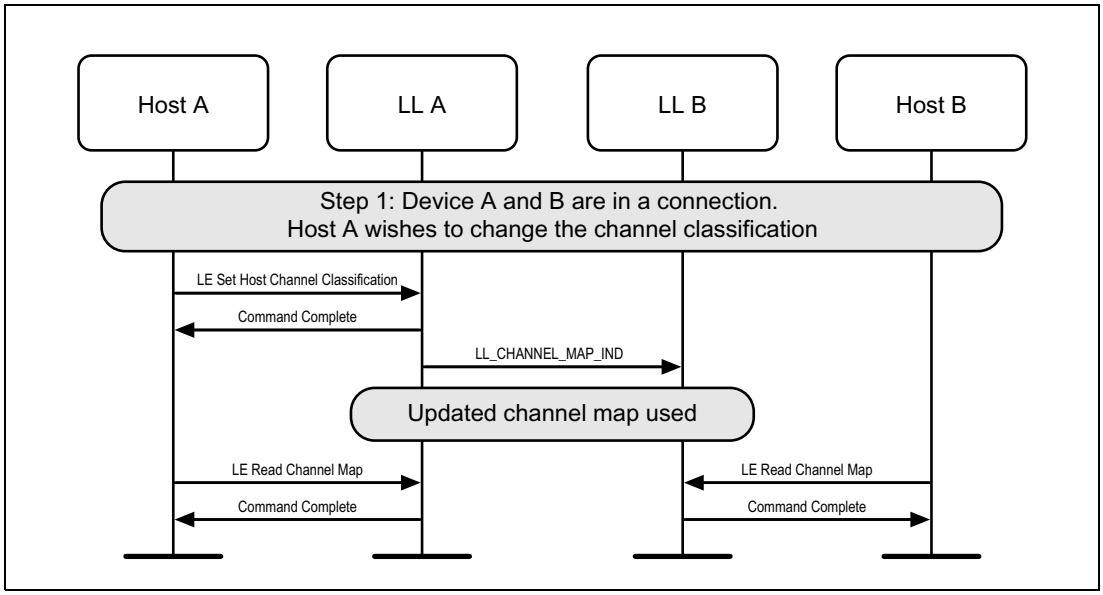

Figure 6.3: Channel Map Update

6.4 FEATURES EXCHANGE

Both the master and slave devices can discover the set of features available on the remote device. To achieve this, the Feature Exchange Link Layer Control Procedure is used (see Figure 6.4 and Figure 6.5).

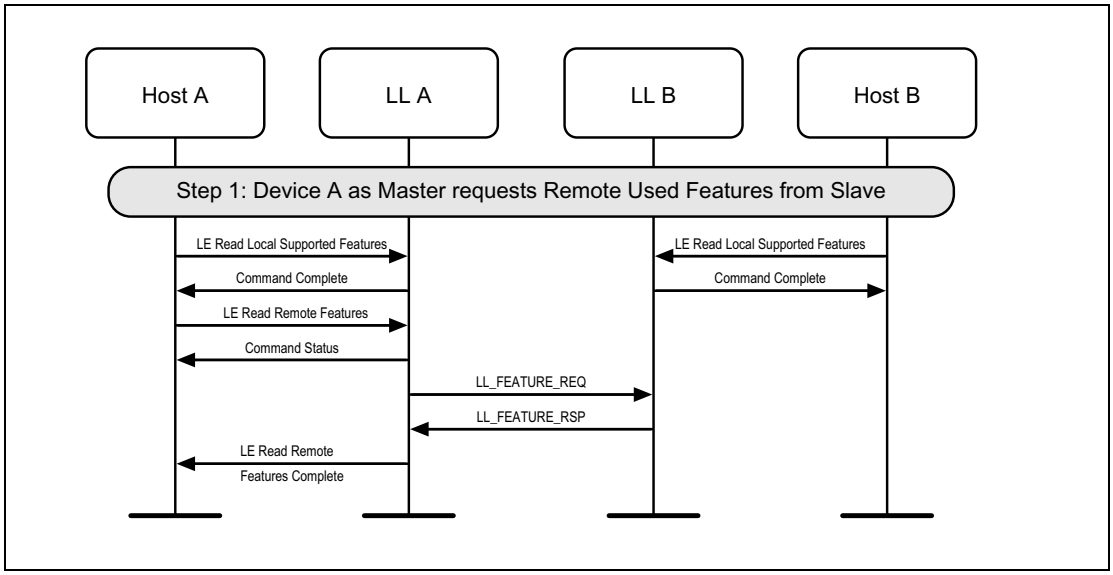

Figure 6.4: Master-initiated Features Exchange

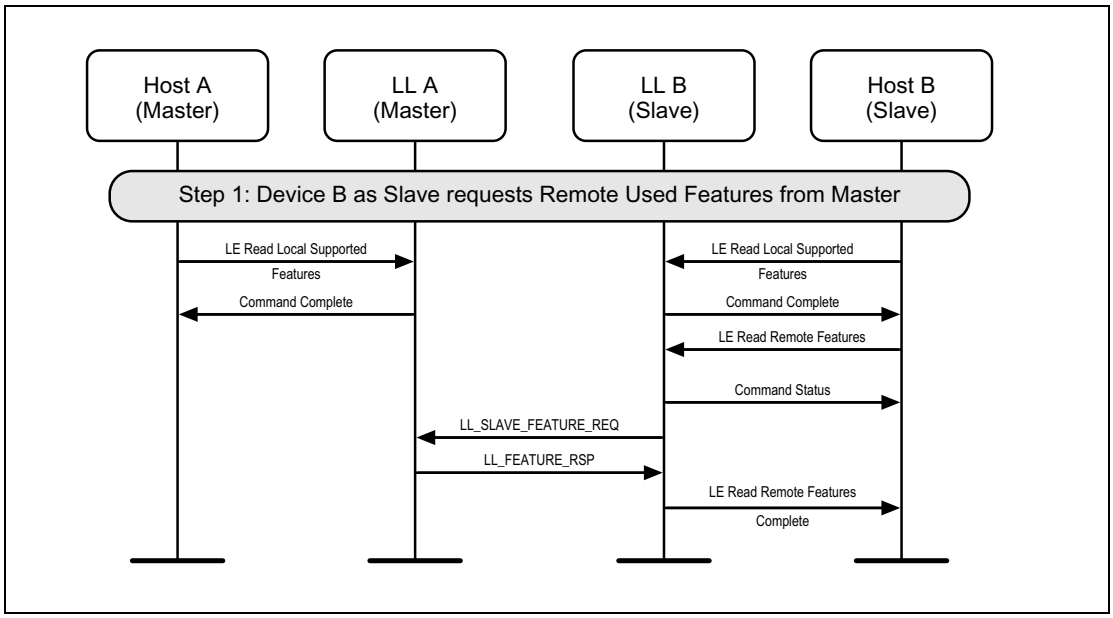

Figure 6.5: Slave-initiated Features Exchange

6.5 VERSION EXCHANGE

Either device may perform a version exchange (see Figure 6.6 and Figure 6.7).

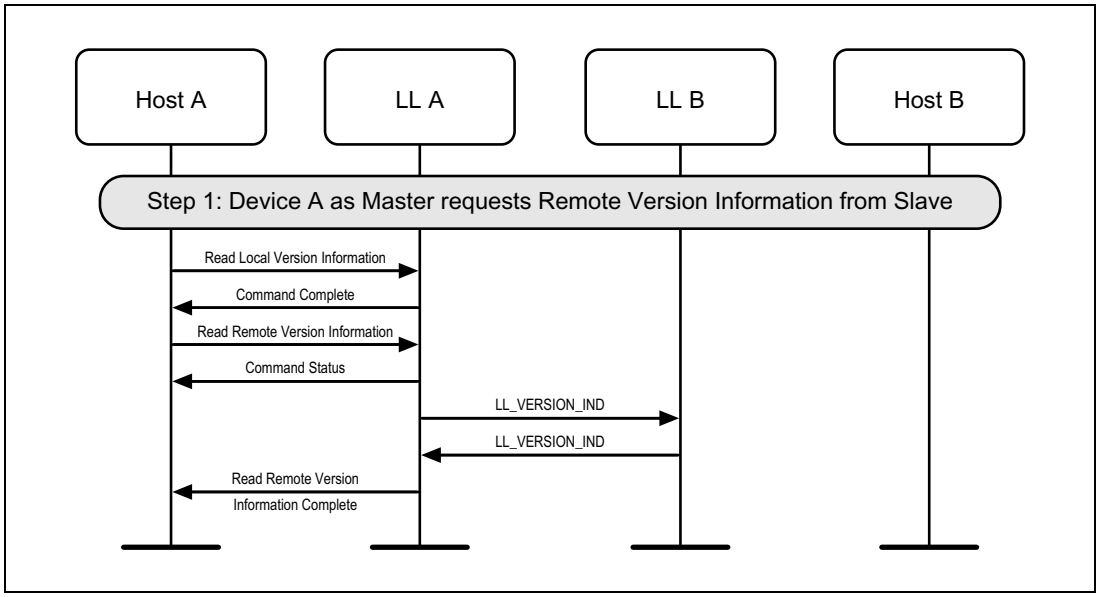

Figure 6.6: Version Exchange from Master

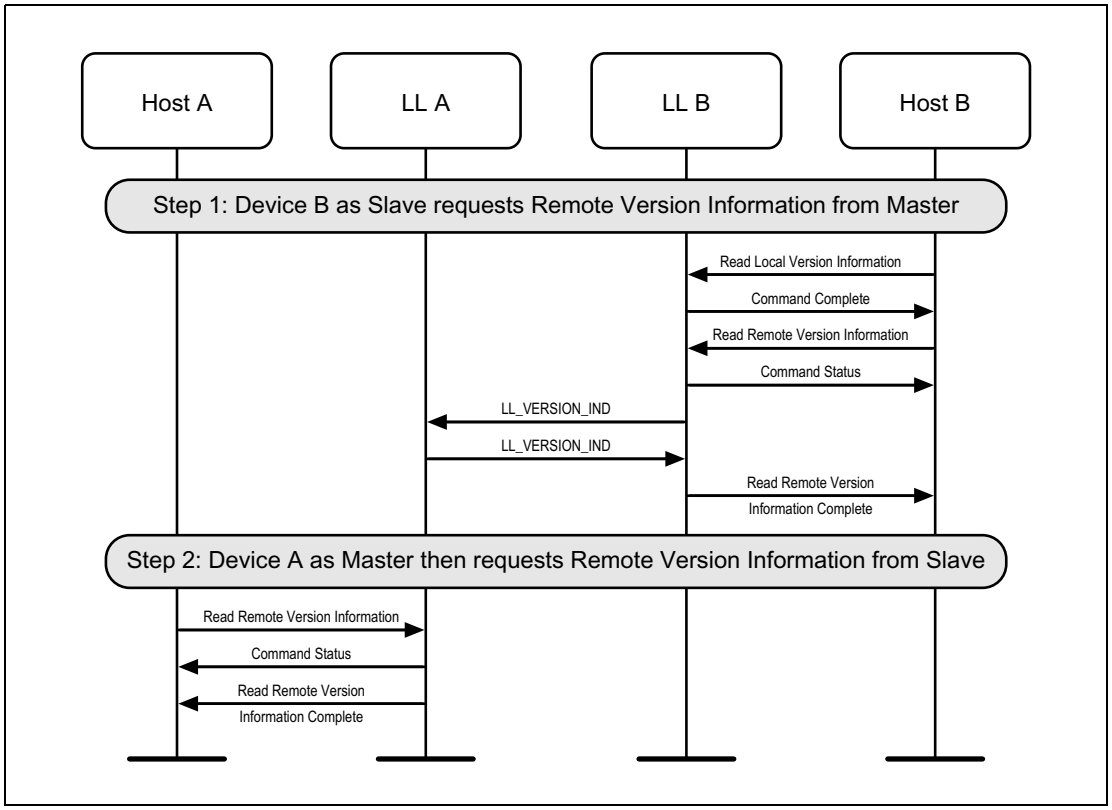

Figure 6.7: Version Exchange from Slave

6.6 START ENCRYPTION

If encryption has not been started on a connection, it may be started by the master (see Figure 6.8).

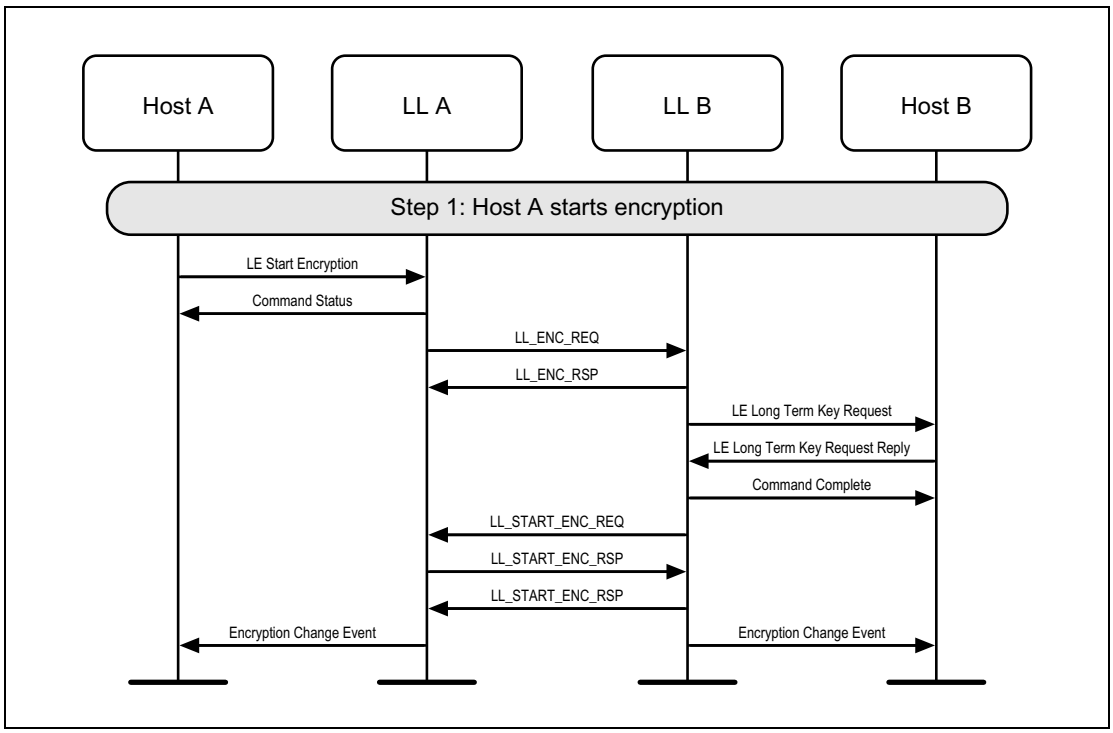

Figure 6.8: Start Encryption

6.7 START ENCRYPTION WITHOUT LONG TERM KEY

If encryption has not been started on a connection, it may be started by the master. Figure 6.9 shows the failure case of the slave not having the long term key for the master.

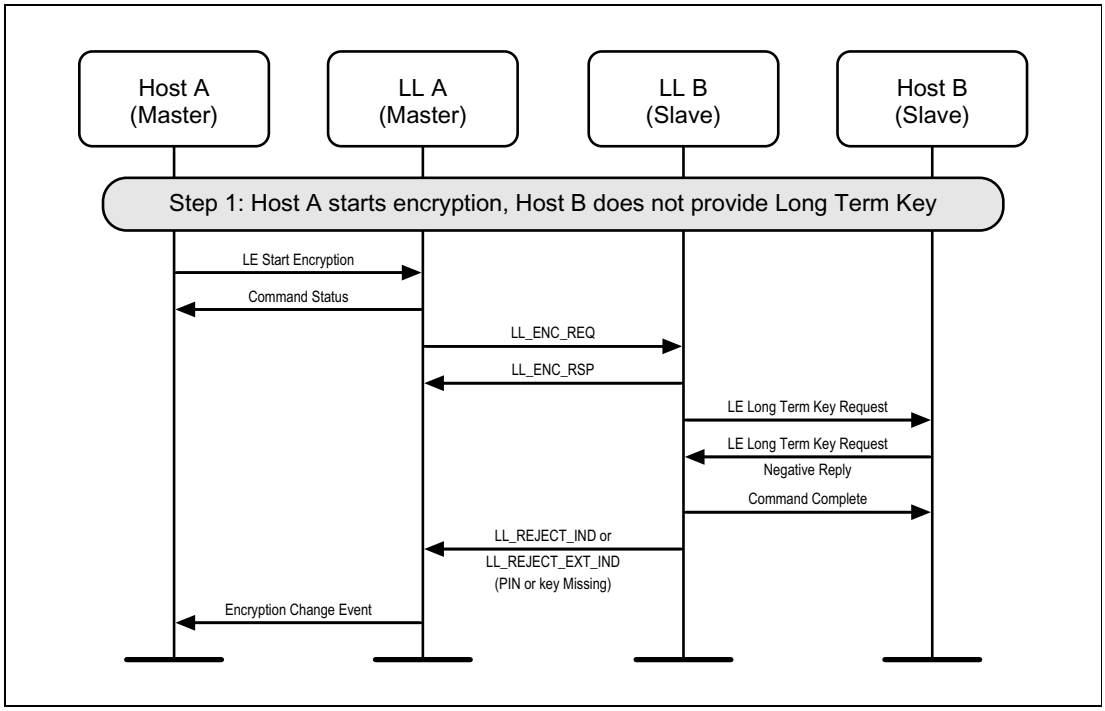

Figure 6.9: Start encryption without long-term key

6.8 START ENCRYPTION WITH EVENT MASKED

If encryption has not been started on a connection, it may be started by the master. Figure 6.10 shows the failure case when the slave has masked out the LE Long Term Key Request event.

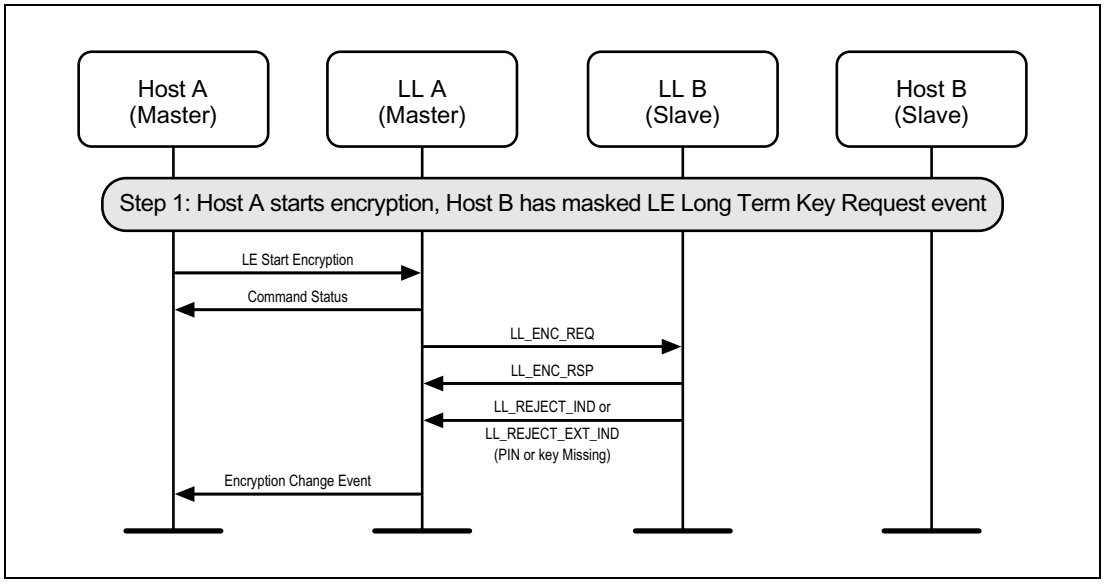

Figure 6.10: Start encryption with slave masking out event

6.9 START ENCRYPTION WITHOUT SLAVE SUPPORTING ENCRYPTION

If Encryption has not been started on a connection, it may be started by the master. Figure 6.11 shows the failure case of the slave that does not support the encryption feature.

