Abstract

This article provides an overview of the flexible, high-performance packet data channel that has been designed for high-rate packet data services over IS-136 TDMA channels. To achieve the highest data rates in the limited 30 kHz channel bandwidth, the packet data channel is designed for adaptive modulation and, in addition to a fixed coding mode, permits operation using an incremental redundancy mode.

GPRS-136: High-Rate Packet Data Service for North American TDMA Digital Cellular Systems

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LUCENT TECHNOLOGIES

Current North American time-division multiple access (TDMA) systems support voice services and circuit data services at a rate limited to 9.6 kb/s. High-rate packet data services are desirable for short bursty transactions as well as applications such as World Wide Web/Internet access, electronic mail, and file transfer. This article provides a general overview of the proposed system, and describes flexible, high-performance medium access control (MAC) and radio resource management procedures that have been adopted by the Telecommunications Industry Association (TIA) for high-rate packet data services over IS-136 TDMA channels. The 30 kHz spectrum usage, symbol rate, and TDMA format (6 time slots every 40 ms) are maintained as in the IS-136 standard [1] for compatibility with existing mobiles and in order to minimize impact on existing infrastructure. Assuming these constraints, a new TDMA packet data channel (PDCH) is defined to carry both user data and information from other higher-layer control and management entities.

Current cellular TDMA systems are designed to achieve good coverage over most of a typical cell, and as a result, the signal to interference plus noise ratio is sufficient to support higher data rates through the use of 8- and 16-level modulations over a large portion of a typical cell. However, current systems rely on the use of only $\pi/4$-differential quadrature phase shift keying (DQPSK) modulation to achieve modest data rates over all operating conditions. The packet data MAC and physical layers are designed to increase throughput over a significant fraction of the cell area by using coherent 8-PSK in addition to $\pi/4$-DQPSK. The standard is designed to permit dynamic adaptation of the modulation scheme based on measured carrier-to-interference ratio (C/I). The modulation schemes are chosen to be the same as those adopted for voice services in order to simplify the development of dual-mode (voice and packet data capable) mobile stations. Hooks are provided in the standard to support a 16-level modulation such as 16-quadrature amplitude modulation (QAM), 16-PSK, or 16-DPSK in the future.

Three wireless data infrastructure options were investigated: Cellular Digital Packet Data (CDPD) infrastructure that is widely deployed in the United States; Global System for Mobile Communications (GSM) General Packet Radio Service (GPRS) infrastructure that is expected to be deployed throughout the world in 1999 and 2000; and the third option considered, an Internet service provider (ISP)-like model with Point-to-Point Protocol (PPP) tunnels to the Internet or corporate intranets. In order to achieve economies of scale and simplify evolution to third-generation systems, the upper layers (layer 3 and above) of the packet data protocol stack were chosen to be the same as that used by GSM GPRS. GPRS-136 is thus a TDMA packet data standard based on GPRS, but utilizing 30 kHz for the physical layer and allowing connection to the American National Standards Institute (ANSI)-41 network [2]. GPRS-136 utilizes most of the existing network elements from the GPRS network reference model. It adds a gateway-mobile switching center (MSC)/visitor location register (VLR) function, which allows connection of the GPRS packet data network to the ANSI-41 based mobile circuit-switched network. The relevant GPRS specification documents can be found in [3–8].

Another benefit of this choice is that the existing GPRS standard is used as a baseline, allowing for quick development. This also enables evolution to the Enhanced General Packet Radio Service (EGPRS), which has been proposed to the International Telecommunication Union (ITU) as a third-generation radio transmission technology for International Mobile Telecommunications in the year 2000 (IMT-2000). The use of EGPRS channels for TDMA packet data will be standardized during 1999 and is to be called GPRS-136HS.

Organization of the Article

The following section provides an overview of the service and network reference model. The GPRS-based protocol stack is described briefly. Provision of voice/data integration and operation with half-duplex and full-duplex terminals is discussed.

