

ets on ports 50-1 . . . 50-N via port interfaces 120-1 . . . 120-N and their associated I/O queues, although in the preferred embodiment, switch engine 100 can forward packets at wire speeds with no intervention from CPU 80.

Switch engine 100 performs the flow identification and processing operations for forwarding packets received via port interfaces 120-1 . . . 120-N. It accesses flow table 70 to look up the forwarding information associated with the flows. Address registers 105 provide address information to assist switch engine 100 in locating appropriate flow processing information in flow table 70. The contents of these registers can be configured by CPU 80 via CPU interface 110, and include the base Ethernet address of ports 50-1 . . . 50-N.

Domain configuration registers 115 provide routing domain configuration information in accordance with routing domains 81-1 . . . 81-R established in configuration table 85. For each port, separate IP and IPX routing domain identifiers associated therewith are stored in domain configuration registers 115, which registers are configured by CPU 80 via interface 110. Routing domain configuration information for IP and IPX networks is maintained and updated by processes executing on CPU 80 and stored as routing domains 81-1 . . . 81-R in configuration table 85. CPU 80 then uses this configuration information to configure domain configuration registers 115 via interface 110.

Although shown singly for clarity, the I/O queue associated with each of port interfaces 120-1 . . . 120-N includes several queues, each having a corresponding priority level that can be configured by the software running on CPU 80. Switch engine 100 forwards packets destined for one of ports 50-1 . . . 50-N using the appropriate queue, in accordance with priority rules configured in the flow table. The number of times in a service interval packets in each queue will be processed is programmed such that higher priority queues get serviced more frequently than lower priority queues. Each flow can be assigned a particular priority level, and thus have a desired QoS, as will be explained in more detail below. Priority level configuration registers 125 provide service level settings for each respective level of priority corresponding to the I/O queues associated with port interfaces 120-1 . . . 120-N.

FIG. 5 further illustrates the contents of flow table 70. In this example, flow table 70 includes address resolution hash 140, address resolution record table 150, protocol entry table 160 and network entry table 170. Flow table 70 further includes priority tags 190, filter tags 200 and mirror tags 210. The contents of these tables, and their interrelations, will be described in more detail below in connection with the creation and maintenance of flow table entries according to the invention. Switch engine 100 has read access of the tables in flow table 70, and CPU 80 has read and write access to the tables.

The operation of the multiprotocol switch of the present invention will now be described in more detail with reference to FIGS. 6 to 14.

After powerup (step S2), and before any packets are received, flow table 70 is empty. Configuration table 85 contains routing domain, filter, mirror, priority, and VLAN configurations that have been established already for the network, and can be updated at any time by a system administrator via software processes executing on CPU 80.

In addition to switching and routing packets, the multiprotocol switch of the present invention performs tasks that are performed by conventional switches and routers such as route determination, routing table updates, and the like.

Such tasks are well known to those skilled in the art and are not depicted in the overall operation of the switch, as illustrated in FIG. 6, so as not to obscure the invention. Of note, however, are the unique capabilities of the multiprotocol switch with respect to multicast group management for IP, AppleTalk and NetBios networks.

In accordance with an object of the invention, virtual LANs are automatically created for every IP multicast group associated with nodes and segments attached to the switch. Upon powerup (step S2), software processes executing on CPU 80 cause the multiprotocol switch to send out host membership query messages (IGMP messages addressed to 224.0.0.1) (step S4). Hosts attached to the switch that belong to multicast groups send IGMP host membership report messages. The switch can thus determine all the multicast groups to which nodes attached to it belong and forward IP multicast packets within multicast groups appropriately.

The switch then enters into an operational state wherein switch engine 100 continually monitors for data packets arriving on each of ports 50 via port interfaces 120-1 . . . 120-N (step S6). When a packet is received (step S8), it is processed in accordance with the algorithm further illustrated in FIG. 7 (step S10). CPU 80 also periodically sends out IGMP queries (step S12 and step S14) to determine all active IP multicast groups to which hosts attached to the ports of the switch belong and keeps its multicast group table updated. Moreover, hosts send IGMP packets to join and leave IP multicast groups. These IGMP packets are intercepted by switch engine 100 and sent to CPU 80. CPU 80 can therefore have up to date information about IP multicast group membership.

Packet processing and switching in the multiprotocol switch of the invention, that can be included in step S10 of FIG. 6 for example, is further illustrated in FIG. 7.

When a packet is received, switch engine 100 first examines the packet header and if the packet is a multicast packet (step S22), the packet is forwarded to CPU 80 for special processing to automatically create and/or update VLAN information (step S24). Whether or not it is a multicast packet, switch engine 100 keeps the packet for further processing.

Layer 3+ switching and routing can be disabled for the system by setting a flag in configuration table 85, for example. In that event, each packet traversing through the port is processed and switched as a Layer 2 packet, regardless of the protocol carried by the packet. Accordingly, if Layer 3+ switching and routing is disabled (as determined in step S24), processing branches to step S26.

All data packet headers include the source and destination Ethernet addresses of the packets. The protocol used by the communicating hosts can also be determined from the Ethernet data packet header. For example, Ethernet Type II packets contain a type field that explicitly indicates the protocol (such as IP, IPX, ARP, RARP and LAT) that packet belongs to. Moreover, it is known that different protocols use different Ethernet frame formats. For example, IP uses Ethernet II or SNAP packet formats. IPX can use all four Ethernet formats (depending on configuration), AppleTalk (a trademark of Apple Computer Corp., Cupertino, Calif.) uses the SNAP packet format and NetBios typically uses the Ethernet 802.2 LLC format. The protocol carried by the packet thus can be learned either explicitly or implicitly from the packet header.

Layer 4 protocols such as Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) are built on top of the Layer 3 IP protocol. In addition to the information

above, the headers for these protocols further contain source and destination socket numbers, which can identify individual applications such as FTP, Telnet, e-mail and HTTP, running on IP hosts. Specifically, the protocol carried field in the IP header identifies the protocol carried by the IP datagram. For example, if the protocol carried field has a value of 6, this indicates that the IP datagram carries a TCP packet, whereas a value of 17 indicates that a UDP packet follows the IP header.

The IPX protocol is also at Layer 3 of the OSI model. Most Novell NetWare (trademark of Novell, Inc. of Provo, Utah) applications run on top of IPX. IPX headers contain source and destination socket numbers which identify applications running on the hosts, in addition to IPX source and destination network and IPX source and destination node addresses, which identify end-to-end IPX hosts. Different Novell Network Layer 4 protocols use the IPX datagram to send and receive packets. The protocol field in the IPX header indicates which protocol (SAP or RIP) the IPX datagram is carrying.

As evident from the foregoing, flows of packets associated with IP and IPX protocols can thus be identified by their IP/IPX source and destination node and/or socket information, and those associated with other protocols can be identified by their source and destination Ethernet addresses. In this example of the invention, flows of packets associated with IP and IPX protocols, as well as ARP and RARP packets, are processed by the multiprotocol switch to support special Layer 3+ processing and/or routing across different networks. Accordingly, as shown in FIG. 7, switch engine 100 determines the protocol type from the packet (step S28). As shown above, this may be explicitly defined in the header as in the Ethernet Type II type field or may be implicitly derived from other information in the IP or IPX header. If the packet is not an IP/IPX or ARP/RARP packet (determined in step S30), processing branches to step S26 and it is processed and switched as a Layer 2 packet, regardless of the protocol carried by the packet. Otherwise, processing advances to step S32 and the packet is processed in accordance with Layer 3+ protocols.

FIG. 8 further illustrates switch engine processing of Layer 3+ packets, which processing can be included in step S32 of FIG. 7 for example.

Switch engine 100 first extracts the address information for both the source and destination ends of the flow with which the packet is associated (step S40). As shown above, headers of packets associated with IP and IPX protocols include IP/IPX source and destination node addresses and may further include socket numbers.

Switch engine 100 then checks to see whether entries exist in the flow table for both ends of the flow (step S42). If entries exist for both ends of the flow (determined in step S44), the packet is forwarded at wire speed in accordance with any filters, mirrors, priorities or VLANs established in the flow table entry (step S46).

If flow table entries do not exist for both ends of the flow, the packet is "unresolved." For unresolved IP/IPX and ARP/RARP packets, switch engine 100 forwards or broadcasts the packet as best it can under the circumstances. If only the destination end of the flow was unresolved (determined in step S48), a flow table entry exists for the source end of the flow, containing a broadcast enable entry for the source. Accordingly, switch engine 100 forwards the packet on the port(s) indicated by the broadcast enable entry associated with the source (step S56).

If only the source end of the flow is unresolved, a flow table entry exists for the destination. In this situation, switch

engine 100 notifies CPU 80 via CPU interface 110 that the packet is unresolved (step S56). The message to the CPU contains the source and destination addresses (and possibly socket numbers), the port on which the packet arrived, and an indication that the source end of the flow was unresolved. As will be described in more detail below, CPU 80 will process the packet, and if appropriate, will create entries in flow table 70 containing forwarding information and links to information relating to any previously-configured filters, priorities, mirrors or VLANs corresponding to the unresolved ends of the flow.

If both the source and destination ends of the flow are unresolved, switch engine 100 notifies CPU 80 via CPU interface 110 that the both ends of the flow were unresolved (step S58). Moreover, switch engine 100 forwards the packet on all ports indicated by the default broadcast enable entry for this protocol. As will be explained in more detail below, default entries exist for IP, IPX, and non-IP/IPX types of flows. Switch engine 100 can determine which ports on which to forward the packet according to the default broadcast enable entry, and causes the packet to be forwarded to a default I/O queue (typically one with lowest priority) associated with each of the indicated ports (step S60).

After the unresolved packet is broadcast or forwarded in steps S50 or S60, the destination node, if attached to the switch, will respond. The response packet will be processed as described above and a flow table entry for the responding node will be created by the CPU as in step S56. At that point, flow table entries for both ends of the flow will have been created so that any subsequent packets belonging to that flow will be forwarded by switch engine 100 at wire speed.

CPU processing for unresolved IP/IPX or ARP/RARP packets, as initiated in step S48 of FIG. 8 for example, is further illustrated in FIG. 9.

First, CPU 80 determines whether the source of the flow is unresolved, from the message sent by switch engine 100 for example (step S70). If so, processing advances to step S72, where a flow table entry for the source of the flow is created by software executing in CPU 80, in accordance with any filters, mirrors, and priorities associated with the source node (that may have been configured by the network administrator) in flow table 70.

Processing then advances to step S74, where CPU 80 determines whether the destination of the flow is unresolved, from the message sent by switch engine 100 for example. If not, then the source was the only unresolved portion of the flow, and so the packet can be forwarded in accordance with the flow table information (step S76).

If the destination of the flow is unresolved, as determined in step S74, processing continues to step S78, where CPU 80 determines whether the packet is addressed to the switch. Such packets can include, for example, ARP packets from hosts that are attempting to get the Ethernet address of their IP gateway. Since the IP address of the gateway is actually associated with a port of the switch, such ARP requests must be processed by the switch and responded to appropriately by, for example, sending an ARP response back to the requesting host containing the Ethernet address of the gateway interface (step S80). Such packets can also include responses to ARP requests sent by CPU 80 to determine the Ethernet address of the host for programming the swap fields of a flow table entry, as will be described in more detail below in connection with the processing of steps S88 and S90. The dashed line connecting steps S80 and S90 in FIG. 9 thus represents the logical processing flow when an ARP request sent by CPU 80 in step S88 is responded to by the

host at the requested IP node, which processing will be further described below.

If the destination of the flow is unresolved and the packet is not addressed to the switch, a flow table entry needs to be created for the destination of the flow. First, it must be determined whether the flow requires switching or routing. This is determined in step S62. If the destination Ethernet address of the packet is the Ethernet address of the port of the switch on which the packet arrived (as determined from address registers 105) and the destination IP or IPX address is not the IP/IPX address of the switch, then the packet needs to be routed. If the destination Ethernet address is not the Ethernet address of the port of the switch, CPU 80 further looks up the routing domains configured in tables 81-1 . . . 81-R in configuration table 85. If a packet is going from a port in one routing domain to a port in another routing domain, then the packet will require routing. Otherwise, it is switched. This is required to support IP multicast routing, as will be described even further below.

If it is determined in step S62 that the unresolved destination is in another network, the Ethernet address of the destination needs to be determined to perform routing. That is, during routing, switch engine 100 needs to replace the source Ethernet address in the packet with the Ethernet address of the switch port on which the packet is being forwarded, and the destination Ethernet address of the packet needs to be replaced by the Ethernet address of the destination node or the router en route to the destination. It is this destination Ethernet address that needs to be determined.

If the packet is an IP packet (as determined in step S86), CPU 80 determines the IP network that the destination belongs to and determines the port(s) that connect to or belong to that network. CPU 80 can do this, for example, by cross-referencing the destination IP address with the contents of routing table 65 (created statically by an administrator or dynamically learned using routing protocols such as RIP and OSPF). If no such network exists, CPU 80 sends an ICMP redirect message to the host indicating that the network was unreachable. If it finds an entry in routing table 65 for the network, CPU 80 sends an ARP request packet on all the ports belonging to that network (step S88). The destination or next hop sends an ARP response containing its Ethernet address. Switch engine 100 sends this response to CPU 80 (step S48 in FIG. 8). CPU 80 extracts the Ethernet address contained in the response packet, and records the port on which the packet arrived (step S80 and step S90). For further information regarding binding machine level addresses with network level addresses using ARP, see generally Douglas E. Comer and David L. Stevens, *Internetworking with TCP/IP—Vol. II: Design, Implementation, and Internals*, 1994, Chapter 4, pp. 39–59.

If the packet is an IPX packet that needs to be routed and the destination address is unresolved (as determined in steps S74 and S86), the Ethernet address of the destination is determined using IPX RIP information in routing tables 65 maintained by CPU 80 (if the destination is a Netware server). If the destination is a Netware client, then the destination Ethernet address is already known. In either event, the Ethernet address associated with the IPX destination address is determined in step S92. For further information regarding route determination and updating using IPX, see generally IPX Routing Guide, published by Novell.

CPU 80 then creates a flow table entry for the destination of the flow (step S94) and programs the Ethernet address

swap field of the entry with the Ethernet address information determined in the preceding steps (step S96).

Processing for creating flow table entries for unresolved packets, as performed in steps S72 and S94 of FIG. 9 for example, is further illustrated in FIG. 10.

First, in step S100, CPU 80 extracts the last twelve (least significant) bits (0–11) of the Ethernet or IP/IPX address that could not be resolved by switch engine 100. CPU 80 uses these twelve bits as a hash into flow table 70 to determine whether an address resolution hash entry exists in address resolution hash table 140 for the unresolved address (step S102). The address resolution hash entry is used as a starting link for all forwarding and other packet processing information associated with the node corresponding to the unresolved address.

Separate hash areas are maintained for Ethernet, IP and IPX address tables. Each hash entry is 32 bits long and has a format as shown below (bit positions of each field shown in parentheses):

Hash Accessed (31)	Record Offset (27–10)	Number of Records (9–2)	Record Link Valid (1)	No Entries Valid (0)
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The Hash Accessed field indicates whether this hash has been accessed by switch engine 100. This field can thus be used to age out hashes using the Least Recently Used (LRU) algorithm, for example. Aging software executing on CPU 80 initially sets this bit on all the hash entries. When a node associated with this hash entry sends data on the network, switch engine 100 clears this bit. The aging software can later and/or periodically delete hash entries that do not have the Hash Accessed bit cleared.

The Record Offset field contains the address offset from the Base Record Address of address resolution record table 150 at which the first record entry for the group of addresses that map to this hash is stored. The first address resolution record entry associated with this hash will thus reside at location (Base Record Address+Record Offset). The Base Record Address is stored in a register within address registers 105. The Record Offset field is originally set to zero, but CPU 80 updates it with the offset of the address resolution record entry for this flow, after such entry is stored in address resolution record table 150, so as to link it to this hash entry.

The Number of Records field indicates the number of addresses (minus one) that the switch has learned map to this hash. This field is originally set to zero, but is updated when CPU 80 creates additional address resolution record entries that are linked to this hash.

The Record Link Valid field, when set, indicates that the data stored at location (Base Record Address+Record Offset+(Number of Records×2)+2) is actually a Link Entry. Since each hash can only point to 128 address resolution record entries (7 bit field), this bit can be used to increase the number of records for this hash value. If this bit is not set, and the No Entries Valid bit is also not set, then the data stored at (Base Record Address+Record Offset+(Number of Records×2)) is the last possible address resolution record for this particular hash entry.

The No Entries Valid bit indicates that there are no valid addresses that map to this hash. This bit is originally set, but is cleared when CPU 80 creates an address resolution record corresponding to this hash entry.

Accordingly, in step S102, when CPU 80 next determines whether a valid hash entry exists in address resolution hash

140 at the position corresponding to the twelve bits of the unresolved address, it inspects the No Entries Valid field of the entry. If the bit is set, CPU 80 clears it and all other bits in the entry, thereby creating a valid hash entry at the position in address resolution hash 140 corresponding to the unresolved address (step S104).

CPU 80 next increments the Number of Records field in the hash entry to indicate that an additional address resolution record entry for this hash will be created (step S106). If the number of records that will exist for this hash exceeds the field size of the Number of Records field, that field is decremented and the Record Link Valid field bit is set.

Processing advances to step S108, where CPU 80 creates an entry in address resolution record table 150 for the host corresponding to the unresolved address. The format of an address resolution record entry is shown below.

Protocol Offset (31-18)			Ethernet Address bits 15-12, 23-16, 31-26 (17-0) OR IP/IPX Address bits 15-12, 23-16, 31-26 (17-0)
Port Number (31-23)	Priority Tag Addr (22-19)	Mirror Enable (18)	Ethernet Address bits 25-24, 39-32, 47-40 (17-0) OR IP/IPX Address bits 25-24 and Socket bits 0-15 (17-0)

CPU 80 fills the Address fields with the remaining 36 bits of the unresolved address that were not used as the initial hash. For non-IP/IPX packets, CPU 80 fills these fields with the remaining most significant bits of the Ethernet address contained in the unresolved entry message from switch engine 100. For IP and IPX packets, CPU 80 fills these fields with the remaining most significant bits of the IP/IPX address and the host application socket number. If no special configurations (filter, mirror or priority) have been configured for the host application, CPU 80 inserts a "don't care" value of hex 0xffff for the socket number to indicate that the packet number is not used to identify the IP/IPX flow with which this entry is associated. Moreover, if the protocol (such as ICMP, IGMP) carrying the packet does not use socket numbers a "don't care" value is used for the socket value.

The Port Number field indicates the port (50-1 . . . 50-N) which this Ethernet (or IP or IPX) address resides. CPU 80 fills this field with the port number contained in the unresolved entry message from switch engine 100.

The Protocol Offset field indicates the offset from the Base Protocol Address at which the entries in the Protocol Table for each protocol associated with this flow are stored.

The Base Protocol Address is stored in a register in address registers 105. The protocol the packet belongs to is used as an increment from the Protocol Offset to point to the appropriate entry. The increments for each protocol are stored in a register in address registers 105. The address of the entry in the Protocol Table for the flow associated with this flow is thus Base Protocol Address + Protocol Offset + Protocol Increment. If and when CPU 80 creates a protocol table entry for this flow, explained in more detail below, CPU 80 fills the Protocol Offset field with the protocol entry to this address resolution record.

The Priority Tag Addr field provides the address to one of the 8-bit priority tags 190. The Base Address for priority tags is stored in a register in address registers 105. The address to the priority tag field for this flow

is located at Base Address+Priority Tag Addr. CPU 80 initially sets the Priority Tag Addr field to zero. If priorities are configured for this flow, as will be explained below, a priority tag will be configured, priority processing will be enabled by setting a bit in the Protocol Offset entry, and the address to the configured priority tag will be programmed in this field to link the priority tag to the address resolution record entry.

The Mirror Enable field qualifies the mirror tag (tag address found in the protocol entry). If this bit is set, mirror processing is enabled for this flow. CPU 80 initially sets this bit to zero. If mirrors are configured for the flow, as explained in more detail below, a mirror tag will be configured, and the mirrors will be enabled by setting this bit.

After creating the address resolution record for the unresolved portion of the flow, processing advances to step S100, where CPU 80 determines how many address resolution records now exist for this hash by examining the Number of Records field in the hash entry. If this is the first address resolution record entry created for this hash, CPU 80 simply stores the address resolution record entry it created in address resolution record table 150 at the address corresponding to Base Record Address+Record Offset (step S112). It then links this entry to the address resolution hash entry by storing the address offset from the Base Record Address where the entry is stored in the Record Offset field of the hash.

If it is determined in step S110 that there are more than one address resolution record entries for this hash, CPU 80 sorts the existing entries with the newly created entry in order of the remaining address bits of the unresolved flow address, and stores them accordingly (step S114). The entries are already linked to the address resolution hash entry by the previous programming of the Record Offset field.

Processing then advances to step S116, where CPU 80 determines whether any special processing has been configured or is otherwise required for this flow. This includes determining whether any filters, mirrors, priorities or VLANs are associated with this flow. CPU 80 does this, by cross-referencing the flow identification information in the unresolved packet with the entries in configuration table 85.

If it is determined in step S116 that no filters, mirrors, priorities, VLANs or swap addresses need to be programmed for this flow (i.e. routing is not configured for the switch), the address resolution record is linked to a default set of protocol entries which are all linked in turn to a default network entry (step S118). If this is a TCP, UDP or IPX packet with a socket number, the socket number portion of the remaining address bits in the address resolution record entry for this flow will be set to the "don't care" value of 0xffff. The default network entry will be described in more detail below.

Otherwise, if it is determined in step S116 that this flow requires special handling, unique entries in protocol table 160 and network table 170 for the flow must be created, and processing by CPU 80 continues by first creating a protocol entry (step S120).

The address pointed to by the Protocol Offset field of the address resolution record indexes a list of entries in protocol table 160. Different filters, mirrors and priorities can be established between two nodes and/or processes depending on the particular protocol used for communication between them. The protocol increment for the particular protocol (provided by address registers 105) points to the appropriate

set of filters, etc. for the flow, as indicated by a 32-bit entry in the protocol table, having the following format:

Fltr Addr (31-27)	Mirror Addr (26-23)	Filter Enable (22)	Priority Queue (21-19)	B/W (18-15)	Priority Enable (14)	Network Offset (13-0)
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The Fltr Addr field provides the address to one of the 32 32-bit filter tags 200. The Base Address for filter tags 200 is stored in a register in address registers 105. Accordingly, the address to the filter tag for this flow is located at Base Address+Fltr Addr. CPU 80 initially sets the Fltr Addr field to zero. If filters are configured for this flow, CPU 80 will create a filter tag in filter tags 200 and program the address of the tag within filter tags 200 in this field to link the configured filter tag to the protocol entry. CPU 80 determines whether any filters are configured for this flow by cross-referencing the filter tables 76-1 . . . 76-F in configuration table 85 with the flow identification information for this side of the flow.

Each 32-bit filter tag contains 8 bits of veto information and 24 bits of match information. CPU 80 configures filter tags for each side (source and destination) of the flow to be filtered. If packets belonging to the flow are to be blocked (as in firewalling), CPU 80 configures the filter tags for the source and destination sides of the flow so that their veto bits do not match and their match bits do match. For example, if a firewall is established between a first network having nodes A, B and C and a second network having nodes D, E and F, CPU 80 may configure the filter tags for nodes A, B and C such that they have match bits of 0x000001 and veto bits of 0x02, while nodes D, E and F are configured with filter tags having match bits of 0x000001 and veto bits of 0x03. Accordingly, nodes A, B and C will be able to communicate with each other, but not with nodes D, E and F, who are also able to communicate with each other. Now assume that node C in the first network is to be given the privilege of communicating with nodes in the second network. This can be done by changing its match bits to 0x000002. Now node C will be able to communicate with all nodes in both networks.

The Mirror Addr field provides the address to one of the 16 16-bit mirror tags 210. If the mirror enable bit in the address resolution record linked to this protocol entry is set, mirroring is enabled for flows to which this node belongs. The Base Address for mirror tags 210 is stored in a register in address registers 105. Accordingly, the address to the mirror tag for this node is located at Base Address+Mirror Addr.

CPU 80 determines whether any mirrors are configured for this flow by cross-referencing the mirror tables 78-1 . . . 78-M in configuration table 85 with the flow identification information for this side of the flow. If any of the established mirrors correspond to this flow, one of the 16 16-bit mirror tags 210 will be configured for it. Each mirror tag field contains 1 bit of match information. CPU 80 initially sets the Mirror Addr field to zero. If traffic belonging to the flow is to be mirrored on another port(s), CPU 80 sets the mirror enable bit in the address resolution entry for each end of the flow, configures a tag in mirror tags 210, and links both ends of the flow to the same tag by filling the Mirror Addr field of both respective protocol entries with the address of the configured tag in mirror tags 210 (offset from the Base Address). Switch engine 100 can thereafter locate the tag by combining the Mirror Addr field with the Base Address for

mirror tags 210 which is stored in a register in address registers 105. The port(s) on which the flow is to be mirrored is configured in the Mirror Entry of the network entry linked to this protocol entry (described below).

The Priority Enable field qualifies the priority tag (addressed by the Priority Tag Addr in the address resolution record entry corresponding to this flow). If this bit is set, the flow is processed at a higher priority. CPU 80 initially sets this bit to zero. If priorities are configured for this flow, a priority tag will be configured, priority processing will be enabled by setting this bit, and the address to the configured priority tag within priority tags 190 will be programmed in the Priority Tag Addr field of the address resolution record entry linked to this protocol entry to link the priority tag to the address resolution record entry.

CPU 80 determines whether any priorities are configured for this flow by cross-referencing the priority tables 77-1 . . . 77-P in configuration table 85 with the flow identification information for this side of the flow. If any of the established priorities correspond to this flow, a priority tag will be configured for it. Each priority tag contains 1 bit of match information. If packets belonging to the flow are to be forwarded with priority, CPU 80 enables priority by setting the Priority Enable field in the protocol entries of both ends of the flow, configures a priority tag in priority tags 190, and links the address resolution records of both ends of the flow to the same configured priority tag. The level of priority associated with this flow is determined by the Priority Queue field and the service level for that queue programmed in priority configuration registers 125.

The Priority Queue field is valid if the Priority Enable bit is set for the flow. CPU 80 initially sets this field to zero. If a priority is configured for this flow, CPU fills this field with the priority level with which all packets belonging to this flow will be forwarded by the switch. For example, if eight levels of priority are supported, there will be eight I/O queues associated with each port 50-1 . . . 50-N, and this field will indicate which one of the queues into which packets belonging to this flow will be placed.

Each queue's corresponding priority level is user configurable. That is, a system administrator can program the number of times per service interval a queue having that priority level should be serviced on a system wide basis. This configuration is stored in priority level configuration registers 125. One such register exists for each priority level/queue. For example, if a value of 5 is programmed into priority configuration register for priority level 4, the queue corresponding to that priority level will be serviced 5 times in a service interval. The service interval is determined by adding together all the priority level values programmed into each priority configuration register. Weighted Fair Queueing is implemented by servicing the queues with equal priority after servicing the queues in accordance with established priorities (i.e. after all the queues are serviced per the priorities in priority level configuration registers 125, service queue 1, once, queue 2 once and so on until all the queues are serviced). This ensures that even the lowest priority queues are serviced once every service interval.

After creating the protocol entry for this unresolved portion of the flow, CPU 80 stores the entry in protocol entry table 160 at the Protocol Increment associated with the protocol used by the hosts of this flow, which increment is referenced to the Protocol Offset for this flow. Then CPU 80 links the protocol entry with the address resolution record entry for this flow by writing the Protocol Offset from the Base Protocol Address where this record is stored in the Protocol Offset field in the address resolution record entry (step S122).



Processing advances to step S124, where CPU 80 creates an entry in network entry table 170 for this unresolved portion of the flow. The Network Offset field points to an entry in network entry table 170 associated with this flow and protocol. The base address of the entry will be Base Network Address+Network Offset. The Base Network Address is stored in a register in address registers 105.

Entries in network entry table 170 contain fields that help configure virtual LANs, fields to configure mirroring, and fields to store the destination Ethernet address values to swap out the ones in the packet if the packet is being routed. At least one network entry exists for every address resolution table entry. However, multiple address resolution entries can share the same network entry. For example, a default network entry exists for every IP, IPX and non-IP/IPX flow that has no associated filters, mirrors, priorities or VLANs configured for it, as will be described in more detail below. Accordingly, for example, all such non-configured IP flows will have address resolution entries that point to the same default protocol entry that in turn points to the same default network entry. The format of each network entry is shown below:

	Broadcast Enable Entry (31-0)		
	Reserved (31-0)		
Unused	Reserved (16-24)	Swap Address Bits 15-0 (15-0)	
	Swap Address Bits 47-16 (31-0)		
	Mirror Entry (31-0)		

The Broadcast Enable field is used to control the ports on which broadcast and multicast packets, originating from this node should be forwarded. This field contains 1 bit of match information corresponding to each port of the switch (32 ports in this example). A 1 in any bit position indicates that a broadcast packet from the node associated with that Broadcast Enable field must be forwarded on that port. For example, if bits 13 and 14 in this field are set, then broadcast or multicast packets from a node having a network entry containing this field will be sent out on ports 14 and 15. CPU 80 initially sets this field to a default value based on the protocol and routing domain associated with the node. Accordingly, broadcasts and multicasts originating from a node will only be forwarded on ports with attached nodes belonging to the same routing domain, if such a routing domain exists. If the node belongs to a VLAN configured on or learned by the switch, CPU 80 sets this field appropriately to make sure that multicasts are forwarded only on ports belonging to that VLAN. For example, if nodes attached to ports 1 and 2 belong to the same VLAN, then the broadcast enable field for those nodes will be 0x00000003 indicating that multicast packets from nodes on those ports should be sent out only on ports 1 and 2.

Every attached node learned by the switch has a network entry containing an associated 32 bit Broadcast Enable field. Separate default network entries having default Broadcast Enable fields are created for each of the IP, IPX and non-IP/IPX protocols. These default network entries are used for nodes that do not have filters, mirrors, priorities or VLANs configured for them. Respective "dummy" protocol entries are further provided to link between unique address resolution record entries and the default network entries. The default Broadcast Enable field of the default network entry to which non-IP/IPX flows are linked is set to 0xfffffff indicating that broadcasts must be forwarded on every port. The default Broadcast Enable fields of the default network entries to which IP and IPX flows are linked are configured

based on routing domains. For example, if there are two IP routing domains comprised of ports 1 through 15 and 16 through 32 respectively, then there will be one default network entry for each routing domain. The first one is associated with all nodes learned on ports 1 through 15 and will have a Broadcast Enable field containing 0x0000ffff. The second is associated with all nodes learned on ports 16 through 32 and will have a Broadcast Enable field containing 0xffff0000. This ensures that broadcasts from nodes in IP routing domain 1 will not be sent to nodes in IP routing domain 2 and vice versa.

When a flow has one or more of a filter, mirror, priority or VLAN configured for it, non-default protocol and network entries will be created for it. When creating the network entry for the node, however, CPU 80 first copies the Broadcast Enable field of the default network entry associated with this flow into the Broadcast Enable field for the newly created network entry.

CPU 80 determines whether any VLANs are configured for this flow by cross-referencing the VLAN tables 79-1 . . . 79-V in configuration table 85 with the flow identification information for this side of the flow. If any VLANs are established the node associated with this side of the flow belongs to any of the established VLANs, a non-default network entry will be configured for it. CPU 80 configures the Broadcast Enable field in accordance with the established VLAN by setting the bits corresponding to the port(s) on which each node belonging to the VLAN is attached.

The Mirror Entry field indicates the ports on which the packets belonging to the flow associated with this network entry should be mirrored on. CPU 80 initially sets these fields to zero. As described above, if mirrors are configured for the flow to which this packet belongs, CPU 80 sets the Mirror Enable bit for both sides of the flow, configures a mirror tag and points both sides of the flow to the same mirror tag, and configures the Mirror Entry by setting the bits corresponding to the port(s) on which packets are to be mirrored on.

The Swap Address Bits fields contains the Ethernet addresses used for address swapping during packet routing. For IP and IPX routing, the swap field bits are filled in with the Ethernet address associated with the destination node as described above. When routing a packet, the switch needs to replace the source Ethernet address with the address of the port through which the packet is being forwarded and the destination Ethernet address in the packet to be routed with the address of the next hop router or the end station. Every node that communicates across networks has a unique network entry associated therewith. The swap field of the network entry is filled by CPU 80 with the Ethernet address of the next hop router or the end station as described above in connection with the processing depicted in FIG. 9. The Ethernet address is determined at the time of entry creation using Address Resolution Protocol (ARP) for IP packets.