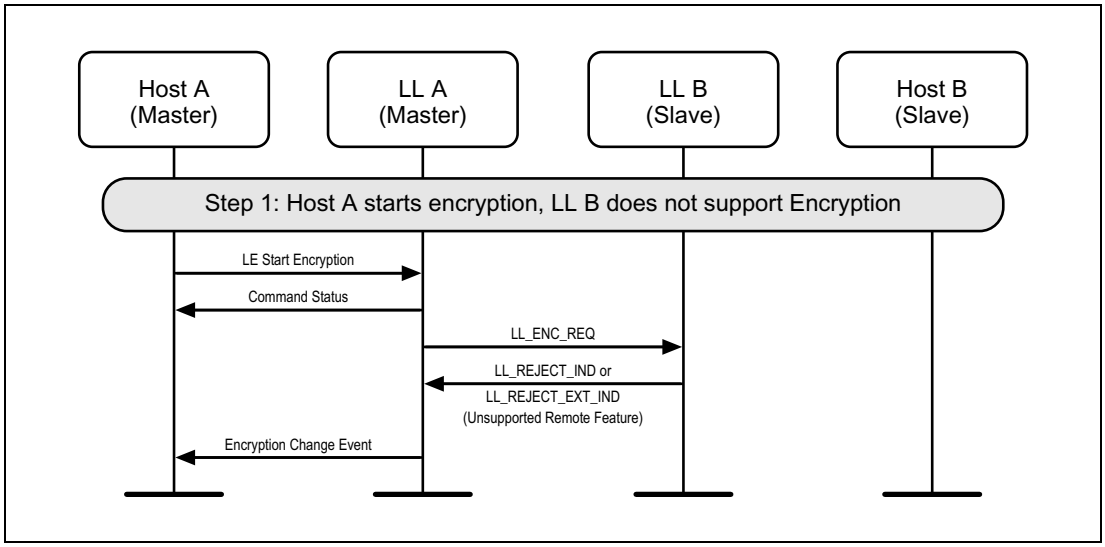

Figure 6.11: Start Encryption failure when slave does not support encryption

6.10 RESTART ENCRYPTION

If encryption has already been started on a connection, it may be restarted by the master. This may be required to use a stronger encryption as negotiated by the Security Manager Protocol (see Figure 6.12).

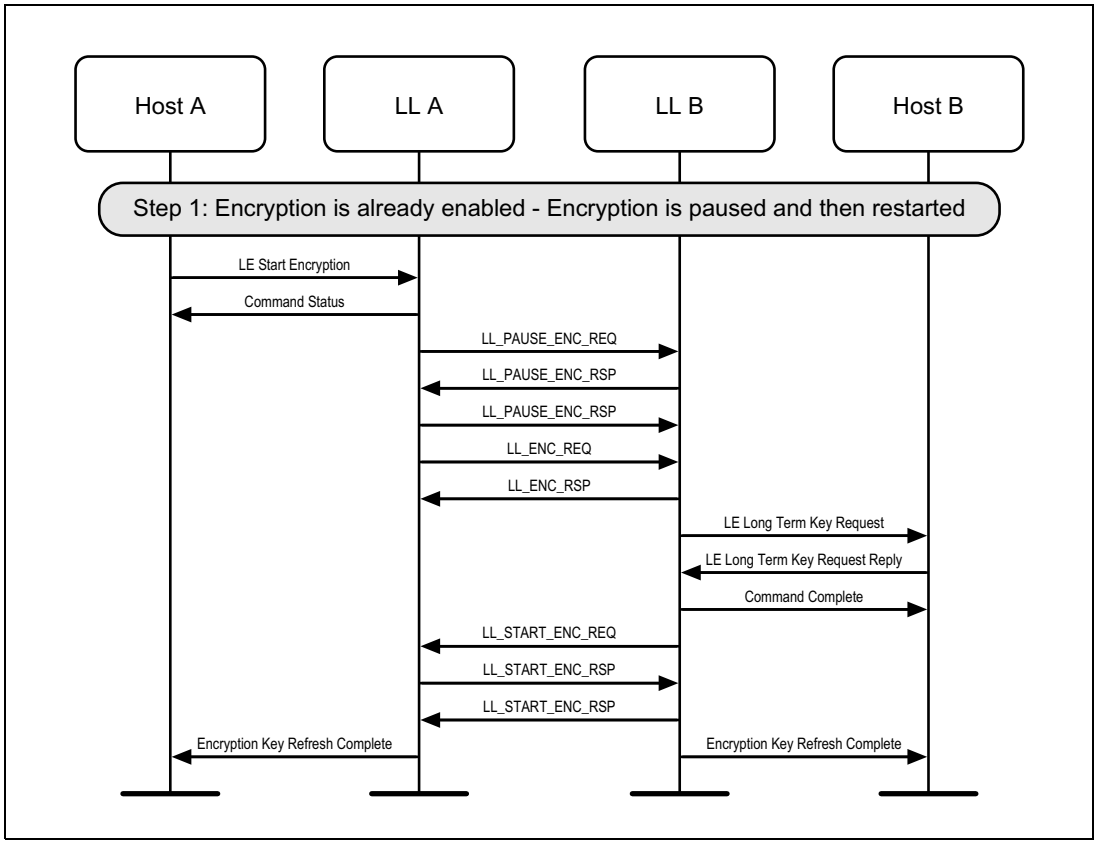

Figure 6.12: Restart Encryption

6.11 DISCONNECT

Once a connection has no need to be kept active, the Host can disconnect it. This can be done by either device (see Figure 6.13 and Figure 6.14).

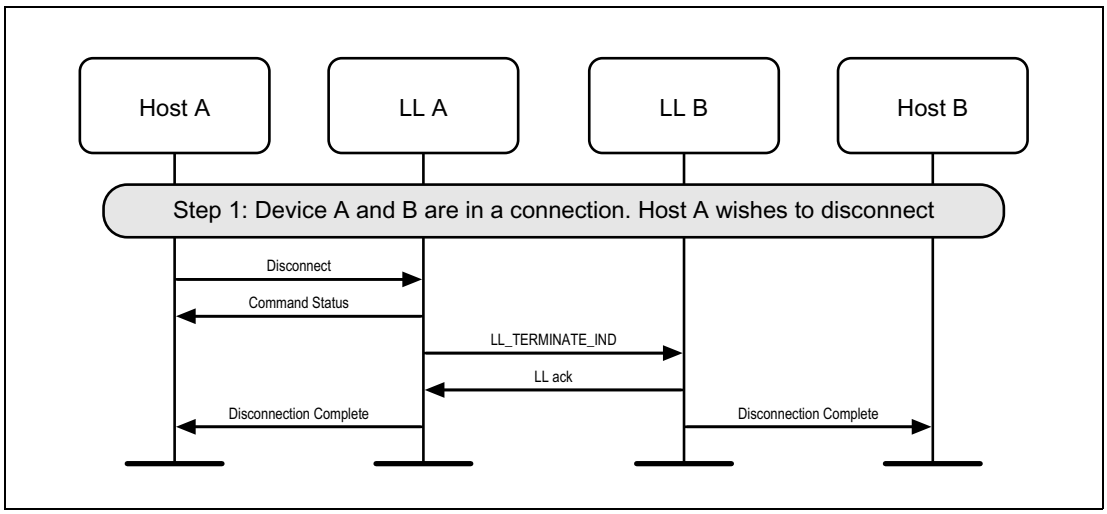

Figure 6.13: Disconnect from Master

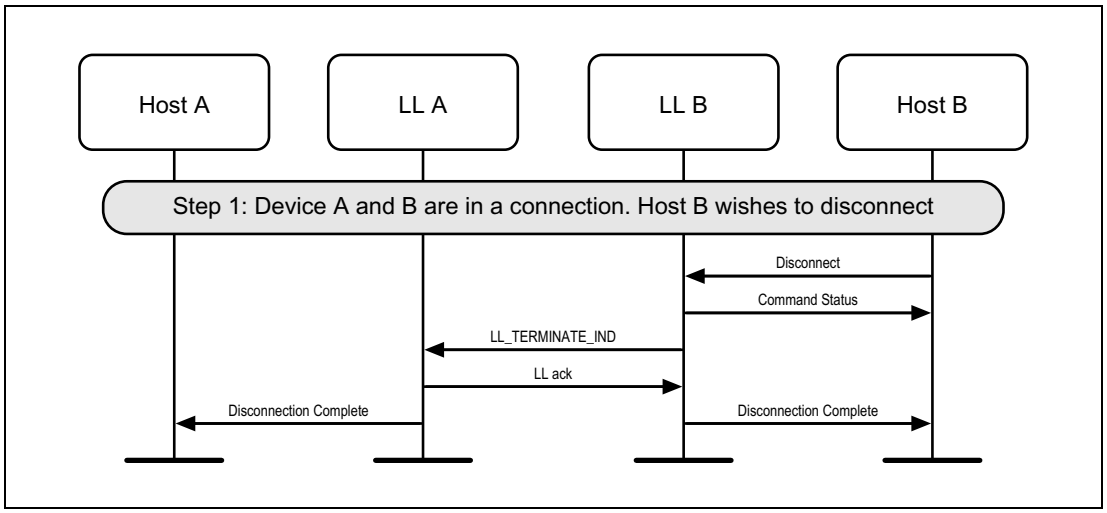

Figure 6.14: Disconnect from Slave

6.12 CONNECTION PARAMETERS REQUEST

The master or the slave of the connection may request change in connection parameters using a Link Layer Control Procedure (see Figure 6.15 to Figure 6.22).

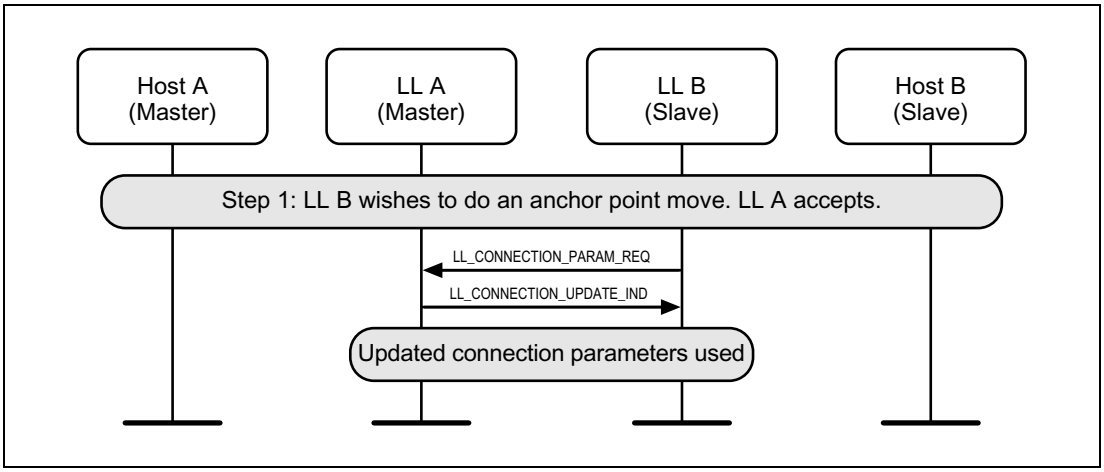

Figure 6.15: Slave-initiated Connection Parameters Request procedure – slave requests a change in anchor points, master accepts

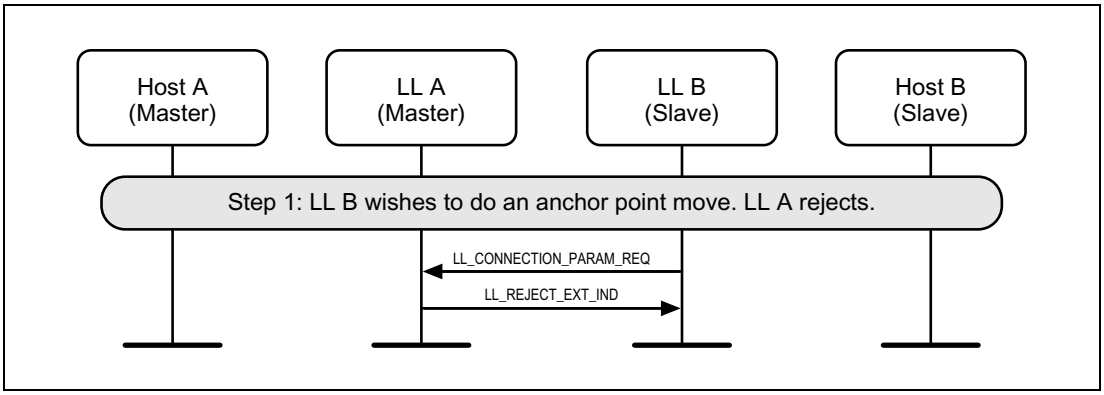

Figure 6.16: Slave-initiated Connection Parameters Request procedure – slave requests a change in anchor points, master rejects

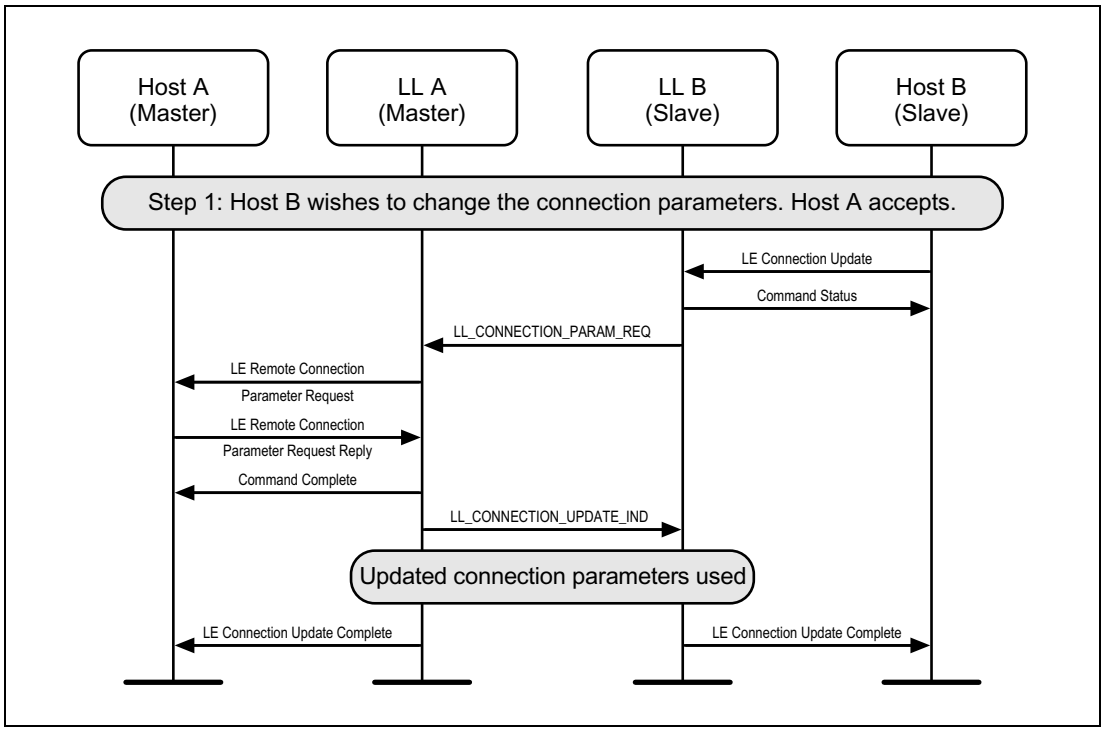

Figure 6.17: Slave-initiated Connection Parameters Request procedure – slave requests change in LE connection parameters, master's Host accepts

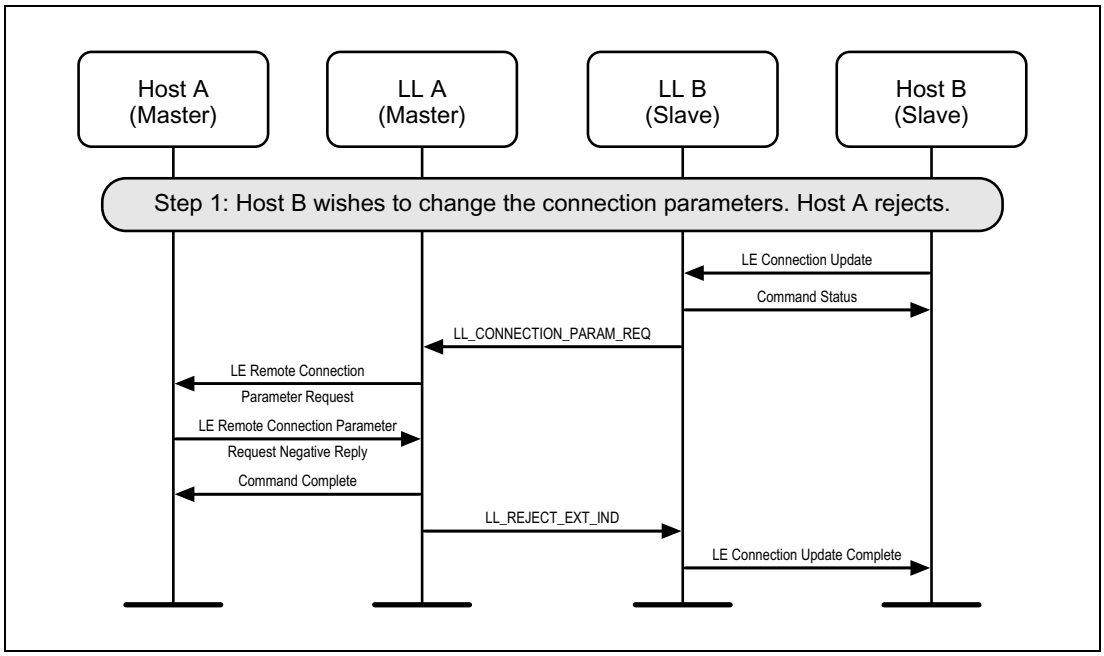

Figure 6.18: Slave-initiated Connection Parameters Request procedure – slave requests change in LE connection parameters, master's Host rejects

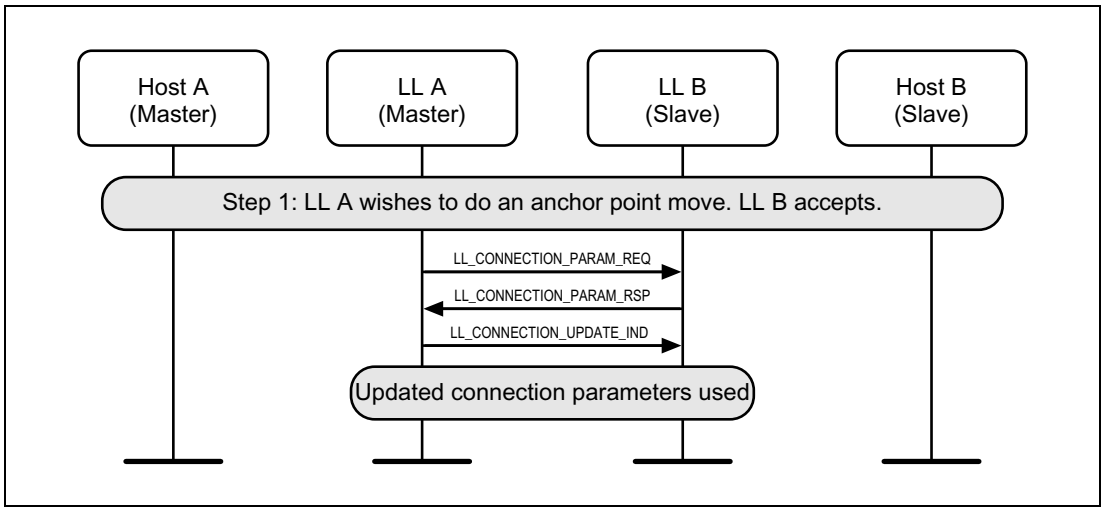

Figure 6.19: Master-initiated Connection Parameters Request procedure –master requests a change in anchor points, slave accepts

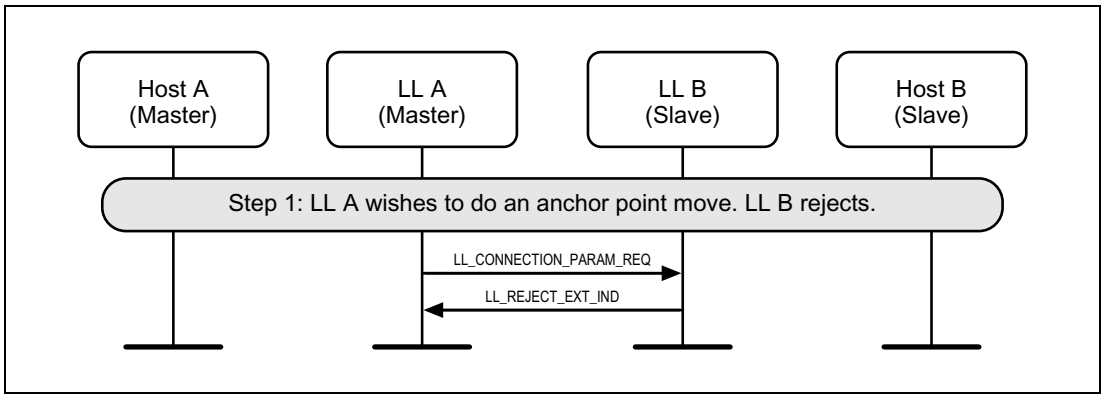

Figure 6.20: Master-initiated Connection Parameters Request procedure –master requests a change in anchor points, slave rejects