The article next describes the logical and physical structure of the PDCH. The allocation of packet paging and packet broadcast channels, and PDCH reselection procedures are described. Multiple-time-slot operation is also discussed. We then describe the MAC layer and uplink media access control procedures, including the use of the packet channel feedback (PCF) mechanism.

The article describes the procedures associated with adaptive modulation (DQPSK and coherent 8-PSK), followed by the incremental redundancy and fixed coding mode radio link protocols (RLPs). The incremental redundancy mode provides approximately 15 percent higher throughput at the cost of additional receiver memory. We provide detailed time slot formats accommodating the fields required by the RLP, MAC, and physical layers. The last section provides a brief summary.

GPRS-136 Network Reference Model and Operation

The Packet Data Network Reference Model

The network elements are as follows:

- Terminal equipment (TE), which typically interfaces with the user and contains packet data applications.
- Mobile termination (MT), which interfaces to the TE, and terminates the radio interface.
- Base station (BS), which constitutes the interface between the network and mobile station, and transfers packet data and signaling messages between serving GPRS support nodes (SGSNs) and mobile stations in its coverage area.
- SGSN, a packet data switch that routes data packets to appropriate mobile stations within its service area.
- Gateway GPRS support node (GGSN), which acts as the logical interface between the GPRS-136 network and external packet data networks. It tunnels IP packets from external networks to the SGSN using the GPRS Tunneling Protocol (GTP).
- GPRS home location register (HLR), accessible from the SGSN and GGSN, contains GPRS-136 subscription and routing information.
- ANSI-41 HLR, accessible from the serving and gateway MSC/VLR functions, contains subscription and routing information for circuit-switched service.
- ANSI-41 gateway MSC/VLR, provides functions such as circuit call routing and circuit service related paging within the GPRS-136 network.
- ANSI-41 serving MSC/VLR, provides circuit switching functions for mobile stations in its service area.
- Message center (MC), receives and accepts requests to deliver teleservice messages to the mobile subscriber.

The Protocol Stack (GPRS-136)

Figure 2 shows the GPRS-136 protocol stack. The MAC and radio resource management procedures are significantly different from GPRS because of the fundamental differences in the IS-136 and GPRS physical layers.

The radio resource (RR) sublayer provides data transfer and control services to LLC and GPRS-136 mobility management. It consists of three cooperating entities: the MAC entity, radio resource management entity (RRME), and broadcast management entity (BME).

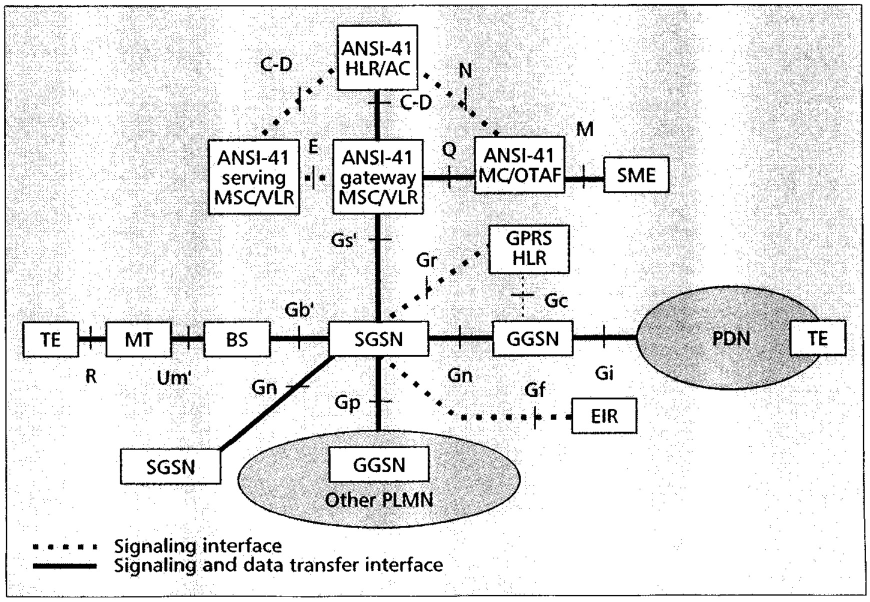
The MAC entity provides services directly to LLC through a SAP. It supports two multiplexed logical links of different priorities, one for normal data transfer and the other for providing expedited data delivery services to higher-layer and management entities.