After creating the network entry as described above, CPU 80 stores it in network entry table 170, then links it to the protocol entry for this portion of the flow by writing the Network Offset relative to the Base Network Address where it is stored in the protocol entry (step S126).

The flow table entry creation processing described above will now be further described by way of the following illustrative and non-limiting examples of the invention.

First, assume that a system administrator sets up a routing domain for a group of users in a network containing a multiprotocol switch of the present invention, for example, the engineering department of a company. Further assume





that these users are connected to ports 1-8 of the switch and that they have been configured with IP addresses in the range 206.233.77.0 to 206.233.77.255, so that the associated IP network is 206.233.77.0 (subnet mask 255.255.255.0).

Once an administrator configures ports 1-8 to belong to routing domain 1 (network address 206.233.77.0), CPU 80 creates a default network entry for that domain in network entry table 170, having a Broadcast Enable field value of 0x000000ff, indicating that broadcasts from any of the nodes attached to ports 1-8 will be sent out only on ports 1-8. CPU 80 then locates an empty space in protocol table 160 sufficient to contain entries for all supported protocols and creates dummy protocol entries that all point to the default network entry for routing domain 1 created in the previous step.

If a user connected to port 1 of the switch wishes to open an FTP session with a user connected to port 2 of the switch, and if this is the first communication between them, there will be no flow table entries for this flow, and the processing depicted in FIG. 10 will be performed for both, the host connected to port 1 and the host connected to port 2 one at a time.

The first packet of the flow is unresolved and is sent to CPU 80 for further processing. CPU 80 creates hash table entries in the IP area of address resolution hash 140 at positions corresponding to the last twelve bits of the IP address of both respective hosts, and clears the No Entries Valid fields in both entries (steps S102 and S104).

Next, CPU 80 creates address resolution record entries in address resolution record table 150, fills the Address fields with the remaining address bits and a "don't care" value of 0xffff for the socket bits, and fills the Port Number fields with the respective port numbers. CPU 80 links the newly created address resolution record entries to the address resolution hash entries by programming the Record Offset fields in the hash entries with the offsets of the address resolution record entries from the Base Record Address in the address resolution record table (steps S108-S112).

CPU 80 determines that no mirrors, filters, priorities or VLANs are associated with this flow, and that no routing is required (step S116). Accordingly, the default protocol and network entries can be used (step S118). CPU 80 links the dummy protocol entry for TCP to both address resolution record entries by programming the Protocol Offset fields of both address resolution record entries with the base address of the dummy protocol entries located in protocol table 160, which dummy protocol entries all point to the default network entry for routing domain 1.

In a next example, assume that a system administrator establishes a firewall that forbids any communications between hosts having Ethernet address A and Ethernet address B, respectively connected to ports 8 and 9 of the switch. This filtering information is stored in filter tables 76-1 . . . 79-F in configuration table 85 and specifies the Ethernet addresses, but not the ports.

If the host having Ethernet address A wishes to send a non-IP/IPX packet to the host having Ethernet address B, and if this is the first attempted communication between them, there will be no flow table entries for this flow, and the processing depicted in FIG. 10 will be performed for both hosts one at a time.

CPU 80 creates hash table entries in the Ethernet area of address resolution hash 140 at positions corresponding to the last twelve bits of Ethernet address A and B for the hosts connected to ports 8 and 9, respectively, and clears the No Entries Valid fields of both entries (steps S102 and S104).

Next, CPU 80 creates address resolution record entries in address resolution record table 150, fills the Address fields with the remaining bits of Ethernet address A and B for the host connected to port 8 and 9, respectively, and fills the Port Number fields with the respective ports (8 and 9). CPU 80 links the newly created address resolution record entries to the address resolution hash entries by programming the Record Offset fields in the hash entries with the offsets of the respective address resolution record entries from the Base Record Address in the address resolution record table (steps S108-S112).

CPU 80 then determines that a filter is associated with this flow by comparing the Ethernet addresses of both hosts with the filter set up in configuration table 85, so further processing is required (step S116). CPU 80 first locates empty spaces in protocol table 160 sufficient to contain entries for all supported protocols and creates respective protocol entries in the spaces at an offset predetermined for Ethernet protocol (step S120). This offset is also programmed in a register in address registers 105. Initially, all bits in the protocol entries are cleared. However, since a filter is associated with this flow, CPU 80 sets up filter tags in filter tags 200 and links the filter tags to the respective protocol entries by programming the Fltr Addr fields of the tags with the offsets of the respective tags in filter tags 200.

CPU 80 establishes a filter between the two hosts by setting the veto bits in their respective filter tags to different values and by setting the match bits to the same values. After the flow table entries for this flow have been created, all non-IP/IPX packets between the two hosts will be dropped by switch engine 100. If IP or IPX communications between these hosts are attempted in the future, similar processing will be performed to create IP or IPX flow table entries which will also cause switch engine 100 to drop all packets for such communications.

CPU 80 then links the protocol entries to the address resolution record entries by programming the Protocol Offset fields of the address resolution record entries with the base addresses of the respective empty spaces located in protocol table 160 (step S122).

Next, CPU 80 creates network entries and clears all bits in them (step S124). The Broadcast Enable fields are programmed with a value of 0xffffffff since no VLANs or routing domains have been configured. Finally, CPU 80 links the network entries by programming the Network Offset fields in the protocol entries with the offsets of the respective network entries from the base of network entry table 170 (step S126).

In a next example, assume that a system administrator establishes a priority for all HTTP communications with hosts belonging to an IP subnet being respectively connected to ports 4-7 of the switch. This priority information is stored in one of priority tables 77-1 . . . 77-P in configuration table 85 and specifies the IP network addresses, protocol type and priority level, but not the ports to which the hosts are attached.

An IP host connected to the switch that wishes to access an external Web site uses the default gateway to connect to it. The multiprotocol switch implementing the present invention will act as the default gateway. It will have routing tables established (through traditional routing protocols such as RIP and OSPF) to determine which port (16, for example) will provide the best route to the destination Web site and the port through which the flow should be forwarded. If this is the first attempted communication between the host and the Web site, there will be no flow table entries for this flow, and

the processing depicted in FIG. 10 will be performed for both sides of the flow one at a time.

CPU 80 creates hash table entries in the IP area of address resolution hash 140 at positions corresponding to the last twelve bits of the IP addresses of the respective hosts, and clears their No Entries Valid fields (steps S102 and S104).

Next, CPU 80 creates address resolution record entries in address resolution record table 150, fills the Address fields with the remaining IP address bits and the socket numbers for both nodes, and fills the Port Number fields with the respective ports. CPU 80 links the newly created address resolution record entries to the address resolution hash entries by programming the Record Offset fields in the hash entries with the offsets of the respective address resolution record entries in the address resolution record table (steps S108-S112).

CPU 80 then determines that a priority is associated with this flow by comparing the IP addresses and protocol with the priority set up in configuration table 85, so further processing is required (step S116). CPU 80 first locates empty spaces in protocol table 160 sufficient to contain entries for all supported protocols and creates protocol entries in the spaces at an offset predetermined for TCP protocol (since HTTP uses TCP as a transport protocol) (step S1120). This offset is also programmed in a register in address registers 105. Initially, all bits in the protocol entries are cleared. However, since a priority is associated with this flow, CPU 80 creates a tag in Priority Tags 190 having bits corresponding to the ports of the respective hosts set, sets the Priority Enable bits in the protocol entries and programs the Priority Tag Addr fields in the address resolution record entries for both ends of the flow with the address of the newly created priority tag. Since the priority tags match, bidirectional priority is established for the flow. CPU 80 also programs the Priority Queue fields with the I/O queue corresponding to the priority level configured for the flow in priority tables 77-1 . . . 77-P. All packets belonging to that flow are then queued in the programmed queue number and are serviced a number of times per service interval as specified by the priority configuration register 125 for that queue (which CPU 80 has already programmed in accordance with a priority level to service level mapping).

(CPU 80 then links the protocol entries to the address resolution record entries by programming the Protocol Offset fields of the address resolution record entries with the base addresses of the respective empty spaces located in protocol table 160 (step S122).

Next, CPU 80 creates network entries and clears all bits (step S124). The Broadcast Enable fields are programmed in accordance with any routing domains or VLANs established (i.e. all ports that belong to the same routing domain have the same broadcast enable field and should send broadcast packets to each other). Since packets belonging to this flow will require routing, swap fields need to be programmed with the destination or next hop Ethernet address. CPU 80 uses Address Resolution Protocol (ARP) to determine these addresses and fills in the Swap Address bits fields accordingly. Finally, CPU 80 links the network entries by programming the Network Offset fields in the protocol entries with the offsets of the respective network entries from the base of network entry table 170 (step S126).

In a final example, assume that a system administrator establishes a mirror so that all Telnet sessions between IP host A and IP host B, respectively connected to ports 4 and 5 of the switch, are mirrored on port 1. This mirror information is stored in one of mirror tables 78-1 . . . 78-M in

configuration table 85 and specifies the IP addresses and process (the socket for Telnet is 23) and mirror port, but not the ports to which the hosts are attached.

If host A wishes to initiate a Telnet session with host B, and if this is the first attempted communication between them, there will be no flow table entries for this flow, and the processing depicted in FIG. 10 will be performed for both hosts one at a time.

The packet will be sent to CPU 80 as an unresolved flow. CPU 80 creates hash table entries in the IP area of address resolution hash 140 at positions corresponding to the last twelve bits of the IP addresses of the respective hosts, and clears the No Entries Valid fields (steps S102 and S104).

Next, CPU 80 creates address resolution record entries in address resolution record table 150, fills the Address fields with the remaining IP address bits and socket bits, and fills the Port Number, fields with the respective ports. CPU 80 links the newly created address resolution record entries to the address resolution hash entries by programming the Record Offset fields in the hash entries with the respective offsets of the address resolution record entries in the address resolution record table (steps S108-S112).

CPU 80 then determines that a mirror is associated with this flow by comparing the IP addresses with the mirror set up in configuration table 85, so further processing is required (step S116). CPU 80 first locates empty spaces in protocol table 160 sufficient to contain entries for all supported protocols and creates protocol entries in the spaces at an offset predetermined for IP protocol (steps S120 and S122). This offset is also programmed in a register in address registers 105. Initially, all bits in the protocol entries are cleared. However, since a mirror is associated with this flow, CPU 80 creates a tag in Mirror Tags 210 having bits corresponding to the ports of the respective hosts set, sets the Mirror Enable bit in the address resolution record entries and programs Mirror Addr fields for both protocol entries with the address of the newly created mirror tag in Mirror Tags 210 to create bidirectional mirroring for the flow.

CPU 80 then links the protocol entries to the address resolution record entries by programming the Protocol Offset fields of the address resolution record entries with the base addresses of the respective empty spaces located in protocol table 160 (step S122).

Next, CPU 80 creates network entries and sets up the bits in the Broadcast Enable fields in accordance with any routing domains and VLANs established. Since a mirror is required for packets in both directions of the flow, the Mirror Entry fields of both network entries should be programmed. CPU 80 sets bit 0 in the fields so switch engine 100 will send traffic from A to B and B to A to port 1 in addition to the ports associated with A and B. Finally, CPU 80 links the network entries by programming the Network Offset fields in the protocol entries with the offsets of the respective network entries from the base of network entry table 170 (step S126).

FIG. 11 further illustrates address resolution processing performed to determine whether packet processing information exists in flow table 70 associated with the flow to which the packet belongs, which processing can be performed in step S42 of FIG. 8 for example.

As shown in FIG. 11, switch engine 100 first extracts the last twelve bits of the address associated with the unresolved end of the flow. For IP and IPX packets for which Layer 3+switching and routing is enabled, the last twelve bits of the IP/IPX address are extracted in step S130; for other protocols, the last twelve bits of the Ethernet address are extracted.

The extracted bits are then used to hash onto the area of address resolution hash 140 corresponding to the protocol carried by the packet (IP, IPX or other) (step S132). If an entry exists in address resolution hash 140 for the flow (determined in S134), processing advances to step S138. Otherwise, address resolution processing ends with a negative result and packet processing control branches to step S44 in FIG. 7 (step S136).

In step S138, switch engine 100 locates in address resolution record table 150 the address resolution record that is linked to the hash entry found in the previous step. This is done by combining the Base Record Address contained in address registers 105 with the Record Offset field contained in the hash entry.

Processing advances to step S140, where it is determined whether an address resolution record entry exists for this end of the flow. If the number of records linked to the hash entry is only one, switch engine 100 can readily locate the address resolution record because the record entry is pointed to by combining the Base Record Address from address registers 105 with the Record Offset indicated in the hash entry as is done in the previous step. If, however, the number of linked address resolution records is more than one (denoted by a value in the Num Records field of the hash entry being greater than zero), switch engine 100 performs a binary search on the linked entries based on the remaining bits of the address from which the twelve bits were extracted. For IP/IPX packets, the entry may contain socket numbers along with addresses (a "don't care" socket value of 0xffff in an entry matches all socket numbers).

If an address resolution record does not exist for the particular flow (determined in step S140), address resolution processing ends with a negative result and packet processing control branches to step S44 in FIG. 8 (step S142).

As described above, the address resolution record identifies one of the ports (50-1 . . . 50-N) to which the host associated with this side of the flow is connected. It also may contain links to entries in protocol entry table 160, and thence to network entry table 170 that can alert switch engine 100 to any filters, priorities, mirrors and VLANs that are configured for the flow.

In step S144, the Protocol Offset field of the address resolution record for this flow is extracted. This field, combined with the Base Protocol Address provided by address registers 105, points to a list of protocol entries for this flow in protocol entry table 160. Different protocol entries may exist for the flow depending on the protocol carried by the packet. To get the protocol entry for this flow and protocol, switch engine 100 extracts the protocol carried by the packet and looks up the Protocol Increment associated with the protocol in address registers 105. This increment is used to point to a particular entry in the list of entries pointed to by the Protocol Offset field in the preceding step, and the protocol entry is thus obtained in step S146.

A pointer to a linked entry in network entry table 170 can be contained within the protocol entry. To get the network entry for this flow and protocol, switch engine 100 obtains the Base Network Address from address registers 105 and combines it with the Network Offset. The result points to the linked entry in network entry table 170 and the network entry for this flow and protocol is thus obtained in step S148.

Switch engine processing for forwarding packets according to flow table information in the multiprotocol switch of the present invention, as performed in step S46 of FIG. 8 and step S76 of FIG. 9 for example, is further illustrated in FIG. 10.

At this point, flow processing information for both the

source and destination sides of the flow have been obtained, as described above in connection with the processing illustrated in FIG. 11.

The filter tag bits for the source and destination, if they are configured (as denoted by the Filter Enable fields of the respective protocol entries), are compared by switch engine 100 (step S150). If they match (i.e., the match bits of the respective filter tags match and the veto bits do not match), then the packet is dropped (S152). Otherwise, processing advances to step S154, where the port associated with the destination is determined from the address resolution record entry for the destination side of the flow. If this is a multicast packet, the port(s) on which the packet should be forwarded is determined from the Broadcast Enable field of the network entry for the destination side of the flow.

In step S156 switch engine 100 determines whether any mirrors have been configured for the flow (as indicated by Mirror Enable bits being set and matching mirror tags for source and destination). If so, these mirror port(s) are determined in step S158.

Packet forwarding processing is performed for each destination port determined in steps S154 and S158. In step S160, switch engine 100 first determines whether the packet needs to be routed to the current destination port. This is done by comparing the contents of the routing domain configuration registers for the source and destination ports. If the source and destination ports are in different routing domains, the packet needs to be routed. In addition, for unicast packets, switch engine 100 compares the destination Ethernet address in the packet with the address of the port on which the packet arrived. If the address matches, then the packet needs to be routed.

For packets that do not need to be routed, processing advances to step S170. For packets to be routed, in step S162, the source address is swapped with the routing domain on which the packet is being forwarded. For unicast packets, the destination Ethernet addresses of the packet is swapped with the address specified in the swap field of the network entry associated with the destination of this flow. The switch engine extracts the hop count from the packet and if the hop count is one or zero for IP or 16 for IPX (as determined in step S166), notifies CPU 80 for further processing (step S168). In addition, switch engine 100 decrements (for IP) or increments (for IPX) the hop count and recomputes the checksum of the packet (for IP packets only) (step S164).

Processing advances to step S170 where, if priority is enabled for the flow (as indicated by the Priority Enable bit in the protocol entry), the priority tags are compared to determine if they match. If so, the Priority Queue field of the destination is determined from the protocol entry associated with the destination of the flow (step S172). Otherwise, a default queue is used (step S174). The packet is then forwarded to the queue determined for this packet and associated with the current destination port (S176). In a service time interval, the queue is serviced the appropriate number of times as specified in priority configuration registers. If this is the last destination port (determined in step S178), packet forwarding processing ends and control branches back to step S12 in FIG. 6.

Switch engine processing of Layer 2 packets in the multiprotocol switch of the present invention, as performed in step S26 of FIG. 7 for example, is further illustrated in FIG. 13. Processing steps that are shaded differentiate those which are preferably performed by CPU 80 rather than switch engine 100 in this example of the invention.

Switch engine 100 first extracts the address information for both the source and destination ends of the flow with

which the packet is associated (step S180). As described above, this includes extracting the source and destination MAC addresses of the packet.

Switch engine 100 then checks to see whether entries exist in the flow table for both ends of the flow (step S182). If entries exist for both ends of the flow (determined in step S184), the packet is forwarded at wire speed in accordance with any filters, mirrors, priorities or VLANs established in the flow table entry (step S186).

If only the source end of the flow was unresolved (determined in step S188), a flow table entry exists for the destination end of the flow, containing the port associated with the destination, as well as any broadcast enable entries that are useful if the packet is a multicast packet. Accordingly, switch engine 100 forwards the packet on the port(s) indicated by the flow table entry associated with the destination (step S190).

If only the destination end of the flow was unresolved (determined in step S192), a flow table entry exists for the source end of the flow, containing a broadcast enable entry for the source. Accordingly, switch engine 100 forwards the packet on the port(s) indicated by the broadcast enable entry associated with the source (step S194).

If both the source and destination ends of the flow are unresolved (determined in steps S184, S188 and S192), switch engine 100 notifies CPU 80 via CPU interface 110 that the source address of the packet is unresolved (step S196). The message to the CPU contains the source and destination addresses, the port on which the packet arrived, and an indication that the source was unresolved. CPU 80 will then create an entry in flow table 70 containing forwarding information and links to information relating to any previously-configured filters, priorities, mirrors or VLANs corresponding to the source end of the flow (step S198), in a manner described above in connection with FIG. 10.

If it is determined in steps S184, S188 and S192 that both ends of the flow are unresolved, the packet is broadcast on all ports. After the unresolved packet is broadcast or forwarded in steps S194 or S200, the destination node, if attached to the switch, will respond. The response packet will be processed as described above and a flow table entry for the responding node will be created by the CPU as in step S198. At that point, flow table entries for both ends of the flow will have been created so that any subsequent packets belonging to that flow will be forwarded by switch engine 100 at wire speed.

Automatic VLAN creation and management in accordance with the present invention, as performed in step S24 in the process illustrated in FIG. 7 for example, is further illustrated in FIG. 14.

Switch engine 100 uses the Broadcast Enable field in the network entry to determine the ports on which broadcast or multicast packets from a node associated with that network entry needs to be sent. Every node that belongs to a VLAN network entry associated with it, and network entries shared by multiple nodes. As described above, the Broadcast Enable field is one of the 32-bit fields in the network entry. A 1 in a bit position of the Broadcast Enable field means that broadcast or multicast packets from that node will be forwarded on that port. A 0 in a bit position of the Broadcast Enable field indicates that broadcast and multicast packets from the node associated with that network entry will not be forwarded on that port. For example, if the Broadcast Enable field bit position 16 is 1 and 17 is 0, a broadcast or multicast packet from that node will be forwarded out on port 17, but not on port 18 of the switch.

If a node is assigned to a VLAN, when a packet first arrives from that node, CPU 80 allocates a network entry for it (if one does not already exist), determines the ports of the switch on which other members of the VLAN are connected and will put a '1' in bit positions corresponding to those ports (e.g. bit 0 for port 1, bit 1 for port 2, etc.). A node can belong to more than one VLAN and in that case, the Broadcast Enable field will be updated appropriately (e.g. it will be a logical "OR" of the two entries). If the destination address of a packet arriving from a node is a broadcast address, then it will be unresolved and the switch engine will use the source address to perform address resolution and network entry lookup, and then broadcast the packet according to the Broadcast Enable of the source if such an entry exists. If the destination address is a multicast address, then the switch engine uses the destination multicast address to perform address resolution and network entry lookup, and will multicast the packet on ports indicated by the Broadcast Enable field of the source if such an entry exists.

As described above, a VLAN can be manually created by a system administrator by configuring one via software processes executing on CPU 80, information regarding which is consequently stored in VLAN tables 79-1 . . . 79-V in configuration table 85. As a further aspect of the invention, however, VLANs can be automatically created, updated and maintained by the switch too correspond to multicast groups instantaneously existing among the hosts connected to ports of the switch. The following automatic VLANs are described below automatic VLANs for nodes using Windows DLC/LLC and NetBios (Windows 95 and Windows NT machines), automatic VLANs for AppleTalk nodes (Apple computers), and automatic VLANs for IP nodes using IP multicasting. It should be noted here that automatic VLAN creation can be disabled by the system administrator by means of setting a flag, for example, in VLAN tables 79-1 . . . 79-V. It should be further noted that automatic VLAN creation can be performed for other types of multicast groups in addition to those described below in accordance with the invention.

When switch engine 100 determines in step S22 that the packet is a multicast packet, it sends the packet to CPU 80 for processing. This includes Windows-95/Windows-NT multicast packets, IP multicasts, IGMP reports and queries, and AppleTalk Zone Information Protocol (ZIP) packets.

Windows-95/Windows-NT (trademarks of Microsoft Corp of Redmond Wash) machines using NetBios protocol on the top of DLC/LLC use a multicast address of 03:00:00:00:00:01 to other Windows-95/NT machines. When a packet is sent by Windows-95 clients and NT servers using this address, switch engine 100 forwards will forward this packet to CPU 80 via CPU interface 110 with a message containing the address and the port on which the packet arrived. When CPU 80 receives this message, processing will advance to step S210. CPU 80 checks to see whether an address resolution record entry exists for this address in flow table 70 (step S212). If not, it creates address resolution hash and address resolution record entries for this multicast address and links them together with a network table entry it further creates for it. Since CPU 80 knows one of the ports on which a node using this multicast protocol resides, it sets the bit corresponding to that port in the Broadcast Enable field of the newly created network table entry. For example, if the packet arrived on port 5, then CPU 80 sets bit 4 of the Broadcast Enable field to 1. If an entry already exists, then CPU 80 simply updates the Broadcast Enable field appropriately (for example, if the Broadcast

Enable field had a 1 in bit position 5 and if the packet arrived on port 2, then bit 1 of the Broadcast Enable field is also set to 1). The VLAN is automatically built in this manner, one step at a time with no administrator intervention.

If the packet is an AppleTalk packet (determined in step S218), processing advances to step S220. In AppleTalk networks, a rough equivalent of an IP subnetwork is a zone. AppleTalk networks use dynamic node address assignment using a protocol called Apple Address Resolution Protocol (AARP). Addresses of nodes can thus change from time to time. However, names of nodes do not change frequently. AppleTalk Name Binding Protocol (NBP) provides a mechanism for translating names into addresses. One such name to address mapping function involves maintaining a mapping between networks and zone names. This is done in AppleTalk routers through Zone Information Protocol (ZIP). Refer to G. S. Sidhu et al., "Inside AppleTalk," pp. 8-1 through 8-24, for more details regarding this protocol.

Zone Information Protocol (ZIP) provides for the following services: maintenance of network-to-zone-name mapping of the internet; support for selection of a zone name by a node at startup; and support for various commands that may be needed by non-router nodes to obtain this mapping. During startup, an AppleTalk node acquires the name of the zone it belongs to. It can either ask the router to put it in a specific zone or it can ask the router to place it in any zone. This is done through ZIP GetNetinfo requests and responses. A datalink multicast address called zone multicast address is associated with a given zone name on a given data link and is determined by the ZIP process in AppleTalk routers. All the nodes that belong to a particular zone use that multicast address instead of a broadcast address.

Switch engine 100 snoops AppleTalk ZIP packets by detecting GetNetinfo responses and ZIP Notify packets. These packets contain the multicast address associated with the zone. When such packets are detected in step S22, they are forwarded to CPU 80 and processing advances to step S220, where CPU 80 checks to see whether flow table entries exist for the multicast address for the zone. If not, it creates an entry for it and automatically adds the sender (which in this case would be the AppleTalk router) and the receiver (which is the end node) to a VLAN based on this multicast address provided that automatic VLAN creation is not disabled. This is done by (step S222) creating an address resolution hash and address resolution record entries for the multicast address if such do not exist already, creating and linking a network table entry thereto, and updating the Broadcast Enable field in the network entry so that subsequent packets addressed to this multicast address are forwarded on the ports which contain these nodes (sender and receiver) by switch engine 100 at wire speed. If it is determined in step S220 that flow table entries already exist for the zone associated with the multicast address, CPU 80 updates the Broadcast Enable field appropriately if necessary.

If the packet is an IP multicast packet, processing advances to step S226. VLANs based on IP multicast groups are established using IGMP and IP multicast protocols. The multiprotocol switch of the present invention performs IGMP spoofing in hardware and automatically determines IP multicast groups to which the nodes attached to the switch belong. The switch creates a VLAN for every IP multicast group. The switch also automatically determines membership of each multicast group associated with nodes attached to the switch and maintains the VLAN accordingly. Thus, IP multicast frames will be forwarded on segments with users registered to receive them so segments without group members are spared of spurious traffic.

Class D IP addresses (in the range of 224.0.0.0 through 239.255.255.255) are used for IP multicast networks (refer to RFC 1112 for more details). IP multicast addresses are resolved in a manner identical to Ethernet multicast addresses (i.e. the destination address is used to perform address lookup). Internet Group Management Protocol (IGMP) as described in RFC 1112 is used for IP multicast group administration. IGMP uses IP datagrams as shown in figure below. If the protocol carried field in the IP header is 2, then the data following the IP header contains IGMP packet. Switch engine 100 detects IGMP packets in step S22 and passes them along to CPU 80 as described above.

IGMP type (4 bits)	IGMP version (4 bits)	Unused (8 bits)	Checksum (16 bits)
Class D IP Multicast Group Address (32 bits)			

There are only two types of IGMP messages: reports and queries. End stations send reports to join or maintain membership in a multicast group. Routers send queries to locate active group members. As described above in connection with FIG. 6, the multiprotocol switch of the present invention, on powerup, joins the "all hosts" multicast group (224.0.0.1) and periodically sends out IGMP queries to the "all hosts" multicast address to determine all the multicast groups that are active on its segments. The group address in this query is set to 0.0.0.0 to indicate that the switch is interested in all active IP multicast groups. When a node receives the query, it will respond with a report indicating the multicast group it belongs to. Nodes also send IGMP reports when they leave the multicast group. During the time a node belongs to a multicast group, all messages it sends to other members of the group are addressed with the IP multicast group address.

Switch engine 100 forwards all IGMP reports and IP messages sent to IP multicast addresses to CPU 80 (step S22). In step S228, CPU 80 first determines whether the message is an IGMP report indicating that a node is leaving an existing group. If not, CPU 80 determines whether if low table entries exist for the multicast group associated with the IP multicast address (either indicated within an IGMP report or contained as the destination address of the packet) (step S230). If not, CPU 80 creates (step S232) or updates (step S234) the VLAN for this IP multicast address, provided that automatic VLAN creation is not disabled. This is done by creating address resolution hash and address resolution record entries for that IP multicast address (if one has not already been created), creating a network table entry and linking it to the address resolution record entry (if not done already), and updating the Broadcast Enable field. Thereafter, multicast packets from nodes in the IP multicast group using that multicast address as a destination are forwarded on all the other ports which have nodes that belong to that IP multicast group at wire speed by switch engine 100. If the packet is an IGMP report indicating that a node is leaving the multicast group, CPU 80 retrieves the network entry associated with that multicast group and clears the bit corresponding to the port on which that node is connected.

Although the present invention has been described in detail hereinabove with reference to the preferred embodiments thereof, those skilled in the art will appreciate that various substitutions and modifications can be made to the examples provided while remaining within the spirit and



scope of the invention as defined in the appended claims. For example, many processing steps have been described that could be ordered or grouped together differently for efficiency, or could be performed in parallel depending on implementation. Those skilled in the art will realize that such different implementations are possible after being taught by the present invention. Accordingly, the examples of the invention provided herein should be seen as illustrative rather than limiting.

I claim:

1. A method for forwarding data packets in a switch having a plurality of ports, said ports being adapted to transmit and receive data packets from hosts coupled thereto, said method comprising:

receiving a first data packet at a first port;  
 firstly extracting flow identification information from said first data packet, said flow identification information indicating that said first data packet belongs to a first flow between certain of said hosts;

corresponding said flow identification information with stored configuration information;

creating flow processing information based on said corresponding stored configuration information, said flow processing information comprising at least one of a filter, a mirror, and a priority, said flow processing information further indicating at least a second port, wherein all data packets belonging to said first flow are forwarded between said first and second ports, said first and second ports being associated with said certain hosts;

storing a first record in a flow table containing said flow processing information;

receiving a second data packet at one of said first and second ports;

secondly extracting said flow identification information from said second data packet;

locating said stored first record in said flow table based on said extracted flow identification information; and

preparing to forward said second data packet to the other of said first and second ports based on said flow processing information contained in said stored first record,

wherein said steps of firstly and secondly extracting said flow identification information each includes:

determining a protocol associated with said first flow; if said protocol is IP or IPX, extracting Layer 3 header information as said flow identification information; and

if said protocol is not IP or IPX, extracting Layer 2 header information as said flow identification information.

2. A method as defined in claim 1, further comprising:

preventing said second data packet from being forwarded to the other of said first and second ports in accordance with said filter.

A method as defined in claim 1, further comprising:

forwarding said second data packet to the other of said first and second ports; and

forwarding said second data packet on certain other of said ports in accordance with said mirror.

A method as defined in claim 1, further comprising:

forwarding said second data packet to the other of said first and second ports; and

optimizing transmission of said second data packet to hosts associated with the other of said first and second ports in accordance with said priority.

5. A method of forwarding data packets between a plurality of switch ports, said method comprising:

receiving a data packet at one of said switch ports;

corresponding flow identification information in said data packet with stored flow processing information, said flow identification information including source and destination addresses, source and destination sockets, and a protocol, said stored flow processing information including a destination port, a filter tag and a broadcast enable, said corresponding including:

locating an address resolution hash record in an address resolution hash table according to a portion of said flow identification information, said address resolution hash record storing a link to an address resolution record;

locating said address resolution record in an address resolution record table in accordance with said address resolution hash record, said address resolution record storing said destination port and a link to a protocol entry;

locating said protocol entry in a protocol entry table in accordance with said address resolution record and said protocol, said protocol entry storing a link to said filter tag and a link to a network entry;

locating said network entry in a network entry table according to said protocol entry, said network entry storing said broadcast enable; and

locating said filter tag in a list of filter tags in accordance with said protocol entry; and

forwarding said data packet in accordance with said stored flow processing information.

6. A method according to claim 5, wherein said stored flow processing information further includes a priority, said protocol entry further storing said priority.

7. A method according to claim 5, further comprising alerting a CPU if no stored flow processing information corresponds to said flow identification information of said data packet.

8. A method of forwarding data packets between a plurality of switch ports, said method comprising:

receiving a data packet at one of said switch ports;

corresponding flow identification information in said data packet with stored flow processing information, said flow identification information including source and destination addresses, source and destination sockets, and a protocol, said stored flow processing information including a destination port, a filter tag and a broadcast enable, said corresponding including:

locating an address resolution hash record in an address resolution hash table according to a portion of said flow identification information, said address resolution hash record storing a link to an address resolution record;

locating said address resolution record in an address resolution record table in accordance with said address resolution hash record, said address resolution record storing said destination port and a link to a protocol entry;

locating said protocol entry in a protocol entry table in accordance with said address resolution record and said protocol, said protocol entry storing a link to said filter tag and a link to a network entry;

locating said network entry in a network entry table according to said protocol entry, said network entry storing said broadcast enable; and

locating said filter tag in a list of filter tags in accordance with said protocol entry; and forwarding said data packet in accordance with said stored flow processing information, wherein said stored flow processing information further includes a mirror tag, said protocol entry further storing a link to said mirror tag, said method further comprising locating said mirror tag in a list of mirror tags in accordance with said protocol entry.