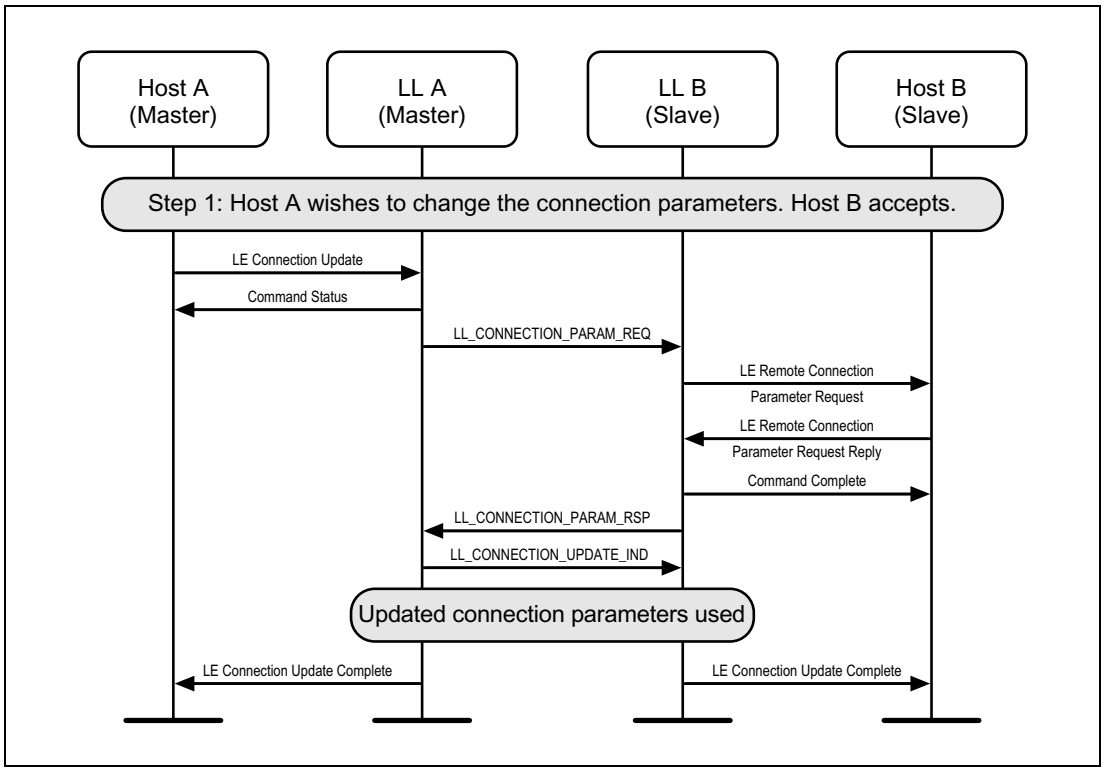

Figure 6.21: Master-initiated Connection Parameters Request procedure – master requests change in LE connection parameters, slave's Host accepts

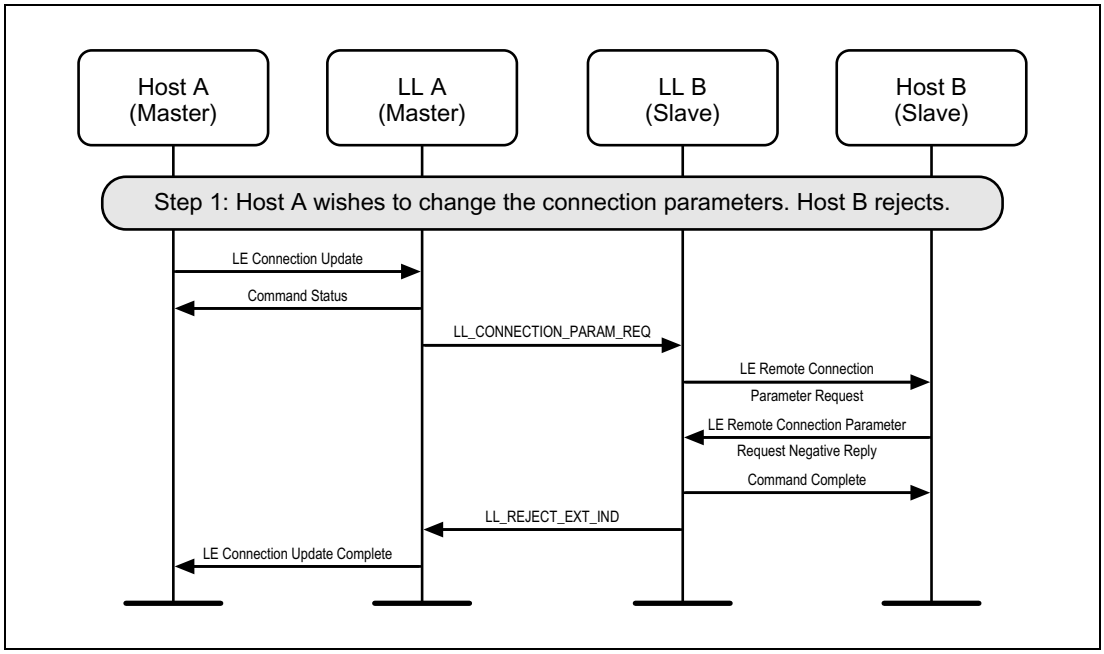

Figure 6.22: Master-initiated Connection Parameters Request procedure – master requests change in LE connection parameters, slave's Host rejects

6.13 LE PING

A Host may use the HCI_Write_Authenticated_Payload_Timeout command to change the maximum interval between packets containing a valid MIC that the link layer will enforce when encryption is used.

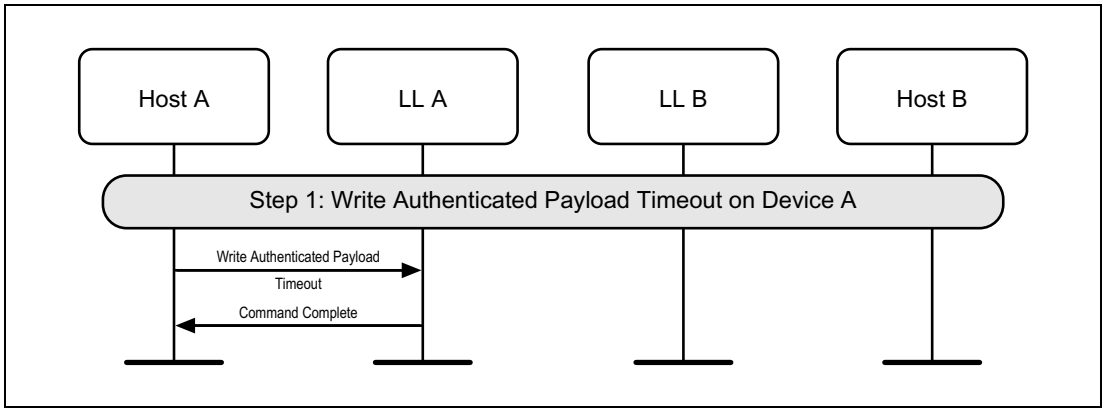

Figure 6.23: Set LE Authenticated Payload Timeout

Either Link Layer can authenticate the remote device using the LE Ping Procedure even if the remote device does not support the LE Ping feature. This procedure can also be used for soliciting a packet from the remote device containing a valid MIC. LL A may be a master or a slave.

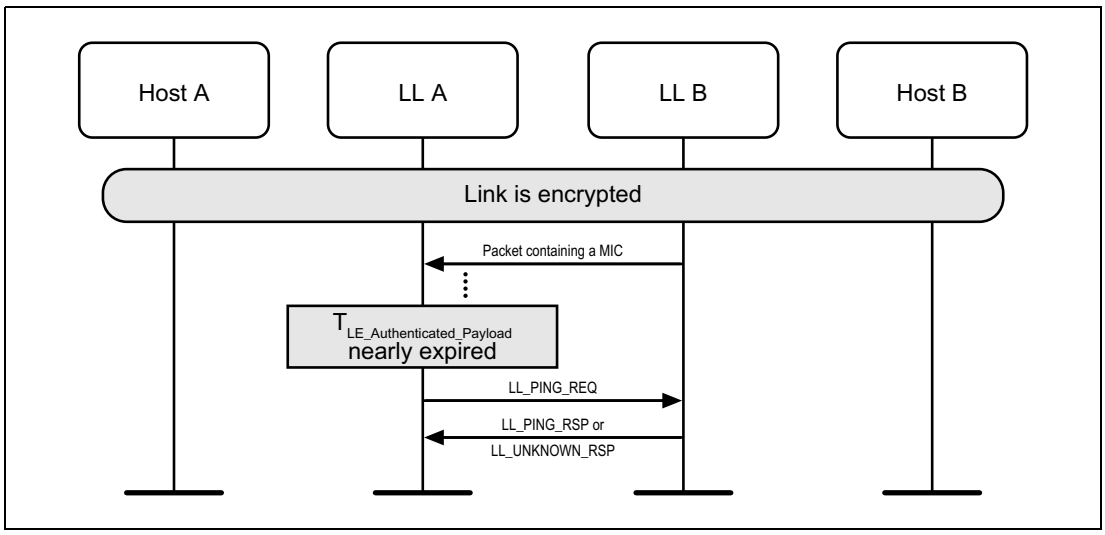

Figure 6.24: Successful LE Ping

When a packet with a valid MIC has not been received within the LE Authenticated Payload Timeout, the Host is notified that the timer has expired.

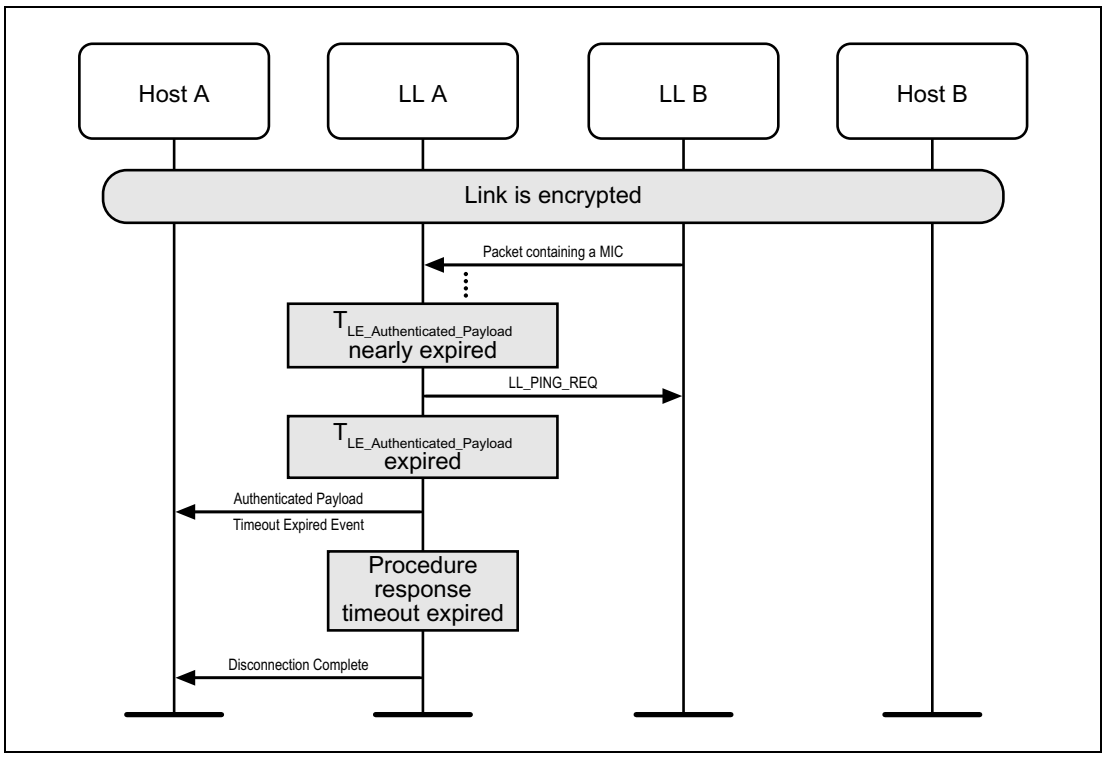

Figure 6.25: Unsuccessful LE Ping

The $T_{LE\_Authenticated\_Payload}$ Timer gets reset when the Host sets the Authenticated Payload Timeout.

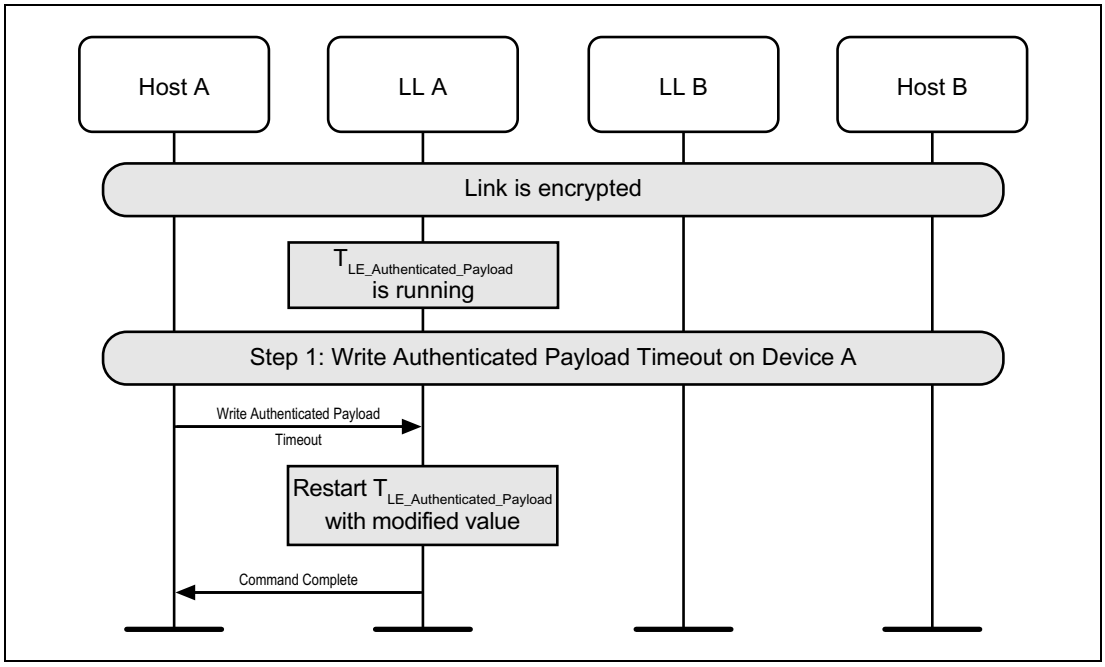

Figure 6.26: $T_{LE\_Authenticated\_Payload}$ Timer reset

6.14 DATA LENGTH UPDATE

Once a connection has been created, the Host may suggest maximum transmission packet size and maximum packet transmission time to be used for the connection. This may be done on either the master or the slave.

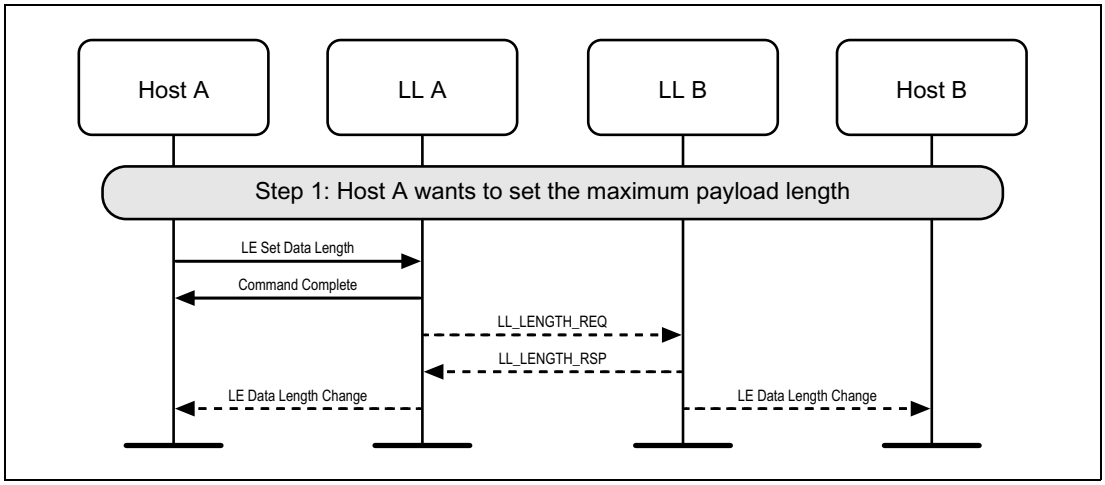

Figure 6.27: Data Length Update

6.15 PHY UPDATE

The master or slave of the connection may request a change in the PHY using a Link Layer Control Procedure (see Figure 6.28 to Figure 6.36).

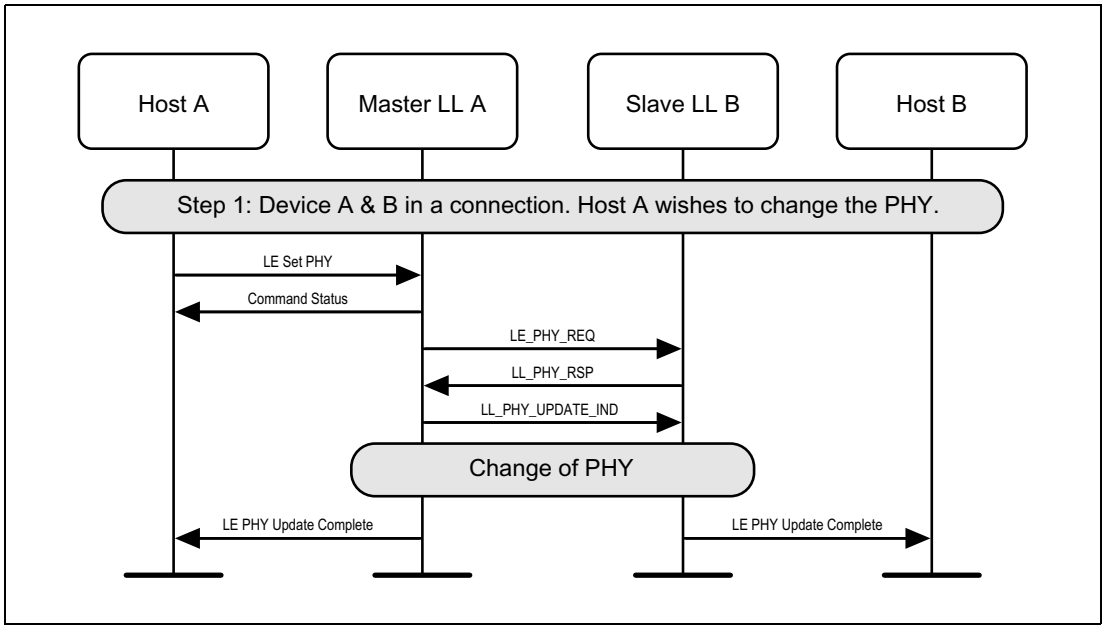

Figure 6.28: Master initiated PHY Update procedure – master requests a change of PHY, PHY changed in at least one direction

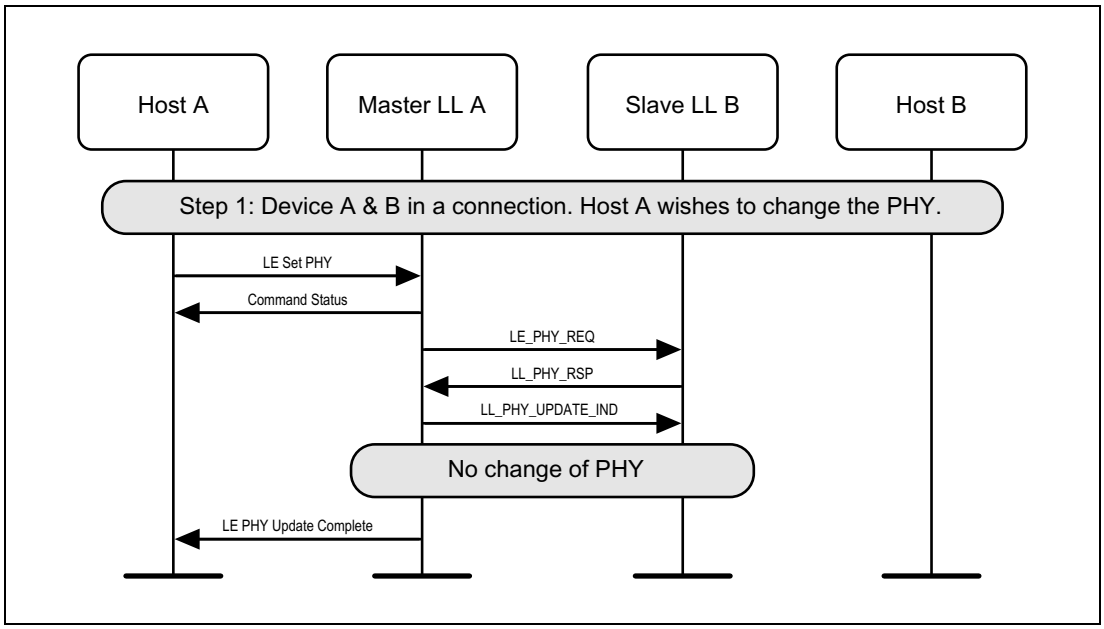

Figure 6.29: Master initiated PHY Update procedure, PHY not changed (either because slave doesn't specify PHYs that the master prefers, or because the master concludes that the current PHYs are still best)