The BME and RRME provide services to the GPRS mobility management layer through two other SAPs, and carry out both voice and packet-data-related signaling functions. These entities use the services of the MAC entity to communicate with their peers, and to control the MAC entity. The core MAC and RRME procedures are generic, and the interfaces can easily be modified to support other protocol stacks.

Joint Voice/Data Operation

In addition to packet data service, GPRS-136 allows subscribers to obtain both IS-136 and ANSI-41-based services (e.g., circuit-switched voice services, short messaging services, intelligent roaming), provided mobile stations support both circuit and packet modes. Two new classes of mobile stations are supported by GPRS-136: dual mode (i.e., circuit and packet mode capable) and packet mode only.

Integration of the GPRS packet network with the ANSI-41 circuit-switched network provides a unique challenge. GPRS provides its own set of registration, authentication, authorization, and mobility management functions which are thoroughly integrated with other GSM services such as circuit-switched voice service. These functions are implemented very differently in the ANSI-41 network. To avoid the complexity of fully integrating these two sets of functions, GPRS-136 provides a method of "tunneling" ANSI-41 signaling messages between a mobile terminal and the gateway MSC/VLR via the SGSN. These messages are tunneled as



■ **Figure 1.** *The GPRS-136 packet data network reference model. (Primed interfaces — e.g., Gb' — indicate ETSI GPRS interfaces that have been modified for GPRS-136.)*

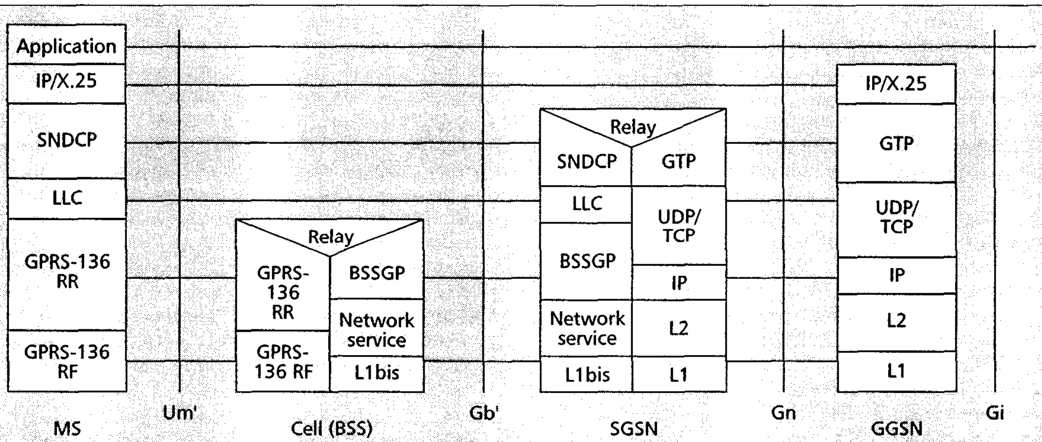
specially marked LLC frames. ANSI-41 registration, authentication, authorization, paging, and short message service (SMS) messages are delivered transparently (tunneled) through the SGSN. This allows the MSC/VLR and SGSN to implement and execute these functions independently as necessary for the proper operation of the ANSI-41 and GPRS networks, respectively. The mobile terminal provides the necessary sequencing of related functions between the ANSI-41 and GPRS networks.