9. A method of forwarding data packets between a plurality of switch ports, said method comprising:

- receiving a data packet at one of said switch ports;
- corresponding flow identification information in said data packet with stored flow processing information, said flow identification information including source and destination addresses, source and destination sockets, and a protocol, said stored flow processing information including a destination port, a filter tag and a broadcast enable, said corresponding including:
- locating an address resolution hash record in an address resolution hash table according to a portion of said flow identification information, said address resolution hash record storing a link to an address resolution record;
- locating said address resolution record in an address resolution record table in accordance with said address resolution hash record, said address resolution record storing said destination port and a link to a protocol entry;
- locating said protocol entry in a protocol entry table in accordance with said address resolution record and said protocol, said protocol entry storing a link to said filter tag and a link to a network entry;
- locating said network entry in a network entry table according to said protocol entry, said network entry storing said broadcast enable; and
- locating said filter tag in a list of filter tags in accordance with said protocol entry; and
- forwarding said data packet in accordance with said stored flow processing information, wherein said stored flow processing information further includes address swapping bits, said network entry further storing said address swapping bits.

10. A method of forwarding data packets between a plurality of switch ports, said method comprising:

- receiving a data packet at one of said switch ports;
- corresponding flow identification information in said data packet with stored flow processing information, said flow identification information including source and destination addresses, source and destination sockets, and a protocol, said stored flow processing information including a destination port, a filter tag and a broadcast enable, said corresponding including:
- locating an address resolution hash record in an address resolution hash table according to a portion of said flow identification information, said address resolution hash record storing a link to an address resolution record;
- locating said address resolution record in an address resolution record table in accordance with said address resolution hash record, said address resolution record storing said destination port and a link to a protocol entry;
- locating said protocol entry in a protocol entry table in accordance with said address resolution record and said protocol, said protocol entry storing a link to said filter tag and a link to a network entry;

locating said network entry in a network entry table according to said protocol entry, said network entry storing said broadcast enable; and

locating said filter tag in a list of filter tags in accordance with said protocol entry; and

forwarding said data packet in accordance with said stored flow processing information,

wherein said forwarding step includes routing said data packet to another network by swapping said source and destination addresses of said data packet in accordance with said address swapping bits.

11. An apparatus for forwarding data packets in a switch having a plurality of ports, said ports being adapted to transmit and receive data packets from hosts coupled thereto, said apparatus comprising:

- means for receiving a first data packet at a first port;
- means for firstly extracting flow identification information from said first data packet, said flow identification information indicating that said first data packet belongs to a first flow between certain of said hosts;
- means for corresponding said flow identification information with stored configuration information;
- means for creating flow processing information based on said corresponding stored configuration information, said flow processing information comprising at least one of a filter, a mirror, and a priority, said flow processing information further indicating at least a second port, wherein all data packets belonging to said first flow are forwarded between said first and second ports, said first and second ports being associated with said certain hosts;
- means for storing a first record in a flow table containing said flow processing information;
- means for receiving a second data packet at one of said first and second ports;
- means for secondly extracting said flow identification information from said second data packet;
- means for locating said stored first record in said flow table based on said extracted flow identification information; and
- means for preparing to forward said second data packet to the other of said first and second ports based on said flow processing information contained in said stored first record,

wherein said means for firstly and secondly extracting said flow identification information each includes:

- means for determining a protocol associated with said first flow;
- means, operative if said protocol is IP or IPX, for extracting Layer 3 header information as said flow identification information; and
- means, operative if said protocol is not IP or IPX, for extracting Layer 2 header information as said flow identification information.

12. An apparatus as defined in claim 11, further comprising:

- means for preventing said second data packet from being forwarded to the other of said first and second ports in accordance with said filter.



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13. An apparatus as defined in claim 11, further comprising:

means for forwarding said second data packet to the other of said first and second ports; and

means for forwarding said second data packet on certain other of said ports in accordance with said mirror.

14. An apparatus as defined in claim 11, further comprising:

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means for forwarding said second data packet to the other of said first and second ports; and

means for prioritizing transmission of said second data packet to hosts associated with the other of said first and second ports in accordance with said priority.

\* \* \* \* \*



US006452915B1

(12) **United States Patent**  
**Jorgensen**

(10) **Patent No.:** US 6,452,915 B1  
(45) **Date of Patent:** Sep. 17, 2002

(54) **IP-FLOW CLASSIFICATION IN A WIRELESS POINT TO MULT-POINT (PTMP) TRANSMISSION SYSTEM**

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(\*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.<sup>7</sup>** ..... H04Q 7/24

(52) **U.S. Cl.** ..... 370/338; 370/328

(58) **Field of Search** ..... 370/338, 328, 370/329, 230, 229, 231, 465, 466, 468, 232, 235; 455/455, 575, 525, 422, 426, 430, 437, 440, 11.1, 456, 404

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*Primary Examiner*—Douglas Olms

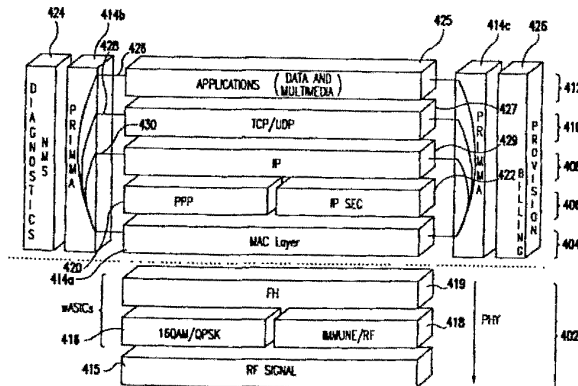
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(57) **ABSTRACT**

An IP flow classification system is used in a wireless telecommunications system. The IP flow classification system groups IP flows in a packet-centric wireless point to multi-point telecommunications system. The classification system includes: a wireless base station coupled to a first data network; one or more host workstations coupled to the first data network; one or more subscriber customer premise equipment (CPE) stations in wireless communication with the wireless base station over a shared bandwidth using a packet-centric protocol; and one or more subscriber workstations coupled to each of the subscriber CPE stations over a second network; a resource allocation device optimizes end-user quality of service (QoS) and allocates shared bandwidth among the subscriber CPE stations; an analyzing and scheduling device analyzes and schedules internet protocol (IP) flow over the shared wireless bandwidth. The analyzing device includes the above IP flow classifier that classifies the IP flow. The classifier can include a device for associating a packet of an existing IP flow with the IP flow. The classifier can include a QoS grouping device that groups a packet of a new IP flow into a QoS class grouping. The QoS grouping device can include a determining device that determines and takes into account QoS class groupings for the IP flow. The QoS grouping device can include an optional differentiated services (Diff Serv) device that takes into account an optional Diff Servs field priority marking for the IP flow.

**163 Claims, 41 Drawing Sheets**



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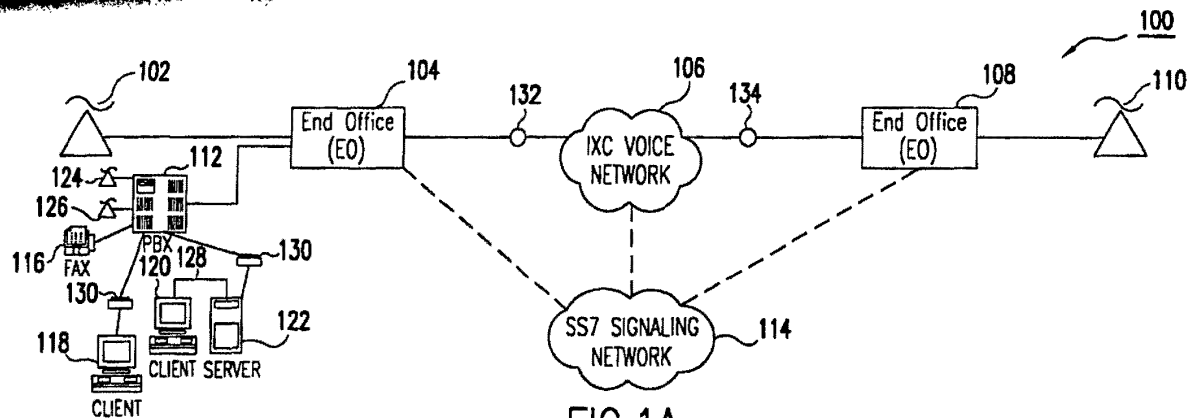


FIG. 1A

FIG. 1B

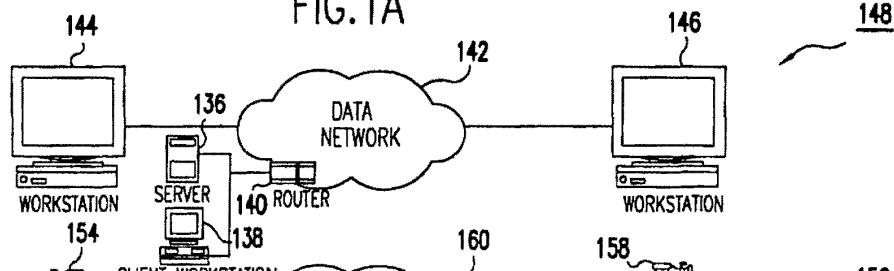
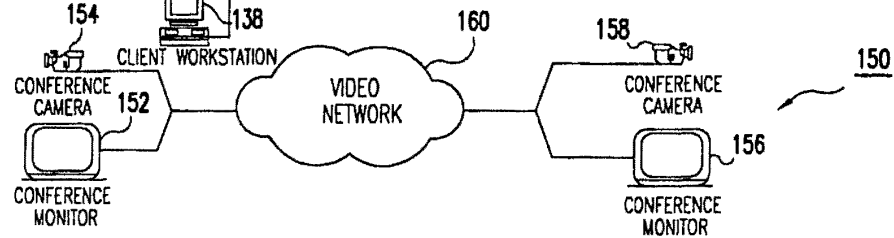


FIG. 1C



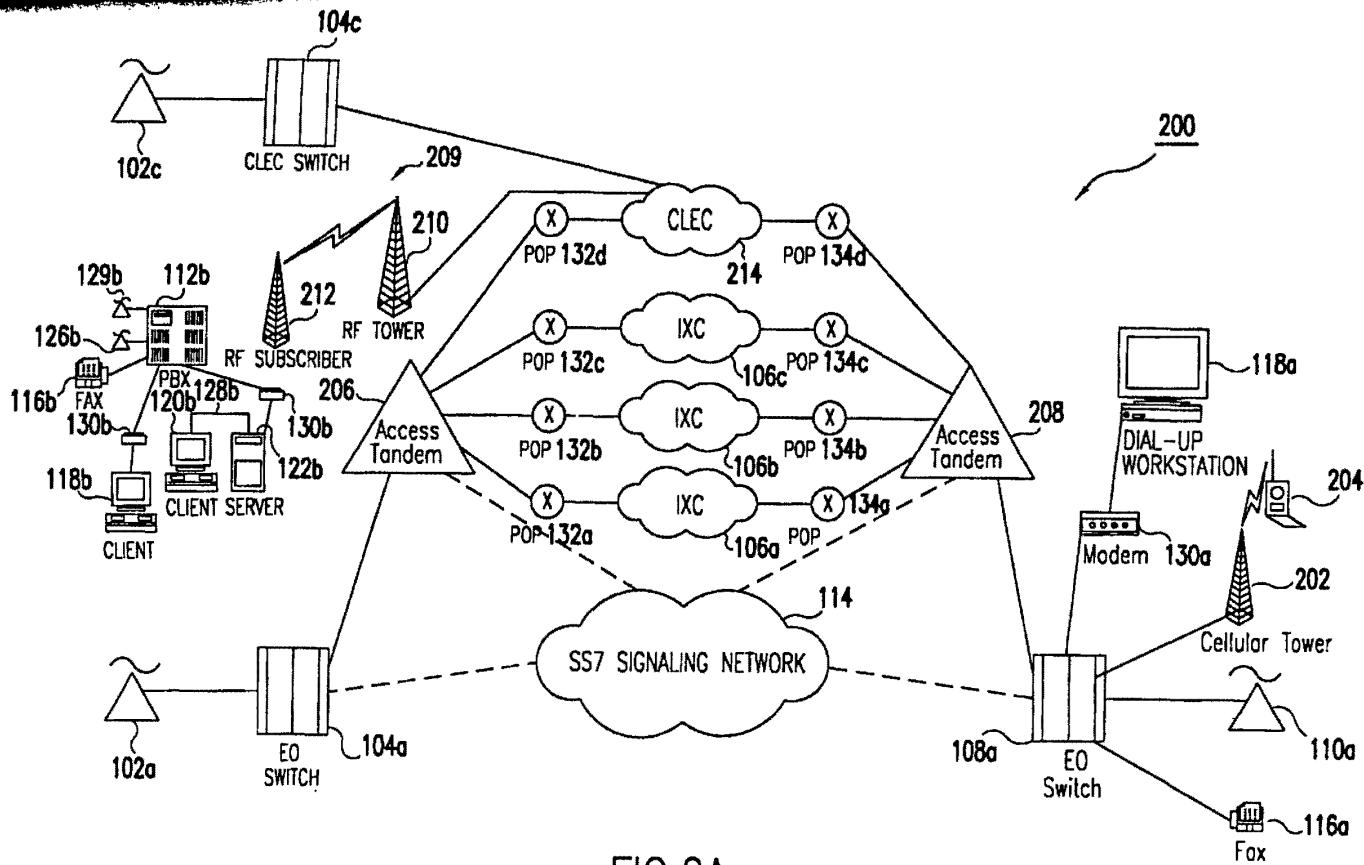


FIG.2A

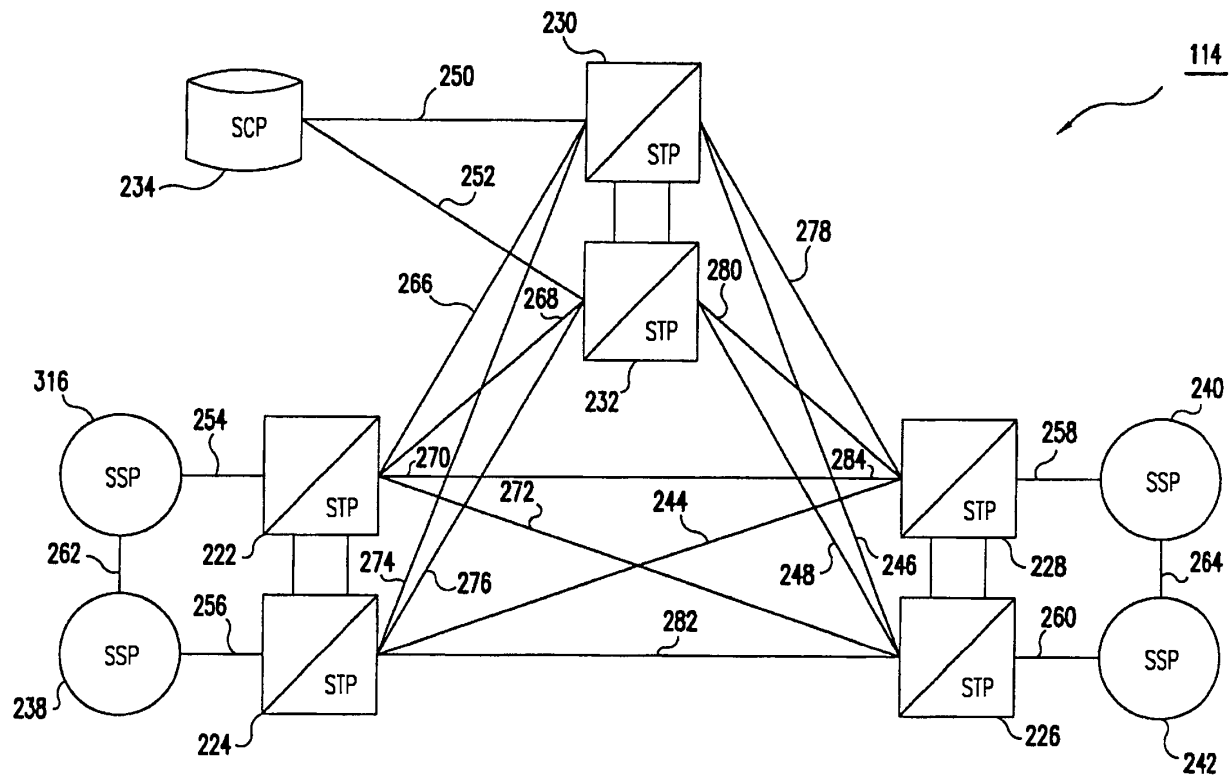


FIG.2B

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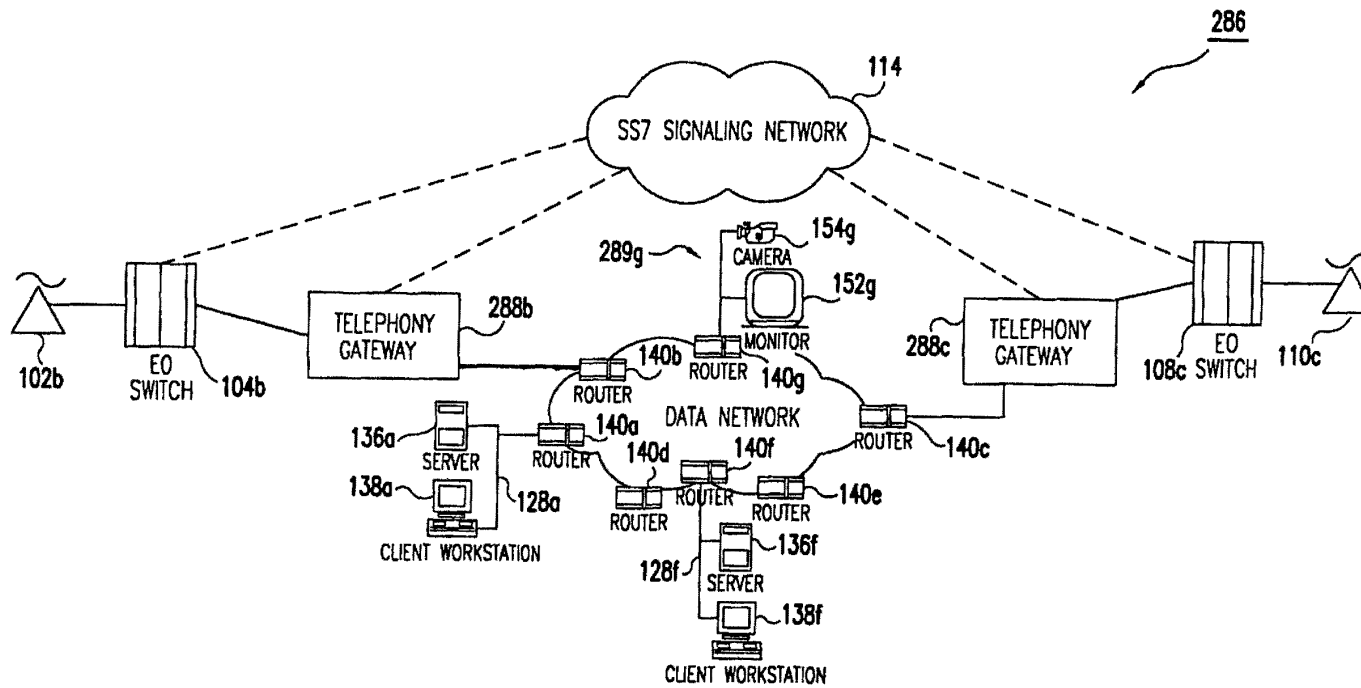


FIG.2C

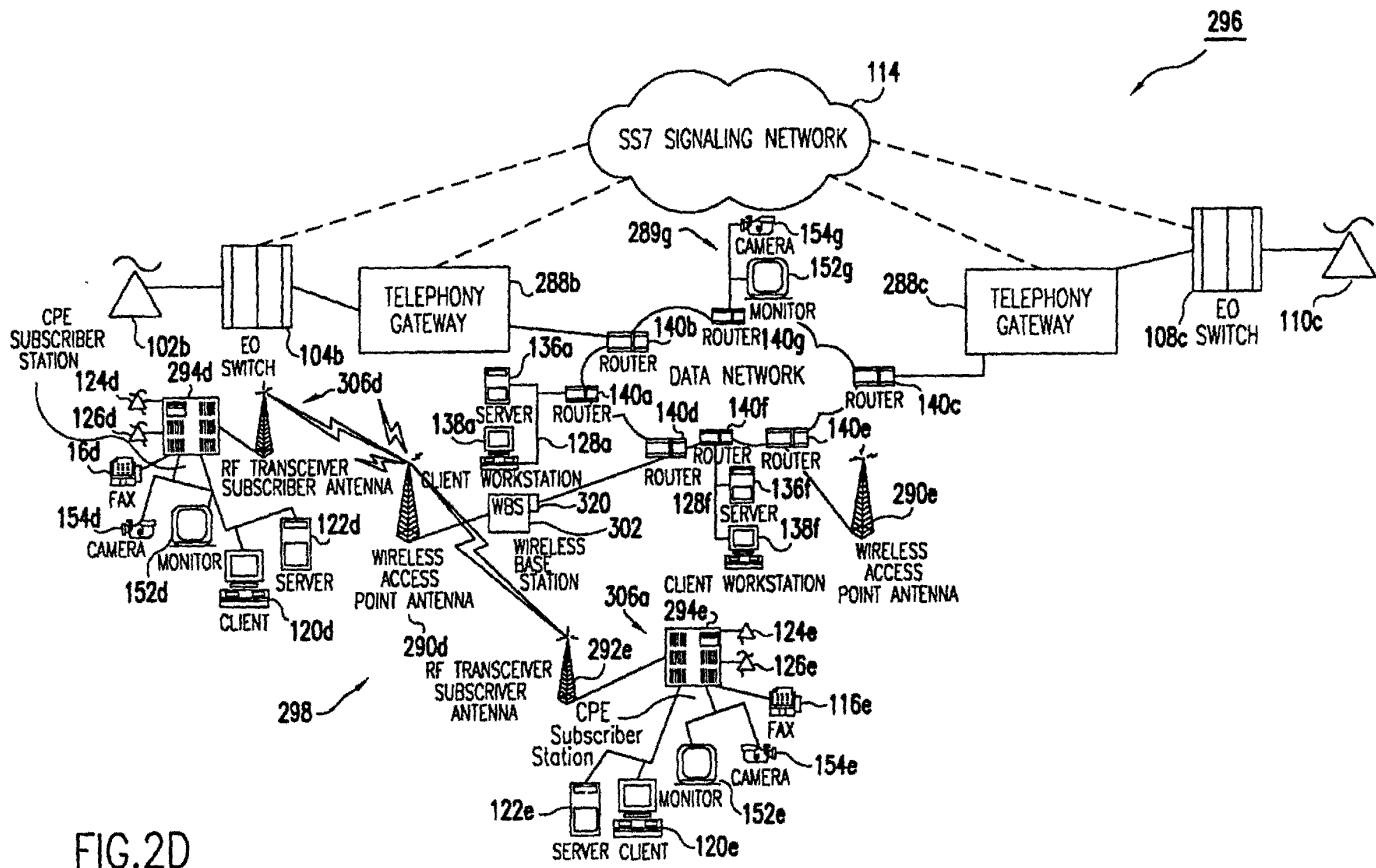
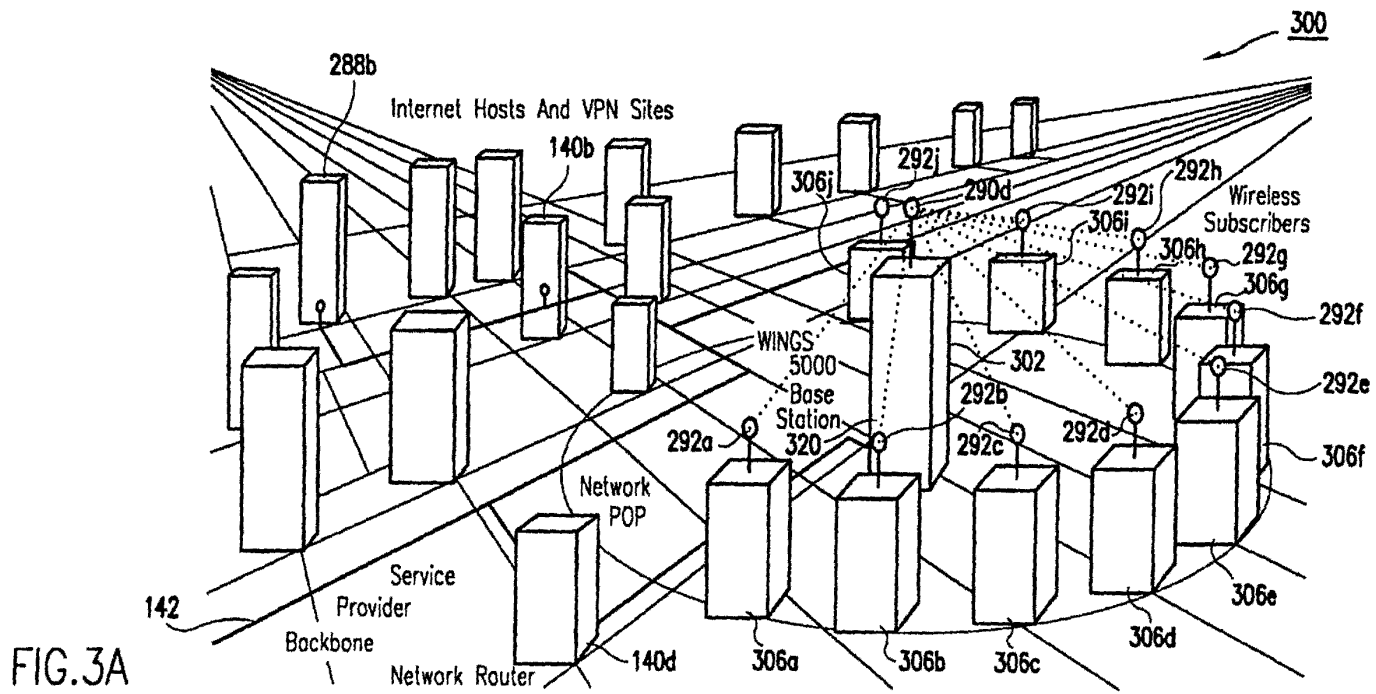
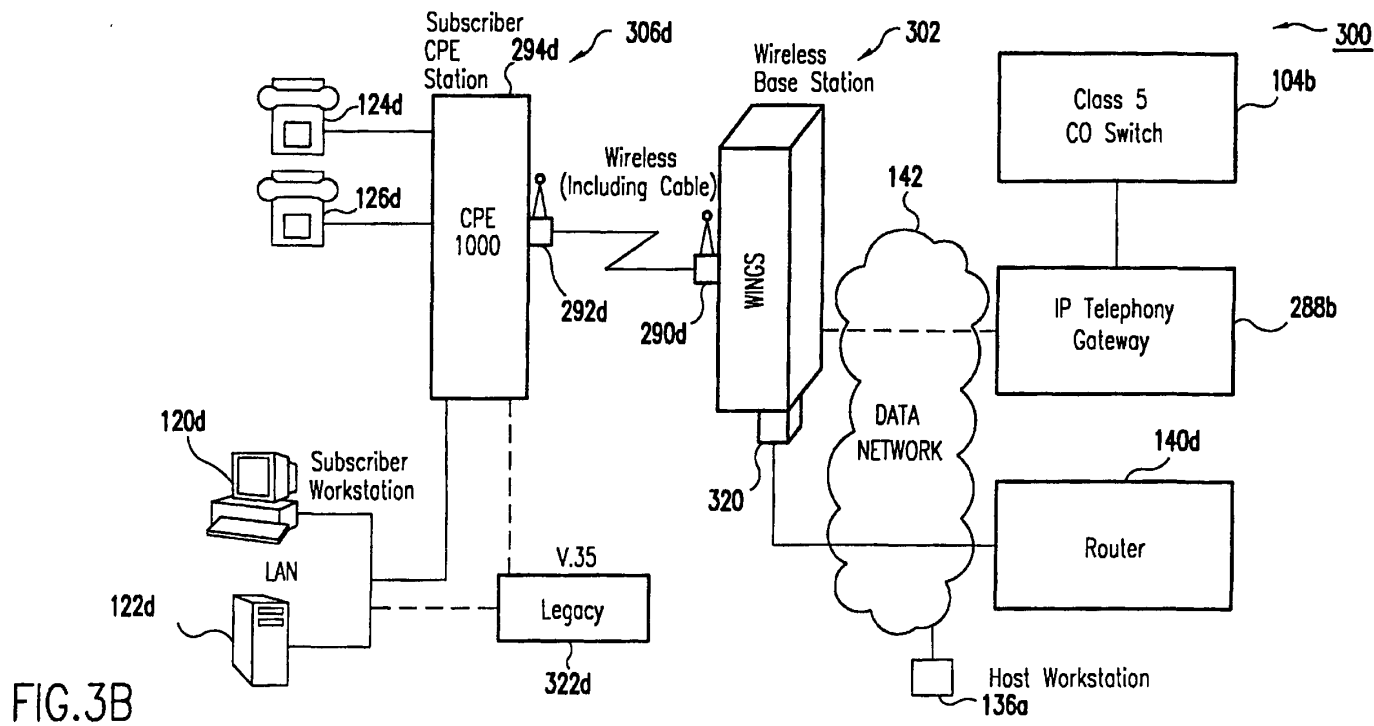


FIG. 2D







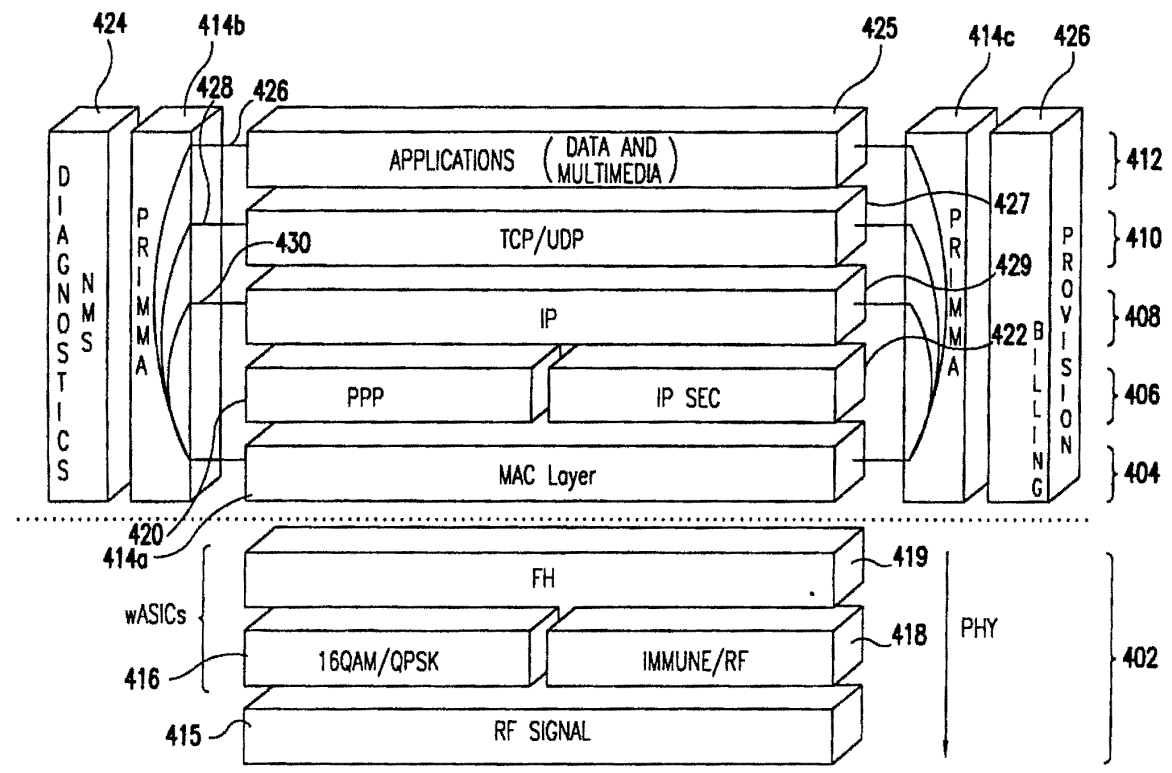
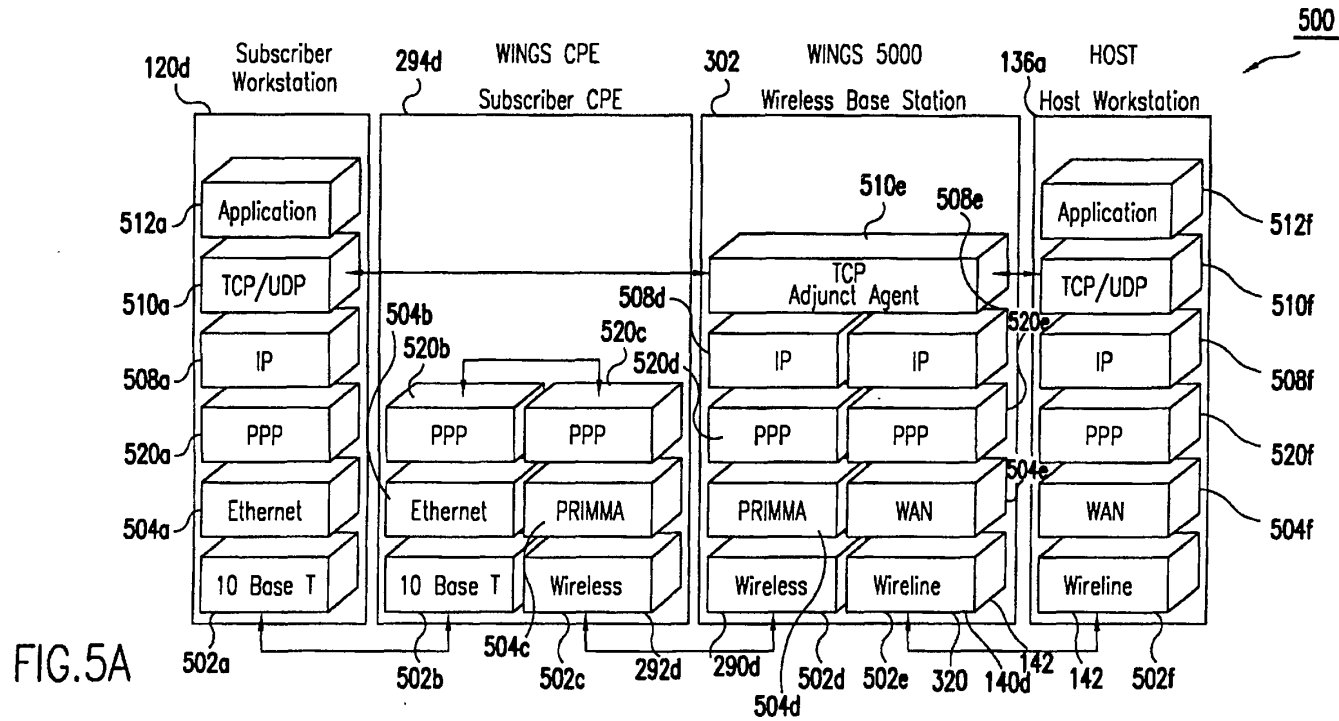