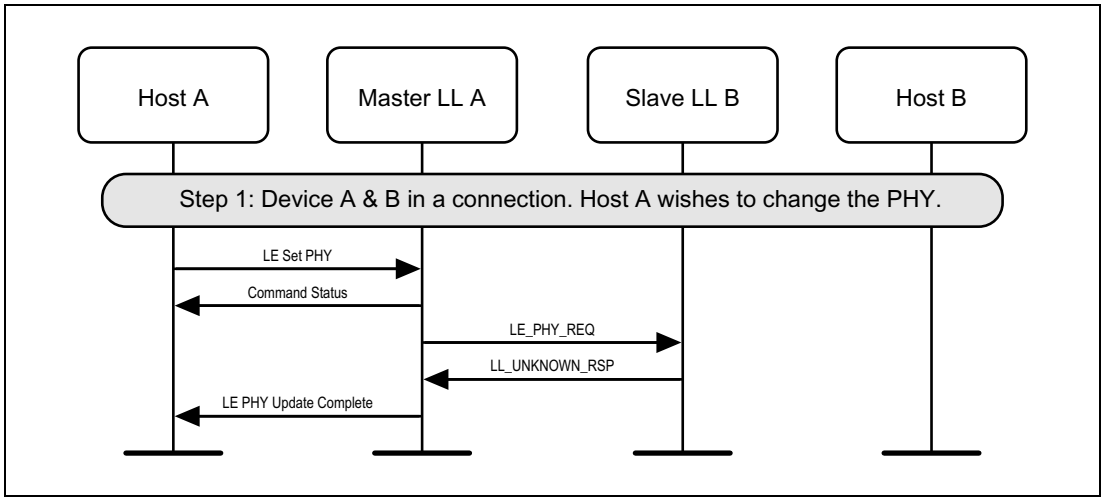

Figure 6.30: Master initiated PHY Update procedure – master requests a change of PHY, slave does not support the feature

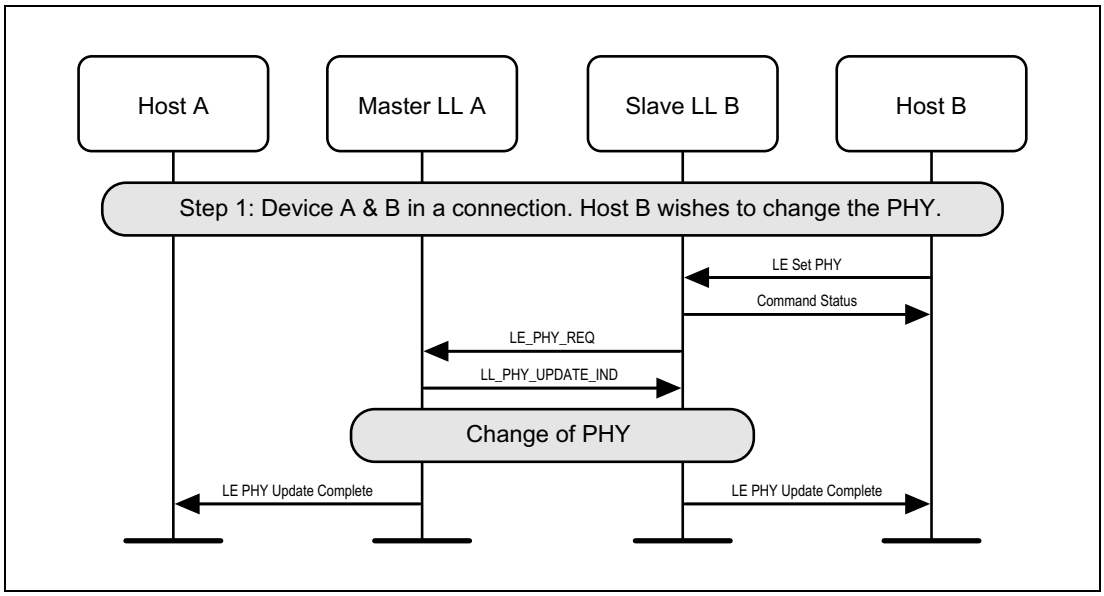

Figure 6.31: Slave initiated PHY Update procedure – slave requests a change of PHY, PHY changed in at least one direction

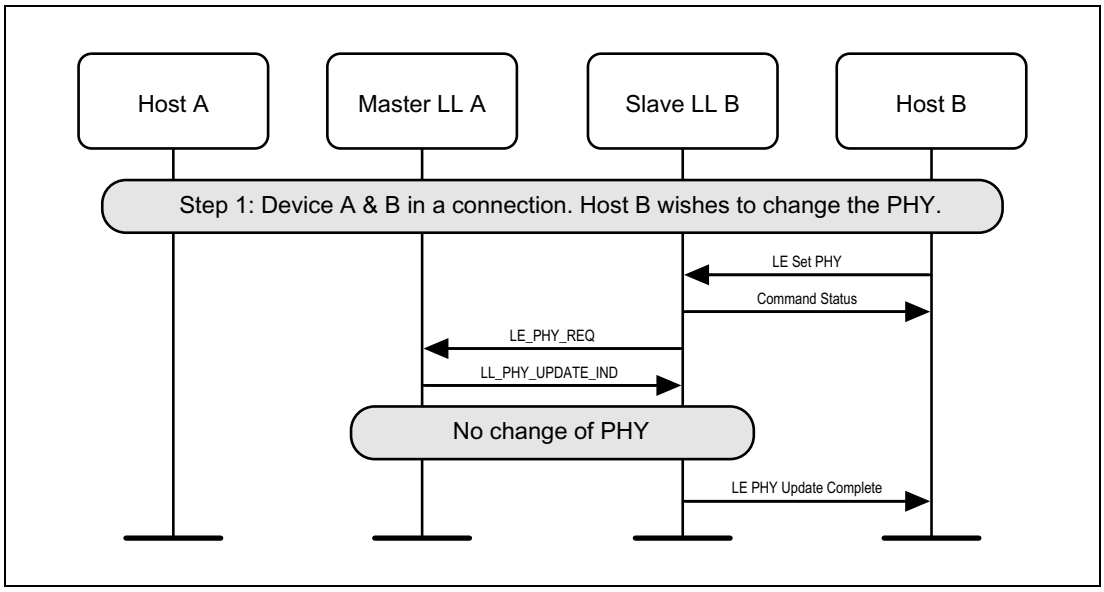

Figure 6.32: Slave initiated PHY Update procedure, PHY not changed (either because slave doesn't specify PHYs that the master prefers, or because the master concludes that the current PHYs are still best)

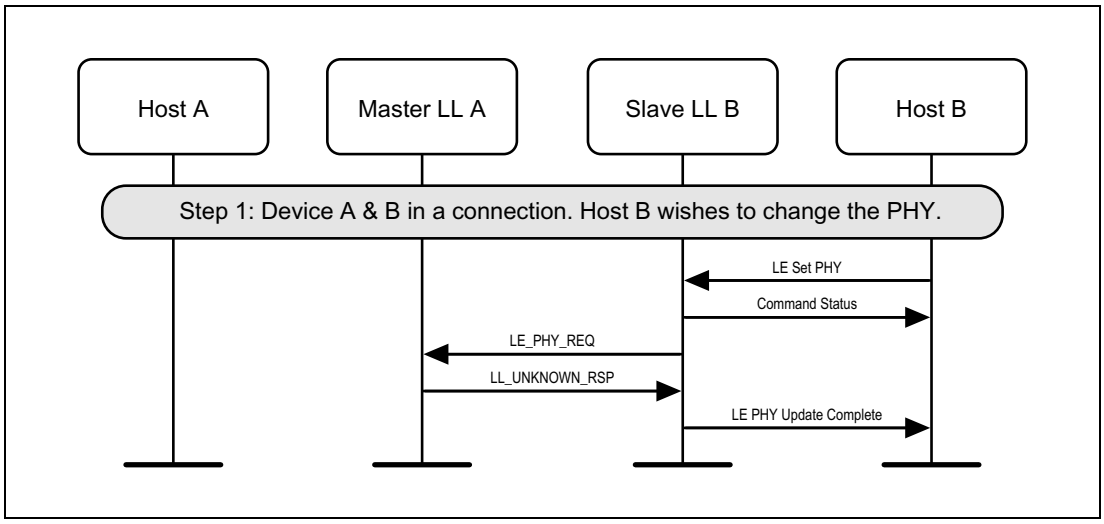

Figure 6.33: Slave initiated PHY Update procedure – slave requests a change of PHY, master does not support the feature

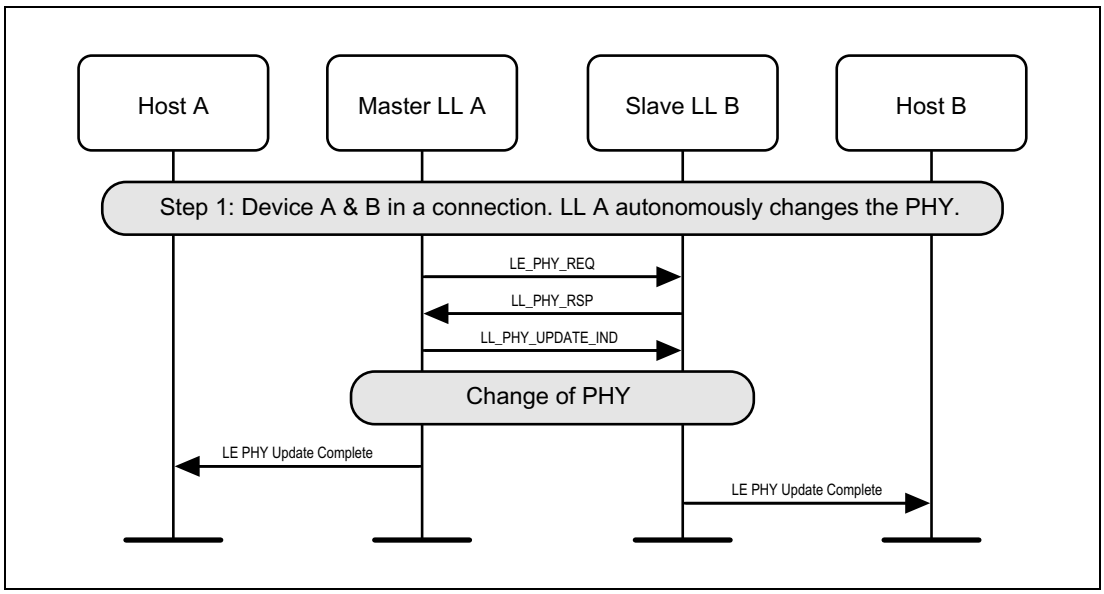

Figure 6.34: Autonomous master-initiated PHY Update procedure – master requests a change of PHY, slave accepts, PHY changed in at least one direction

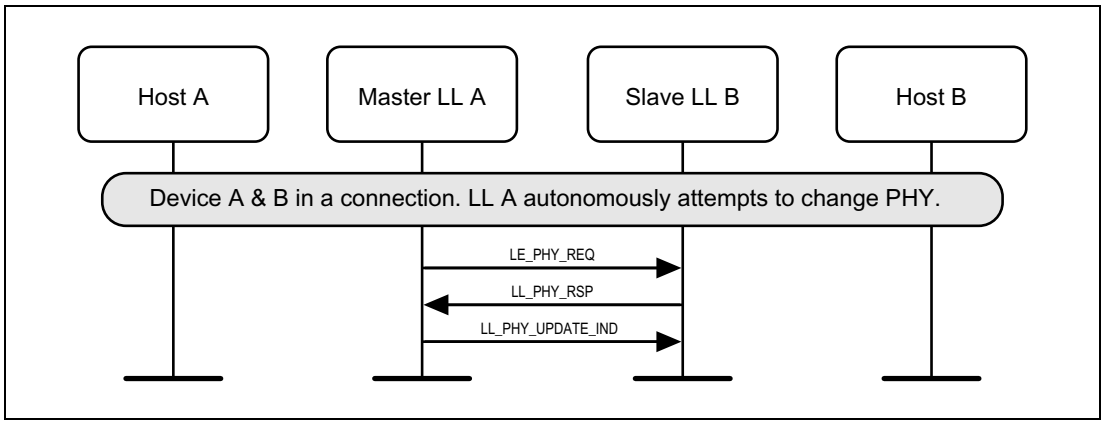

Figure 6.35: Autonomous master-initiated PHY Update procedure – master requests a change of PHY, PHY not changed (either because slave doesn't specify PHYs that the master prefers, or because the master concludes that the current PHYs are still best)

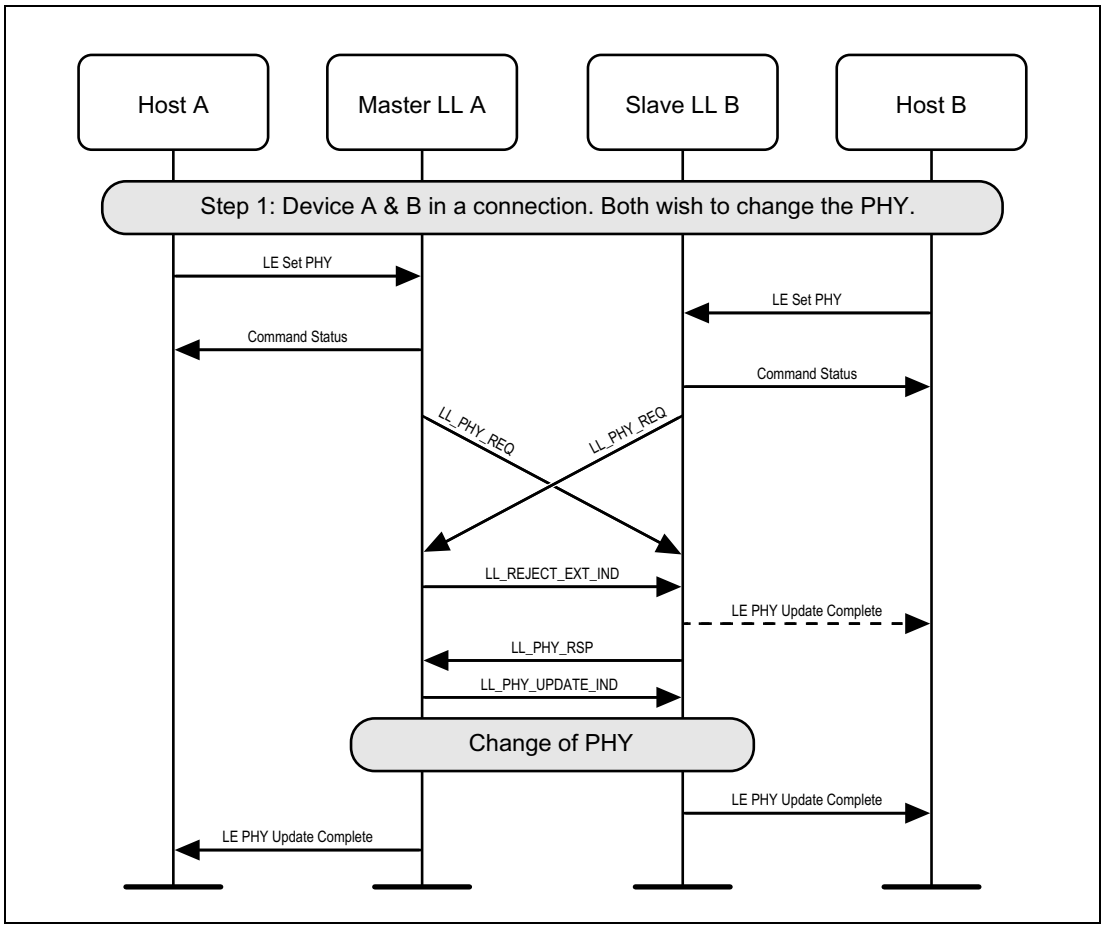

Figure 6.36: Master and slave crossover PHY Update procedure – master and slave request a change of PHY concurrently

6.16 MINIMUM NUMBER OF USED CHANNELS REQUEST

Where a slave device supports the Minimum Number of Used Channels procedure, it can request that a certain minimum number of channels be used on the indicated PHY. The example shows a successful request, resulting in a channel map update with the requested minimum number of channels used for the connection.

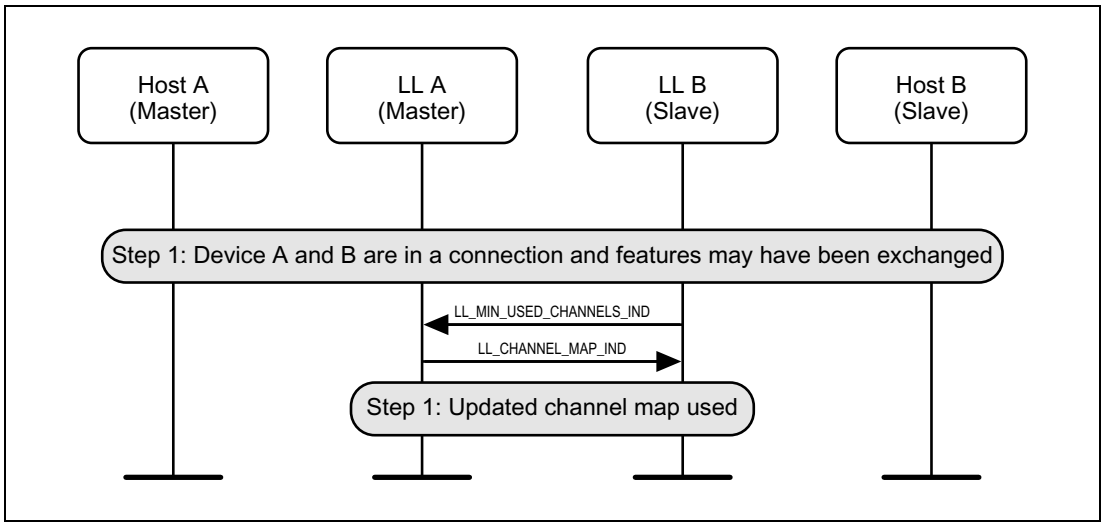

Figure 6.37: Requesting minimum number of used channels

6.17 LL PROCEDURE COLLISION

The Link Layers of both the master and slave may initiate the same LL procedure at the same time.

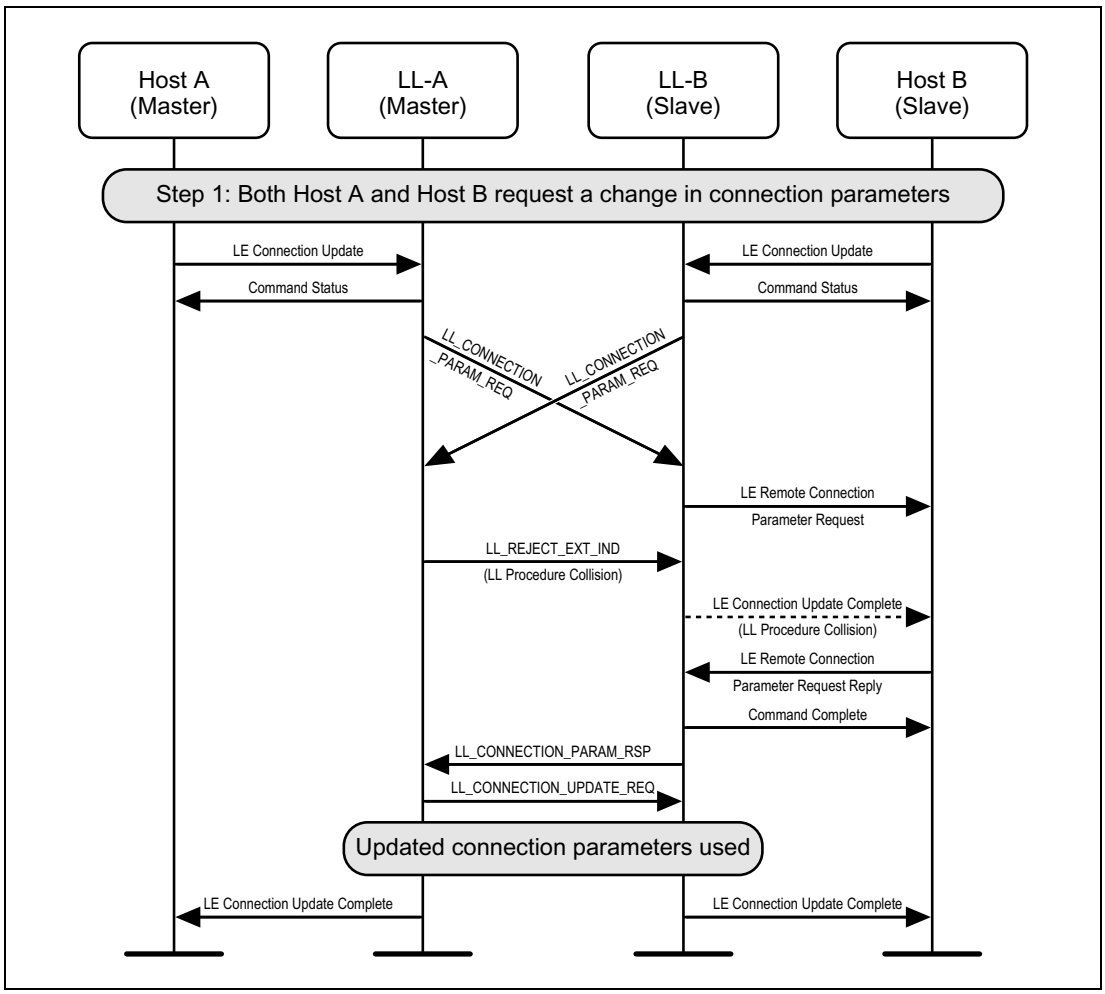

Figure 6.38: LL Procedure Collision

LOW ENERGY LINK LAYER SECURITY

This part of the specification describes the Link Layer security for Bluetooth low energy.