The GPRS-136 mobility management layer consists of two entities: GPRS mobility management (GMM) and 136 mobility management (136MM), which support mobility management functions specific to packet data and circuit-switched services, respectively. A new tunneling function is defined in the SGSN, and the GPRS LLC and BSSGP protocols have been modified in order to route 136MM signaling messages to the mobile station over the PDCH.

Dual-mode mobile stations perform registration, authentication, authorization, and location update functions independently and in parallel with the ANSI-41 and GPRS networks while the mobile is camped on a PDCH. If an ANSI-41 SMS message needs to be delivered while a mobile is camped on a PDCH, it is delivered on the PDCH along with other packet data as tunneled LLC data. An incoming circuit call is indicated to a mobile with an ANSI-41 page message tunneled from the gateway MSC/VLR to the mobile. The mobile moves to an IS-136 control channel to respond to the page and accept the incoming call. Similarly, to initiate a circuit call, the mobile stops any activity on the PDCH and moves to the IS-136 control channel. Circuit calls take precedence over packet data transactions. When a circuit call is completed, the dual mode mobile station returns to camping on a PDCH.

Half-Duplex Operation

Half-duplex devices have complexity, size, and battery life benefits which make them attractive for applications that do not require full duplex (i.e., simultaneous transmission and reception) capability. Full-rate operation (i.e., similar to IS-136 voice) is half-duplex by definition because of fixed time offsets between the uplink and downlink [1]. The support of downlink double- and triple-rate (multislot) operation for packet data is quite straightforward, and is enabled by occasionally scheduling uplink time slots for obtaining automatic

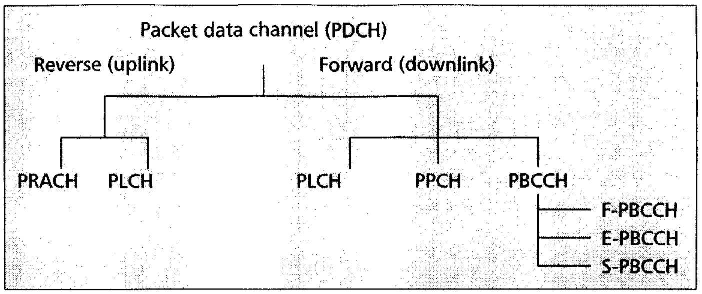


Legend:

- GPRS Tunneling Protocol (GTP) [7]: This protocol tunnels user data and signaling between GPRS support nodes in the GPRS backbone network.
- Transmission Control Protocol (TCP) carries GTP protocol data units (PDUs) in the GPRS backbone network for protocols that need a reliable data link. TCP provides flow control and protection against lost and corrupted GTP PDUs. User Datagram Protocol (UDP) carries GPT PDUs for protocols that do not need a reliable data link. UDP provides protection against corrupted GTP PDUs.
- Internet Protocol (IP) is the GPRS backbone network protocol used for routing user data and control signaling.
- Subnetwork Dependent Convergence Protocol (SNDCP) [4]: This transmission functionality maps network-level characteristics onto the characteristics of the underlying network. It provides the following services to the network layer: header compression, encryption, segmentation, and reassembly.
- Logical link control (LLC) [3]: This layer provides a highly reliable ciphered logical link, and is independent of the underlying radio interface protocols. In additional to the service access points described in [3], two additional service access points with different priorities are supported for the tunneling of signaling messages between the MS and the circuit-switched network.
- Relay: In the base station system (BSS), this function relays LLC PDUs between the Um' and Gb' interfaces. In the SGSN, this function relays PDUs between the Gb' and Gn interfaces.
- BSS GPRS Protocol (BSSGP) [6]: This layer conveys routing and quality of service related information between the BSS and SGSN.
- Network service (NS) [5]: This layer transports BSSGP PDUs, and is based on the frame relay connection between BSS and SGSN. The interface may traverse a network of frame relay switching nodes.
- GPRS-136 radio resource (GPRS-136 RR): This sublayer consists of the medium access control (MAC) entity, radio resource management entity (RRME), and broadcast management entity (BME). The MAC function provides reliable in-sequence delivery of LLC data and expedited control (radio resource signaling) over the GPRS-136 physical channel.
- GPRS-136 RF: The 30 kHz channels and time slot structure are as defined in IS-136. The GPRS-136 specification defines the modulation schemes and different fields in the time slot for the PDCH.