FIG. 4



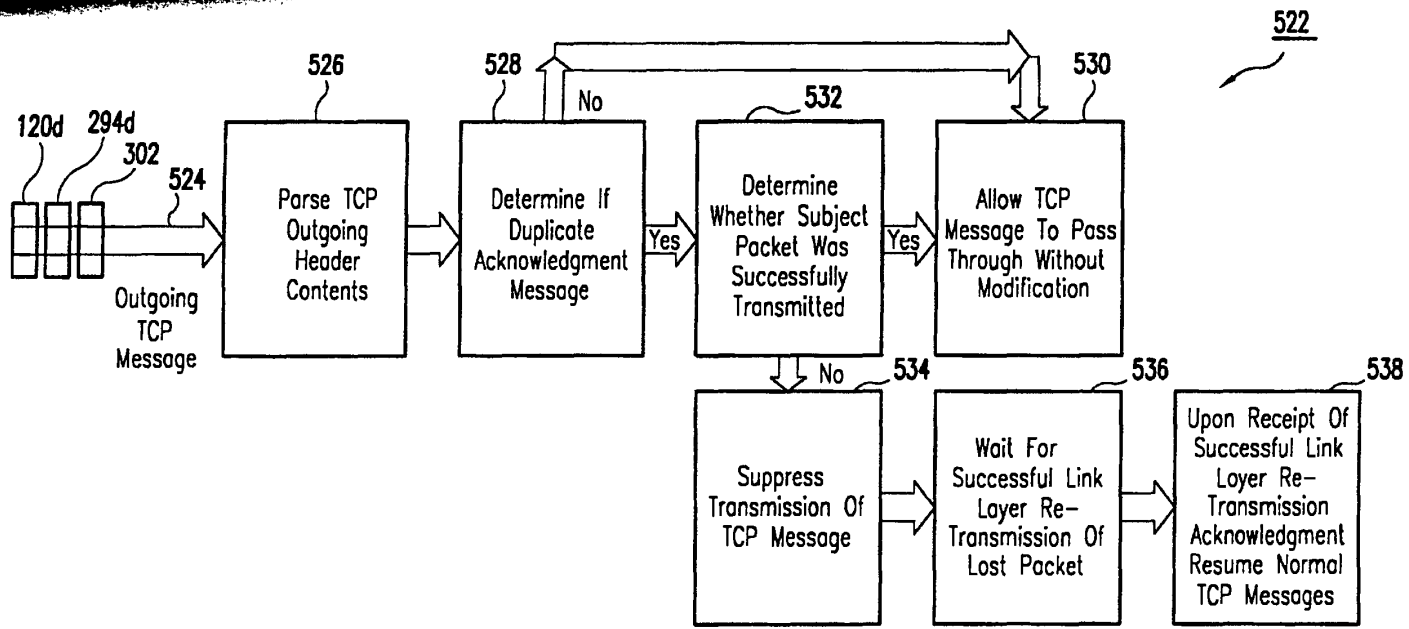


FIG.5B

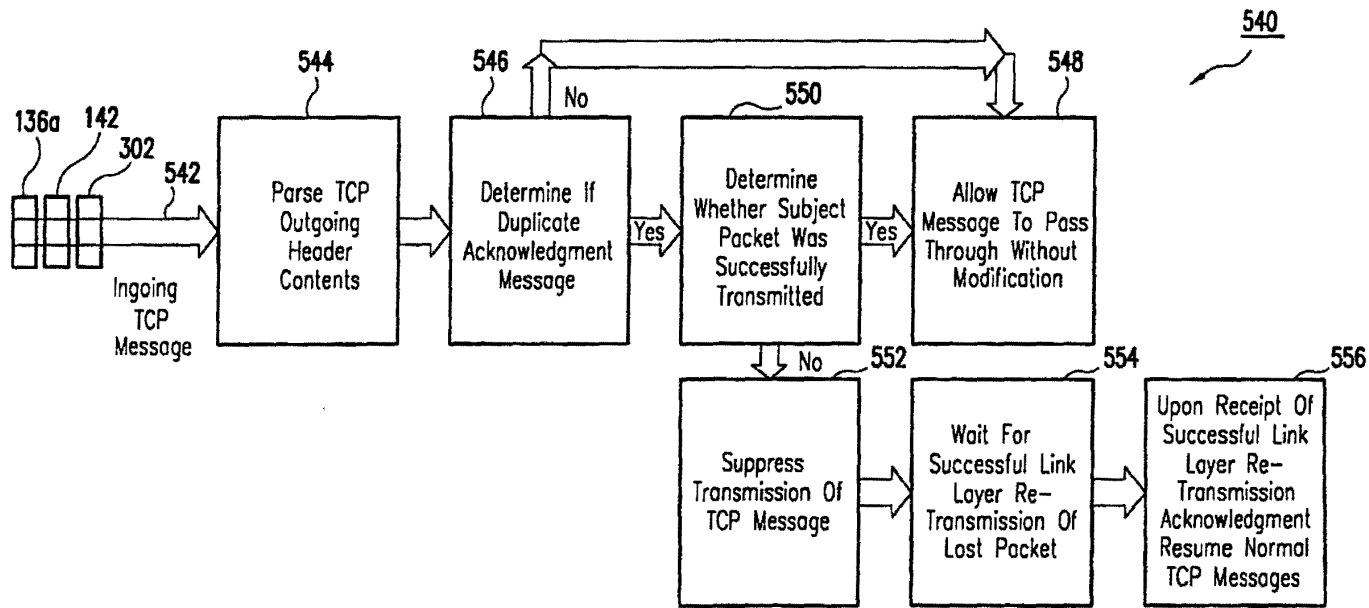
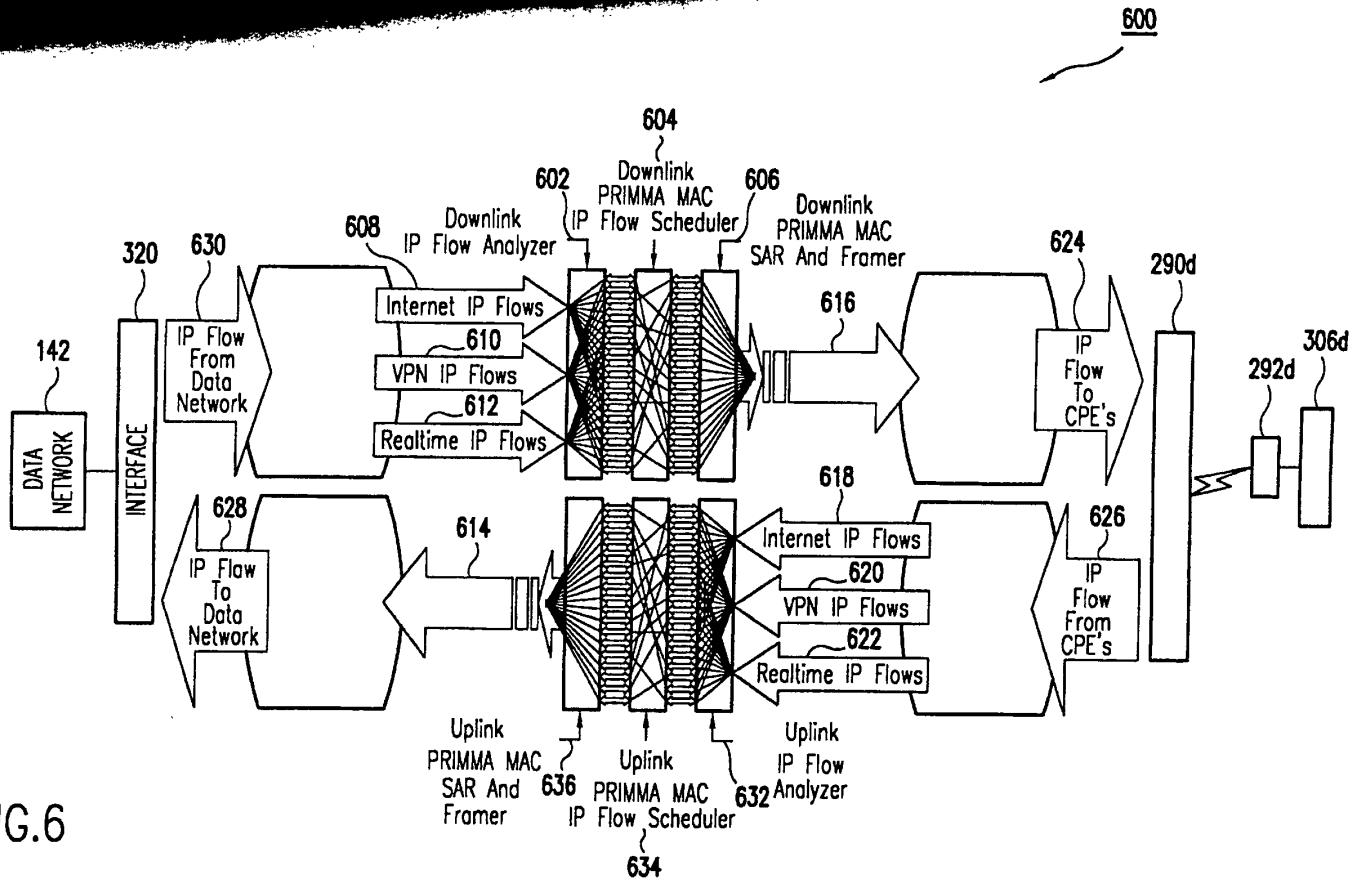


FIG.5C

FIG.6



700

- IP Header Fields: 702
  - Source And Destination IP Addresses
  - IP TOS (Type Of Service)
  - IP TTL (Time To Live)
  - Protocol
- UDP Header Fields: 704
  - Source And Destination Port Numbers
- TCP Header Fields: 706
  - Source And Destination Port Numbers
  - Window Size
  - Urgent Pointer
  - Flags (SYN, ISN, PSH, RST, FIN)
  - MSS (Maximum Segment Size)
- RTP, RTCP Header Fields: 708