CONTENTS

1 ENCRYPTION AND AUTHENTICATION OVERVIEW

The Link Layer provides encryption and authentication using Counter with Cipher Block Chaining-Message Authentication Code (CCM) Mode, which shall be implemented consistent with the algorithm as defined in IETF RFC 3610 (http://www.ietf.org/rfc/rfc3610.txt) in conjunction with the AES-128 block cipher as defined in NIST Publication FIPS-197 (http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf). A description of the CCM algorithm can also be found in the NIST Special Publication 800-38C (http://csrc.nist.gov/publications/PubsSPs.html).

This specification uses the same notation and terminology as the IETF RFC except for the Message Authentication Code (MAC) that in this specification is called the Message Integrity Check (MIC) to avoid confusion with the term Media Access Controller.

CCM has two size parameters, M and L. The Link Layer defines these to be:

- M = 4; indicating that the MIC (authentication field) is 4 octets
- L = 2; indicating that the Length field is 2 octets

CCM requires a new temporal key whenever encryption is started. CCM also requires a unique nonce value for each Data Channel PDU protected by a given temporal key. The CCM nonce shall be 13 octets.

The Link Layer connection may be either encrypted and authenticated or unencrypted and unauthenticated. In an encrypted and authenticated connection, all the Data Channel PDUs with a non-zero length Payload shall be encrypted and authenticated. Authentication is performed by appending a MIC field to the Payload. The MIC shall be calculated over the Data Channel PDU's Payload field and the first octet of the header ([Vol 6] Part B, Section 2.4) with the NESN, SN and MD bits masked to zero.

Encryption shall be applied to the Data Channel PDU's Payload field and MIC.

Each new Data Channel PDU with a non-zero length Payload shall be decrypted and authenticated before being sent to the Host or processed by the Link Layer. Authentication is unrelated to Link Layer acknowledgment scheme; authentication does not have to be performed before the packet is acknowledged by the Link Layer.

In the unlikely event of an authentication failure being detected, the connection shall be considered lost. The Link Layer shall not send or receive any further packets on that connection. The Link Layer shall exit the Connection State and transition to the Standby State. The Host shall be notified of the loss of connection due to an authentication failure. The peer Link Layer will detect this loss of connection through the supervision timeout procedure.

2 CCM

This section provides the details for using the CCM algorithm. As specified, the CCM algorithm requires the payload and some additional parameters to be formatted into the CCM nonce, counter-mode blocks and encryption blocks. The CCM nonce provides uniqueness to each packet. The counter-mode blocks are used to calculate the MIC. The encryption blocks provide the keystream that is used to encrypt the payload and the MIC of the Data Channel PDU.

Sample data of the blocks (see Section 2.2 and Section 2.3) can be found in [Vol 6] Part C, Section 1 and Section 1.2.

2.1 CCM NONCE

The CCM nonce is constructed from a 39-bit *packetCounter*, 1-bit *directionBit* and an 8-octet IV (initialization vector). The format of the 13-octet nonce shall be as shown in Table 2.1.

Octet	Field	Size (octets)	Value	Description
0	Nonce0	1	variable	Octet0 (LSO) of *packetCounter*
1	Nonce1	1	variable	Octet1 of *packetCounter*
2	Nonce2	1	variable	Octet2 of *packetCounter*
3	Nonce3	1	variable	Octet3 of *packetCounter*
4	Nonce4	1	variable	Bit 6 – Bit 0: Octet4 (7 most significant bits of *packetCounter*, with Bit 6 being the most significant bit) Bit7:*directionBit*
5	Nonce5	1	variable	Octet0 (LSO) of IV
6	Nonce6	1	variable	Octet1 of IV
7	Nonce7	1	variable	Octet2 of IV
8	Nonce8	1	variable	Octet3 of IV
9	Nonce9	1	variable	Octet4 of IV
10	Nonce10	1	variable	Octet5 of IV
11	Nonce11	1	variable	Octet6 of IV
12	Nonce12	1	variable	Octet7 (MSO) of IV

Table 2.1: CCM nonce format

The Link Layer shall maintain one *packetCounter* per Role for each connection.

For each connection, the *packetCounter* shall be set to zero for the first encrypted Data Channel PDU sent during the encryption start procedure. The *packetCounter* shall then be incremented by one for each new Data Channel PDU that is encrypted. The *packetCounter* shall not be incremented for retransmissions.

The *directionBit* shall be set to 1 for Data Channel PDUs sent by the master and set to 0 for Data Channel PDUs sent by the slave.

The IV is common for both Roles of a connection. Whenever encryption is started or restarted, a new 8-octet IV shall be used for each pair of communicating devices. The IV is determined as specified in [Vol 6] Part B, Section 5.1.3.1.

2.2 COUNTER MODE BLOCKS

For calculating the MIC, the multiple counter mode blocks are generated according to the CCM specification. These are referred to as blocks B_0 – B_n. Table 2.2 defines the format of block B_0. Table 2.3 defines the format of block B_1 that is devoted to the authentication of the additional authenticated data. Additional B blocks are generated as needed for authentication of the payload.

Offset (octets)	Field	Size (octets)	Value	Description
0	Flags	1	0x49	As per the CCM specification
1	Nonce	13	variable	The nonce as described in Table 2.1. Nonce0 shall have offset 1. Nonce12 shall have offset 13.
14	Length[MSO]	1	0x00	The most significant octet of the length of the payload
15	Length[LSO]	1	variable	The least significant octet of the length of the payload

Table 2.2: Block B_0 format

Offset	Field	Size (octets)	Value	Description
0	AAD_Length[MSO]	1	0x00	The most significant octet of the length of the additional authenticated data
1	AAD_Length[LSO]	1	0x01	The least significant octet of the length of the additional authenticated data

Table 2.3: Block B_1 format

Offset	Field	Size (octets)	Value	Description
2	AAD	1	variable	The data channel PDU header's first octet with NESN, SN and MD bits masked to 0
3	Padding	13	0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00	These octets are only used to pad the block. They are not part of the packet and never transmitted.

Table 2.3: Block B_1 format

2.3 ENCRYPTION BLOCKS

The CCM algorithm uses the A_i blocks to generate keystream that is used to encrypt the MIC and the Data Channel PDU payload. Block A_0 is always used to encrypt and decrypt the MIC. Block A_1 is always used to encrypt and decrypt the first 16 octets of the Payload. Subsequent blocks are always used to encrypt and decrypt the rest of the Payload as needed.

Offset (octets)	Field	Size (octets)	Value	Description
0	Flags	1	0x01	As per the CCM specification
1	Nonce	13	variable	The nonce as described above Nonce0 shall have offset 1. Nonce12 shall have offset 13.
14	i[MSO]	1	variable	The most significant octet of the counter i
15	i[LSO]	1	variable	The least significant octet of the counter i

Table 2.4: Block A_i format

DIRECT TEST MODE

This part of the specification describes the Direct Test Mode for RF PHY testing of Bluetooth low energy devices.

CONTENTS

1 INTRODUCTION

Direct Test Mode is used to control the Device Under Test (DUT) and provides a report back to the Tester.

Direct Test Mode shall be set up using one of two alternate methods:

1. over HCI (as defined in Section 2) or
2. through a 2-wire UART interface (as defined in Section 3)

Each DUT shall implement one of the two Direct Test Mode methods in order to test the Low Energy PHY layer. Figure 1.1 illustrates the alternatives for Direct Test Mode setup.

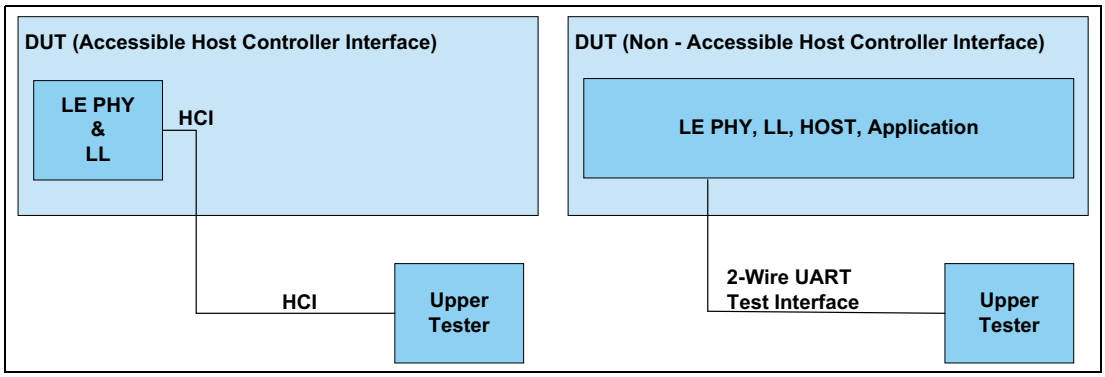

Figure 1.1: Setup alternatives for LE Direct Test Mode: Designs with accessible HCI (left) and designs without accessible HCI (right)

Figure 1.2 illustrates the Bluetooth LE Direct Test Mode setup principle using a 2-wire UART interface.

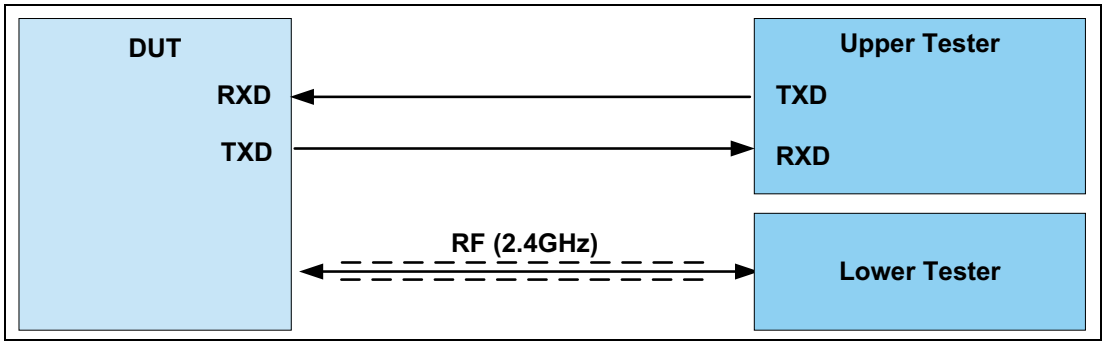

Figure 1.2: RF PHY test setup for Direct Test Mode (UART control)

2 LOW ENERGY TEST SCENARIOS

2.1 TEST SEQUENCES

These sequences are used as routines and used to control an LE DUT with an accessible HCI or a 2-wire UART interface for RF testing.

The following mapping shall be performed from the RF testing commands to HCI commands and events or 2-wire UART commands and events:

RF Test Command / Event	HCI Command / Event	2-wire UART Command / Event
LE_TRANSMITTER_TEST	LE Transmitter Test command or LE Enhanced Transmitter Test command	LE Transmitter Test
LE_RECEIVER_TEST	LE Receiver Test command or LE Enhanced Receiver Test command	LE Receiver Test
LE_TEST_END	LE Test End command	LE Test End
LE_STATUS	Command Complete event	LE Test Status
LE_PACKET_REPORT	Command Complete event	LE Packet Report

Table 2.1: Mapping table of HCI / 2-wire Commands/Events

The HCI commands and events used in Direct Test Mode are defined in [Vol 2] Part E, Section 7.8.

2.2 MESSAGE SEQUENCE CHARTS

Transmitter Test

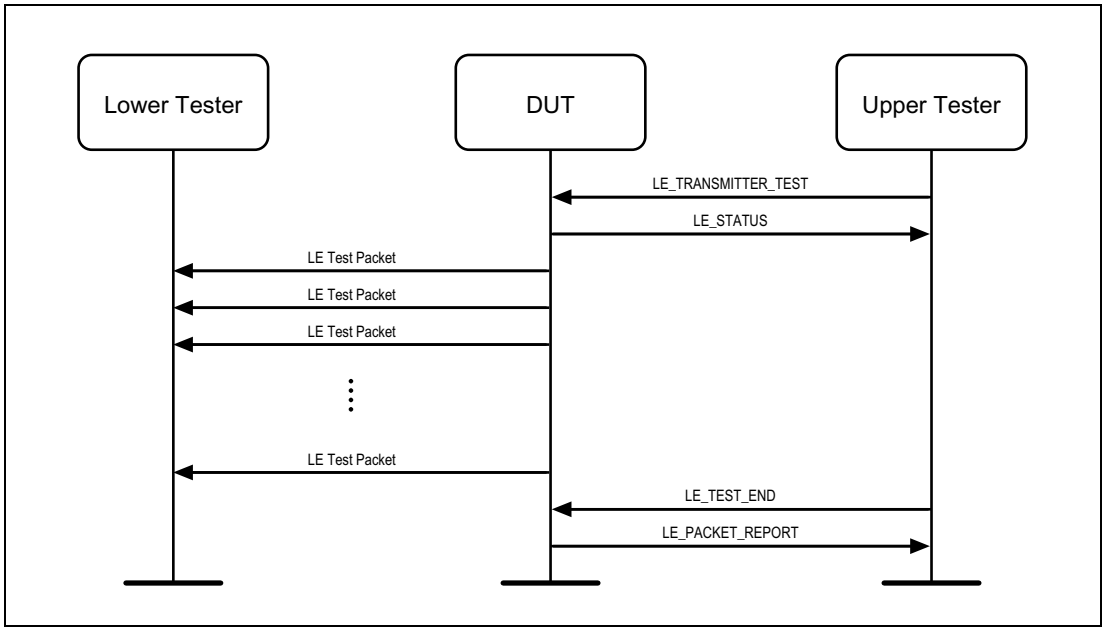

Figure 2.1: Transmitter Test MSC

Receiver Test

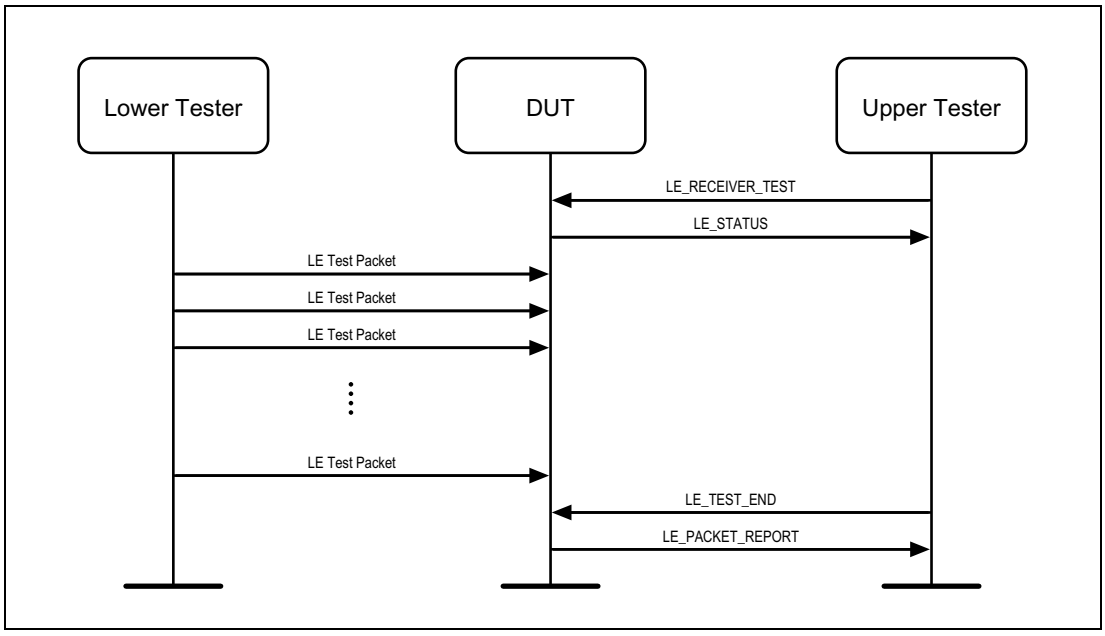

Figure 2.2: Receiver Test MSC

3 UART TEST INTERFACE

3.1 UART INTERFACE CHARACTERISTICS

The UART interface characteristics shall be set to use the following parameters:

- Baud rate: One of the following shall be supported by the DUT:
  1200, 2400, 9600, 14400, 19200, 38400, 57600, 115200
- Number of data bits: 8
- No parity
- 1 stop bit
- No flow control (RTS or CTS)

3.2 UART FUNCTIONAL DESCRIPTION

The Upper Tester shall always initiate any a test scenario using the UART interface. The DUT shall respond to the commands from the Upper Tester.

The Upper Tester sends test commands to the DUT. The DUT shall respond with a test status event or packet report event.

The Upper Tester shall not transmit further commands before it receives a response from the DUT. If the Upper Tester does not receive a response from the DUT within the time $t_{TIMEOUT}$, the Upper Tester shall transmit a reset command (i.e., a test setup command with the control argument set to 0x00) to the DUT and display an appropriate error message. For the reset command, $t_{RESPONSE}$ and $t_{TIMEOUT}$ do not apply.

On reception of a reset command, the DUT shall reset all parameters to their default state.

Definitions

- All Commands and Events consist of 16 bits (2 bytes).
- The most significant bit is bit number 15.
- The least significant bit is bit number 0.
- The most significant byte is from bit 15 to 8.
- The least significant byte is from bit 7 to 0.
- Commands and Events are sent most significant byte (MSB) first, followed by the least significant byte (LSB).

3.3 COMMANDS AND EVENTS

3.3.1 Command and Event Behavior

Table 3.1 outlines the set of commands which can be received by the DUT and the corresponding response events that can be transmitted by the DUT.

Command (DUT RXD)	Event (DUT TXD)
LE_Test_Setup	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Receiver_Test	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Transmitter_Test	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Test_End	LE_Packet_Report LE_Test_Status FAIL

Table 3.1: 2-Wire command and event behavior

3.3.2 Commands

Command packet formats are shown in Figure 3.1 and Figure 3.2.

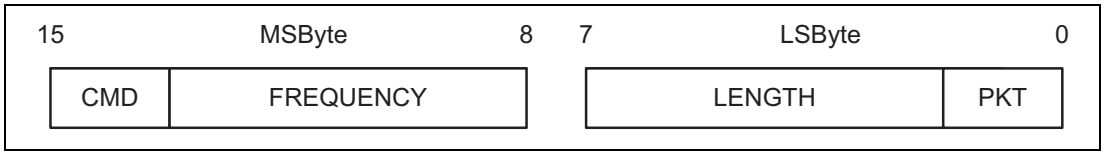

Figure 3.1: Command message format for Transmitter Test and Receiver Test commands

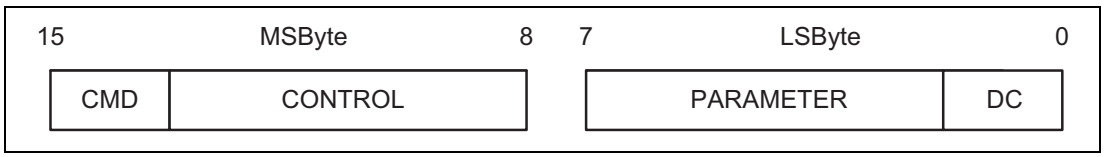

Figure 3.2: Command message format for Test Setup and Test End commands

CMD (command): *Size: 2 Bits*

Value b_1b_0	Parameter Description
00	Test Setup
01	Receiver Test
10	Transmitter Test
11	Test End

Test Setup Command: *Size: 12 Bits*

Control (6 bits)	Parameter (6 bits)	Description
0x00	0x00	RESET; the upper 2 bits of the data length for any Transmitter or Receiver commands following are set to 00, the PHY is set to LE 1M, and the receiver assumes the transmitter has a standard modulation index
	0x01 – 0x3F	Reserved for future use
0x01	0x00 – 0x03	Set the upper 2 bits of the data length for any Transmitter or Receiver commands following (to enable a length greater than 0x3F to be used)
	0x04 – 0x3F	Reserved for future use
0x02	0x00	Reserved for future use
	0x01	PHY set to LE 1M
	0x02	PHY set to LE 2M
	0x03	PHY set to LE Coded; transmitter is to use S=8 data coding
	0x04	PHY set to LE Coded; transmitter is to use S=2 data coding
	0x05 – 0x3F	Reserved for future use
0x03	0x00	Receiver assumes transmitter has a standard modulation index
	0x01	Receiver assumes transmitter has a stable modulation index
	0x02 - 0x3F	Reserved for future use
0x04	0x00\	Read the test case supported features. The Test Status event will return the state of the test case supported features as detailed in the Test Status event (Section 3.4.1).
	Any other value	Reserved for future use

Control (6 bits)	Parameter (6 bits)	Description
0x05	0x00	Read supportedMaxTxOctets (see [Vol 6] Part B, Section 4.5.10)
	0x01	Read supportedMaxTxTime (see [Vol 6] Part B, Section 4.5.10)
	0x02	Read supportedMaxRxOctets (see [Vol 6] Part B, Section 4.5.10)
	0x03	Read supportedMaxRxTime (see [Vol 6] Part B, Section 4.5.10)
	Any other value	Reserved for future use

Test End Command: *Size: 12 Bits*

Control (6 bits)	Parameter (6 bits)	Description
0x00	0x00	Test End Command
0x00	0x01 – 0x3F	Reserved for future use
0x01 – 0x3F	0x00 – 0x3F	Reserved for future use

Transmit and receive commands:

Frequency: *Size: 6 Bits*

Value	Parameter Description
0x00 – 0x27	The frequency to be used; a value of N represents a frequency of (2N+2402) MHz (the available range is therefore even MHz values from 2402 to 2480 inclusive)
0x28 – 0x3F	Reserved for future use

Length: *Size: 6 Bits*

Value	Parameter Description
0x00 - 0x3F	The lower 6 bits of the packet length in bytes of payload data in each packet (the top two bits are set by the Test Setup command)

PKT (Packet Type): *Size: 2 Bits*

Value b_1b_0	Parameter Description
00	PRBS9 Packet Payload
01	11110000 Packet Payload
10	10101010 Packet Payload
11	On the LE Uncoded PHYs: Vendor Specific On the LE Coded PHY: 11111111

3.4 EVENTS

There are two types of events sent by the DUT:

1. LE_Test_Status_Event
2. LE_Packet_Report_Event

The event packet format is shown in Figure 3.3. This packet format is used for both Test Status Events and Packet Report Events.