■ **Figure 2.** *The GPRS-136 packet data protocol stack.*

repeat request (ARQ) feedback. However, mobile stations cannot support more than full-rate operation on the uplink without simultaneous transmission and reception. GPRS-136 supports half-duplex operation on both the uplink and downlink for all mobile stations regardless of their multislot (or bandwidth) capability. Double- or triple-rate half-duplex operation on the uplink is made possible by carrying out a fixed allocation of a sequential number of time slots. No downlink transmissions are scheduled for the device during this period.



■ **Figure 3.** *Logical PDCHs.*

Packet Data Channel Structure

Logical Channel Structure

The PDCH consists of the following logical channels (Fig. 3):

- Packet broadcast control channel (PBCCH) for indicating generic system configuration related information
- Packet paging channel (PPCH) dedicated to delivering pages
- Downlink packet payload channel (PLCH) for delivering data generated by LLC, RRME, and GMM
- Packet channel feedback (PCF) for support of random access and reserved access on the uplink
- Uplink packet random access channel (PRACH) used by mobile stations to request packet data access to the system
- Uplink packet payload channel (PLCH) for delivering data generated by LLC and GMM

Physical Channel Structure

The PDCH uses 30 kHz RF channels and the time-slot structure specified in IS-136 [1]. Each 40 ms frame on a 30 kHz RF channel consists of six time slots (three time slot pairs), numbered 1 to 6. One or more time slot pairs may be allocated to a PDCH. The remaining time slot pairs may be allocated to a digital control channel (DCCH) and/or digital traffic channel (DTC).

Multirate Channels – A PDCH may be full-rate, double-rate, or triple-rate, depending on whether one, two, or three time slot pairs are allocated to the channel within each 40 ms frame. The channel bandwidth is indicated through system broadcast information.

Superframe Structure – Sleep mode is defined for mobile stations on the PDCH in order to improve mobile station standby time. A superframe structure similar to the IS-136 DCCH is defined on each full-rate portion of a PDCH in order to manage sleep mode. The total number of time slots per superframe is 32. The superframe phase (SFP) is a modulo 32 up-counter which increments every 20 ms and helps mobile stations find the start of the superframe. If a double- or triple-rate PDCH is allocated on a particular frequency, superframe synchronization across the individual full-rate portions is required.

Primary and Supplementary Phases – A multirate PDCH operates on a single channel frequency and consists of the following:

- Primary phase
- Supplementary phase(s)

In this context, a phase corresponds to a full-rate portion of a multirate PDCH. The primary phase always corresponds to a full-rate channel, and is the part of a multirate channel that contains logical broadcast and paging channels on the downlink. The supplementary phases on a multirate PDCH correspond to all time slots that are not part of the primary phase. The possible allocation of primary and supplementary phases is provided in Table 1.

The primary phase superframe consists of time slots that are reserved for the PBCCH. Nominal paging time slots are determined from among the remaining time slots using a standard hashing algorithm that relies on mobile station (subscriber) identity. The actual number of PPCH slots per superframe are configurable through a fast broadcast message. Except for the assignment of broadcast and paging channels and SFP management, a mobile station views a double- or triple-rate PDCH as one common channel (i.e., a fat pipe) regarding data transmission or reception.