FIG. 7



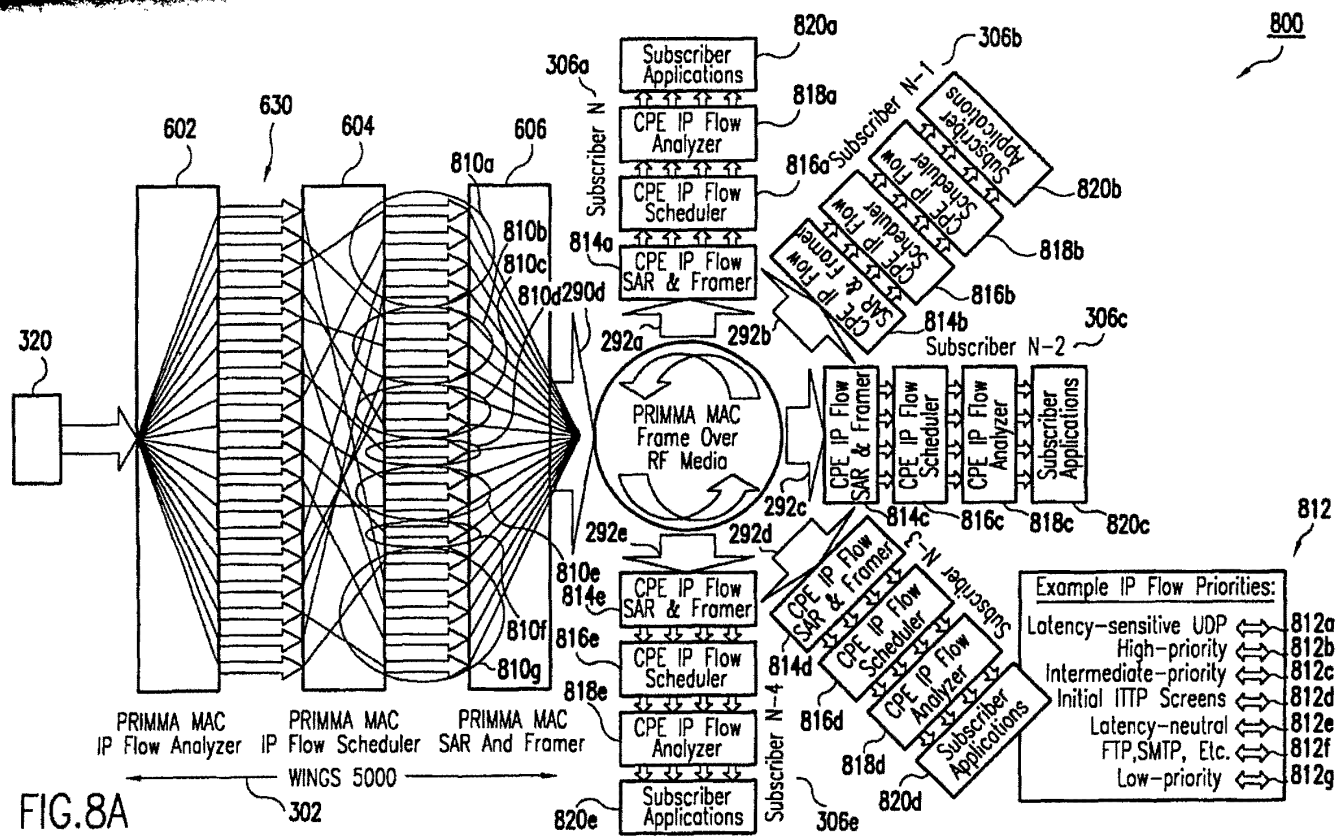


FIG. 8A

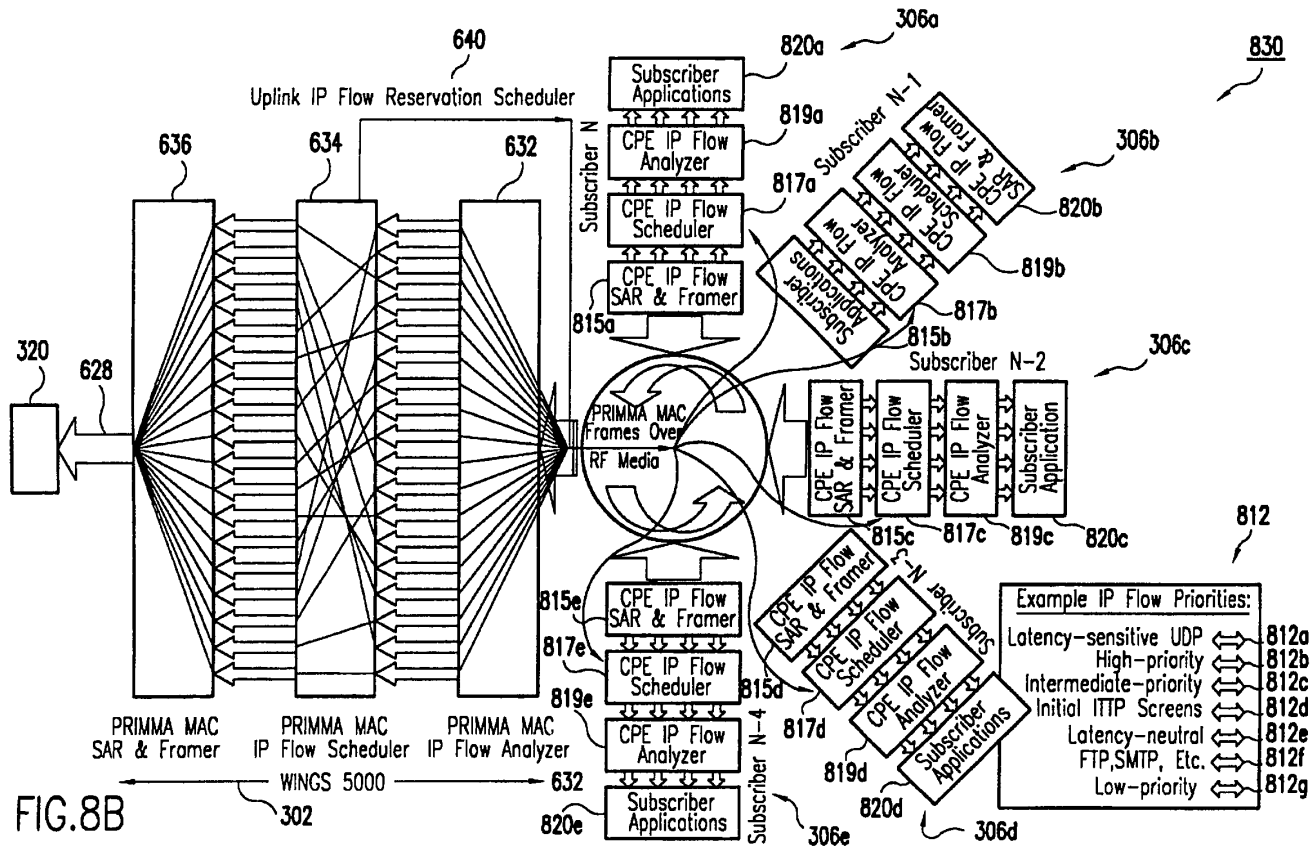


FIG.8B

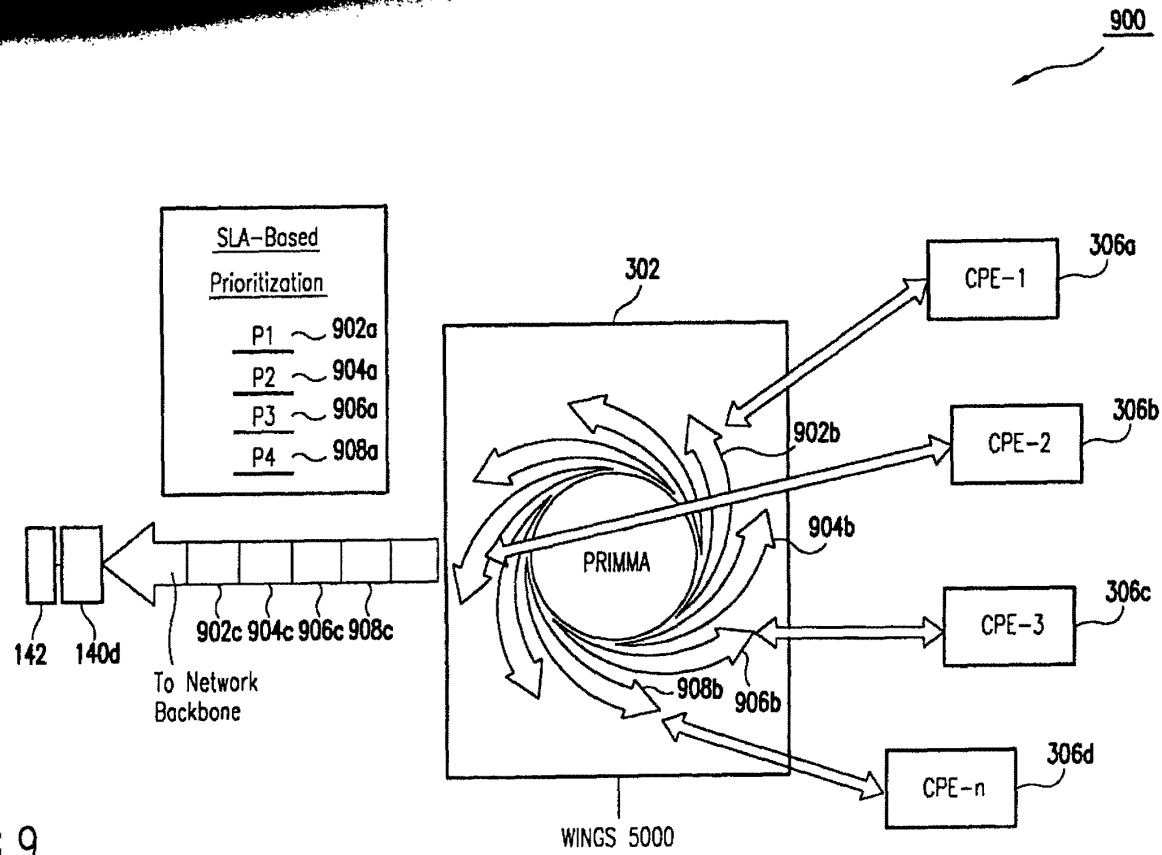


FIG. 9

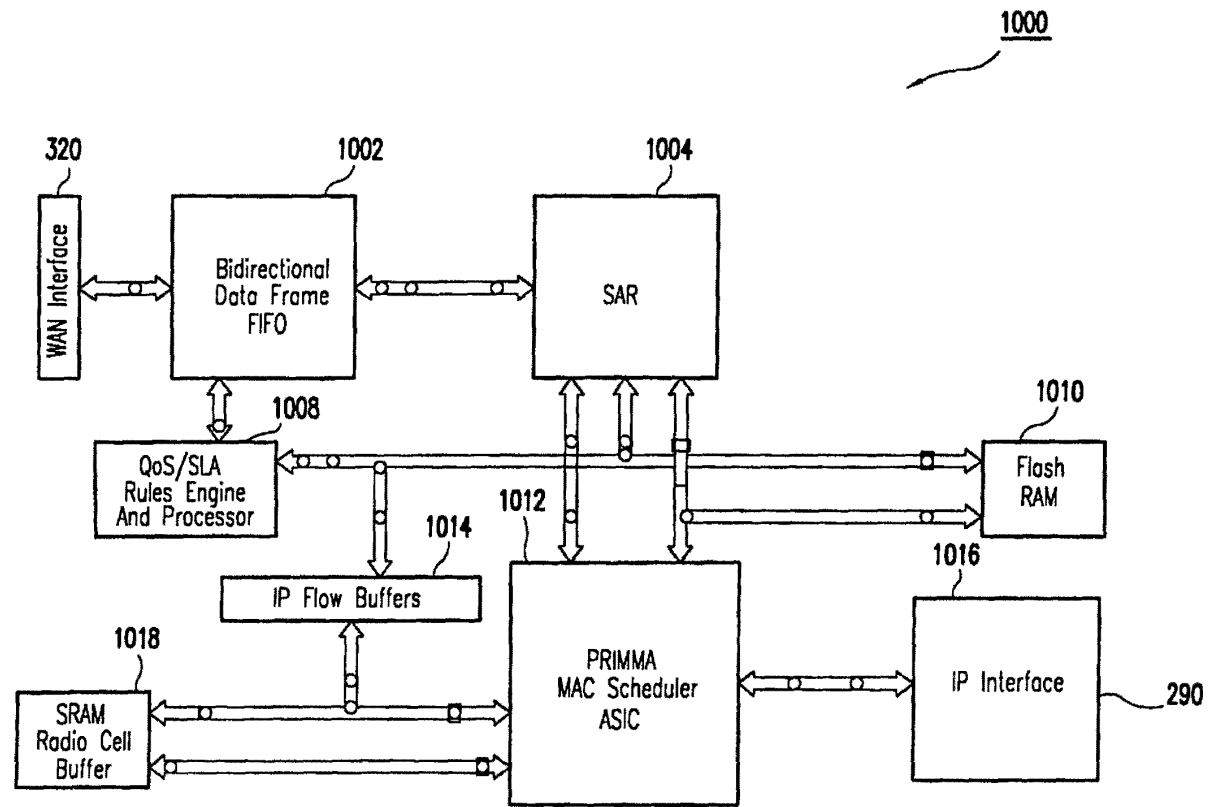


FIG.10

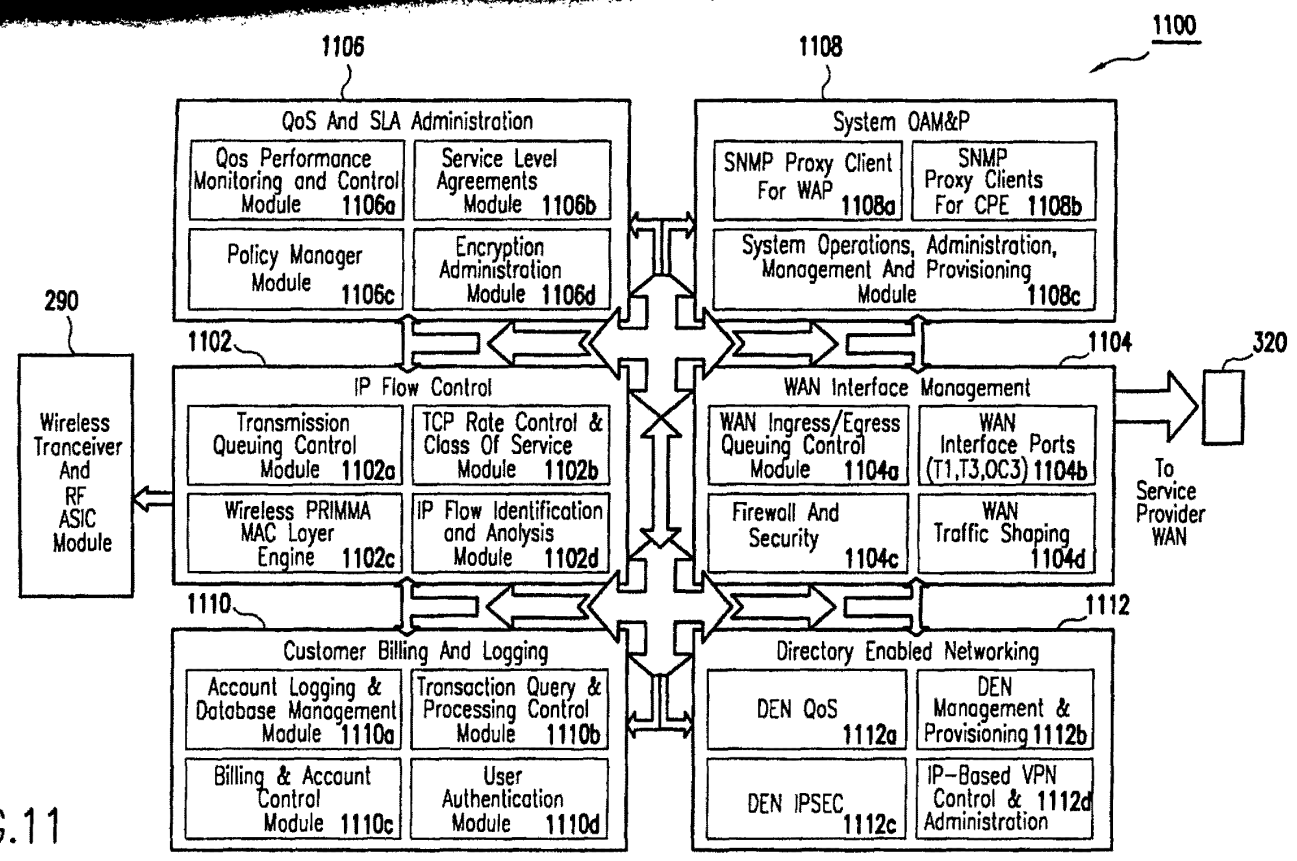


FIG.11

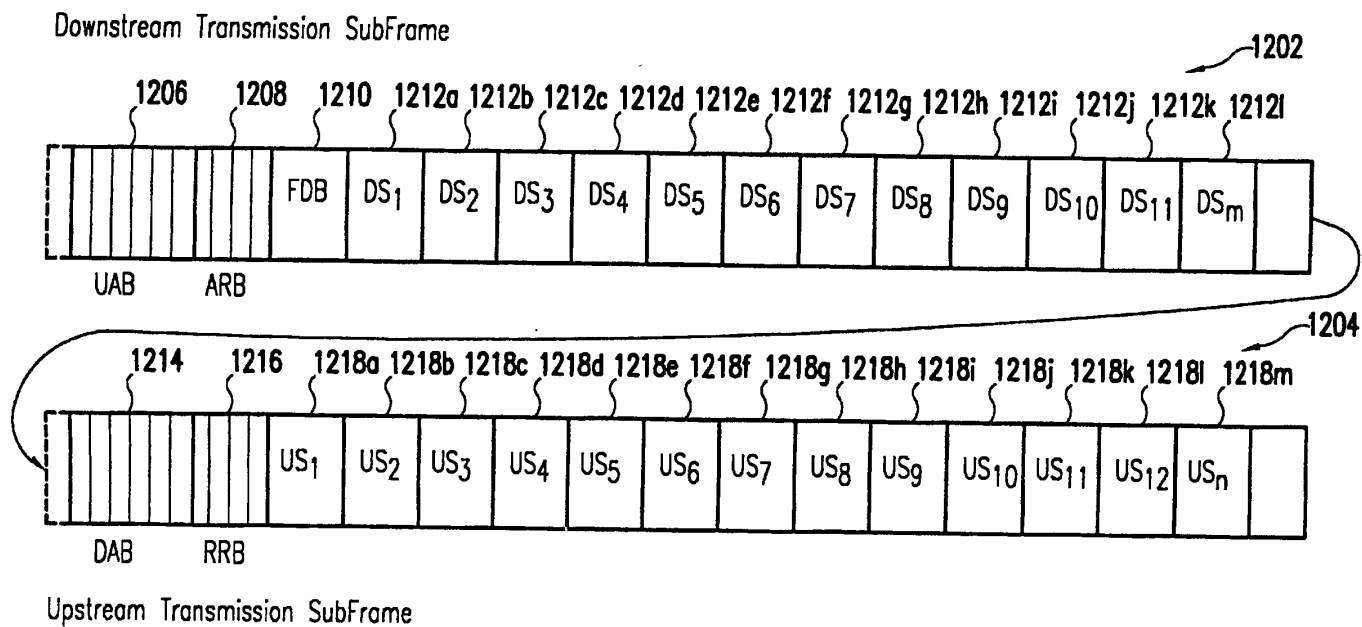


FIG.12A

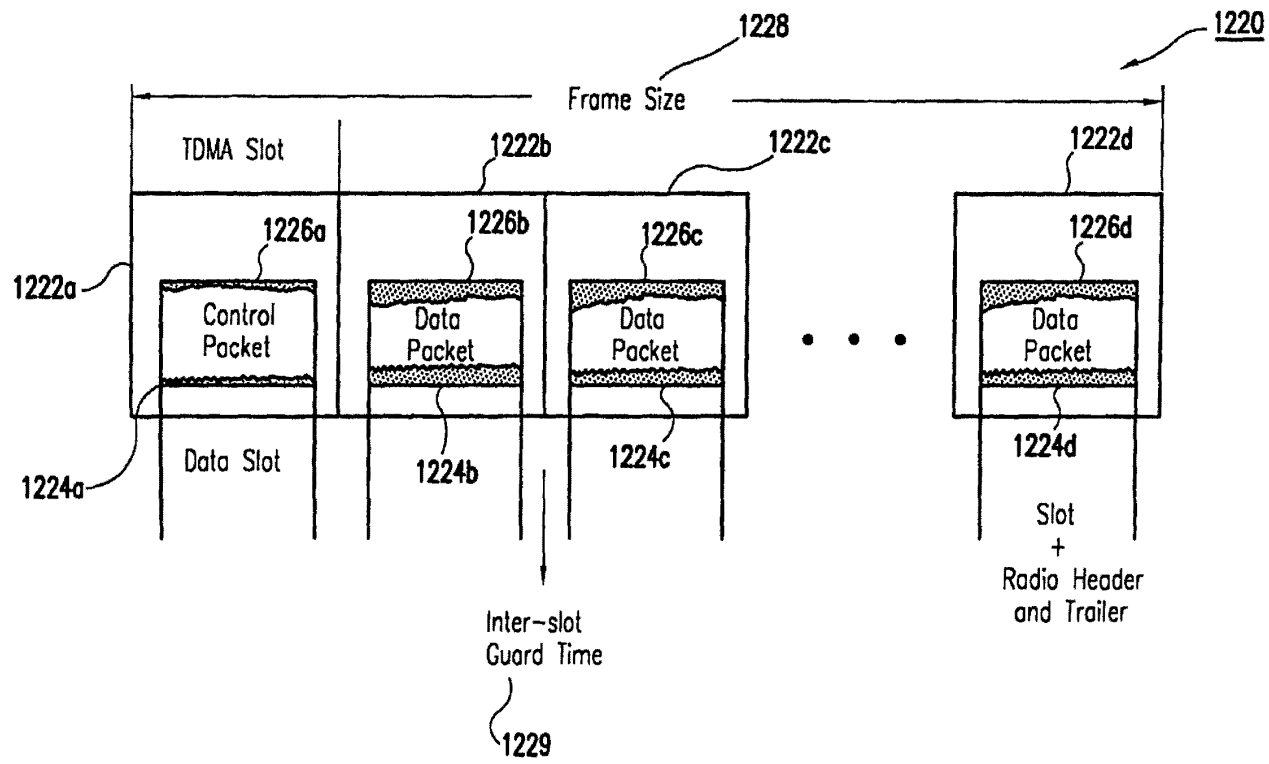


FIG.12B

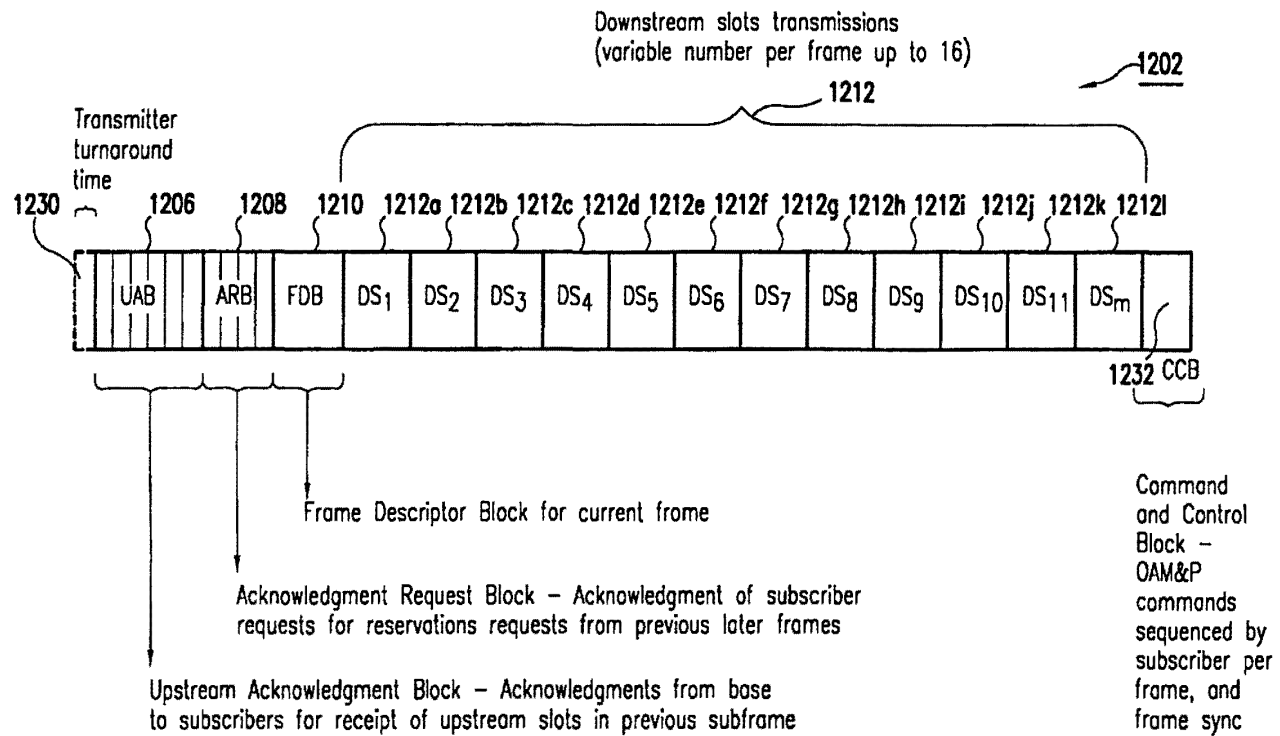


FIG.12C



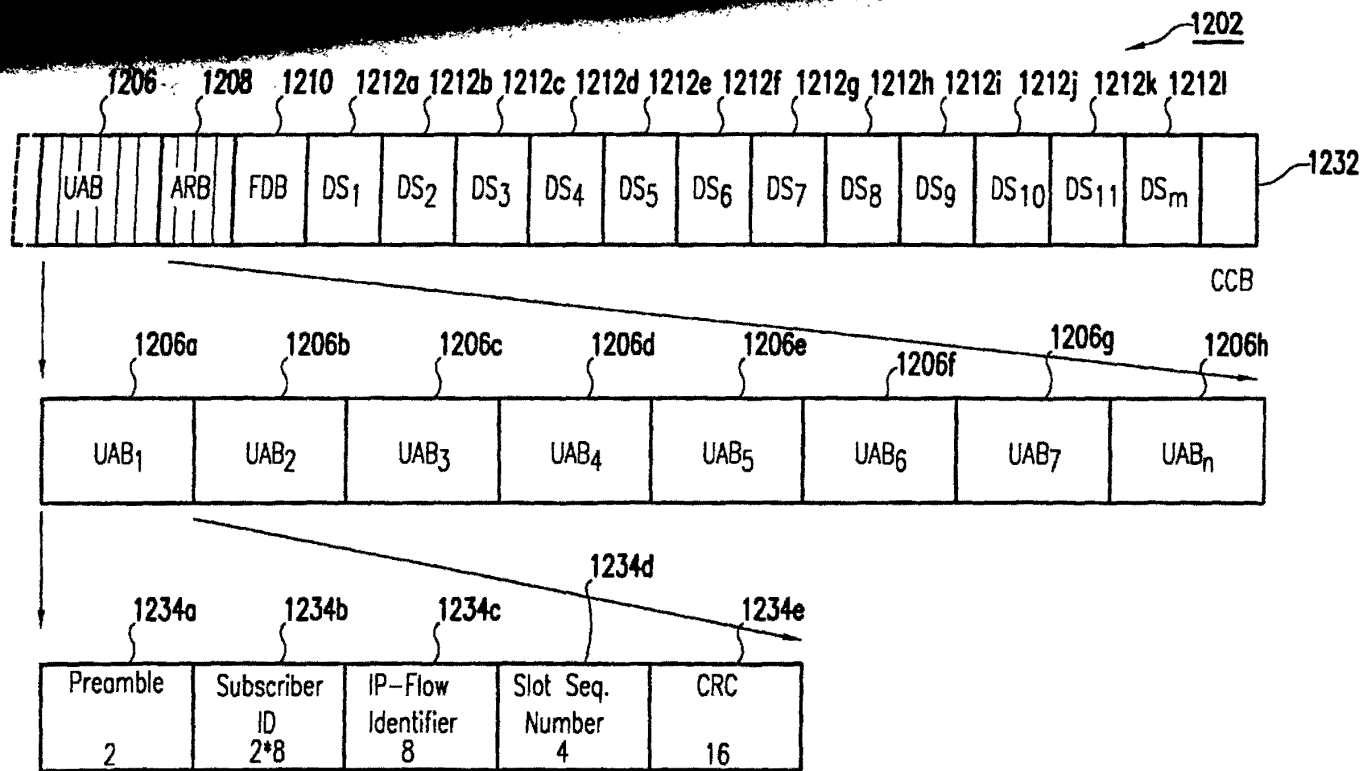


FIG. 12D

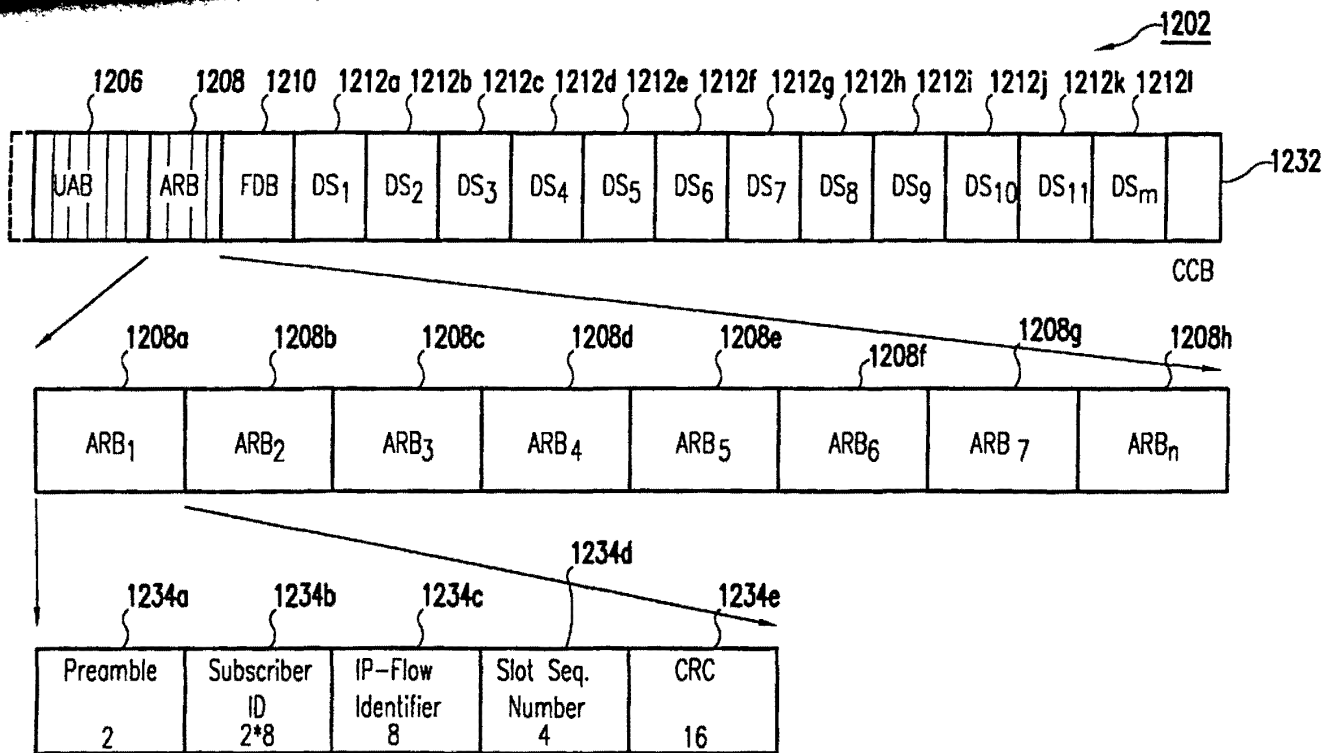


FIG. 12E

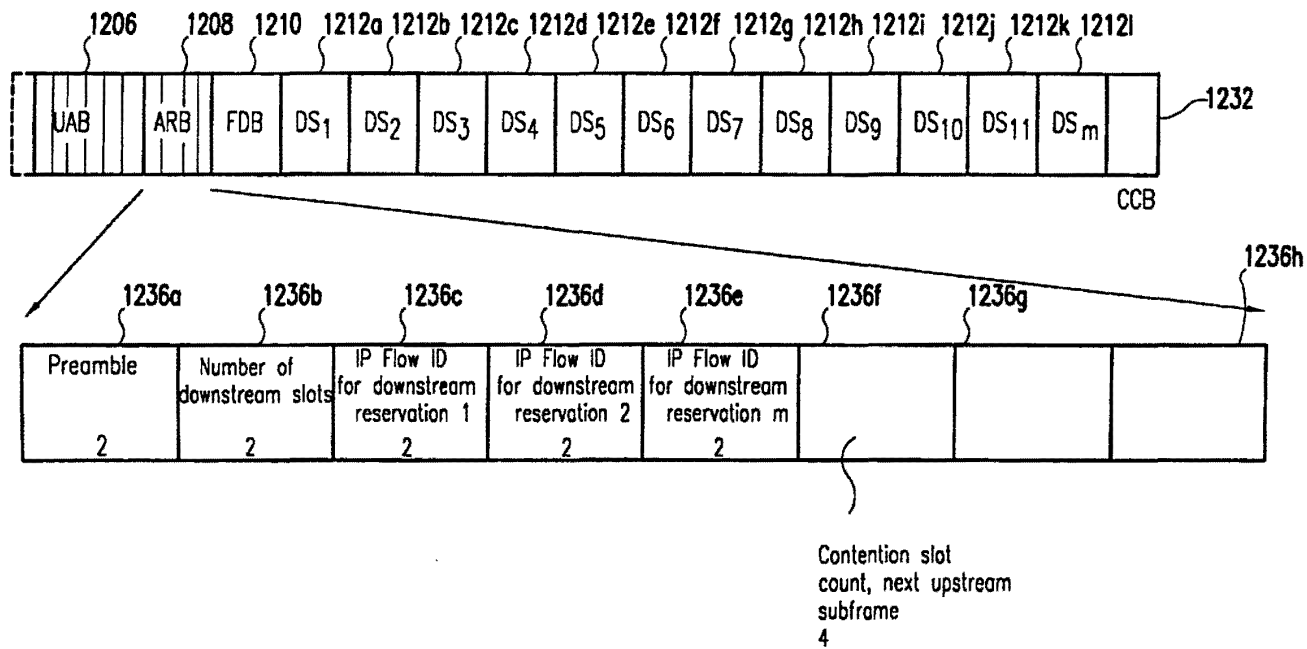


FIG. 12F

MAC linked-list sequence number 4	Reservation request index number 8	Compressed IP-Flow Identifier 8		Compressed IP-Flow Priority and Type 4	Slot Payload 512*8	CRC 16
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FIG.12G

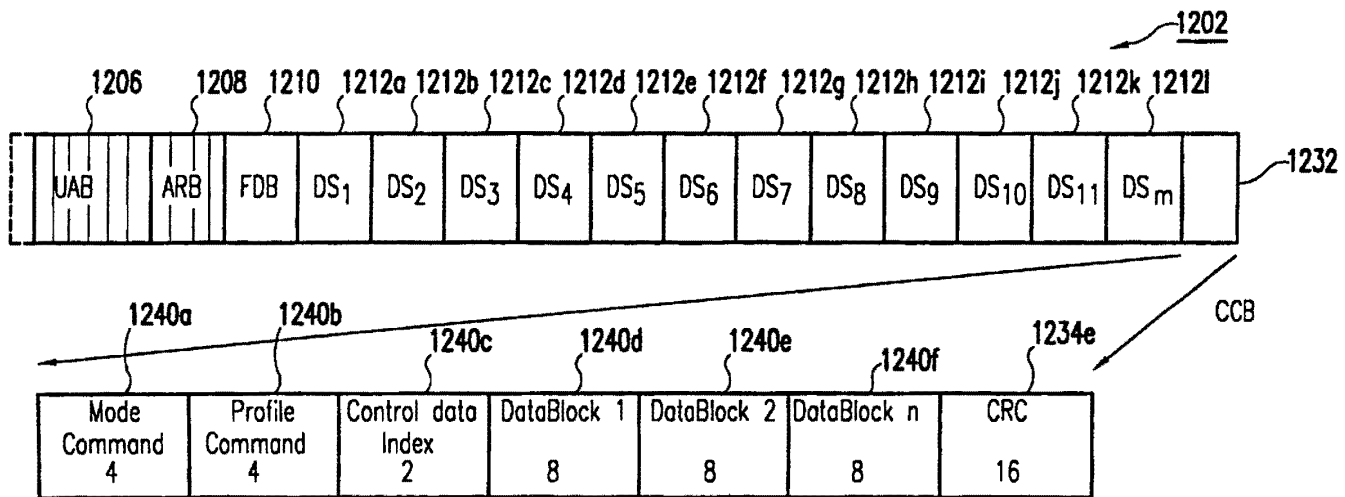


FIG.12H

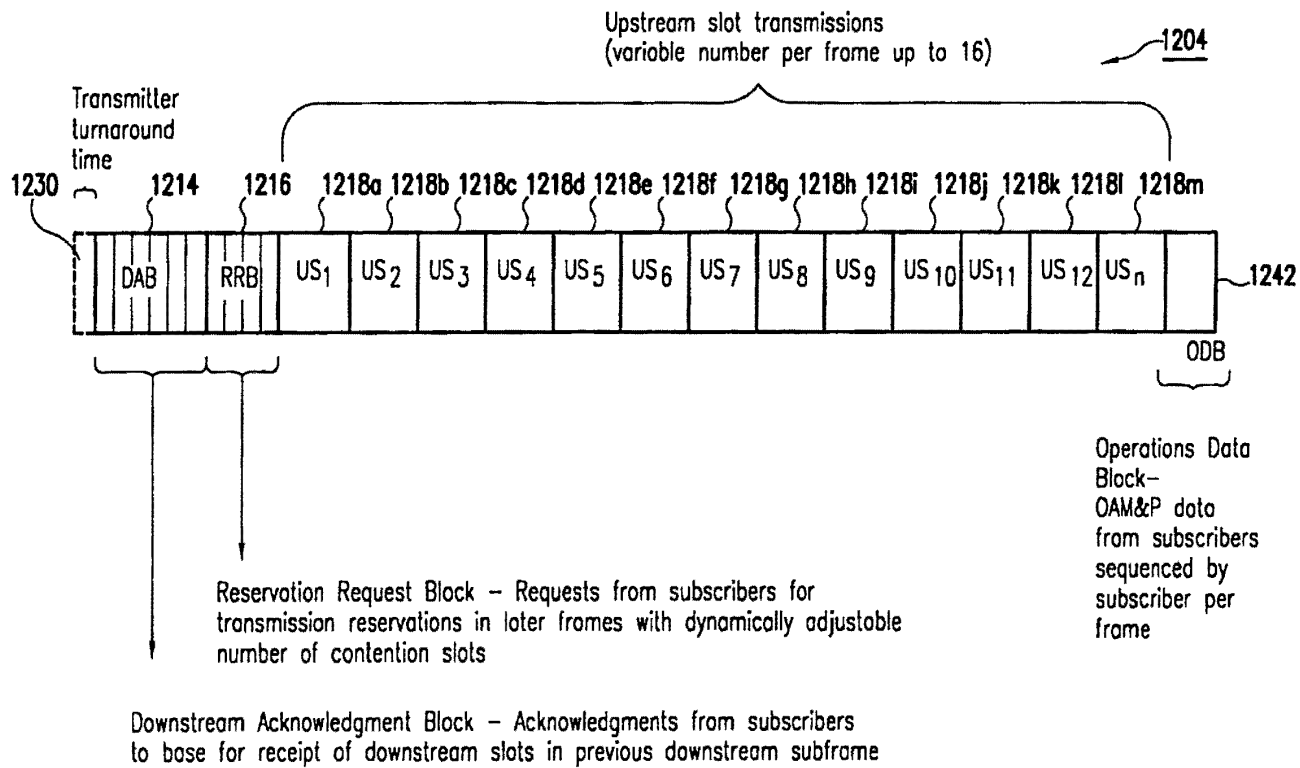
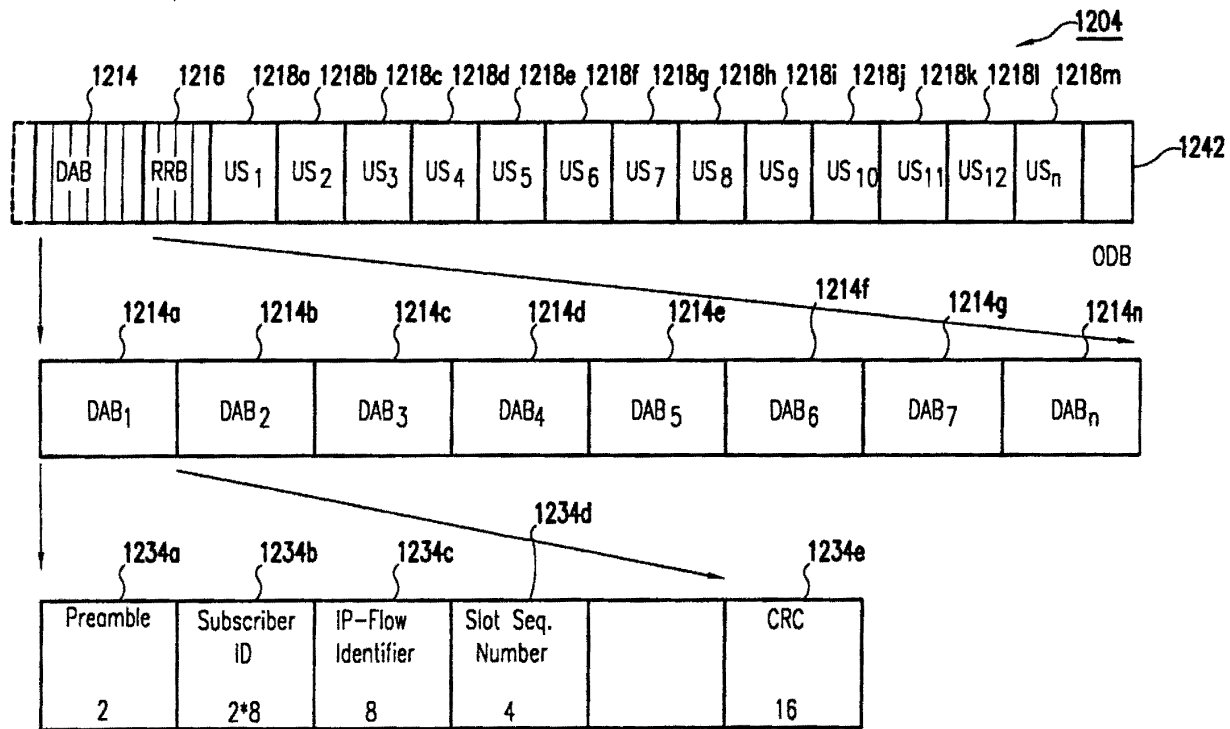
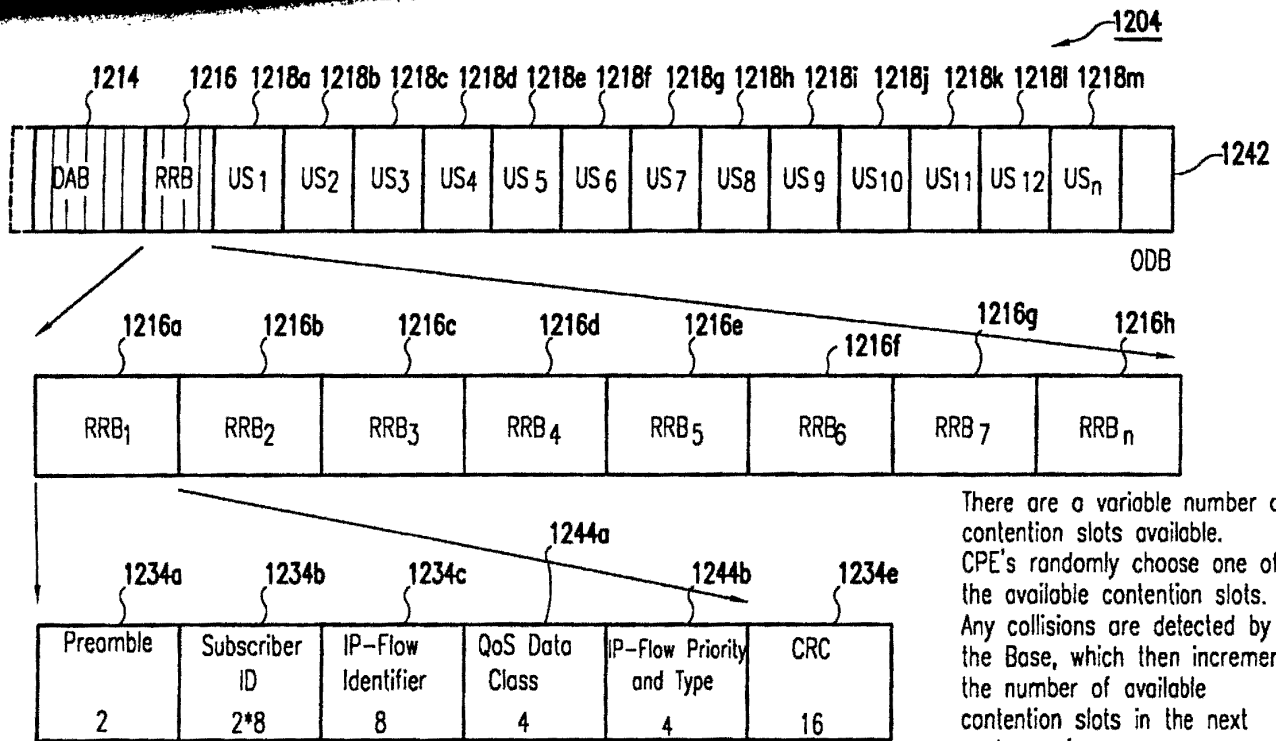


FIG. 12I



CPE Acknowledging Receipt of Slot Transmitted from Base

FIG.12J



CPE Requesting a Reservation for Upstream Transmission of Slot

FIG.12K

There are a variable number of contention slots available. CPE's randomly choose one of the available contention slots. Any collisions are detected by the Base, which then increments the number of available contention slots in the next upstream frame.



1246	1238b	1238c		1238d	1238e	1234e
CPE linked-list sequence number	Reservation request index number	Compressed IP-Flow Identifier		Compressed IP-Flow Priority and Type	Slot Payload	CRC
4	8	8		4	512*8	16