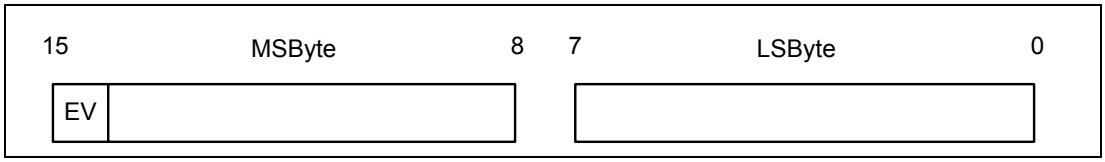

Figure 3.3: Event packet format

EV (Event): *Size: 1 Bit*

Value	Parameter Description
0	LE_Test_Status_Event
1	LE_Packet_Report_Event

3.4.1 LE_Test_Status_Event

The LE_Test_Status_Event packet format is as shown in Figure 3.4.

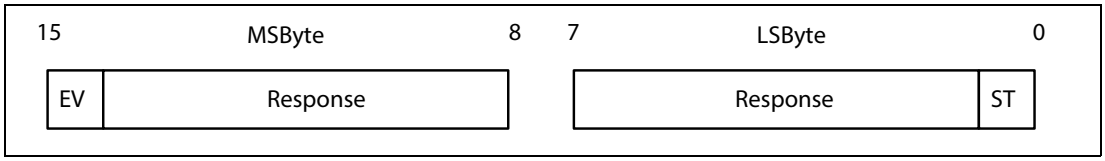

Figure 3.4: LE Test Status event

ST (status): *Size: 1 Bit*

Value	Parameter Description
0	Success
1	Error

Response[1] *Size: 14 Bits*

Test Setup command control parameter	Value bits 1 to 14[2]	
0x04	Bit 1	LE Data Packet Length Extension feature supported
	Bit 2	LE 2M PHY supported
	Bit 3	Transmitter has a Stable Modulation Index
	Bits 4 to 14	Reserved for future use
0x05	Bits 1 to 14	Maximum transmit or receive time divided by 2 or maximum number of payload octets (depending on the parameter in the original query) that the local Controller supports for transmission of a single Link Layer Data Channel PDU. Range 0x00A4-0x2148 for times or 0x001B-0x00FF for number of octets (all other values reserved for future use).
All other values		Reserved for future use

1 If the event has a status of "Error" or was generated in response to a command other than Test Setup, then this field is Reserved for future use.

2 This field is described as having bits 1 to 14 rather than 0 to 13 to avoid confusion.

3.4.2 LE_Packet_Report_Event

The LE_Packet_Report_Event packet format is shown in Figure 3.5. The *Packet Count* parameter indicates the number of received LE Test Packets. The *Packet Count* in the Packet Report ending a transmitter test shall be 0.

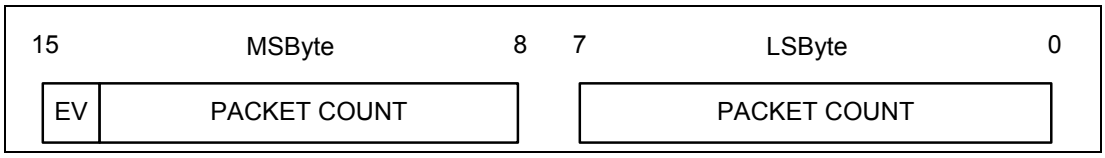

Figure 3.5: LE Packet Report event

PACKET COUNT: *Size: 15 Bits*

Value	Parameter Description
N	N is the number of packets received Range = 0 to 32767.

Note: The DUT is not responsible for any overflow conditions of the packet counter. That responsibility belongs with the RF PHY Tester or other auxiliary equipment.

3.5 TIMING – COMMAND AND EVENT

The timing requirements are as shown in Table 3.2.

Symbol	Parameter	Min.	Max.	Unit
b_{ERR}	Baud rate accuracy		±5	%
t_{MIN}	The time between the first and second byte of the command (end of stop bit to start of start bit)	0	5	ms
$t_{RESPONSE}$	The time from a DUT receiving a command (end of stop bit) until the DUT responds (start of start bit)	0	50	ms
$t_{TURNAROUND}$	The time from when the tester receives a response (end of stop bit) until the tester sends another command (start of start bit)	5	-	ms
$t_{TIMEOUT}$	The time from when a tester sends a command (end of stop bit) until the tester times out (not having received end of the stop bit in the response)	51	100	ms

Table 3.2: Parameter requirements table for 2-wire UART interface

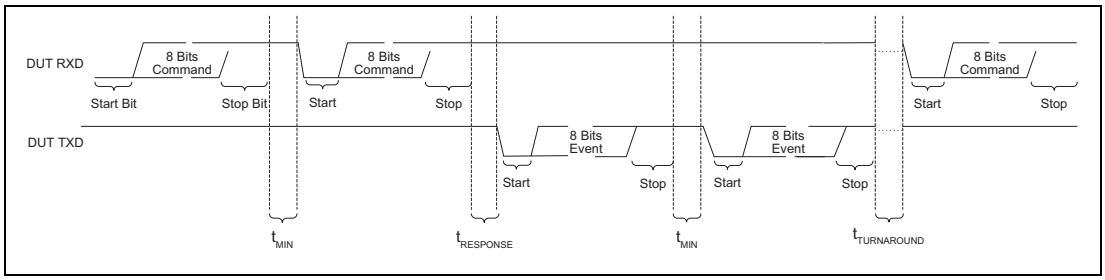

Figure 3.6: Command and event timing on 2-wire UART interface

The commands and events shall be transmitted with two 8-bit bytes with a maximum time between the 2 transmissions. A timeout is required for no response or an invalid response from the DUT.

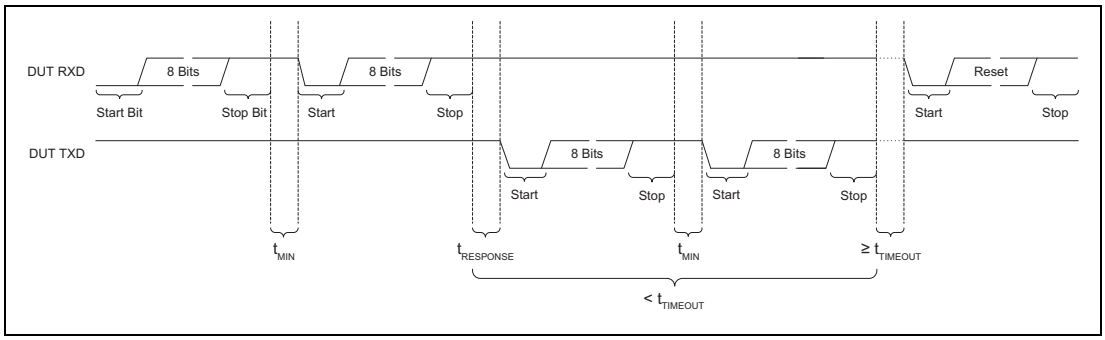

Figure 3.7: Command and event timing on 2-wire UART interface showing timeout

4 LE TEST PACKET DEFINITION

4.1 LE TEST PACKETS FORMAT

The LE Test packet format for the LE Uncoded PHYs shall be as shown in Figure 4.1. The LE Test packet format for the LE Coded PHY shall be as shown in Figure 4.2. LE test packets are required for LE RF PHY conformance testing using Direct Test Mode.

Depending on the test, the packet payload content may vary.

For the LE Uncoded PHYs, the LE test packet consists of the following fields; preamble (8 bits with the LE 1M PHY or 16 bits with the LE 2M PHY), synchronization word (32 bits), PDU header (8 bits), PDU length (8 bits), payload (0-2040 bits) and CRC (24 bits).

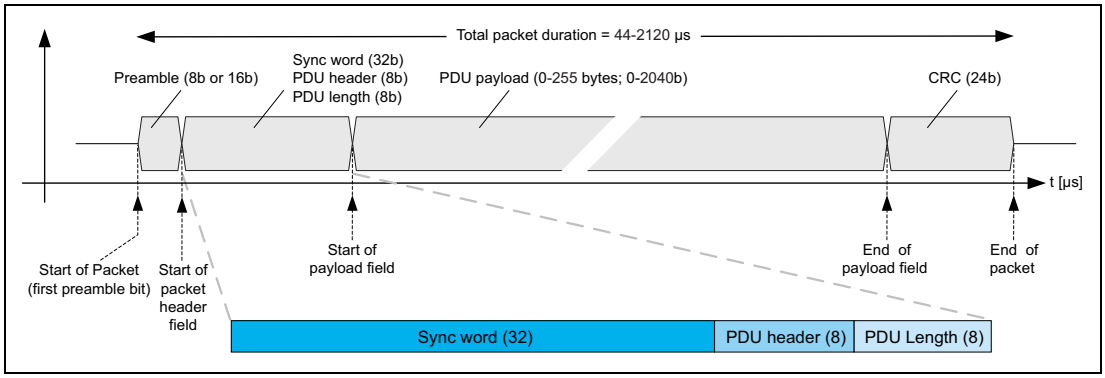

Figure 4.1: LE Test packet format for the LE Uncoded PHYs

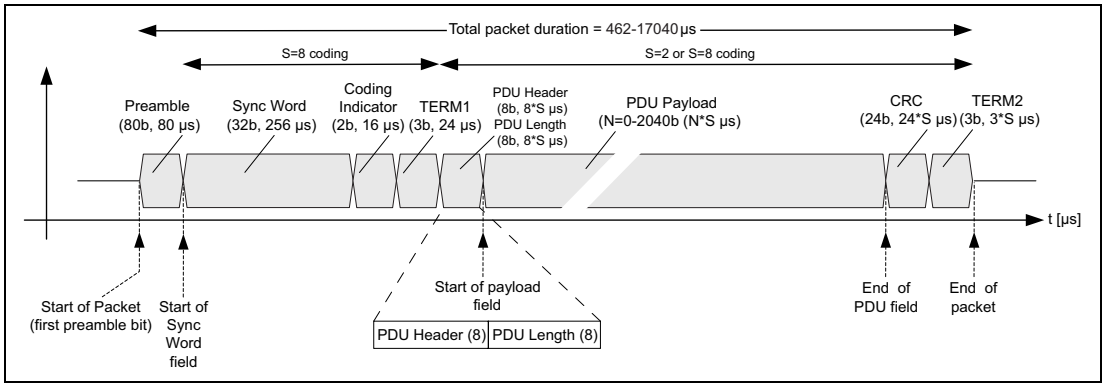

Figure 4.2: LE Test packet format for the LE Coded PHY

4.1.1 Whitening

LE test packets shall not use whitening.

4.1.2 Preamble and Synchronization Word

LE test packets shall have ‘10010100100000100110111010001110’ (in transmission order) as the synchronization word. The preamble for all LE test packets is thus ‘10101010’ (in transmission order) when the device under test is configured for the LE 1M PHY, ‘1010101010101010’ (in transmission order) if the device under test is configured for the LE 2M PHY, and the preamble described in [Vol 6] Part B, Section 2.1.1 if the device under test is configured for the LE Coded PHY.

4.1.3 CRC

The CRC shift register shall be preset with 0x555555 for every LE test packet.

4.1.4 LE Test Packet PDU

The LE test packet PDU consists of an 8-bit header, an 8-bit length field and a variable size payload. Its structure is as shown in Figure 4.3.

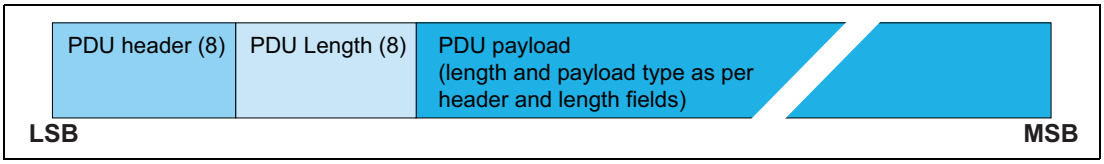

Figure 4.3: LE Test packet PDU structure

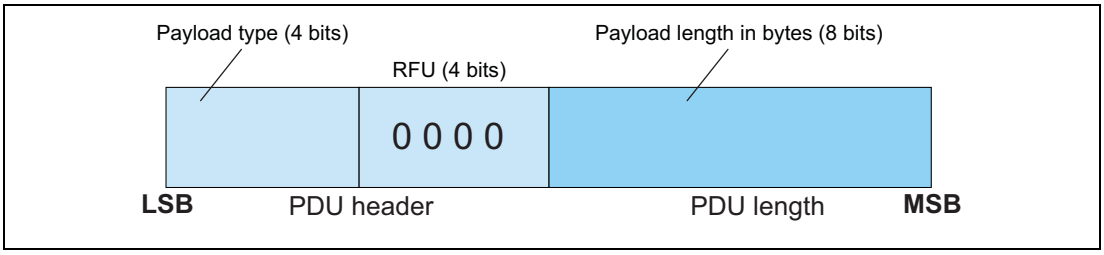

Figure 4.4: LE Test packet header and length field structure

The first four bits of the PDU header field indicate the payload content type as defined in Table 4.1. The length field expresses the payload field length in bytes.

Note: On the LE Coded PHY, this section defines the PDU contents before coding.

Payload type $b_3b_2b_1b_0$	**Payload description**
0000b	PRBS9 sequence ‘11111111100000111101…’ (in transmission order) as described in Section 4.1.5
0001b	Repeated ‘11110000’ (in transmission order) sequence as described in Section 4.1.5
0010b	Repeated ‘10101010’ (in transmission order) sequence as described in Section 4.1.5
0011b	PRBS15 sequence as described in Section 4.1.5
0100b	Repeated ‘11111111’ (in transmission order) sequence
0101b	Repeated ‘00000000’ (in transmission order) sequence
0110b	Repeated ‘00001111’ (in transmission order) sequence
0111b	Repeated ‘01010101’ (in transmission order) sequence

Table 4.1: LE test packet PDU header’s Type field encoding

Example: For LE test packets with 0x0F payload contents (‘11110000’ in transmission order) and with an LE test packet payload length of 37 bytes (296 bits), the LE test packet header and length type field will be ‘1000000010100100’ in transmission order.

4.1.5 LE Test Packet Payload Description

The LE test packet payload content alternatives required for the Bluetooth low energy RF PHY conformance tests are:

PRBS9:

A 9-bit pseudorandom binary sequence used for wanted signal payload content. The PRBS9 sequence repeats itself after the (2^9 -1 = 511) bit. The PRBS9 sequence may be generated in a nine stage shift register whose 5th and 9th stage outputs are added in a modulo-two addition stage (see Figure 4.5) and the result is fed back to the input of the first stage. The sequence begins with the first ONE of 9 consecutive ONEs (i.e. the shift register is initialized with nine ONEs).

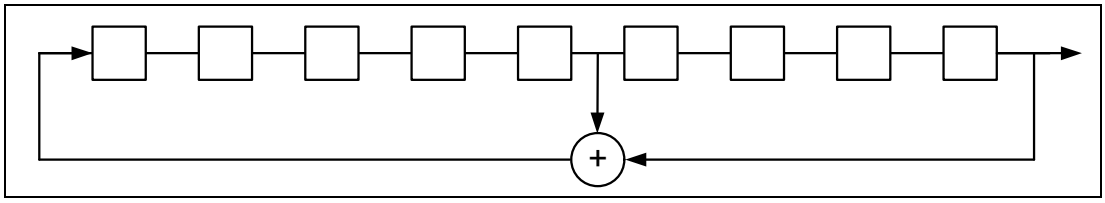

Figure 4.5: Linear feedback shift register for generation of the PRBS9 sequence

The same pseudorandom sequence of bits shall be used for each transmission (i.e. the packet is repeated).

PRBS15:

A 15-bit pseudorandom binary sequence that is used for the interfering signal and can optionally be used for wanted signal payload content. The PRBS15 sequence repeats itself after the (2^{15} -1 = 32767) bit. The PRBS15 sequence may be generated in a fifteen stage shift register whose 14th and 15th stage outputs are added in a modulo-two addition stage (See Figure 4.6) and the result is fed back to the input of the first stage. The sequence begins with the first ONE of 15 consecutive ONEs (i.e., the shift register is initialized with fifteen ONEs).

This PRBS15 definition is consistent with ITU T-REC-01 150-199605-I. SERIES O: SPECIFICATIONS OF MEASURING EQUIPMENT - Equipment for the measurement of digital and analogue/digital parameters.

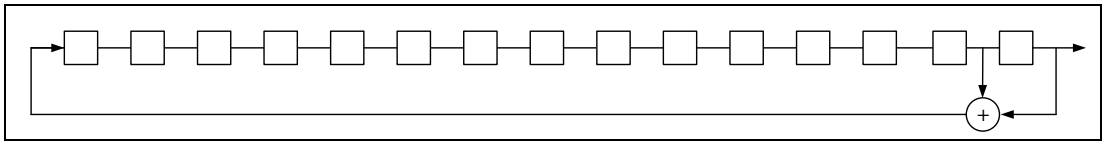

Figure 4.6: Linear feedback shift register for generation of the PRBS15 sequence

The same pseudorandom sequence of bits shall be used for each transmission (i.e. the packet is repeated).

10101010:

Repeated sequence of alternating 1's and 0's, starting at the first payload bit and ending at the start of the first bit in the CRC field. This pattern is used to verify the frequency deviation and the Gaussian filtering properties of the transmitter modulator.

11110000:

Repeated sequence of alternating 0's and 1's in groups of four (i.e. 1111000011110000…), starting at the first payload bit and ending at the start of the first bit in the CRC field. This pattern is used to verify the frequency deviation and the Gaussian filtering properties of the transmitter modulator.

4.1.6 LE Test Packet Interval

While in LE direct TX mode, LE test packets shall be transmitted from the EUT with a packet interval I(L) as defined below; see the top half of Figure 4.7 for reference.

While in LE direct RX mode, the nominal packet interval of the LE test packets transmitted from the tester is I(L), but the tester packet interval may be extended to a maximum of T(L) upon change of the dirty transmitter parameter settings and during verification of the EUT PER reporting functionality. See the bottom half of Figure 4.7 for reference.

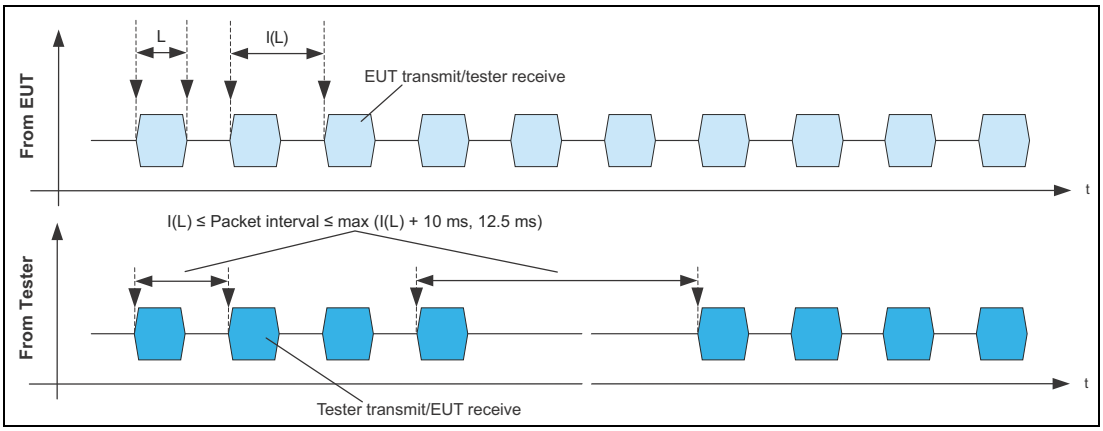

Figure 4.7: LE Test packet interval in LE Direct Test Mode

For an LE Test Packet length of L µs, I(L) = ceil((L + 249) / 625) * 625 µs, where ceil(x) is the smallest integer greater than or equal to x, and T(L) = max (I(L) + 10 ms, 12.5 ms).