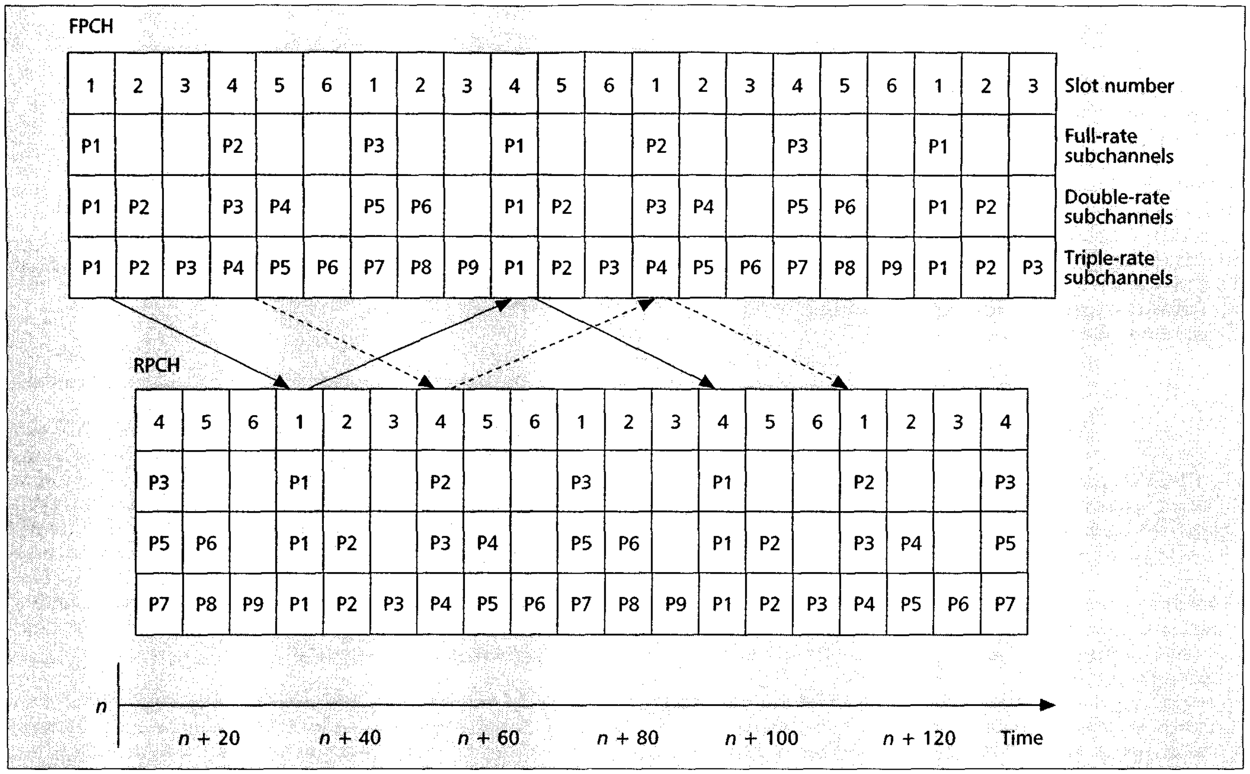
Downlink and Uplink Burst Associations – Subchannels are defined on the uplink in order to allow sufficient processing time at both the mobile station and BS in conjunction with a random access event. The full-rate PDCH is defined to consist of three subchannels; there are six subchannels in each double-rate PDCH and nine subchannels in each triple-rate PDCH (Fig. 4).

An enhanced packet channel feedback (PCF) field that relies on this association is defined on the downlink for uplink resource management. PCF flags are carried in downlink time slots to provide feedback for bursts sent previously on the uplink and to indicate subsequent assignments on the uplink. Mobile stations identify access opportunities on the uplink by reading PCF on the corresponding downlink time slots. The PCF field allows the support of contention access and reserved access on the same channel, and assumes different flag definitions depending on the context. These flags are reliably encoded to ensure good performance even under poor channel conditions.