FIG.12L

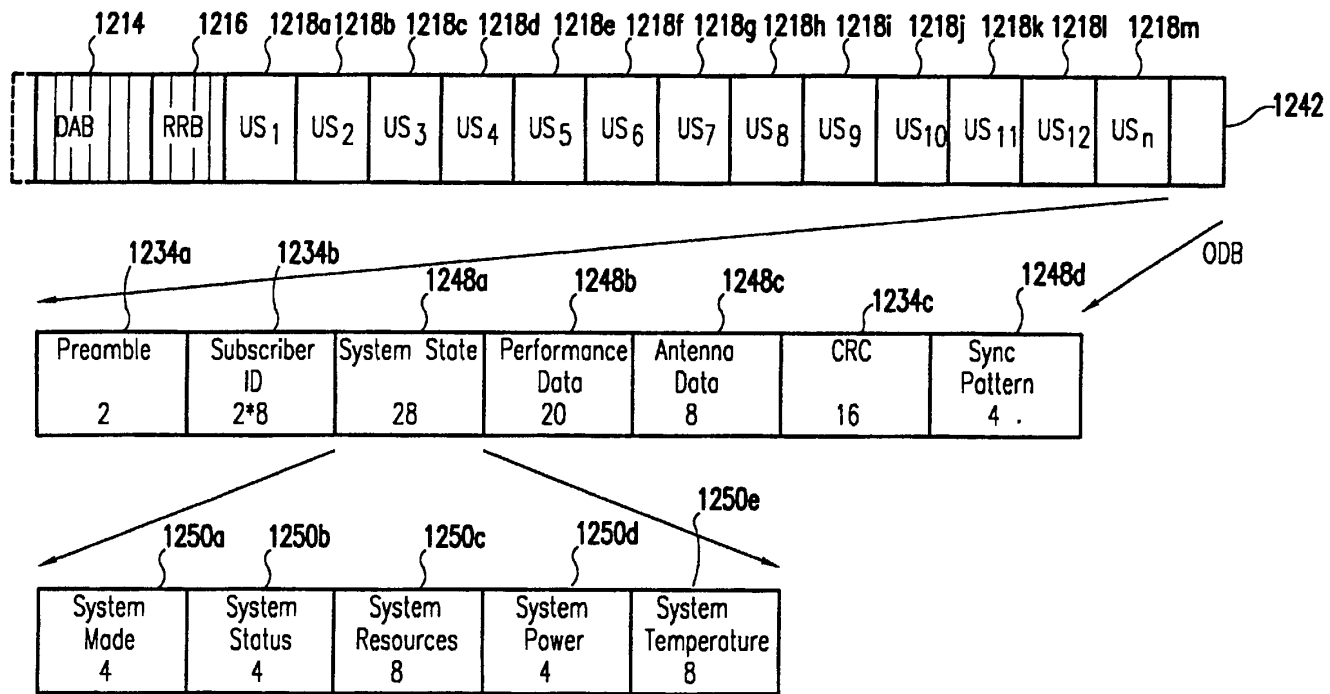


FIG.12M

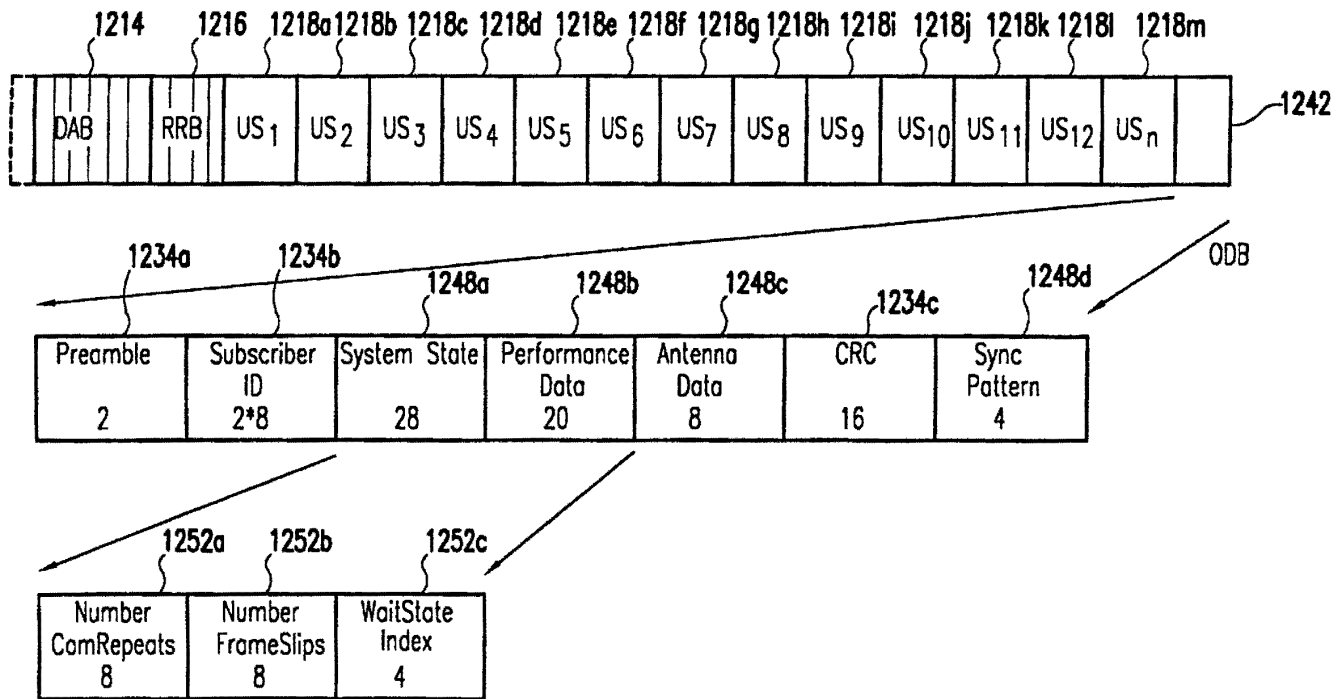


FIG.12N

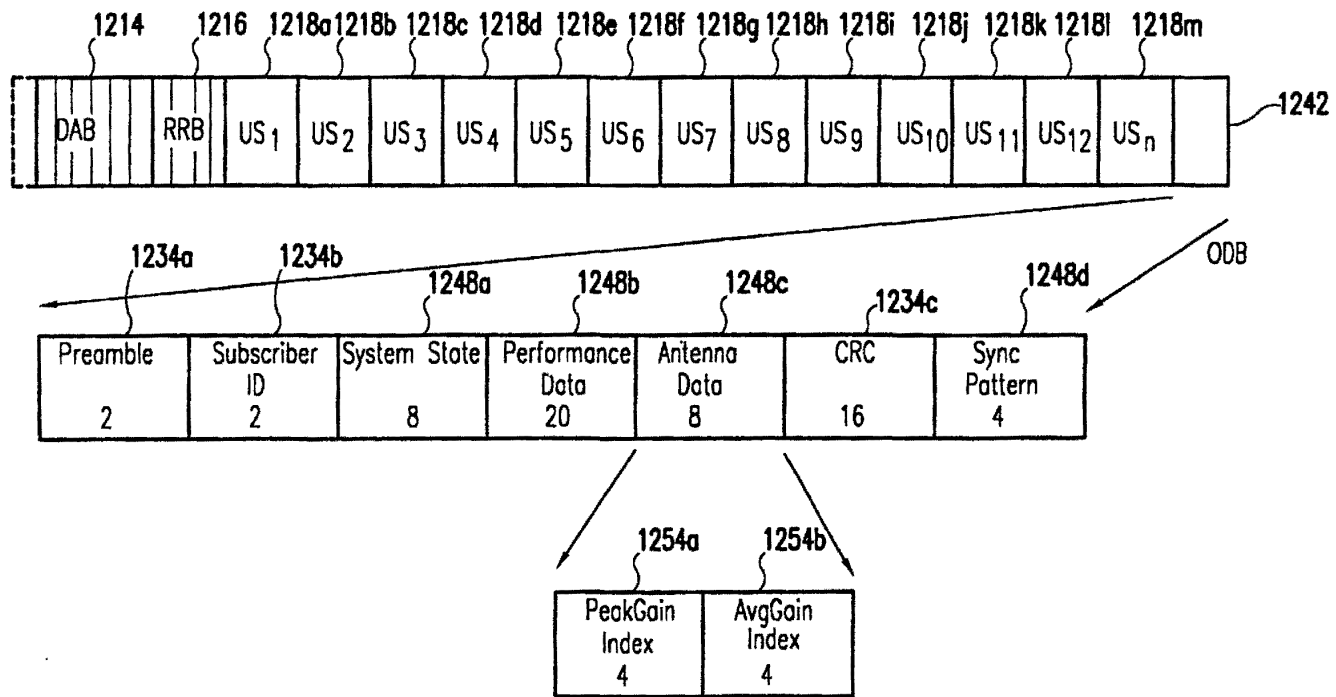
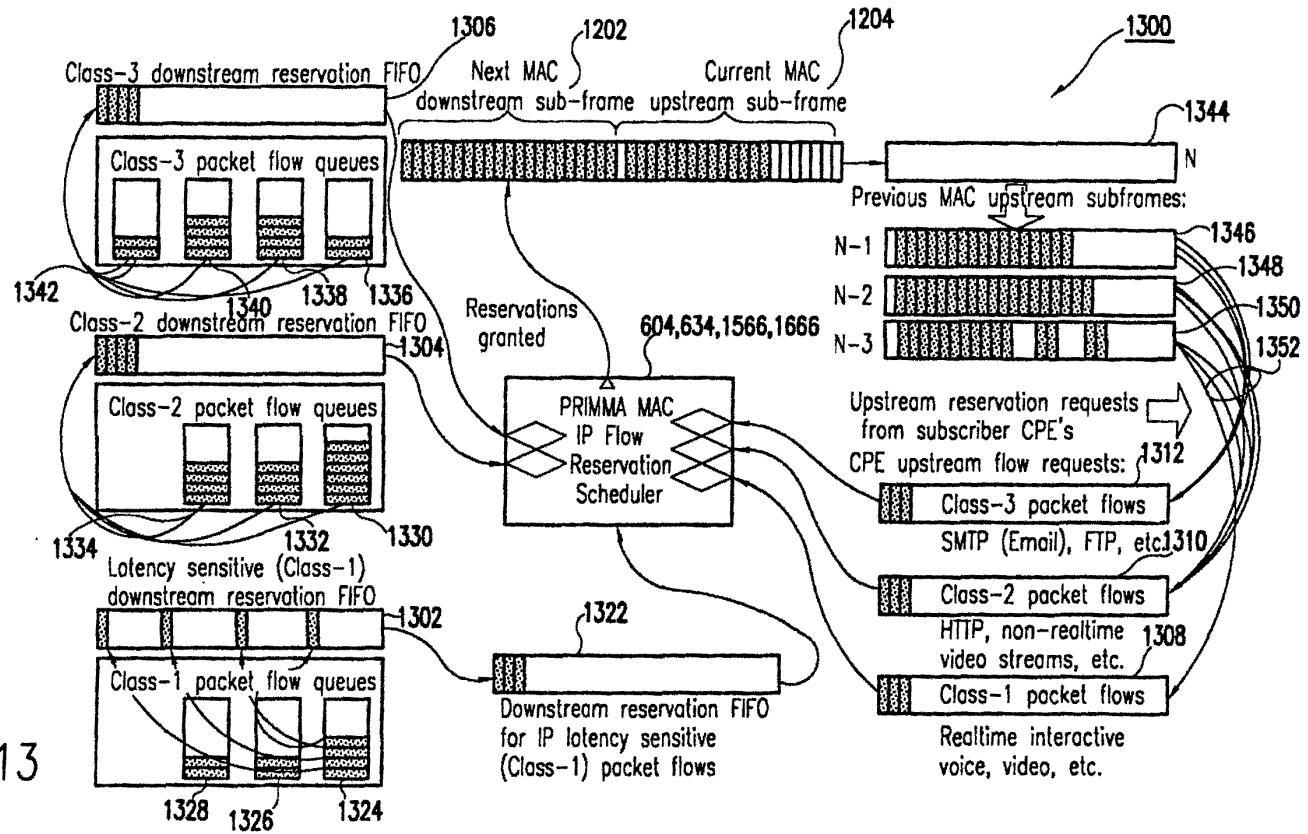


FIG. 120

FIG. 13



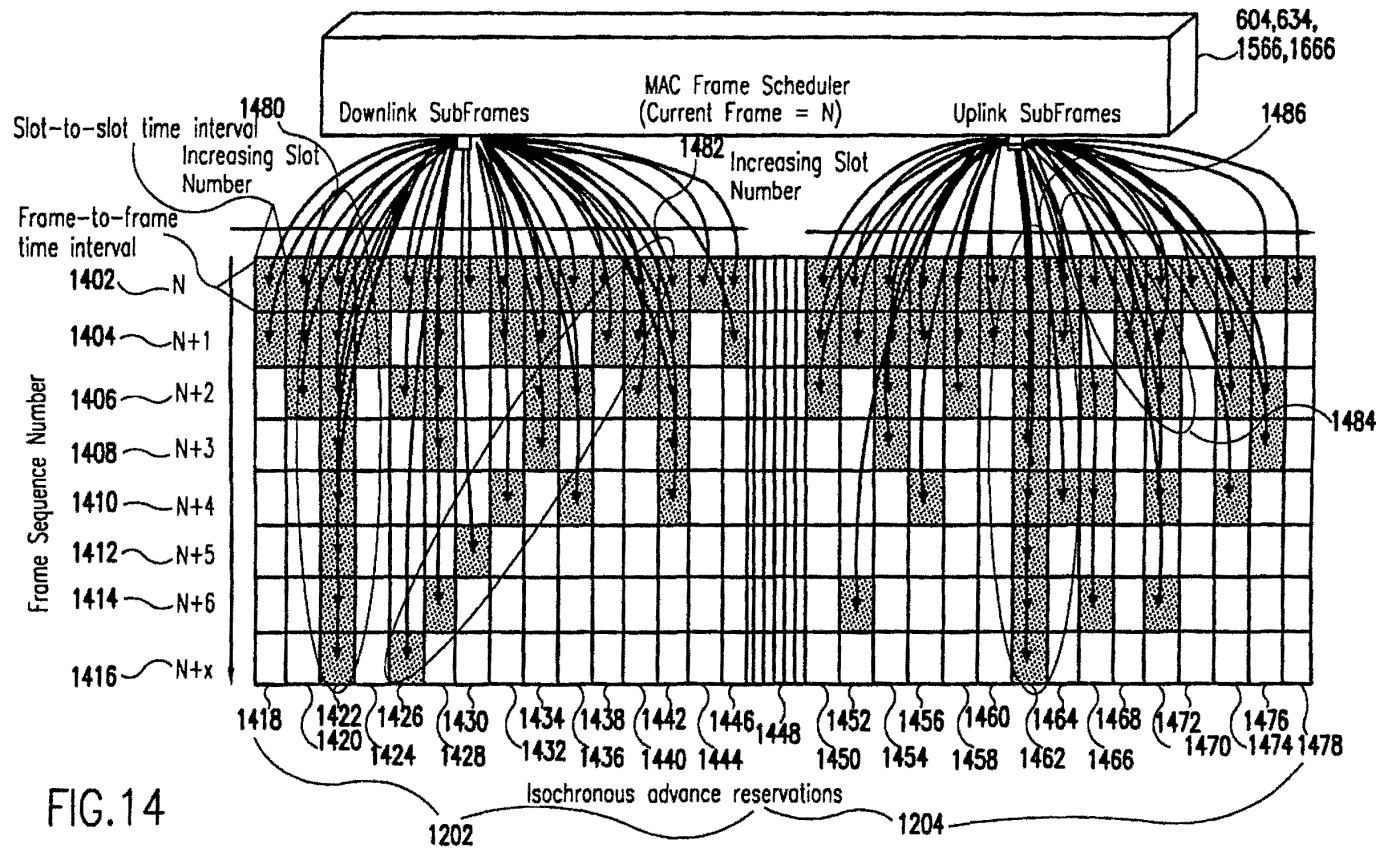


FIG. 14

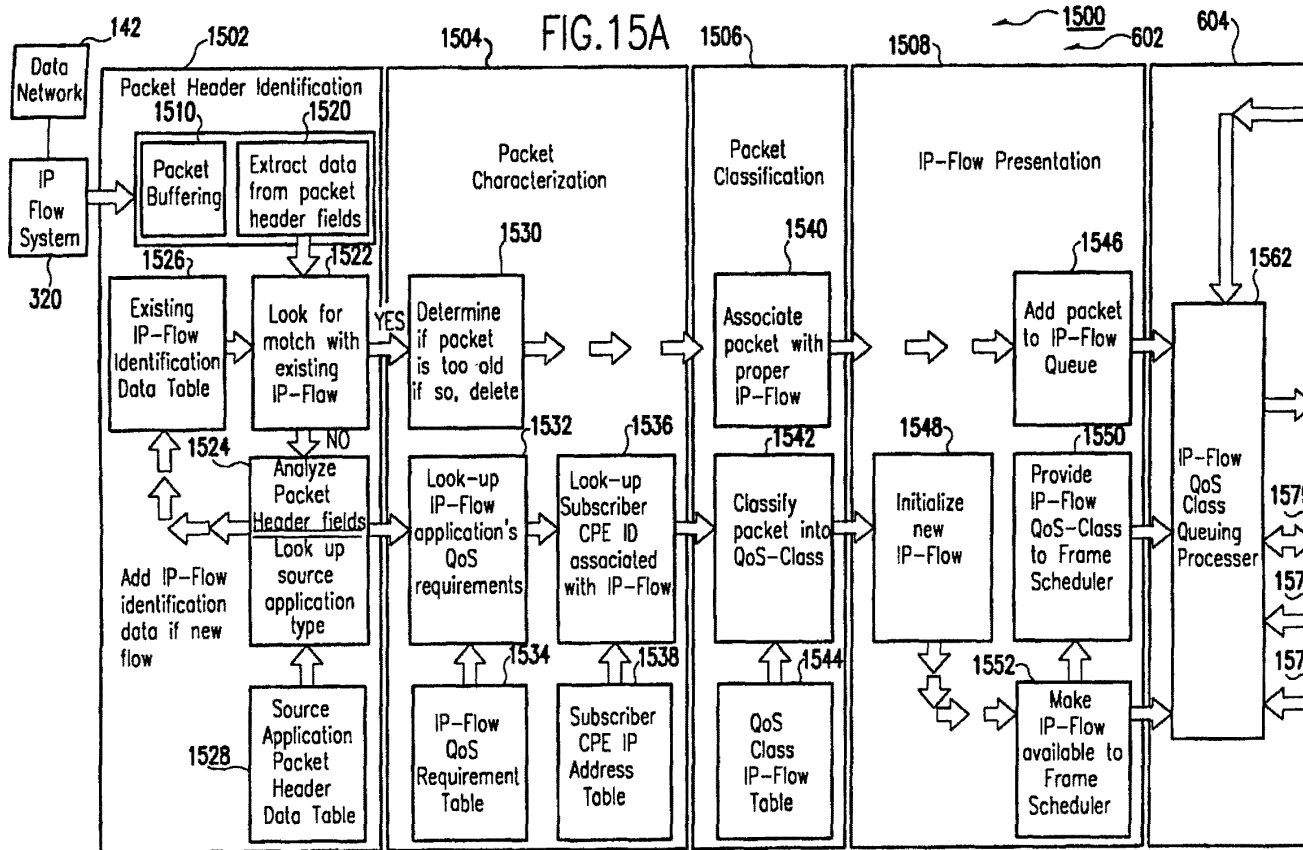
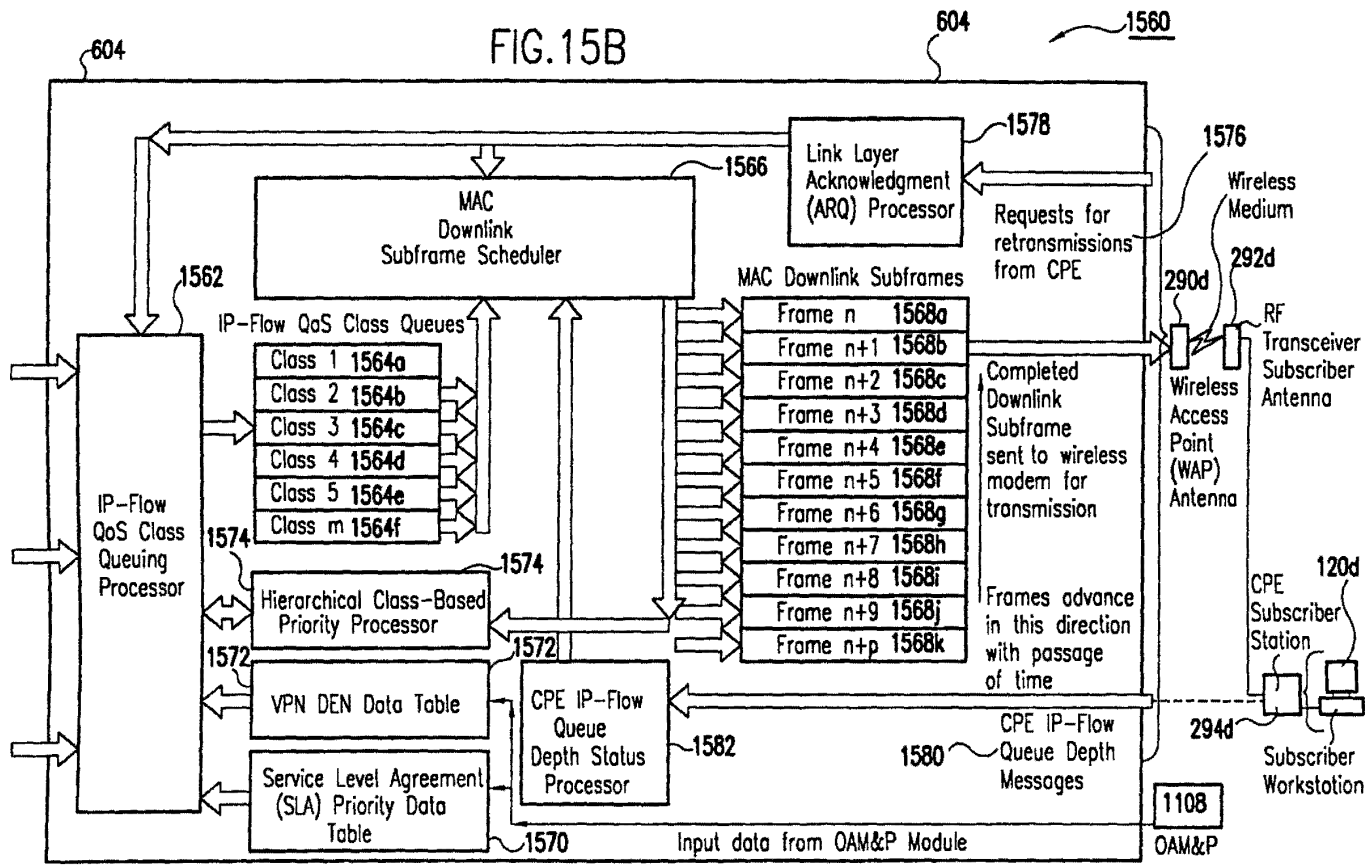
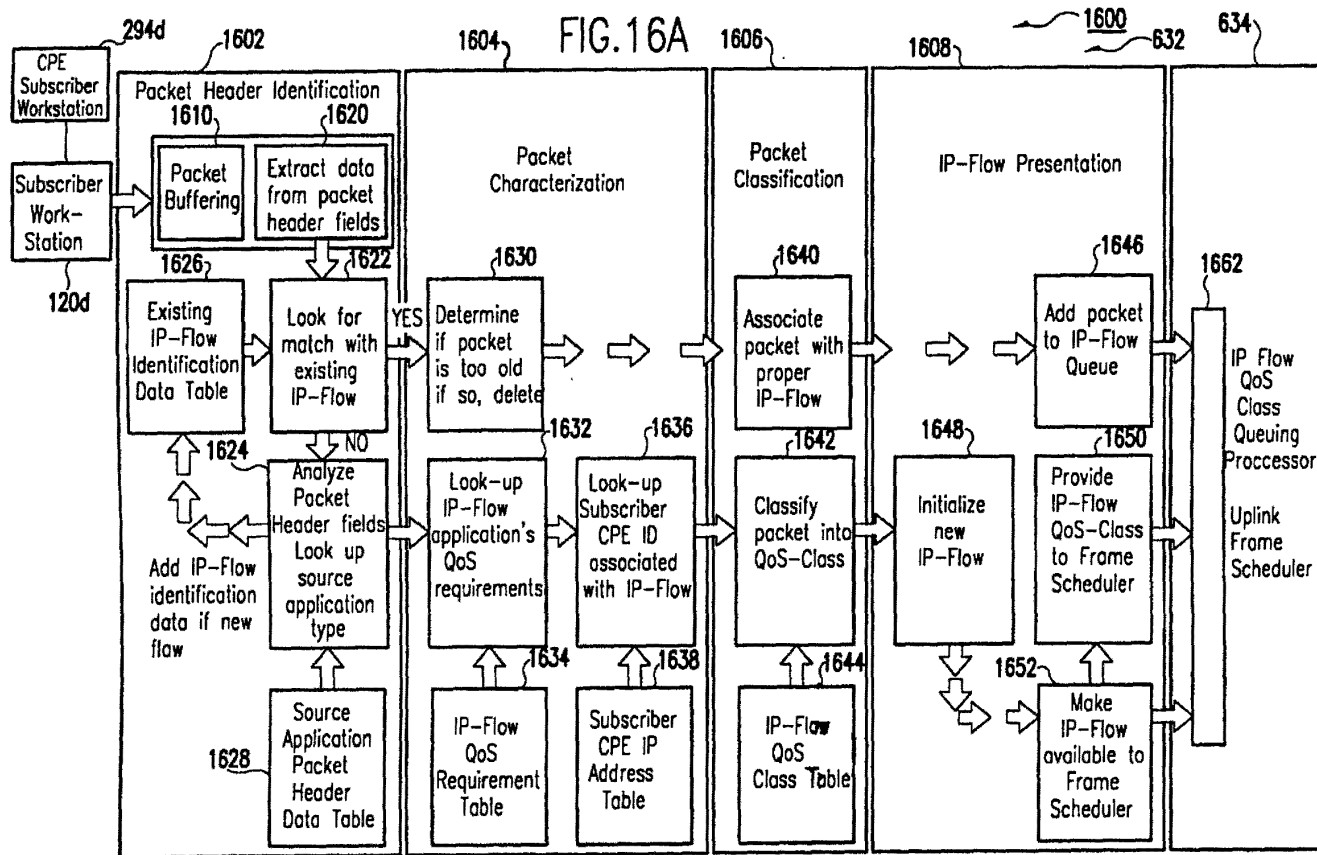
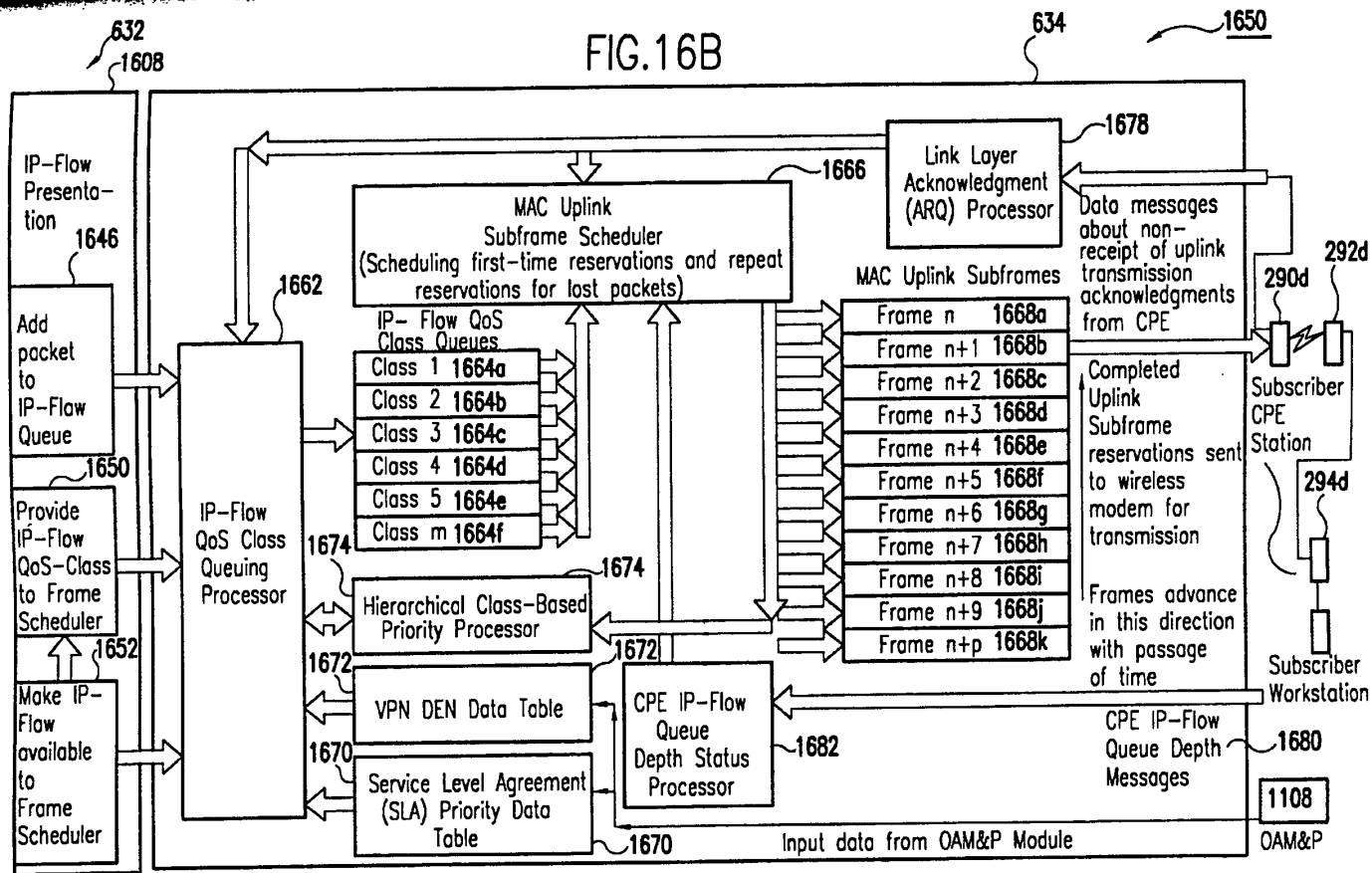


FIG. 15B









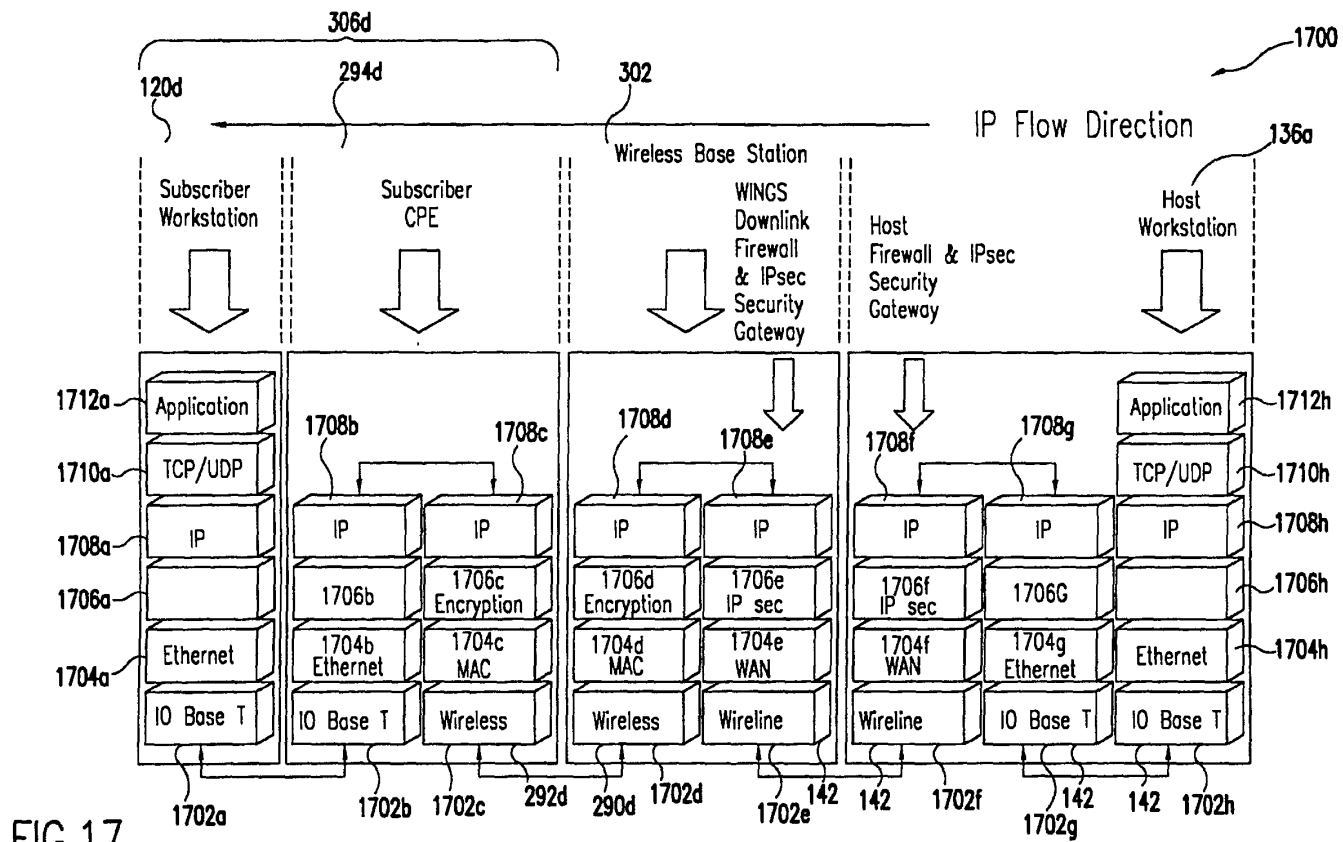


FIG. 17

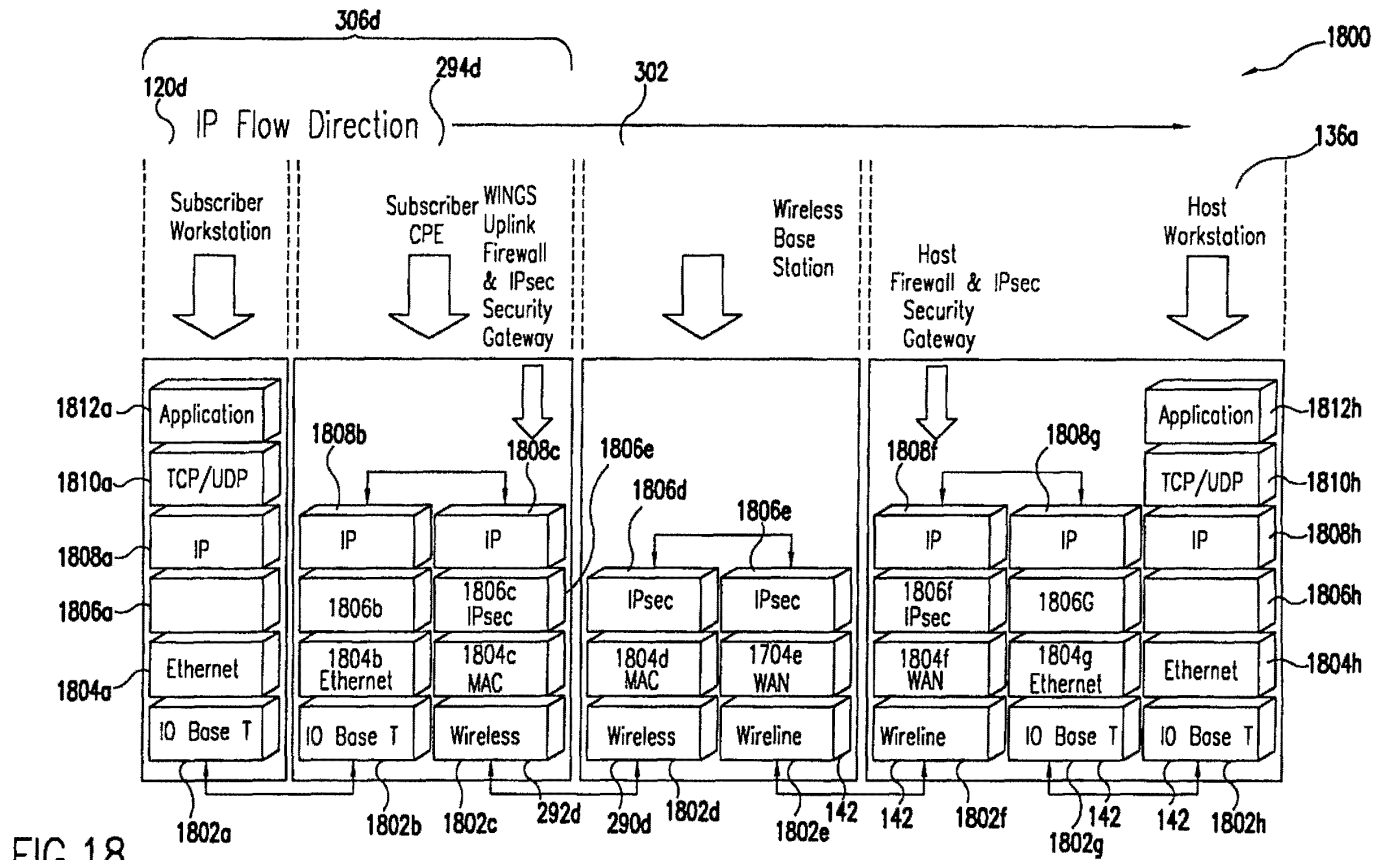


FIG. 18

**IP-FLOW CLASSIFICATION IN A WIRELESS  
POINT TO MULTI-POINT (PTMP)  
TRANSMISSION SYSTEM**

This application claims benefit of priority from U.S. Provisional Patent Application No. 60/092,452, filed Jul. 10, 1998.