Core System Package [Wireless Coexistence volume]

Specification of the Bluetooth® System

Specification Volume 7

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Revision History

The Revision History is shown in the [Vol 0] Part C, Appendix.

Contributors

The persons who contributed to this specification are listed in the [Vol 0] Part C, Appendix.

Web Site

This specification can also be found on the official Bluetooth web site:
https://www.bluetooth.org/en-us/specification/adopted-specifications

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MWS COEXISTENCE LOGICAL SIGNALING SPECIFICATION

This part specifies the Mobile Wireless Standards (MWS) coexistence logical interface between the Host Controller and an MWS device.

CONTENTS

1 INTRODUCTION

This part of the Bluetooth Core Specification describes the MWS Coexistence Logical Signaling. A Bluetooth Controller may incorporate a real-time transport interface to transport the logical signals defined in this section between the Bluetooth Controller and an MWS device.

Figure 1.1 depicts the signaling and messaging architecture.

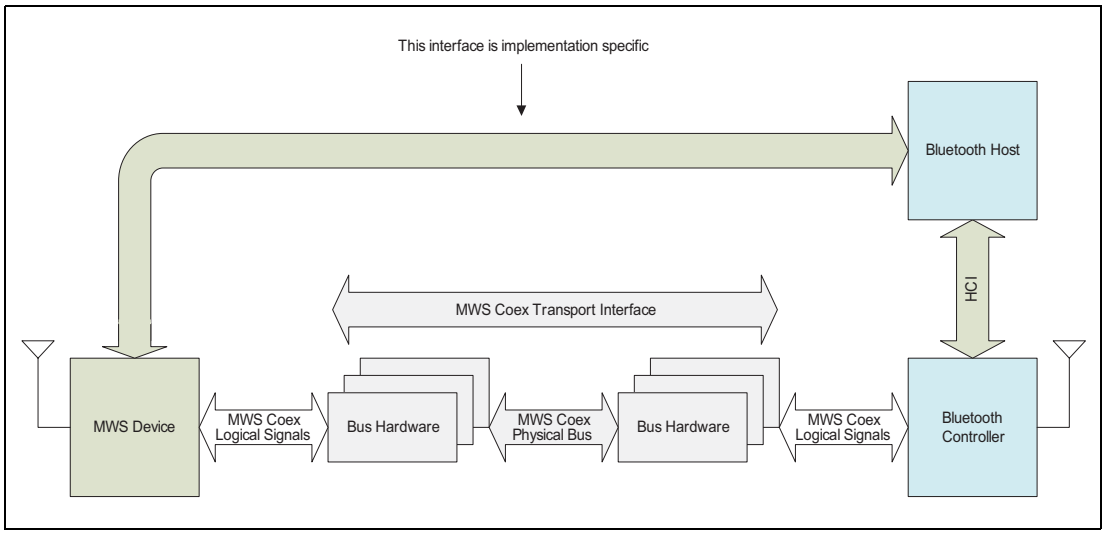

Figure 1.1: Coexistence signaling/messaging architecture

MWS Coexistence logical signaling is designed to enable a standard interface to allow an MWS device and a Bluetooth Controller to exchange information and support cooperative coexistence.

MWS Coexistence logical signaling defines a set of signals between the collocated Bluetooth Controller and MWS device. Those signals carry time critical, real-time information such as the start point of an MWS frame. The coexistence logical signaling architecture also includes a transparent data messaging mechanism to enable passing of information between the MWS device and Bluetooth Controller when such information cannot tolerate the long latency (tens of milliseconds) of the signaling path via the Bluetooth Host.

2 LOGICAL INTERFACE

2.1 COEXISTENCE SIGNALS

Table 2.1 defines the logical signals. These logical signals assist in time alignment, protecting the MWS device and the Bluetooth Controller from mutual interference, thus maximizing the usability of the Bluetooth radio.

Name	Direction	Description
FRAME_SYNC	MWS → Bluetooth	See Section 2.1.1
MWS_RX	MWS → Bluetooth	See Section 2.1.2
BLUETOOTH_RX_PRI	Bluetooth → MWS	See Section 2.1.3
BLUETOOTH_TX_ON	Bluetooth → MWS	See Section 2.1.4
MWS_PATTERN	MWS → Bluetooth	See Section 2.1.5
MWS_TX	MWS → Bluetooth	See Section 2.1.6
802_RX_PRI	Bluetooth → MWS	See Section 2.1.7
802_TX_ON	Bluetooth → MWS	See Section 2.1.8
MWS_INACTIVITY_DURATION	MWS → Bluetooth	See Section 2.1.9
MWS_SCAN_FREQUENCY	MWS → Bluetooth	See Section 2.1.10

Table 2.1: Coexistence signals

The first 8 of these (FRAME_SYNC, MWS_RX, BLUETOOTH_RX_PRI, BLUETOOTH_TX_ON, MWS_PATTERN, MWS_TX, 802_RX_PRI, and 802_TX_ON) are also referred to as the "real-time coexistence signals".

Many of the signals have associated parameters, which are configured by the Bluetooth Host using HCI commands. There is no requirement for signals that are used internally to be connected to an external interface, although testing requires external control of the FRAME_SYNC signal. For example, a combo-device that integrates a Bluetooth Controller and an MWS radio together does not need to bring out the coexistence signals.

Section 2.2 provides recommended values for the defined offset and jitter parameters.

2.1.1 FRAME_SYNC

The FRAME_SYNC signal is sent by the MWS device to indicate the time of the beginning of MWS frames according to the MWS network timing. It provides the anchor point for the Bluetooth Controller to properly align Bluetooth transmission and reception activity with the MWS network frame structure. The time when FRAME_SYNC is sent over the transport, adjusted for Ext_Frame_Sync_Assert_Offset, indicates the start time of the first

Period_Duration parameter in the HCI_Set_External_Frame_Configuration command.

The MWS device will inform the Bluetooth Controller about changes to the layout and timing of the MWS frame by issuing new HCI_Set_External_Frame_Configuration commands.

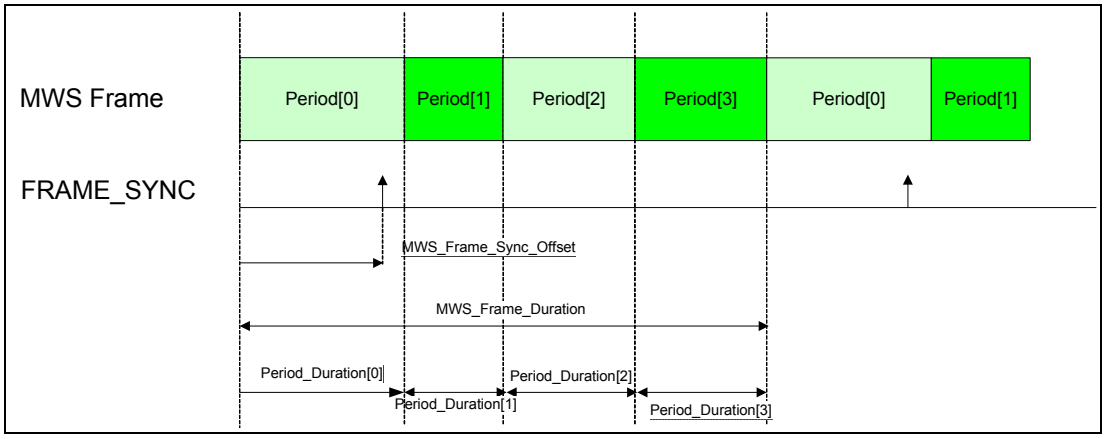

Figure 2.1: Illustration of FRAME_SYNC

2.1.2 MWS_RX

The MWS_RX signal is sent by the MWS device to indicate that an MWS reception is occurring and to request that the Bluetooth Controller cease ongoing transmission and not start a new transmission. The Bluetooth Controller can occasionally disregard the MWS_RX signal for critical transmissions.

The MWS RX signal should be de-asserted at the time an MWS device stops actively receiving. If there are multiple distinct periods of reception within an MWS downlink duration, the signal may stay asserted until the last period has finished receiving.

2.1.3 BLUETOOTH_RX_PRI

The BLUETOOTH_RX_PRI signal is used by the Bluetooth Controller to request that the MWS device cease its transmission and/or refrain from starting a transmission because the Bluetooth Controller is expecting a high priority reception.

The signal should be used minimally by the Bluetooth system so as not to adversely affect the MWS system. There is no guarantee that the MWS device will honor the signal and not transmit or abort an ongoing transmission.

2.1.4 BLUETOOTH_TX_ON

The BLUETOOTH_TX_ON signal is sent by the Bluetooth Controller to indicate that it is actively transmitting.

2.1.5 MWS_PATTERN

The MWS_PATTERN signal is sent by the MWS device to inform the Bluetooth Controller which MWS_PATTERN is in use.

Up to three different MWS_PATTERNs can be selected: 0, 1, and 2. The MWS device may indicate that the MWS_PATTERN has not changed by setting it to 3. The definitions of the patterns are communicated to the Bluetooth Controller using the HCI_Set_MWS_PATTERN_Configuration command. If the pattern is not currently configured, the behaviour is equivalent to setting a pattern that allows unrestricted activity by the Bluetooth Controller.

At the start of each MWS Frame, as defined by the FRAME_SYNC signal plus the MWS_Frame_Sync_Offset, the most recent MWS_PATTERN value takes effect as follows.

- If it is 3, the current pattern continues in use.
- If it is the index of the current pattern, then that pattern is restarted.
- Otherwise the indicated pattern is started.

2.1.6 MWS_TX

The MWS_TX signal is sent by the MWS device to indicate its transmission state.

The signal should be asserted at the beginning of an MWS transmission and de-asserted at the end of a transmission. If there are multiple transmission periods during an uplink frame, the signal may stay asserted until the end of the last transmission period.

2.1.7 802_TX_ON

Bluetooth technology and 802.11 may be collocated and share an interface to coordinate access to the 2.4 GHz ISM band.

The 802_TX_ON is used by the 802.11 device to indicate the state of the 802.11 transmission.

Interference generated by 802.11 to the MWS device will not necessarily be distinguishable from interference created by Bluetooth transmissions.

This signal allows the MWS device to distinguish the interference generated by 802.11 transmissions from the interference generated by the Bluetooth transmissions. The MWS device can use that information to optimize its channel access.

2.1.8 802_RX_PRI

This signal requests that the MWS device stop or refrain from any transmission because the WLAN device collocated with the Bluetooth Controller is expecting a high priority reception.

The signal should be used minimally by the 802.11 system so as not to adversely affect the MWS system. There is no guarantee that the MWS device will honor the signal and not transmit or abort an ongoing transmission.

2.1.9 MWS_INACTIVITY_DURATION

The MWS_INACTIVITY_DURATION signal provides the time duration until the MWS device is active again. Subsequent MWS_INACTIVITY_DURATION signals override previously sent time durations.

MWS_INACTIVITY_DURATION may be set to zero (i.e. cancel), infinite, or a positive finite duration. The transport layer defines the value for infinite duration and the set of finite durations available.

2.1.10 MWS_SCAN_FREQUENCY

The MWS_SCAN_FREQUENCY signal provides an index to a table of RF frequencies during MWS scan operation.

The MWS device signals MWS_SCAN_FREQUENCY if it starts an inter-frequency scan.

Setting MWS_SCAN_FREQUENCY to a non-zero value indicates the start of the MWS scan period. Setting MWS_SCAN_FREQUENCY to zero indicates the end of the scan period.

The Bluetooth Controller should avoid any transmissions that can interfere with the scan while a scan is active. The Bluetooth Controller can occasionally disregard the signal for critical transmissions.

2.2 TOLERANCES FOR OFFSETS AND JITTER

This section lists the recommended tolerances for the signal assertion and de-assertion offsets and jitter for those signals. Note: The transmitting side should use a value within the range and the receiving side should accept any value within the range and may accept other values.

An offset is a static advance notification or delay between the real physical event and the time when the corresponding signal is issued.

Jitter is variation in the timing of each signal from ideal timing.

Signals that are turned on and off around a period of time have specified values for both assertion and de-assertion offsets and jitter. Signals that represent a single event at a single instant in time have only assertion offset and jitter timing specified.

All jitter values are given as an unsigned value representing the maximum allowable jitter in positive and negative directions. De-assertion and MWS_Frame_Sync_Assert_Offset may be negative (i.e., signal is asserted before the event) or positive (i.e., signal is asserted after the event). All other assertion signals should be negative (i.e., signal is issued before the event).

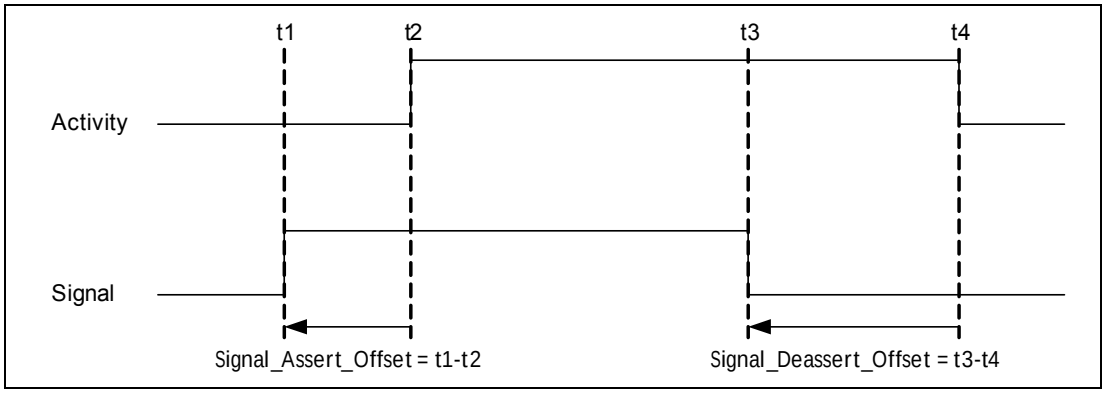

Figure 2.2: Signal with negative Assert Offset and negative De-assert Offset

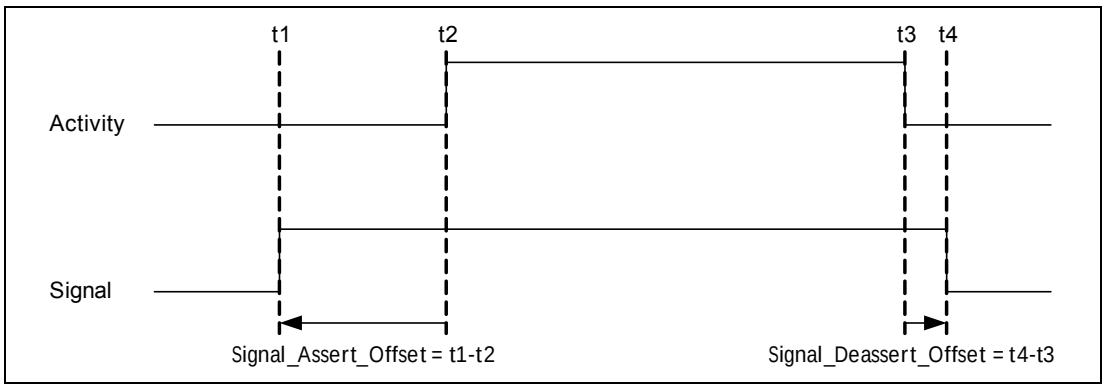

Figure 2.3: Signal with negative Assert Offset and positive De-assert Offset

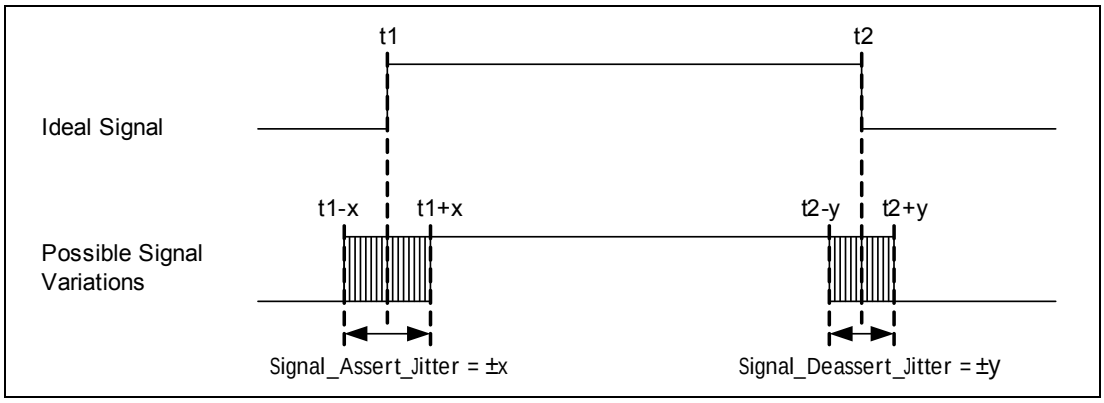

Figure 2.4: Signal assertion and de-assertion jitter

Parameter	Earliest	Latest
MWS_Frame_Sync_Assert_Offset	-Ext_Frame_Duration	+Ext_Frame_Duration
MWS_Frame_Sync_Assert_Jitter	N/A	±3 µs
MWS_Rx_Assert_Offset	-2 ms	-20 µs
MWS_Rx_Assert_Jitter	N/A	±5 µs
MWS_Rx_Deassert_Offset	-2 ms	0
MWS_Rx_Deassert_Jitter	N/A	±5 µs
MWS_Tx_Assert_Offset	-2 ms	0
MWS_Tx_Assert_Jitter	N/A	±5 µs
MWS_Tx_Deassert_Offset	-2 ms	0
MWS_Tx_Deassert_Jitter	N/A	±5 µs
MWS_Pattern_Assert_Offset	0	+Ext_Frame_Duration
MWS_Pattern_Assert_Jitter	N/A	±5 µs
MWS_Inactivity_Duration_Assert_Offset	0	+Ext_Frame_Duration
MWS_Inactivity_Duration_Assert_Jitter	N/A	±5 µs
MWS_Scan_Frequency_Assert_Offset	-2 ms	-20 µs
MWS_Scan_Frequency_Assert_Jitter	N/A	±5 µs
Bluetooth_Rx_Priority_Assert_Offset	-1 ms	0
Bluetooth_Rx_Priority_Assert_Jitter	N/A	±5 µs
Bluetooth_Rx_Priority_Deassert_Offset	-1 ms	0
Bluetooth_Rx_Priority_Deassert_Jitter	N/A	±5 µs
802_Rx_Priority_Assert_Offset	-1 ms	0
802_Rx_Priority_Assert_Jitter	N/A	±5 µs

Table 2.2: Tolerances for offsets and jitter

Parameter	Earliest	Latest
802_Rx_Priority_Deassert_Offset	-1 ms	0
802_Rx_Priority_Deassert_Jitter	N/A	±5 µs
Bluetooth_Tx_On_Assert_Offset	-100 µs	0
Bluetooth_Tx_On_Assert_Jitter	N/A	±5 µs
Bluetooth_Tx_On_Deassert_Offset	0	100 µs
Bluetooth_Tx_On_Deassert_Jitter	N/A	±5 µs
802_Tx_On_Assert_Offset	-100 µs	0
802_Tx_On_Assert_Jitter	N/A	±5 µs
802_Tx_On_Deassert_Offset	0	100 µs
802_Tx_On_Deassert_Jitter	N/A	±5 µs
MWS_Priority_Assert_Offset_Request	-1 ms	-200 µs

Table 2.2: Tolerances for offsets and jitter

WIRELESS COEXISTENCE INTERFACE 1 (WCI-1) TRANSPORT SPECIFICATION

This part specifies the MWS Wireless Coexistence Interface 1 (WCI-1) Transport Interface between the Bluetooth Controller and an MWS device.

CONTENTS

1 INTRODUCTION

This part of the Bluetooth Core Specification describes the MWS Wireless Coexistence Interface 1 (WCI-1) Transport for a Bluetooth Controller. It provides a half-duplex UART carrying logical signals framed as UART characters. Only the TXD and RXD UART signals are used.

Note: The physical layers for WCI-1 and WCI-2 (See [Vol 7] Part C) differ but the transport layers are identical.

2 PHYSICAL LAYER

The WCI-1 physical layer multiplexes the UART TXD and RXD onto a single wire, using drive strengths to resolve contention. The MWS device uses direct drive to transmit its signals, while the Bluetooth Controller uses a pull up / pull down drive to transmit its signals. The configuration is illustrated in Figure 2.1.