For a full-rate PDCH, the uplink and downlink time slots are multiplexed to create three distinct access paths, as shown in Fig. 4. Assuming that path 1 (P1) in the downlink indicates that the next P1 time slot on the uplink is designated as a contention slot and is selected for a random access attempt, a mobile station sends the first burst of its access at that time

Rate	Slot numbers	Primary phase slots	Slots for supplementary phase(s)
Full-rate PDCH	1, 4	1,4	–
Full-rate PDCH	2, 5	2,5	–
Full-rate PDCH	3, 6	3,6	–
Double-rate PDCH	1, 2, 4, 5	1, 4	2, 5
Double-rate PDCH	2, 3, 5, 6	2, 5	3, 6
Double-rate PDCH	1, 3, 4, 6	1, 4	3, 6
Triple-rate PDCH	1, 2, 3, 4, 5, 6	1, 4	2, 3, 5, 6

■ **Table 1.** *Multirate PDCH phase allocations.*



■ **Figure 4.** *Downlink and uplink burst associations.*

(24.8 ms after receiving the full P1 slot on the downlink). The mobile station then starts reading the PCF flags in the next downlink P1 slot (21.8 ms after transmitting its burst) to determine the reception status of its initial access.

Similarly, there are six access paths on each double-rate channel and nine access paths on each triple-rate channel. In general, a mobile station which has data to send transmits 24.8 ms after obtaining an assignment via PCF on the downlink. The mobile station reads PCF on the downlink 21.8 ms after transmission in order to obtain the reception status of its transmitted burst.

The Medium Access Control Function

PDCH Selection, Reassignment, and Reselection

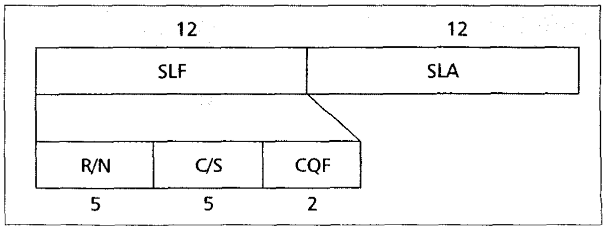
Mobile stations are directed to a PDCH through IS-136 DCCH broadcast information. In cases where there are multiple PDCHs per sector, mobile stations are directed to a beacon PDCH. The beacon PDCH broadcast information indicates the number of PDCHs, as well as the bandwidth (full-, double-, or triple-rate) of each PDCH supported. Mobile stations then hash onto a particular PDCH depending on their identity and the number of PDCHs. Load balancing may be carried out by reassigning mobile stations across radio resources, and the performance may be further improved by maintaining MAC/RLP state across reassignments. Cell reselection procedures ensure continuity of service across cell boundaries since mobile stations autonomously perform PDCH reselection when they detect a stronger signal from a neighbor cell.

Active Mobile Identity Management

Each mobile station is assigned a 7 bit temporary local identifier called an active mobile identity (AMI) which remains valid for one or several closely spaced transactions. The AMI is used to identify uplink time slot assignments and identify the recipient of data on the downlink. Of the 128 possible AMI values, only 89 are allowed for mobile stations engaged in point-to-point transactions. The all-zero AMI is excluded for PCF-related functions and also for identifying point-to-multipoint information on the downlink. The remaining 38 AMIs closest to the all-zero codeword are excluded in order to increase PCF reliability.

AMI assignment procedures are executed for both uplink and downlink transactions spanning more than one time slot. If a valid AMI has not already been assigned, the AMI assignment is carried out as a part of the transaction initiation procedure. Once an AMI has been assigned to a mobile station, it is used for transactions in both directions (i.e., the AMI is assigned on the initiation of an uplink or downlink transaction, whichever begins first, and remains assigned until released). AMI release is based on the expiration of timers at both the mobile station and BS. The AMI release procedures are designed to ensure the following:

- The availability of the same AMI to the mobile station for



■ **Figure 5.** *Logical format of the PCF. The SLF is context-dependent and contains either an AMI for providing feedback to contention slots, or three fields for providing feedback to reserved slots.*

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