**CROSS-REFERENCE TO OTHER  
APPLICATIONS**

The following applications of common assignee contain common disclosure:

- U.S. patent application Ser. No. 09/349,477 entitled "Transmission Control Protocol/Internet Protocol (TCP/IP) Packet-Centric Wireless Point to Multi-Point (PtMP) Transmission System Architecture," filed Jul. 9, 1999,
- U.S. patent application Ser. No. 09/349,480 entitled "Quality of Service (QoS)—Aware Wireless Point to Multi-Point (PtMP) Transmission System Architecture," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,126 entitled "Method for Providing Dynamic Bandwidth Allocation Based on IP-Flow Characteristics in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,118 entitled "Method for Providing for Quality of Service (QoS)—Based Handling of IP-Flows in a Wireless Point to Multi-Point Transmission System," filed Jul. 9, 1999,
- U.S. patent application Ser. No. 09/347,356 entitled "IP-Flow Identification in a Wireless Point to Multi-Point Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,150 entitled "IP-Flow Characterization in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,476 entitled "IP-Flow Prioritization in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,170 entitled "Method of Operation for Providing for Service Level Agreement (SLA) Based Prioritization in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,481 entitled "Method for Transmission Control Protocol (TCP) Rate Control With Link-Layer Acknowledgments in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,159 entitled "Transmission Control Protocol/Internet Protocol (TCP/IP)—Centric QoS Aware Media Access Control (MAC) Layer in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/347,857 entitled "Use of Priority-Based Scheduling for the Optimization of Latency and Jitter Sensitive IP Flows in a Wireless Point to Multi-Point Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,475 entitled "Time Division Multiple Access/Time Division Duplex (TDMA/TDD) Access Method for a Wireless Point to Multi-Point Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,483 "Reservation Based Prioritization Method for Wireless Transmission of Latency and Jitter Sensitive IP-Flows in a Wireless Point to Multi-Point Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,479 entitled "Transmission of Internet-Prioritized Internet Protocol (IP)—

Flows into Wireless System Resource Allocations in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.

- U.S. patent application Ser. No. 09/350,162 "Method of Operation for the Integration of Differentiated services (Diff-serv) Marked IP-Flows into a Quality of Service (QoS) Priorities in a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,975 entitled "Method for the Recognition and Operation of Virtual Private Networks (VPNs) over a Wireless Point to Multi-Point (PtMP) Transmission System," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/350,173 entitled "Time Division Multiple Access/Time Division Duplex (TDMA/TDD) Transmission Media Access Control (MAC) Air Frame," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,482 entitled "Application—Aware, Quality of Service (QoS) Sensitive, Media Access Control (MAC) Layer," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,478 entitled "Transmission Control Protocol/Internet Protocol (TCP/IP) Packet-Centric Wireless Point to Point (PtP) Transmission System Architecture," filed Jul. 9, 1999.
- U.S. patent application Ser. No. 09/349,474 entitled "Transmission Control Protocol/Internet Protocol (TCP/IP) Packet-Centric Cable Point to Multi-Point (PtMP) Transmission System Architecture," filed Jul. 9, 1999.

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

The present invention relates generally to telecommunications and, more particularly, to a system and method for implementing a QoS aware wireless point-to-multi-point transmission system.

**2. Related Art**

Telecommunication networks such as voice, data and video networks have conventionally been customized for the type of traffic each is to transport. For example, voice traffic is very latency sensitive but quality is less important, so voice networks are designed to transport voice traffic with limited latency. Traditional data traffic, such as, e.g., a spreadsheet, on the other hand is not latency sensitive, but error-free delivery is required. Conventional telecommunications networks use circuit switching to achieve acceptable end user quality of service (QoS). With the advent of new packet switching high bandwidth data networks, different types of traffic can be transported over a data network. Specifically, convergence of separate voice, data and video networks into a single broadband telecommunications network is enabled. To ensure end user satisfaction, a system is desired that provides QoS for various types of traffic to be transported.

Wireless networks present particular challenges over their wireline counterparts in delivering QoS. For example, wireless networks traditionally exhibit high bit error rates (BER) due to a number of reasons. Conventional wireless networks also implement circuit switched connections to provide reliable communications channels. However the use of circuit switched connections allocates bandwidth between communicating nodes whether or not traffic is constantly being transferred between the nodes. Therefore, circuit switched connections use communications bandwidth rather inefficiently.

Packet switching makes more efficient use of available bandwidth than does traditional circuit switching. Packet

switching breaks up traffic into so-called "packets" which can then be transported from a source node to a destination for reassembly. Thus a particular portion of bandwidth can be shared by many sources and destinations yielding more efficient use of bandwidth.

A wireless broadband access telecommunications system is desired which can provide a QoS capability that is comparable to that delivered by wireline broadband access devices. Conventionally, one of the barriers to the deployment of wireless broadband access systems has been the absence of acceptable QoS characteristics, while at the same time delivering bandwidth sufficient to qualify as broadband. Delivery of raw bandwidth over wireless media without acceptable QoS would not benefit end users. Likewise, the delivery of a high level of QoS at the cost of sufficient bandwidth would also not benefit end users.

Conventional efforts to provide wireless broadband access systems have not granted sufficient priority to QoS as a guiding principle in architecting the wireless systems, resulting in sub-optimal designs. With the rapid emergence of the Internet, the packet switching paradigm, and transmission control protocol/internet protocol (TCP/IP) as a universal data protocol, it has become clear that a new wireless system design has become necessary.

What is needed then is an IP-centric wireless broadband access system with true QoS capabilities.

#### SUMMARY OF THE INVENTION

The present invention is directed to an IP flow classification system used in a wireless telecommunications system. More specifically, the IP flow classification system groups IP flows in a packet-centric wireless point to multipoint telecommunications system.

The classification system includes: a wireless base station coupled to a first data network; one or more host workstations coupled to the first data network; one or more subscriber customer premise equipment (CPE) stations in wireless communication with the wireless base station over a shared bandwidth using a packet-centric protocol; and one or more subscriber workstations coupled to each of the subscriber CPE stations over a second network; a resource allocation device optimizes end-user quality of service (QoS) and allocates shared bandwidth among the subscriber CPE stations; an analyzing and scheduling device analyzes and schedules internet protocol (IP) flow over the shared wireless bandwidth. The analyzing device includes the above IP flow classifier that classifies the IP flow.

In one embodiment, the classifier includes a means for associating a packet of an existing IP flow with the IP flow. The classifier can include a QoS grouping device that groups a packet of a new IP flow into a QoS class grouping. The QoS grouping device can include a determining device that determines and takes into account QoS class groupings for the IP flow. The QoS grouping device can include an optional differentiated services (Diff Serv) device that takes into account an optional Diff Servs field priority marking for the IP flow. The QoS grouping device can also include an optional type of service (TOS) device that takes into account any optional type of service (TOS) field priority marking for said IP flow.

The cross-referenced applications are incorporated herein by reference in their entireties.

#### BRIEF DESCRIPTION OF THE FIGURES

The present invention will be described with reference to the accompanying figures, wherein:

FIG. 1A is a block diagram providing an overview of a standard telecommunications network providing local exchange carrier services within one or more local access and transport areas;

FIG. 1B depicts an exemplary network including workstations coupled to a data network;

FIG. 1C illustrates a conventional video network, such as for example a cable television (CATV) network;

FIG. 2A is a block diagram illustrating an overview of a standard telecommunications network providing both local exchange carrier and interexchange carrier services between subscribers located in different local access and transport areas;

FIG. 2B illustrates a signaling network in detail;

FIG. 2C illustrates an exemplary network carrying voice, data and video traffic over a data network;

FIG. 2D depicts a network including a point-to-multipoint wireless network coupled via a router to a data network;

FIG. 3A depicts an exemplary perspective diagram of a point-to-multipoint network;

FIG. 3B depicts a block diagram further illustrating a wireless point-to-multipoint network;

FIG. 4 depicts a wireless Internet protocol network access architecture of the present invention;

FIG. 5A depicts Internet protocol flows from a subscriber host to a wireless base station, and through a wireline connection to a destination host;

FIG. 5B illustrates a functional flow diagram including an example functional description of a transmission control protocol adjunct agent performing an outgoing transmission control protocol spoof function;

FIG. 5C illustrates a functional flow diagram including an exemplary functional description of a transmission control protocol adjunct agent performing an incoming transmission control protocol spoof function;

FIG. 6 illustrates a block diagram representing scheduling of mixed Internet protocol flows;

FIG. 7 illustrates packet header field information which can be used to identify Internet protocol flows and the quality of service requirements of the Internet protocol flows;

FIG. 8A is a block diagram summarizing an exemplary downlink analysis, prioritization and scheduling function;

FIG. 8B is a block diagram summarizing an exemplary uplink analysis prioritization and scheduling function;

FIG. 9 illustrates how a downlink flow scheduler can take into account a service level agreement in prioritizing a frame slot and scheduling resource allocation;

FIG. 10 depicts an embodiment of an inventive media access control hardware architecture;

FIG. 11 is an exemplary software organization for a packet-centric wireless point to multi-point telecommunications system;

FIG. 12A illustrates an exemplary time division multiple access media access control air frame;

FIG. 12B illustrates an exemplary structure for a time division multiple access/time division duplex air frame;

FIG. 12C illustrates an exemplary downstream transmission subframe;

FIG. 12D illustrates an exemplary upstream acknowledgment block field of a downstream transmission subframe;

FIG. 12E illustrates an exemplary acknowledgment request block field of a downstream transmission subframe;

FIG. 12F illustrates an exemplary frame descriptor block field of a downstream transmission subframe;

FIG. 12G illustrates an exemplary downstream media access control payload data unit of a downstream transmission subframe;

FIG. 12H illustrates an exemplary command and control block of a downstream transmission subframe;

FIG. 12I illustrates an exemplary upstream transmission subframe;

FIG. 12J illustrates an exemplary downstream acknowledgment block of an upstream transmission subframe;

FIG. 12K illustrates an exemplary reservation request block of an upstream transmission subframe 1204;

FIG. 12L illustrates an exemplary media access control payload data unit of an upstream transmission subframe;

FIGS. 12M, 12N and 12O illustrate an exemplary operations data block of an upstream transmission subframe;

FIG. 13 illustrates how an exemplary flow scheduler for the present invention functions;

FIG. 14 is an exemplary two-dimensional block diagram of an advanced reservation algorithm;

FIG. 15A is an exemplary logical flow diagram for a downlink flow analyzer;

FIG. 15B is an exemplary logical flow diagram for a downlink flow scheduler;

FIG. 16A is an exemplary logical flow diagram for an uplink flow analyzer;

FIG. 16B is an exemplary logical flow diagram for an uplink flow scheduler;

FIG. 17 illustrates Internet protocol flow in a downlink direction, including Internet protocol security encryption; and

FIG. 18 illustrates an uplink direction of Internet protocol security support.

In the figures, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The figure in which an element first appears is indicated by the leftmost digit(s) in the reference number.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. An Example Environment

The present invention is described in terms of an example environment. The example environment uses a fixed wireless point-to-multi-point (PtMP) connection to transmit packetized data information including for example, IP telephony, video, data, received from a telecommunications carrier. As used herein, a telecommunications carrier can include US domestic entities (see Definitions below at section II) such as, e.g., ILECs, CLECs, IXCs, NGTs and Enhanced Service Providers (ESPs), as well as global entities such as PTTs and NEs, recognized by those skilled in the art. In addition, as used herein a telecommunications system includes domestic systems used by entities such as, e.g., ILECs, CLECs, IXCs and Enhanced Service Providers (ESPs), as well as global systems recognized by those skilled in the art.

In the preferred embodiment, the traffic arrives from a wide area network (WAN) connection.

Data traffic is received from a data network through a network router and can be demodulated from internet protocol (IP) format to, for example, the point-to-point protocol (PPP). Network routers can include, for example, a general purpose computer, such as the SUN workstation running

routing software or a dedicated routing device such as various models from CISCO of San Jose, Calif., ASCEND of Alameda, Calif., NETOPIA of Alameda, Calif., or 3COM of Santa Clara, Calif.

In the alternative, a virtual private networking protocol, such as the point-to-point tunneling protocol (PPTP), can be used to create a "tunnel" between a remote user and a corporate data network. A tunnel permits a network administrator to extend a virtual private network from a server (e.g., a Windows NT server) to a data network (e.g., the Internet).

Although the invention is described in terms of this example environment, it is important to note that description in these terms is provided for purposes of illustration only.

It is not intended that the invention be limited to this example environment or to the precise inter-operations between the above-noted devices. In fact, after reading the following description, it will become apparent to a person skilled in the relevant art how to implement the invention in alternative environments.

II. Definitions

Table 1 below defines common telecommunications terminology. These terms are used throughout the remainder of the description of the invention.

TABLE 1

Term	Definition
access tandem (AT)	An AT is a class 3 switch used to switch calls between EOs in a LATAs. An AT provides subscribers access to the IXCs, to provide long distance calling services. An access tandem is a network node. Other network nodes can include, for example, a CLEC, or other enhanced services provider (ESP), an international gateway or global point-of-presence (GPOP), or an intelligent peripheral (IP).
bearer (B) channels	Bearer (B) channels are digital channels used to carry both digital voice and digital data information. An ISDN bearer channel is 64,000 bits per second, which can carry PCM-digitized voice or data.
called party	The called party is the caller receiving a call sent over a network at the destination or termination end.
calling party	The calling party is the caller placing a call over any kind of network from the origination end.
central office (CO)	A CO is a facility that houses an EO homed. EOs are often called COs.
class 1 switch	A class 1 switching office, the Regional Center (RC), is the highest level of local and long distance switching, or "office of last resort" to complete a call.
class 3 switch	A class 3 switching office was a Primary Center (PC); an access tandem (AT) has class 3 functionality.
class 4 switch	A class 4 switching office was a Toll Center (TC) if operators were present or else a Toll Point (TP); an access tandem (AT) has class 4 functionality.
class 5 switch	A class 5 switching office is an end office (EO) or the lowest level of local and long distance switching, a local central office. The switch closest to the end subscriber.
competitive LEC (CLEC)	CLECs are telecommunications services providers of local services that can compete with ILECs. Interprise and Century 21 are examples. A CLEC may or may not handle IXC services as well. Teligent and Winstar are examples.
competitive access providers (CAPS) customer premises equipment (CPE)	CPE refers to devices residing on the premises of a customer and used to connect to a telephone network, including ordinary telephones, key telephone systems, PBXs, video conferencing devices and modems.

TABLE 1-continued

Term	Definition
digitized data (or digital data)	Digitized data refers to analog data that has been sampled into a binary representation (i.e., comprising sequences of 0's and 1's). Digitized data is less susceptible to noise and attenuation distortions because it is more easily regenerated to reconstruct the original signal.
egress end office	The egress EO is the node or destination EO with a direct connection to the called party, the termination point. The called party is "homed" to the egress EO.
egress	Egress refers to the connection from a called party or termination at the destination end of a network, to the serving wire center (SWC).
end office (EO)	An EO is a class 5 switch used to switch local calls within a LATA. Subscribers of the LEC are connected ("homed") to EOs, meaning that EOs are the last switches to which the subscribers are connected.
Enhanced Service Provider (ESP) equal access	A network services provider.  1 + dialing as used in US domestic calling for access to any long distance carrier as required under the terms of the modified final judgment (MFJ) requiring divestiture of the Regional Bell Operating Companies (RBOCs) from their parent company, AT&T.
global point of presence (GPOP)	A GPOP refers to the location where international telecommunications facilities and domestic facilities interface, an international gateway POP.
incumbent LEC (ILEC)	ILECs are traditional LECs in the US, which are the Regional Bell Operating Companies (RBOCs). Bell South and US West are examples. ILEC can also stand for an independent LEC such as a GTE.
ingress end office	The ingress EO is the node or serving wire center (SWC) with a direct connection to the calling party, the origination point. The calling party is "homed" to the ingress EO.
ingress	Ingress refers to the connection from a calling party or origination.
integrated service digital network (ISDN) basic rate interface (BRI) line	An ISDN Basic Rate Interface (BRI) line provides 2 bearer B channels and 1 data D line (known as "2B+D" over one or two pairs) to a subscriber.
integrated services digital network (ISDN)	ISDN is a network that provides a standard for communications (voice, data and signaling), end-to-end digital transmission circuits, out-of-band signaling, and a features significant amount of bandwidth.
inter-machine trunk (IMT)	An inter-machine trunk (IMT) is a circuit between two commonly-connected switches.
inter-exchange carrier (IXC)	IXCs are US domestic long distance telecommunications services providers. AT&T, MCI, Sprint, are examples.
Internet protocol	IP is part of the TCP/IP protocols. It is used to recognize incoming messages, route outgoing messages, and keep track of Internet node addresses (using a number to specify a TCP/IP host on the Internet). IP corresponds to the network layer of OSI.
Internet service provider (ISP)	An ISP is a company that provides Internet access to subscribers.
ISDN primary rate interface (PRI)	An ISDN Primary Rate Interface (PRI) line provides the ISDN equivalent of a T1 circuit. The PRI delivered to a customer's premises can provide 23B+D (in North America) or 30B+D (in Europe) channels running at 1.544 megabits per second and 2.048 megabits per second, respectively.
local exchange carrier (LEC) access and transport area	LECs are local telecommunications services providers. Bell Atlantic and US West are examples. A LATA is a region in which a LEC offers services. There are over 160 LATAs of these local

TABLE 1-continued

Term	Definition
5 (LATA)	geographical areas within the United States.
local area network (LAN)	A LAN is a communications network providing connections between computers and peripheral devices (e.g., printers and modems) over a relatively short distance (e.g., within a building) under standardized control.
10 modified final judgment (MFJ)	Modified final judgment (MFJ) was the decision requiring divestiture of the Regional Bell Operating Companies (RBOCs) from their parent company, AT&T.
network node	A network node is a generic term for the resources in a telecommunications network, including switches, DACS, regenerators, etc. Network nodes essentially include all non-circuit (transport) devices. Other network nodes can include, for example, equipment of a CLEC, or other enhanced service provider (ESP), a point-of-presence (POP), an international gateway or global point-of-presence (GPOP).
15 new entrant (NE) next generation telephone (NGT)	A new generation global telecommunications. A new telecommunications services provider, especially IP telephony providers. Examples are Level 3 and Qwest.
20 packetized voice or voice over a backbone	One example of packetized voice is voice over internet protocol (VOIP). Voice over packet refers to the carrying of telephony or voice traffic over a data network, e.g. voice over frame, voice over ATM, voice over Internet Protocol (IP), over virtual private networks (VPNs), voice over a backbone, etc.
30 Pipe or dedicated communications facility point of presence (POP)	A pipe or dedicated communications facility connects an ISP to the internet.  A POP refers to the location within a LATA where the IXC and LEC facilities interface.
35 point-to-point tunneling protocol (PPTP)	A virtual private networking protocol, point-to-point tunneling protocol (PPTP), can be used to create a "tunnel" between a remote user and a data network. A tunnel permits a network administrator to extend a virtual private network (VPN) from a server (e.g., a Windows NT server) to a data network (e.g., the Internet).
40 point-to-point (PPP) protocol	PPP is a protocol permitting a computer to establish a connection with the Internet using a modem. PPP supports high-quality graphical front ends, like Netscape.
45 postal telephone telegraph (PTT) private branch exchange (PBX)	State regulated telephone companies, many of which are being deregulated. NIT is an example. A PBX is a private switch located on the premises of a user. The user is typically a private company which desires to provide switching locally.
50 private line with a dial tone	A private line is a direct channel specifically dedicated to a customer's use between two specified points. A private line with a dial tone can connect a PBX or an ISP's access concentrator to an end office (e.g. a channelized T1 or PRI). A private line can also be known as a leased line.
55 public switched telephone network (PSTN)	The PSTN is the worldwide switched voice network.
60 regional Bell operating companies (RBOCs)	RBOCs are the Bell operating companies providing LEC services after being divested from AT&T.
7 signaling system 7 (SS7)	SS7 is a type of common channel interoffice signaling (CCIS) used widely throughout the world. The SS7 network provides the signaling functions of indicating the arrival of calls, transmitting routing and destination signals, and monitoring line and circuit status.
65	



TABLE 1-continued

Term	Definition
switching hierarchy or office classification	An office class is a functional ranking of a telephone central office switch depending on transmission requirements and hierarchical relationship to other switching centers. Prior to AT&T's divestiture of the RBOCs, an office classification was the number assigned to offices according to their hierarchical function in the U.S. public switched network (PSTN). The following class numbers are used: class 1 = Regional Center (RC), class 2 = Sectional Center (SC), class 3 = Primary Center (PC), class 4 = Toll Center (TC) if operators are present or else Toll Point (TP), class 5 = End Office (EO) a local central office. Any one center handles traffic from one to two or more centers lower in the hierarchy. Since divestiture and with more intelligent software in switching offices, these designations have become less firm. The class 5 switch was the closest to the end subscriber. Technology has distributed technology closer to the end user, diffusing traditional definitions of network switching hierarchies and the class of switches.
telecommunications carrier	A LEC, a CLEC, an IXC, an Enhanced Service Provider (ESP), an intelligent peripheral (IP), an international/global point-of-presence (GPOP), i.e., any provider of telecommunications services.
transmission control protocol (TCP)	TCP is an end-to-end protocol that operates at the transport and sessions layers of OSI, providing delivery of data bytes between processes running in host computers via separation and sequencing of IP packets.
transmission control protocol/internet protocol (TCP/IP)	TCP/IP is a protocol that provides communications between interconnected networks. The TCP/IP protocol is widely used on the Internet, which is a network comprising several large networks connected by high-speed connections.
trunk	A trunk connects an access tandem (AT) to an end office (EO).
wide area network (WAN)	A WAN is a data network that extends a LAN over the circuits of a telecommunications carrier. The carrier is typically a common carrier. A bridging switch or a router is used to connect the LAN to the WAN.

III. Introduction

A. Quality of Service (QoS) in a Wireless Environment

The concept of quality of service (QoS) is one of the most difficult and least understood topics in data networking. Although a common term in data networking, there are many different usages and definitions for QoS, leading to confusion regarding an exact meaning in precise or quantitative terms. Even further confusion is found when attempts are made to measure or specify numeric quantities sufficient to allow comparison of equipment or network performance with respect to QoS.

The confusion about QoS in general data networking is transferred and magnified when applied to wireless data communications. Wireless transmission has a higher inherent bit error rate (BER) than does wireline transmission. The addition of, e.g., a point-to-multipoint (PtMP) topology for multiple users sharing a wireless medium makes it desirable that QoS be defined in a manner that specifically addresses the multiple complicating factors in wireless data communications.

To provide a non-ambiguous definition of QoS that applies to wireless data communications, the nature of the problem that QoS is meant to solve is helpful. Many of the problems of data communications over wireless are unique and distinct from those of wireline data communications, while some are in fact shared. For wireless broadband access

systems, the problems of quality delivery are somewhat more complex than for the wireline analog. Like its wireline counterpart, the problems encountered in wireless delivery of data include, e.g., slow peripheral access, data errors, "drop-outs," unnecessary retransmissions, traffic congestion, out-of-sequence data packets, latency, and jitter. In addition to these problems, wireless delivery adds problems including, e.g., high inherent bit error rates (BERs), limited bandwidth, user contention, radio interference, and TCP traffic rate management. A QoS-aware wireless system is desired to address all these problems.

There are a number of ways in which users or subscribers to a data network experience difficulties. One network difficulty is due to a lack of network availability. Depending on the access technology being used, this can include a "modem no-answer" condition, "network busy" condition, or a sudden unexpected "drop" of a network connection. These conditions would not be described as being consistent with high QoS. Once network connectivity is achieved, slow traffic caused by congestion, local access bottlenecks, and network failures can be experienced as slow web page loading, slow file transfers, or poor voice/video quality in streaming multimedia applications. Poor quality in streaming multimedia applications can instead result from high "jitter," or large and rapid variations in latency, leading to interruptions, distortion, or termination of session. Many different conditions can lead to actual data errors, which in some contexts can be catastrophic, such as in the file transfer of a spreadsheet. It is desirable that these problems of a data communications network be minimized or eliminated.

1. Quality

In data networking, quality usually implies the process of delivering data in a reliable and timely manner. What is reliable and timely is dependent on the nature of the traffic being addressed. These terms may include references to limitations in data loss, expectations of data accuracy, limitations of data latency variations (also known as jitter), and limitations of data retransmissions and limitations of data packet order inversions. Therefore, QoS is a complex concept, which can require a correspondingly complex mechanism to implement it.

QoS can be a relative term, finding different meanings for different users. A casual user doing occasional web browsing, but no file transfer protocol (FTP) file downloads or real time multimedia sessions may have different a different definition of QoS than a power user doing many FTP file downloads of large database or financial files, frequent H.323 video conferencing and IP telephony calls. Also, a user can pay a premium rate (i.e. a so-called service level agreement (SLA)) for high network availability, low latency, and low jitter, while another user can pay a low rate for occasional web surfing only, and on weekends only. Therefore, perhaps it is best to understand QoS as a continuum, defined by what network performance characteristic is most important to a particular user and the user's SLA. Maximizing the end-user experience is an essential component of providing wireless QoS.

2. Service

In data networking, a service can be defined as a type of connection from one end of a network to another. Formerly, this could have been further defined to be protocol specific, such as, e.g., IBM's systems network architecture (SNA), Novell's IPX, Digital's DECnet. However, it appears that TCP/IP (i.e. including user datagram protocol(UDP)) has evolved to become the overwhelming protocol of choice, and will continue to be in the foreseeable future. Therefore, service can be defined to be a particular type of TCP/IP

connection or transmission. Such service types might include, e.g., FTP file transfers, e-mail traffic, hypertext transfer protocol (HTTP) traffic, H.323 videoconferencing sessions. It is desirable that a QoS mechanism deal with these differing types of service, in addition to dealing with the different types of quality as discussed previously.

### 3. QoS as a Mechanism

QoS can be thought of as a mechanism to selectively allocate scarce networking, transmission and communications resources to differentiated classes of network traffic with appropriate levels of priority. Ideally, the nature of the data traffic, the demands of the users, the conditions of the network, and the characteristics of the traffic sources and destinations all modify how the QoS mechanism is operating at any given instant. Ultimately, however, it is desirable that the QoS mechanism operate in a manner that provides the user with optimal service, in whatever manner the user defines it.

#### a. Circuit-Switched QoS

In legacy networks created primarily for voice traffic by telephone companies, data transmission was accomplished with reference to a circuit-centric definition of QoS. In this definition, QoS implied the ability to carry asynchronous (i.e. transmission of data through start and stop sequences without the use of a common clock) as well as isochronous (i.e. consistent timed access of network bandwidth for time-sensitive voice and video) traffic. Circuit-switched QoS was accomplished by dedicating an end-to-end circuit for each connection or service, whether it was voice (see FIG. 1A) or data. The circuit-centric QoS mechanism was simply the provision of this circuit for exclusive use by the user. Of course, this approach dedicates the circuit, all transmission channels associated with the circuit, and the transport media itself to a single user for the entire duration of the session, regardless of whether data is actually being transmitted every instant of the session. It was generally believed that only in this manner could true QoS be achieved. Therefore, traditional designs for wireless broadband access systems (see FIG. 2A) also used this approach, dedicating a wireless radio channel to each particular data connection, regardless of the application or whether indeed any data was being transmitted at any given moment. This circuit-centric approach to QoS is fairly expensive, in terms of the cost of the equipment, and the utilization factors for the transmission media itself.

#### b. Asynchronous Transfer Mode (ATM) QoS

With ATM networking, telephone companies could continue to provide a circuit-centric QoS mechanism with the establishment of permanent virtual connections (PVCs) (i.e. a virtual path or channel connection (VPC or VCC) provisioned for indefinite use) and switched virtual connections (SVCs) (i.e. a logical connection between endpoints established by an ATM network on demand based upon signaling messages received from the end user or another network) in an analogous manner to the legacy voice circuit mechanism. However, several new concepts were needed, including admission policy, traffic shaping, and mechanisms such as, e.g., leaky-buckets, in order to handle traffic that was now categorized as variable bit rate (VBR), constant bit rate (CBR), and unspecified bit rate (UBR).

Virtual circuits were to be established for data transmission sessions, again regardless of the data application or whether data was being transmitted at any given moment. Although ATM provides QoS for broadband network traffic, the underlying assumptions of ATM design include the low BER characteristic of wireline networks, not the high BER of the wireless medium. Without a recognition of the char-

acteristics of the traffic that is being carried by the ATM mechanism and the high inherent BER of wireless, true QoS can not be provided. ATM QoS mechanisms do not address the unique challenges associated with wireless communication.

#### c. Packet-Switched QoS

Packet-switching is revolutionizing data communications, so conventional circuit-switch and ATM networking concepts and their legacy QoS mechanisms are in need of update. With packet-switched data communications, one cannot dedicate a circuit to a particular data communications session. Indeed, a strength of packet-switching lies in route flexibility and parallelism of its corresponding physical network. Therefore, the QoS mechanism cannot work in the same manner as the legacy circuit-centric QoS mechanism did.

Simply providing "adequate" bandwidth is not a sufficient QoS mechanism for packet-switched networks, and certainly not for wireless broadband access systems. Although some IP-flows are "bandwidth-sensitive," other flows are latency- and/or jitter-sensitive. Real time or multimedia flows and applications cannot be guaranteed timely behavior by simply providing excessive bandwidth, even if it were not cost-prohibitive to do so. It is desirable that QoS mechanisms for an IP-centric wireless broadband access system recognize the detailed flow-by-flow requirements of the traffic, and allocate system and media resources necessary to deliver these flows in an optimal manner.

#### d. Summary—QoS Mechanisms

Ultimately, the end-user experience is the final arbiter of QoS. It is desirable that an IP-centric wireless broadband access system assign and regulate system and media resources in a manner that can maximize the end-user experience. For some applications such as an initial screen of a Web page download, data transmission speed is the best measure of QoS. For other applications, such as the download or upload of a spreadsheet, the best measure of QoS can be the minimization of transmission error. For some applications, the best measure of QoS can be the optimization of both speed and error. For some applications, the timely delivery of packets can be the best measure of QoS. It is important to note that fast data transmission may not be the same as timely delivery of packets. For instance, data packets that are already "too old" can be transmitted rapidly, but by being too old can be of no use to the user. The nature of the data application itself and the desired end-user experience then can provide the most reliable criteria for the QoS mechanism. It is desired that an IP-centric wireless broadband access system provide a QoS mechanism that can dynamically optimize system behavior to each particular IP flow, and can also adapt to changes with changing network load, congestion and error rates.

#### 4. Service Guarantees and Service Level Agreements (SLAs)

Service guarantees can be made and service level agreements (SLAs) can be entered into between a telecommunications service provider and a subscriber whereby a specified level of network availability can be described, and access charges can be based upon the specified level. Unfortunately, it is difficult to quantify the degree of network availability at any given time, and therefore this becomes a rather crude measure of service performance. It is desired that data delivery rate, error rate, retransmissions, latency, and jitter be used as measures of network availability, but measuring these quantities on a real-time basis can be beyond the capability of conventional network service providers (NSPs).

Another level of service discrimination desired by network service providers is a service level agreement (SLA) that provides for differing traffic rates, network availability, bandwidth, error rate, latency and jitter guarantees. It is desired that an IP-centric wireless broadband access system be provided that can provide for SLAs, enabling service providers to have more opportunities for service differentiation and profitability.

#### 5. Class of Service and Quality of Service

In order to implement a practical QoS mechanism, it is desired that a system be able to differentiate between types of traffic or service types so that differing levels of system resources can be allocated to these types. It is customary to speak of "classes of service" as a means of grouping traffic types that can receive similar treatment or allocation of system and media resources.

Currently, there are several methods that can be used in wireline network devices to implement differentiated service classes. Example methods include traffic shaping, admission control, IP precedence, and differential congestion management. It is desired that an IP-centric wireless broadband access system use all of these methods to differentiate traffic into classes of service, to map these classes of service against a QoS matrix, and thereby to simplify the operation and administration of the QoS mechanism.

#### B. QoS and IP-Centric Wireless Environment

In a point-to-multipoint (PtMP) wireless system like the present invention, it is desirable that the QoS mechanism cope not only with wireline networking considerations, but also with considerations particular to the wireless environment. As stated earlier, it is desired that the inherent BER of wireless be handled. The high BER can require that error detection, correction, and re-transmission be done in an efficient manner. It is desired that a BER handling mechanism also work efficiently with the re-transmission algorithms of TCP/IP so as to not cause further unnecessary degradation of bandwidth utilization. An additional challenge of wireless is contention among users for limited wireless bandwidth. It is desirable that the system handle service requests from multiple users in a radio medium subject to interference and noise, which can make efficient allocation of radio bandwidth difficult.

As discussed above, the change from circuit-switched and ATM data networks to packet-switched data networks has impacted the definition of QoS mechanisms. The present invention provides a novel QoS mechanism in a point-to-multipoint IP-centric wireless system for packet-switched network traffic. In order for the system to provide optimal QoS performance, it is desirable that it include a novel approach to QoS mechanisms. The use of QoS as the underlying guide to system architecture and design constitutes an important, substantial and advantageous difference of the IP-centric wireless broadband access system of the present invention over existing wireless broadband access systems designed with traditional circuit-centric or ATM cell circuit-centric approaches such as those used by Teligent and Winstar.