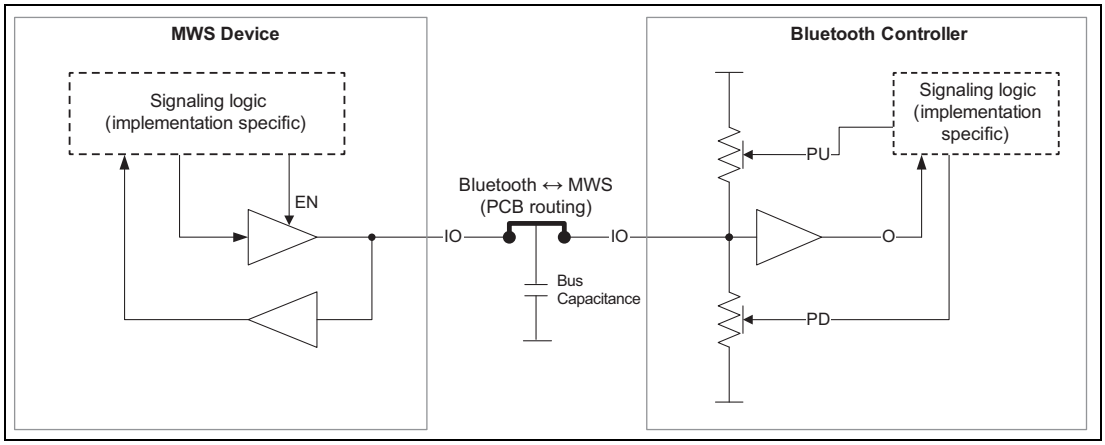

Figure 2.1: WCI-1 physical interface

A high voltage on the wire shall be interpreted as a logical 1 and a low voltage shall be interpreted as a logical 0. The actual voltage levels are vendor specific.

The MWS device output buffer shall be in the high impedance state when it is not transmitting. The Bluetooth Controller shall be in the pulled-up state when it is not transmitting.

The MWS device may transmit at any time, using the waveform illustrated in Figure 2.2.

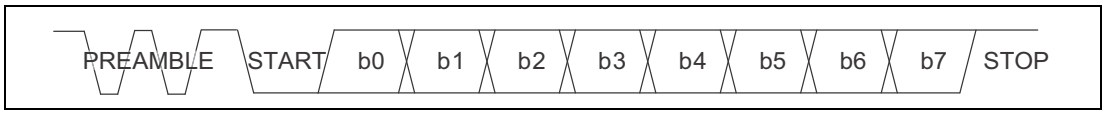

Figure 2.2: UART waveform for MWS-to-Bluetooth signals

Every MWS-to-Bluetooth message shall be preceded by a preamble, which consists of 5 bits ‘01011’ (in transmission order). The preamble is sent at a baud rate that is at least twice the baud rate of Bluetooth-to-MWS signals[1]. The nominal drive strength for the preamble should be targeted at no more than 250Ω equivalent output resistance. The Bluetooth Controller shall be able to detect the preamble and go into the reception mode to receive the message

1. The preamble baud rate should be one that is supported by the underlying UART of the Bluetooth device.

that follows. If the Bluetooth Controller detects a preamble while it is transmitting, it shall stop the transmission and go into the reception mode. After completion of the reception, it may retransmit the message that was interrupted.

When the Bluetooth Controller is not in the reception mode, it may transmit a message using the pull up / pull down mechanism. The nominal pull strength should be targeted at 4 kΩ ± 1 kΩ equivalent resistance for both pull up and pull down. The Bluetooth-to-MWS waveform is illustrated in Figure 2.3.

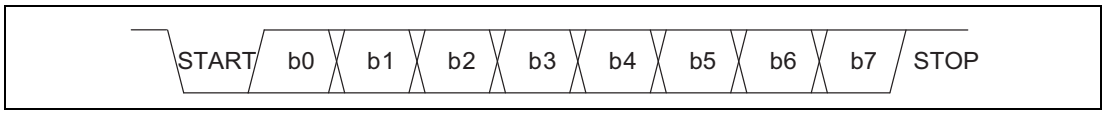

Figure 2.3: UART waveform for Bluetooth-to-MWS signals

2.1 PHYSICAL SIGNAL SPECIFICATIONS (INFORMATIVE)

The tables below provide more complete specifications for the physical signals. They are provided as a reference to device makers:

Symbol	Parameter	Condition	Value	
			Min	Max
V_{IL}	Low level input voltage	V_{DD}=1.8~2.5V[1]	-0.5V	0.2V_{DD}
V_{IH}	High level input voltage	V_{DD} =1.8~2.5V[1]	0.8 V_{DD}	V_{DD}+0.5V
V_{OL}	Low level output voltage (with extra pull high R_B)	V_{DD} =1.8~2.5V[1] R_B=2.5kΩ	0	0.1V_{DD}
V_{OH}	High level output voltage (with extra pull low R_B)	V_{DD}=1.8~2.5V[1] R_B=2.5kΩ	0.9V_{DD}	V_{DD}
C_{IO}	Capacitance for I/O		--	5pF
CB	Capacitive load for bus		--	10pF
R_{ON}	Turn on impedance			250Ω
T_R	Rise time (10% to 90% swing time, with extra pull low R_B and capacitive load C_L = C_B + other IO)	R_B=2.5kΩ C_L=15pF	--	50 ns
T_F	Fall time (90% to 10% swing time, with extra pull high R_B and capacitive load C_L = C_B + other IO)	R_B=2.5kΩ C_L=15pF	--	50 ns

Table 2.1: WCI-1 UART physical signal specification for the MWS device

Symbol	Parameter	Condition	Value	
			Min	Max
F	Frequency		(1-1%)*4MHz[2]	(1+1%)*4MHz[2]
CLK_j	Clock jitter			1%

Table 2.1: WCI-1 UART physical signal specification for the MWS device

Symbol	Parameter	Condition	Value	
			Min	Max
V_{IL}	Low level input voltage	V_{DD} =1.8~2.5V[1]	-0.5V	$0.2V_{DD}$
V_{IH}	High level input voltage	V_{DD} =1.8~2.5V[1]	$0.8V_{DD}$	V_{DD}+0.5V
V_{OL}	Low level output voltage	V_{DD} =1.8~2.5V[1]	0	$0.1V_{DD}$
V_{OH}	High level output voltage	V_{DD} =1.8~2.5V[1]	$0.9V_{DD}$	V_{DD}
C_{IO}	Capacitance for I/O		--	5 pF
CB	Capacitive load for bus		--	10 pF
R_P	Pull up/pull down resistance		3kΩ	5kΩ
T_R	Rise time (10% to 90% swing time, with capacitive load $C_L = C_B$ + other IO)	C_L=15pF	--	220 ns
T_F	Fall time (90% to 10% swing time, with capacitive load $C_L = C_B$ + other IO)	C_L =15pF	--	220 ns
F	Frequency		(1-1%)*1MHz[2]	(1+1%)*1MHz[2]
CLK_j	Clock jitter			1%

Table 2.2: WCI-1 UART physical signal specification for the Bluetooth Controller

Notes:

1. The voltage levels are vendor specific. The tables in this section do not cover all possible ranges of voltage for all devices, nor is it required that a single device be able to operate in the full range indicated here.
2. The frequencies are vendor specific.

3 TRANSPORT LAYER

The transport layer defines the mapping of the logical coexistence signals (see [Vol 7] Part A) onto the physical transport channel.

The 8-bit UART character is divided into two portions with three bits for the message type indicator and five bits for the message body. The bit with index 0 is the LSB and shall be transmitted first.

b0	b1	b2	b3	b4	b5	b6	b7
Type[0]	Type[1]	Type[2]	MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]

Table 3.1: Transport layer format

3.1 MESSAGE TYPES

This section describes the message formats for the logical coexistence signals. The message types are listed in Table 3.2.

Message Type Indicator	Direction	Message Type
0	MWS ↔ Bluetooth	Real-time Signal message
1	MWS ↔ Bluetooth	Transport Control message
2	MWS ↔ Bluetooth	Transparent Data message
3	MWS ⟶ Bluetooth	MWS Inactivity Duration message
	Bluetooth ⟶ MWS	RFU
4	MWS ⟶ Bluetooth	MWS Scan Frequency message
	Bluetooth ⟶ MWS	RFU
5	MWS ⟶ Bluetooth	RFU
	Bluetooth ⟶ MWS	RFU
6		Vendor specific
7		Vendor specific

Table 3.2: Message types

The logical coexistence signals are listed in Table 3.3.

Signal Name	Description
FRAME_SYNC	See [Vol 7] Part A, Section 2.1.1

Table 3.3: Coexistence signals

Signal Name	Description
MWS_RX	See [Vol 7] Part A, Section 2.1.2
BLUETOOTH_RX_PRI	See [Vol 7] Part A, Section 2.1.3
BLUETOOTH_TX_ON	See [Vol 7] Part A, Section 2.1.4
MWS_PATTERN	See [Vol 7] Part A, Section 2.1.5
MWS_TX	See [Vol 7] Part A, Section 2.1.6
802_TX_ON	See [Vol 7] Part A, Section 2.1.7
802_RX_PRI	See [Vol 7] Part A, Section 2.1.8
MWS_INACTIVITY_DURATION	See [Vol 7] Part A, Section 2.1.9
MWS_SCAN_FREQUENCY	See [Vol 7] Part A, Section 2.1.10

Table 3.3: Coexistence signals

3.1.1 Real-time Signal Message (Type 0)

The Real-time Signal message is used to transport the real-time coexistence signals (see [Vol 7] Part A) over the WCI-1 transport interface.

The Real-time Signal message conveys all the real-time coexistence signals in one message. The time reference point for the Real-time Signal message is the end of MSG[4] (i.e. the transition to the STOP bit).

Two Real-time Signal messages are defined, one from the Bluetooth Controller to the MWS device and another from the MWS device to the Bluetooth Controller.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
FRAME_SYNC	MWS_RX	MWS_TX	MWS_PATTERN[0]	MWS_PATTERN[1]

Table 3.4: Real-time Signal message from MWS device to Bluetooth Controller

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
BLUETOOTH_RX_PRI	BLUETOOTH_TX_ON	802_RX_PRI	802_TX_ON	RFU

Table 3.5: Real-time Signal message from Bluetooth Controller to MWS device

3.1.2 Transport Control Message (Type 1)

The Transport Control message can request state information from the MWS device's coexistence interface.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
RESEND_REAL_TIME	RFU	RFU	RFU	RFU

Table 3.6: Transport Control message

Signal Name	Description
RESEND_REAL_TIME	This bit is set if a device wants to get a status update of the real-time coexistence signals. The signal is usually used after wake-up from sleep of the transport interface. If the receiving device's transport interface is awake it shall send a Real-time message with the current status of the real-time coexistence signals within 4 UART character periods. If the signal is not received within 4 UART character periods the device is considered asleep.

Table 3.7: Transport control signals

3.1.3 Transparent Data Message (Type 2)

The Transparent Data message can be used to exchange non-time critical signals between the MWS device and the Bluetooth Controller. The interface does not guarantee the delivery of a message. Protocol and content of the message are vendor specific.

The least significant nibble of each octet shall be transmitted first.

A least significant nibble shall be discarded if the next nibble is a least significant nibble. A most significant nibble shall only be accepted if the preceding nibble was a least significant nibble.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
NIBBLE_POSITION	DATA[0] / DATA[4]	DATA[1] / DATA[5]	DATA[2] / DATA[6]	DATA[3] / DATA[7]

Table 3.8: Transparent Data message

Signal Name	Description
NIBBLE_POSITION	0 – Least Significant Nibble 1 – Most Significant Nibble
DATA[n]; n = 0..7	Data bits of the message octet

Table 3.9: Transparent data bits

3.1.4 MWS Inactivity Duration Message (Type 3)

The MWS Inactivity Duration message is used to send the MWS_INACTIVITY_DURATION signal from the MWS device to the Bluetooth Controller.

The message is sent at the beginning of an MWS inactivity period.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
DURATION[0]	DURATION[1]	DURATION[2]	DURATION[3]	DURATION[4]

Table 3.10: MWS Inactivity Duration message

The MWS Inactivity Duration is encoded in 5 bits. DURATION is unsigned.

When DURATION = 0, MWS_INACTIVITY_DURATION is cancelled.
When DURATION = 31, MWS_INACTIVITY_DURATION is infinite.
Otherwise, MWS_INACTIVITY_DURATION is given by the formula:

MWS_INACTIVITY_DURATION = DURATION * 5 ms

3.1.5 MWS Scan Frequency Message (Type 4)

The MWS Scan Frequency message is used to send the MWS_SCAN_FREQUENCY signal from the MWS device to the Bluetooth Controller.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
FREQ[0]	FREQ[1]	FREQ[2]	FREQ[3]	FREQ[4]

Table 3.11: MWS Scan Frequency message

The MWS Scan Frequency index is encoded in 5 bits. FREQ is unsigned.

WIRELESS COEXISTENCE INTERFACE 2 (WCI-2) TRANSPORT SPECIFICATION

This part specifies the MWS Wireless Coexistence Interface 2 (WCI-2) Transport Interface between the Bluetooth Controller and an MWS device.

CONTENTS

1 INTRODUCTION

This part of the Bluetooth Core Specification describes the MWS Wireless Coexistence Interface 2 (WCI-2) Transport Interface for a Bluetooth Controller.

Note: The physical layers for WCI-2 and WCI-1 (see volume 7 part B) differ but the transport layers are identical.

2 PHYSICAL LAYER

The WCI-2 Transport is based on a standard full duplex UART carrying logical signals framed as UART characters. Only the TXD and RXD UART signals are used. The interface supports multiple logical channels.

The messaging is based on a standard UART format.

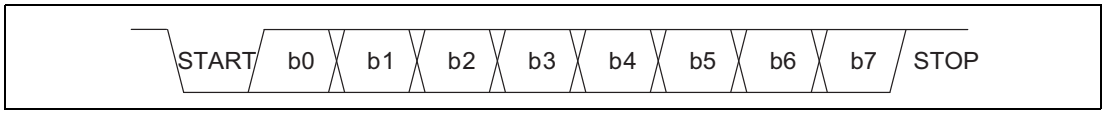

Figure 2.1: UART waveform

The UART signals shall be connected in a null-modem fashion; i.e. the local TXD shall be connected to the remote RXD and vice versa.

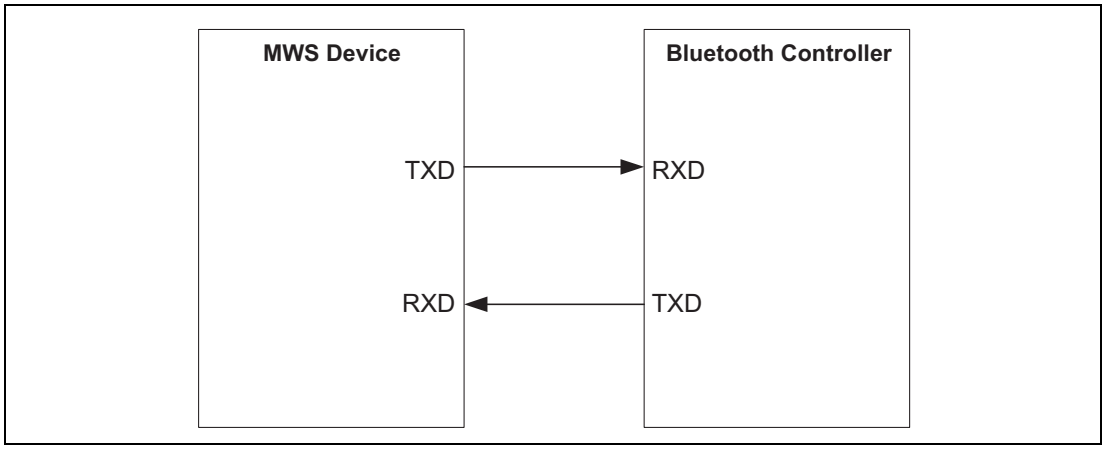

Figure 2.2: WCI-2 physical interface

3 TRANSPORT LAYER

The transport layer defines the mapping of the logical signals (see [Vol 7] Part A) onto the physical transport channel.

The 8 bit UART character is divided into two portions with three bits for the message type indicator and five bits for the message body. The bit with index 0 is the LSB and shall be transmitted first.

b0	b1	b2	b3	b4	b5	b6	b7
Type[0]	Type[1]	Type[2]	MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]

Table 3.1: Transport layer format

3.1 MESSAGE TYPES

This section describes the message formats for the logical coexistence signals. The message types are listed in Table 3.2.

Message Type Indicator	Direction	Message Type
0	MWS ↔ Bluetooth	Real-time Signal message
1	MWS ↔ Bluetooth	Transport Control message
2	MWS ↔ Bluetooth	Transparent Data message
3	MWS ⟶ Bluetooth	MWS Inactivity Duration message
	Bluetooth ⟶ MWS	RFU
4	MWS ⟶ Bluetooth	MWS Scan Frequency message
	Bluetooth ⟶ MWS	RFU
5	MWS ⟶ Bluetooth	RFU
	Bluetooth ⟶ MWS	RFU
6		Vendor specific
7		Vendor specific

Table 3.2: Message types

The logical coexistence signals are listed in Table 3.3.

Logical Signal Name	Description
FRAME_SYNC	See [Vol 7] Part A, Section 2.1.1

Table 3.3: Coexistence signals

Logical Signal Name	Description
MWS_RX	See [Vol 7] Part A, Section 2.1.2
BLUETOOTH_RX_PRI	See [Vol 7] Part A, Section 2.1.3
BLUETOOTH_TX_ON	See [Vol 7] Part A, Section 2.1.4
MWS_PATTERN	See [Vol 7] Part A, Section 2.1.5
MWS_TX	See [Vol 7] Part A, Section 2.1.6
802_TX_ON	See [Vol 7] Part A, Section 2.1.7
802_RX_PRI	See [Vol 7] Part A, Section 2.1.8
MWS_INACTIVITY_DURATION	See [Vol 7] Part A, Section 2.1.9
MWS_SCAN_FREQUENCY	See [Vol 7] Part A, Section 2.1.10

Table 3.3: Coexistence signals

3.1.1 Real-time Signal Message (Type 0)

The Real-time Signal message is used to transport the real-time coexistence signals (see [Vol 7] Part A) over the WCI-2 transport.

The Real-time Signal message conveys all the real-time coexistence signals in one message. The time reference point for the Real-time Signal message is the end of MSG[4] (i.e. the transition to the Stop bit).

Two Real-time Signal messages are defined, one from the Bluetooth Controller to the MWS device and another from the MWS device to the Bluetooth Controller.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
FRAME_SYNC	MWS_RX	MWS_TX	MWS_PATTERN[0]	MWS_PATTERN [1]

Table 3.4: Real-time Signal message from MWS device to Bluetooth Controller

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
BLUETOOTH_RX_PRI	BLUETOOTH_TX_ON	802_RX_PRI	802_TX_ON	RFU

Table 3.5: Real-time Signal message from Bluetooth Controller to MWS device

3.1.2 Transport Control Message (Type 1)

The Transport Control message can request state information from the MWS device's coexistence interface.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
RESEND_REAL_TIME	RFU	RFU	RFU	RFU

Table 3.6: Transport Control message

Signal Name	Description
RESEND_REAL_TIME	This bit is set if a device wants to get a status update of the real-time coexistence signals. The signal is usually used after wake-up from sleep of the transport interface. If the receiving device's transport interface is awake it shall send a Real-time message with the current status of the real-time coexistence signals within 4 UART character periods. If the signal is not received within 4 UART character periods the device is considered asleep.

Table 3.7: Transport control signals

3.1.3 Transparent Data Message (Type 2)

The Transparent Data message can be used to exchange non-time critical messages between the MWS device and the Bluetooth Controller. The interface does not guarantee the delivery of a message. Protocol and content of the message are vendor specific.

The least significant nibble of each octet shall be transmitted first.

A least significant nibble shall be discarded if the next nibble is a least significant nibble. A most significant nibble shall only be accepted if the preceding nibble was a least significant nibble.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
NIBBLE_POSITION	DATA[0]/ DATA[4]	DATA[1]/ DATA[5]	DATA[2]/ DATA[6]	DATA[3]/ DATA[7]

Table 3.8: Transparent Data message

Signal Name	Description
NIBBLE_POSITION	0 – Least Significant Nibble 1 – Most Significant Nibble
DATA[n]; n=0 .. 7	Data bits of the message octet

Table 3.9: Transparent data bits

3.1.4 MWS Inactivity Duration Message (Type 3)

The MWS Inactivity Duration message is used to send the MWS_INACTIVITY_DURATION signal from the MWS device to the Bluetooth Controller.

The message is sent at the beginning of the MWS inactivity period.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
DURATION[0]	DURATION[1]	DURATION[2]	DURATION[3]	DURATION[4]

Table 3.10: MWS Inactivity Duration message

The MWS Inactivity Duration is encoded in 5 bits. DURATION is unsigned.

When DURATION = 0, MWS_INACTIVITY_DURATION is cancelled.
When DURATION = 31, MWS_INACTIVITY_DURATION is infinite.
Otherwise, MWS_INACTIVITY_DURATION is given by the formula:

MWS_INACTIVITY_DURATION = DURATION * 5 ms

3.1.5 MWS Scan Frequency Message (Type 4)

The MWS Scan Frequency message is used to send the MWS_SCAN_FREQUENCY signal from the MWS device to the Bluetooth Controller.

MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG[4]
FREQ[0]	FREQ[1]	FREQ[2]	FREQ[3]	FREQ[4]

Table 3.11: MWS Scan Frequency message

The MWS Scan Frequency index is encoded in 5 bits. FREQ is unsigned.

unthinkably connected