#### C. IP-Centric Wireless Broadband Access QoS and Queuing Disciplines

##### 1. Managing Queues

Queuing is a commonly accepted tool required for manipulating data communications flows. In order for packet headers to be examined or modified, for routing decisions to be made, or for data flows to be output on appropriate ports, it is desirable that data packets be queued. However, queuing introduces, by definition, a delay in the traffic streams that can be detrimental, and can even totally

defeat the intent of queuing. Excessive queuing can have detrimental effects on traffic by delaying time sensitive packets beyond their useful time frames, or by increasing the RTT (Round Trip Time), producing unacceptable jitter or even causing the time-out of data transport mechanisms. Therefore, it is desired that queuing be used intelligently and sparingly, without introducing undue delay in delay-sensitive traffic such as real-time sessions.

In a wireless environment where time division multiple access (TDMA), forward error detection (FEC), and other such techniques can be necessary, it is desirable that queuing be used merely to enable packet and radio frame processing. However, in the case of real-time flows, the overall added delay in real-time traffic can preferably be held to below approximately 20 milliseconds.

The use of queue management as the primary QoS mechanism in providing QoS-based differentiated services is a simple and straight forward method for wireless broadband systems. However, wireless systems are usually more bandwidth constrained and therefore more sensitive to delay than their wireline counterparts. For this reason, it is desirable that QoS-based differentiated services be provided with mechanisms that go beyond what simple queuing can do. However, some queuing can still be required, and the different queuing methods are now discussed.

##### 2. First in, First out (FIFO) Queuing

First in, first out (FIFO) queuing can be used in wireless systems, like wireline systems, in buffering data packets when the downstream data channel becomes temporarily congested. If temporary congestion is caused by bursty traffic, a FIFO queue of reasonable depth can be used to smooth the flow of data into the congested communications segment. However, if the congestion becomes severe in extent, or relatively long in duration, FIFO can lead to the discarding of packets as the FIFO queues are filled to capacity, and the network is not capable of accepting additional packets causing discarding of packets, i.e. so-called "packet-tossing." Although this can have a detrimental effect on QoS in and of itself, the discarding of packets may cause future problems with traffic flow as the TCP protocol causes the retransmission of lost packets in the proper sequence, further exacerbating the problem. The problem of packet discards can be minimized by increasing the size of the FIFO buffers so that more time can pass before discards occur. Unfortunately, eventually the FIFO can become large enough that packets can become too old and the round-trip time (RTT) can increase to the point that the packets are useless, and the data connection is virtually lost.

In a wireless broadband environment, the requirement for FIFO queuing is partially dependent upon the type of RF access method being used. For time division multiple access/time division duplex (TDMA/TDD), it can be desirable that data be queued even for collecting enough data for the construction of data frames for transmission. Frequency division multiple access (FDMA) and code-division multiple access (CDMA) are not as "sequential" in nature as TDMA, and therefore have less of a requirement for FIFO queuing. However, generally for all wireless access techniques, noise and interference are factors that can lead to retransmissions, and therefore further delays and consequent adverse effect on QoS.

Using FIFO queuing, shared wireless broadband systems can uniformly delay all traffic. This can seem to be the "fairest" method, but it is not necessarily the best method if the goal is to provide high QoS to users. By using different types of queue management, a much better base of overall QoS can be achieved.

### 3. Priority Queuing

The shared wireless broadband environment can include a constricted bandwidth segment as data is transmitted over the RF medium. Therefore, regardless of access technique, these systems can require some amount of queuing. However, using FIFO queuing can result in a constant delay to all traffic, regardless of the priority or type of traffic. Most data communications environments can consist of a mixture of traffic, with combinations of real time interactive data, file and data downloads, web page access, etc. Some of these types of traffic are more sensitive to delay, and jitter, than others. Priority queuing simply reorders data packets in the queue based on their relative priorities and types, so that data from more latency- and jitter-sensitive traffic can be moved to the front of the queue.

Unfortunately, if there is downlink data channel congestion, or congestion caused by an overabundance of high priority traffic, the condition of "buffer starvation" can occur. Because of the relative volume of high priority packets consuming a majority of buffer space, little room is left for lower priority packets. These lower priority packets can experience significant delays while system resources are devoted to the high priority packets. In addition to low priority packets being held in buffers for long periods of time, or never reaching the buffers, resulting in significantly delayed data flows for these packets, the actual applications corresponding to these low priority packets can also be disrupted, and stop working. Because of the nature of this queuing approach, overall latency and jitter and RTT for lower priority packets can be unpredictable, having an adverse effect on QoS.

If queue sizes are small, reordering data within the queues can have little beneficial effect on the QoS. In fact, processing required to examine packet headers in order to obtain the information necessary to reorder the queues may itself add significant delay to the data stream. Therefore, particularly for wireless broadband data environments, priority queuing can be not much better than FIFO queuing as a QoS mechanism.

### 4. Class Based Queuing

By allocating queue space and system resources to packets based on the class of the packets, buffer starvation can be avoided. Each class can be defined to include of data flows with certain similar priorities and types. All classes can be given a certain minimum level of service so that one high priority data flow cannot monopolize all system resources. With the classification approach, because no data flow is ever completely shut off, the source application can receive information about the traffic rate, and can be able to provide TCP-mediated transmission rate adjustment supporting smooth traffic flow.

Although this approach can work better than FIFO queuing in wireless broadband systems, latency and jitter sensitive flows can still be adversely affected by high priority flows of large volume.

### 5. Weighted Fair Queuing

A weighted fair queuing method can attempt to provide low-volume flows with guaranteed queuing resources, and can then allow remaining flows, regardless of volume or priority, to have equal amounts of resource. Although this can prevent buffer starvation, and can lead to somewhat better latency and jitter performance, it can be difficult to attain stable performance in the face of rapidly changing RF downlink channel bandwidth availability.

Providing a high quality of service can require a QoS mechanism that is more sophisticated than simple queue management.

## D. IP-Centric Wireless Broadband Access QoS and TCP/IP

### 1. TCP/IP

The TCP/IP protocol stack has become the standard method of transmitting data over the Internet, and increasingly it is becoming a standard in virtual private networks (VPNs). The TCP/IP protocol stack includes not only internet protocol (IP), but also transmission control protocol (TCP), user datagram protocol (UDP), and internet control message protocol (ICMP). By assuming that the TCP/IP protocol stack is the standard network protocol for data communications, the creation of a set of optimal QoS mechanisms for the wireless broadband data environment is more manageable. QoS mechanisms can be created that can span the entire extent of the network, including both the wireline and the wireless portions of the network. These mechanisms can integrate in a smooth and transparent manner with TCP rate control mechanisms and provide end-to-end QoS mechanisms that are adaptive to both the wireline and wireless portions of the network. Of course, segments of the wireline network that are congested or are experiencing other transport problems cannot be solved by a wireless QoS mechanism. However, a wireless QoS mechanism can optimize data flows in a manner that can enhance the end user experience when there is no severe wireline network congestion or bottleneck present.

### 2. Differentiation by Class

Data traffic can be handled based on classes of service, as discussed above. To differentiate traffic by class, data traffic (or a sequence of data packets associated with a particular application, function, or purpose) can be classified into one of several classes of service. Differentiation can be done on the basis of some identifiable information contained in packet headers. One method can include analyzing several items in, e.g., an IP packet header, which can serve to uniquely identify and associate the packet and other packets from that packet flow with a particular application, function or purpose. As a minimum, a source IP address, a source TCP or UDP port, a destination IP address, and a destination IP or UDP port can serve to associate packets into a common flow, i.e. can be used to classify the packets into a class of service.

By creating a finite and manageable number of discrete classes of service, multiple IP flows can be consolidated and handled with a given set of QoS parameters by the QoS mechanisms. These classes can be defined to provide common and useful characteristics for optimal management in the combined wireline and wireless network segments.

### 3. Per-Flow Differentiation

A finite and discrete set of classes of service, can enable QoS mechanisms to be less compute-intensive, to use less memory, fewer state machines, and therefore have better scalability than having individual QoS mechanisms (or sets of parameters) for each individual IP flow. However, in a network access device such as, e.g., a point to multi-point (PtMP) wireless broadband access system, the total number of simultaneous IP flows typically will not exceed the range of 1000, and therefore the amount of processing overhead that could be required could permit a per-flow QoS differentiation without resorting to classes of service. However, class of service consolidation of IP flows provides advantages related to marketing, billing and administration.

Prior to the present invention, per-flow differentiation has not been used in a wireless environment (including radio frequencies transmitted over coaxial cables and satellite communications).

## 4. Using IP Precedence for Class of Service

IP precedence bits in a type of service (IP TOS) field, as described in Internet Engineering Task Force (IETF) 1992b, can theoretically be used as a means to sort IP flows into classes of service. IETF RFC1349 proposed a set of 4-bit definitions with 5 different meanings: minimize delay; maximize throughput; maximize reliability; minimize monetary cost; and normal service.

These definitions could add significantly to networks, routers and access devices in differentiating different types of flow so that resources could be appropriately allocated, resulting in improved QoS. However, the proposal has not been widely used. Several proposals in the IETF could make use of this field, along with resource reservation protocol (RSVP), to improve network handling of packets.

Although the type of service (TOS) field has been an integral component of the TCP/IP specification for many years, the field is not commonly used. Absent appropriate bits in the field being set by a source processor, the access devices, the network and network routers cannot implement QoS mechanisms.

## 5. TCP-Mediated Transmission Rate Mechanisms

The manner in which TCP governs transmission rate can be incorporated and managed by an IP-centric wireless QoS mechanism. If a TCP mechanism is not managed, any wireless QoS mechanism can be overwhelmed or countered by wireless bandwidth factors. Before addressing the specific wireless factors that can impact TCP transmission speed, a review of TCP transmission rate mechanism is needed.

TCP can control transmission rate by "sensing" when packet loss occurs. Because TCP/IP was created primarily for wireline environment with its extremely low inherent BER, such as those found over fiber optic lines, any packet loss is assumed by TCP to be due to network congestion, not loss through bit error. Therefore, TCP assumes that the transmission rate exceeded the capacity of the network, and responds by slowing the rate of transmission. However, packet loss in the wireless link segment is due primarily to inherently high BER, not congestion. The difference turns out to be not insubstantial.

TCP can initially cause the transmission rate to ramp-up at the beginning of a packet flow, and is called slow-start mode. The rate can be continuously increased until there is a loss or time-out of the packet-receipt acknowledgment message. TCP can then "back-off", can decrease the transmission window size, and then can retransmit lost packets in the proper order at a significantly slower rate. TCP can then slowly increase the transmission rate in a linear fashion, which can be called congestion-avoidance mode.

If multiple users share a wireless radio link as with the present invention, the inherently high BER of the medium could potentially cause frequent packet loss leading to unproductive TCP retransmission in congestion avoidance mode. Because wireless bandwidth can be a precious commodity, a IP-centric wireless QoS mechanism preferably provides for packet retransmission without invoking TCP retransmission and consequent and unnecessary "whip-sawing" of the transmission rate. This, along with several other factors, makes desirable creation of an IP-centric wireless media access control (MAC) layer. One function of an IP-centric MAC layer can be to mediate local retransmission of lost packets without signaling TCP and unnecessarily altering the TCP transmission speed. A primary task of the IP-centric wireless MAC layer is to provide for shared access to the wireless medium in an orderly and efficient manner. The MAC layer according to the present invention,

Proactive Reservation-based Intelligent Multimedia-aware Media Access (PRIMMA) layer, available from Malibu Networks Inc., of Calabasas, Calif., can also schedule all packet transmissions across the wireless medium on the basis of, e.g., IP flow type, service level agreements (SLAs), and QoS considerations.

## 6. TCP Congestion Avoidance in an IP-Centric Wireless System

## a. Network Congestion Collapse, Global Synchronization and IP-Centric Wireless TCP Congestion Avoidance

The inherently high bit error rate (BER) of wireless transmission can make an occurrence of problems known as congestion collapse or global synchronization collapse more likely than in a wireline environment. When multiple TCP senders simultaneously detect congestion because of packet loss, the TCP senders can all go into TCP slow start mode by shrinking their transmission window sizes and by pausing momentarily. The multiple senders can then all attempt to retransmit the lost packets simultaneously. Because they can all start transmitting again in rough synchrony, a possibility of creating congestion can arise, and the cycle can start all over again.

In the wireless environment, an occurrence of burst noise can cause packet loss from many IP streams simultaneously. The TCP transmission rate mechanisms of the TCP senders can assume that packet loss was due to congestion, and they can all back-off in synchrony. When the TCP senders restart, the senders can restart in rough synchrony, and indeed can now create real congestion in the wireless link segment. This cyclical behavior can continue for some time, and can possibly cause unpredictable system performance. This can be due in part to overflowing system queues which can cause more packets to be dropped and can cause more unproductive retransmissions. This can degenerate into a "race" state that could take many minutes before re-establishing stability; this can have an obvious negative impact on QoS.

In the wireline world, random early detection (RED) can be used to circumvent global synchronization. By randomly selecting packets from randomly selected packet flows before congestion collapse occurs, global synchronization can be avoided. Queues can be monitored, and when queue depth exceeds a preset limit, RED can be activated, activating a synchronously the TCP senders' transmission rate controllers. This can avoid the initial congestion which would otherwise result in collapse and then global synchronization.

Instead of purely random packet discards, the packets to be discarded can be done with consideration to packet priority or type. While still random, the probability of discard for a given flow can be a function of the by packet priority or type. In a wireless system, weighted random early detection (WRED) can be used without the concern of retransmission and TCP rate reset by preferentially selecting UDP packets of real time IP flows such as streaming audio, and H.323 flows with a more critical packet Time-to-Live parameter. These IP flows are more sensitive to latency and jitter, and less sensitive to packet loss.

In the wireless environment, with an appropriately designed MAC layer, packet loss due to BER that might otherwise trigger congestion collapse and global synchronization can best be managed with local retransmission of lost packets according to the present invention and without RED and the unnecessary retransmission of packets by the TCP sender and the resulting reset of TCP transmission rate. The IP-centric wireless system separately manages the TCP transmission window of the TCP sender remotely by transmitting a packet receipt-acknowledgment before the TCP

sender detects a lost packet and initiates retransmission along with an unnecessary reset of the transmission rate. This IP-centric wireless system TCP transmission window manager communicates with the MAC layer in order to be aware of the status of all packets transmitted over the wireless medium.

b. The Effect of Fractal Self-Similar Network Traffic Characteristics vs. Poisson Distributions on Network Congestion

Conventionally, it has been believed that network traffic can be modeled with a Poisson distribution. Using this distribution leads to the conclusion, through system simulations, that the sum of thousands of individual traffic flows with Poisson distributions results in a uniform overall network traffic distribution. In other words, the overall network can "average-out" the burstiness of individual traffic flows. Using this model, network congestion behavior, burst behavior, and dynamic traffic characteristics have been used to create conventional congestion avoidance strategies, design queue buffer sizes in network devices, and traffic and capacity limitation predictions.

More recent studies have demonstrated that TCP/IP-based traffic causes networks to behave in a fractal, or self-similar fashion. With this model, when the burstiness of individual traffic flows is summed for the entire network, the entire network becomes bursty. The bursty nature of network traffic flow is seen over all time scales and flow scales of the network. This has huge implications both in design of an IP-centric wireless broadband system according to the present invention, and in the design of congestion avoidance strategies in the network as a whole. With this new perspective on network behavior, it has become clear that network routers, switches and transmission facilities in many cases have been "under-engineered." This under-engineering has led to a further exacerbation of the congestion behavior of the network.

The implications for IP-centric wireless system architecture and design range from queue buffer capacity to local congestion avoidance strategies. Because wireless systems have the added burden of a high inherent BER, the effect of network-wide congestion behavior on local (wireless media channel) congestion avoidance strategies must be properly gauged and countered. For this reason, it is desirable that congestion avoidance algorithms of the IP-centric wireless system be crafted to optimize traffic flow with new mathematical and engineering considerations that until very recently were not apparent or available to system designers.

With these considerations in mind, IP-centric wireless system design cannot be done with the conventional wireline system design approaches without resulting in very low system performance characteristics. With traditional design approaches of a circuit-centric wireless system, bandwidth utilization, real time multimedia quality, and overall system QoS provide for a dramatically lower end-user experience.

7. Application-Specific Flow Control in an IP-Centric Wireless System

With a range of data flows, each having different bandwidth, latency and jitter requirements, for the achievement of high QoS as perceived by the end user, it is desirable that the IP-centric wireless system be able to manage QoS mechanism parameters over a wide range, and in real time. The QoS mechanism must be able to alter system behavior to the extent that one or more data flows corresponding to specific applications be switched on and off from appropriate end users in a transparent manner. This approach is in contrast to other QoS mechanisms that seek to achieve high QoS by establishing circuit-centric connections from end to end without regard for an underlying application's actual

QoS requirements. By using the present invention, providing a QoS mechanism that is application-specific rather than circuit-specific, scarce wireless bandwidth can be conserved and dynamically allocated where needed by the QoS mechanisms associated with each application type.

B. QoS and IP-Centric Wireless Media Access Control

1. Proactive Reservation-based Intelligent Multimedia-aware Media Access (PRIMMA) MAC Layer

The present invention's proactive reservation-based intelligent multimedia-aware media access (PRIMMA) media access control (MAC) layer provides an application switching function of the IP-centric wireless QoS mechanism. Once the nature and QoS requirements of each IP stream are determined by other portions of the system, this information is communicated to the PRIMMA MAC layer so that the IP flows of each application can be switched to appropriate destinations in a proper priority order.

2. PRIMMA IP Protocol Stack Vertical Signaling

For IP streams that originate from a local user's CPE, application-level information about the nature of the application can be used by the system to assign appropriate QoS mechanism parameters to the IP stream. For IP streams that originate from a non-local host, information about the IP streams for use in configuring the appropriate QoS mechanism parameters can be extracted from packet headers. The information about the IP streams is communicated "vertically" in the protocol stack model from the application layer (i.e. OSI level 7) to the PRIMMA MAC layer (i.e. OSI level 2) for bandwidth reservation and application switching purposes. Although this violates the conventional practice of providing isolation and independence to each layer of the protocol stack, thereby somewhat limiting the degree of interchangeability for individual layers of the stack, the advantages far outweigh the negatives in an IP-centric wireless broadband access system.

3. PRIMMA IP Flow Control and Application Switching

Based on a specific set of QoS requirements of each IP application flow in the IP-centric wireless system, applications are switched in a "proactive" manner by appropriate reservations of bandwidth over the wireless medium. The wireless transmission frames in each direction are constructed in a manner dictated by the individual QoS requirements of each IP flow. By using QoS requirements to build the wireless transmission frames, optimal QoS performance can result over the entire range of applications being handled by the system. For example, latency and jitter sensitive IP telephony, other H.323 compliant IP streams, and real-time audio and video streams can be given a higher priority for optimal placement in the wireless transmission frames. On the other hand, hypertext transport protocol (HTTP) traffic, such as, e.g., initial web page transmissions, can be given higher bandwidth reservation priorities for that particular application task. Other traffic without latency, jitter, or bandwidth requirements such as, e.g., file transfer protocol (FTP) file downloads, email transmissions, can be assigned a lower priority for system resources and placement in the wireless transmission frame.

4. PRIMMA TCP Transmission Rate Agent

Wireless end users are separated from a high speed, low BER wireline backbone by a lower speed, high BER wireless segment which can be subject to burst error events. TCP/IP traffic that traverses the wireless segment can experience frequent packet loss that, without intervention, can create congestion collapse and global synchronization as previously discussed. Therefore, it is desirable that the present invention's IP-centric wireless system make use of a TCP transmission rate agent that can monitor packet loss

over the wireless segment, and can manage the remote TCP transmission rate function by recreating and transmitting any lost packet acknowledgments. The PRIMMA MAC layer can itself retransmit any lost packets over the wireless medium.

The IP-centric wireless TCP transmission rate agent or "adjunct" can also flow-control the IP streams when necessary, and in accordance with the QoS requirements of the IP flows. All IP-centric wireless TCP transmission rate agent functionality can be transparent to both local and remote hosts and applications.

#### F. Telecommunications Networks

##### 1. Voice Network

###### a. Simple Voice Network

FIG. 1A is a block diagram providing an overview of a standard telecommunications network 100 providing local exchange carrier (LEC) services within one or more local access and transport areas (LATAs). Telecommunications network 100 can provide a switched voice connection from a calling party 102 to a called party 110. FIG. 1A is shown to also include a private branch exchange 112 which can provide multiple users access to LEC services by, e.g., a private line. Calling party 102 and called party 110 can be ordinary telephone equipment, key telephone systems, a private branch exchange (PBX) 112, or applications running on a host computer. Network 100 can be used for modem access as a data connection from calling party 102 to, for example, an Internet service provider (ISP) (not shown). Network 100 can also be used for access to, e.g., a private data network. For example, calling party 102 can be an employee working on a notebook computer at a remote location who is accessing his employer's private data network through, for example, a dial-up modem connection.

FIG. 1A includes end offices (EOs) 104 and 108. EO 104 is called an ingress EO because it provides a connection from calling party 102 to public switched telephone network (PSTN) facilities. EO 108 is called an egress EO because it provides a connection from the PSTN facilities to a called party 110. In addition to ingress EO 104 and egress EO 108, the PSTN facilities associated with telecommunications network 100 include an access tandem (AT) (not shown) at points of presence (POPs) 132 and 134 that can provide access to, e.g., one or more inter-exchange carriers (IXCs) 106 for long distance traffic, see FIG. 2A. Alternatively, it would be apparent to a person having ordinary skill in the art that IXC 106 could also be, for example, a CLEC, or other enhanced service provider (ESP), an international gateway or global point-of-presence (GPOP), or an intelligent peripheral (IP).

FIG. 1A also includes a private branch exchange (PBX) 112 coupled to EO 104. PBX 112 couples calling parties 124 and 126, fax 116, client computer 118 and associated modem 130, and local area network 128 having client computer 120 and server computer 122 coupled via an associated modem 130. PBX 112 is a specific example of a general class of telecommunications devices located at a subscriber site, commonly referred to as customer premises equipment (CPE).

Network 100 also includes a common channel interactive signaling (CCIS) network for call setup and call tear down. Specifically, FIG. 1 includes a Signaling System 7 (SS7) signaling network 114. Signaling network 114 will be described further below with reference to FIG. 2B.

###### b. Detailed Voice Network

FIG. 2A is a block diagram illustrating an overview of a standard telecommunications network 200, providing both LEC and IXC carrier services between subscribers located in

different LATAs. Telecommunications network 200 is a more detailed version of telecommunications network 100. Calling party 102a and called party 110a are coupled to EO switches 104a and 108a, respectively. In other words, calling party 102a is homed to ingress EO 104a in a first LATA, whereas called party 110a is homed to an egress EO 108a in a second LATA. Calls between subscribers in different LATAs are long distance calls that are typically routed to IXCs. Sample IXCs in the United States include AT&T, MCI and Sprint.

Telecommunications network 200 includes access tandems (AT) 206 and 208. AT 206 provides connection to points of presence (POPs) 132a, 132b, 132c and 132d. IXCs 106a, 106b and 106c provide connection between POPs 132a, 132b and 132c (in the first LATA) and POPs 134a, 134b and 134c (in the second LATA). Competitive local exchange carrier (CLEC) 214 provides an alternative connection between POP 132d and POP 134d. POPs 134a, 134b, 134c and 134d, in turn, are connected to AT 208, which provides connection to egress EO 108a. Called party 110a can receive calls from EO 108a, which is its homed EO.

Alternatively, it would be apparent to a person having ordinary skill in the art that an AT 206 can also be, for example, a CLEC, or other enhanced service provider (ESP), an international gateway or global point-of-presence (GPOP), or an intelligent peripheral.

Network 200 also includes calling party 102c homed to CLEC switch 104c. Following the 1996 Telecommunications Act in the U.S., CLECs gained permission to compete for access within the local RBOCs territory. RBOCs are now referred to as incumbent local exchange carriers (ILECs).

###### i. Fixed Wireless CLECs

Network 200 further includes a fixed wireless CLEC 209. Example fixed wireless CLECs are Teligent Inc., of Vienna, Va., WinStar Communications Inc., Advanced Radio Telecom Corp. And the BizTel unit of Teleport Communications Group Inc. Fixed wireless CLEC 209 includes a wireless transceiver/receiver radio frequency (RF) tower 210 in communication over an RF link to a subscriber transceiver RF tower 212. Subscriber RF tower 212 is depicted coupled to a CPE box, PBX 112b. PBX 112b couples calling parties 124b and 126b, fax 116b, client computer 118b and associated modem 130b, and local area network 128b having client computer 120b and server computer 122b coupled via an associated modem 130b.

Network 200 also includes called party 110a, a fax 116a, client computer 118a and associated modem 130a, and cellular communications RF tower 202 and associated cellular subscriber called party 204, all coupled to EO 108a, as shown.

EO 104a, 108a and AT 206, 208 are part of a switching hierarchy. EO 104a is known as a class 5 office and AT 208 is a class 3/4 office switch. Prior to the divestiture of the regional Bell Operating Companies (RBOCs) from AT&T following the modified final judgment, an office classification was the number assigned to offices according to their hierarchical function in the U.S. public switched network (PSTN). An office class is a functional ranking of a telephone central office switch depending on transmission requirements and hierarchical relationship to other switching centers. A class 1 office was known as a Regional Center (RC), the highest level office, or the "office of last resort" to complete a call. A class 2 office was known as a Sectional Center (SC). A class 3 office was known as a Primary Center (PC). A class 4 office was known as either a Toll Center (TC) if operators were present, or otherwise as a Toll Point (TP).

A class 5 office was an End Office (EO), i.e., a local central office, the lowest level for local and long distance switching, and was the closest to the end subscriber. Any one center handles traffic from one or more centers lower in the hierarchy. Since divestiture and with more intelligent software in switching offices, these designations have become less firm. Technology has distributed functionality closer to the end user, diffusing traditional definitions of network hierarchies and the class of switches.

### ii. Connectivity to Internet Service Providers (ISPs)

In addition to providing a voice connection from calling party 102a to called party 110a, the PSTN can provide calling party 102a a data connection to an ISP (i.e. similar to client 118b).

Network 200 can also include an Internet service provider (ISP) (not shown) which could include a server computer 122 coupled to a data network 142 as will be discussed further below with reference to FIG. 1B. The Internet is a well-known, worldwide network comprising several large networks connected together by data links. These links can include, for example, Integrated Digital Services Network (ISDN), T1, T3, FDDI and SONET links. Alternatively, an internet can be a private network interconnecting a plurality of LANs and/or WANs, such as, for example, an intranet. An ISP can provide Internet access services for subscribers such as client 118b.

To establish a connection with an ISP, client 118b can use a host computer connected to a modem (modulator/demodulator) 130b. The modem can modulate data from the host computer into a form (traditionally an analog form) for transmission to the LEC facilities. Typically, the LEC facilities convert the incoming analog signal into a digital form. In one embodiment, the data is converted into the point-to-point protocol (PPP) format. (PPP is a well-known protocol that permits a computer to establish a connection with the Internet using a standard modem. It supports high-quality, graphical user-interfaces.) As those skilled in the art will recognize, other formats are available, including, e.g., a transmission control program, internet protocol (TCP/IP) packet format, a user datagram protocol, internet protocol (UDP/IP) packet format, an asynchronous transfer mode (ATM) cell packet format, a serial line interface protocol (SLIP) protocol format, a point-to-point (PPP) protocol format, a point-to-point tunneling protocol (PPTP) format, a NETBIOS extended user interface (NETBEUI) protocol format, an Appletalk protocol format, a DECnet, BANYAN/VINES, an internet packet exchange (IPX) protocol format, and an internet control message protocol (ICMP) protocol format.

### iii. Communications Links

Note that FIGS. 1A, 2A and other figures described herein include lines which may refer to communications lines or which may refer to logical connections between network nodes, or systems, which are physically implemented by telecommunications carrier devices. These carrier devices include circuits and network nodes between the circuits including, for example, digital access and cross-connect system (DACS), regenerators, tandems, copper wires, and fiber optic cable. It would be apparent to persons having ordinary skill in the art that alternative communications lines can be used to connect one or more telecommunications systems devices. Also, a telecommunications carrier as defined here, can include, for example, a LEC, a CLEC, an IXC, an Enhanced Service Provider (ESP), a global or international services provider such as a global point-of-presence (GPOP), and an intelligent peripheral.

EO 104a and AT 206 are connected by a trunk. A trunk connects an AT to an EO. A trunk can be called an inter

machine trunk (IMT). AT 208 and EO 108a are connected by a trunk which can be an IMT.

Referring to FIG. 1A, EO 104 and PBX 112 can be connected by a private line with a dial tone. A private line can also connect an ISP (not shown) to EO 104, for example. A private line with a dial tone can be connected to a modem bay or access converter equipment at the ISP. Examples of a private line are a channelized T1 or integrated services digital network (ISDN) primary rate interface (PRI). An ISP can also attach to the Internet by means of a pipe or dedicated communications facility. A pipe can be a dedicated communications facility. A private line can handle data modem traffic to and from an ISP.

Trunks can handle switched voice traffic and data traffic. For example, trunks can include digital signals DS1-DS4 transmitted over T1-T4 carriers. Table 2 provides typical carriers, along with their respective digital signals, number of channels, and bandwidth capacities.

TABLE 2

Digital signal	Number of channels	Designation of carrier	Bandwidth in Megabits per second (Mbps)
DS0	1	None	0.064
DS1	24	T1	1.544
DS2	96	T2	6.312
DS3	672	T3	44.736
DS4	4032	T4	274.176

Alternatively, trunks can include optical carriers (OCs), such as OC-1, OC-3, etc. Table 3 provides typical optical carriers, along with their respective synchronous transport signals (STSs), ITU designations, and bandwidth capacities.

TABLE 3

Optical carrier (OC) signal	Electrical signal, or synchronous transport signal (STS)	International Telecommunications Union (ITU) terminology	Bandwidth in Megabits per second (Mbps)
OC-1	STS-1		51.84
OC-3	STS-3	STM-1	155.52
OC-9	STS-9	STM-3	466.56
OC-12	STS-12	STM-4	622.08
OC-18	STS-18	STM-6	933.12
OC-24	STS-24	STM-8	1244.16
OC-36	STS-36	STM-12	1866.24
OC-48	STS-48	STM-16	2488.32

As noted, a private line is a connection that can carry data modem traffic. A private line can be a direct channel specifically dedicated to a customer's use between two specified points. A private line can also be known as a leased line. In one embodiment, a private line is an ISDN/primary rate interface (ISDN PRI) connection. An ISDN PRI connection can include a single signal channel (called a data or D channel) on a T1, with the remaining 23 channels being used as bearer or B channels. (Bearer channels are digital channels that bear voice and data information.) If multiple ISDN PRI lines are used, the signaling for all of the lines can be carried over a single D channel, freeing up the remaining lines to carry only bearer channels.

### iv. Telecommunications Traffic

Telecommunications traffic can be sent and received from any network node of a telecommunications carrier. A telecommunications carrier can include, for example, a LEC, a CLEC, an IXC, and an Enhanced Service Provider (ESP). In an embodiment, this traffic can be received from a network



node which is, for example, a class 5 switch, such as EO 104a, or from a class 3/4 switch, such as AT 206. Alternatively, the network system can also be, for example, a CLEC, or other enhanced service provider (ESP), an international gateway or global point-of-presence (GPOP), or an intelligent peripheral.

Voice traffic refers, for example, to a switched voice connection between calling party 102a and called party 110a. It is important to note that this is on a point-to-point dedicated path, i.e., that bandwidth is allocated whether it is being used or not. A switched voice connection is established between calling party 102a and EO 104a, then to AT 206 then over an IXC's network such as that of IXC 106a to AT 208 and then to EO 108a and over a trunk to called party 110a. In another embodiment, AT 206 or IXC 106a can also be, for example, a CLEC, or other enhanced service provider (ESP), an international gateway or global point-of-presence (GPOP), or an intelligent peripheral.

It is possible that calling party 102a is a computer with a data connection to a server over the voice network. Data traffic refers, for example, to a data connection between a calling party 102a (using a modem) and a server 122b that could be part of an ISP. A data connection can be established, e.g., between calling party 102a and EO 104a, then to AT 206, then to CLEC 214, then over a fixed wireless CLEC 209 link to PBX 112b to a modem 130b associated with server 122b.

c. Signaling Network

FIG. 2B illustrates signaling network 114 in greater detail. Signaling network 114 is a separate network used to handle the set up, tear down, and supervision of calls between calling party 102 and called party 110. Signaling network 114 in the given example is the Signaling System 7 (SS7) network. Signaling network 114 includes service switching points (SSPs) 236, 238, 240 and 242, signal transfer points (STPs) 222, 224, 226, 228, 230 and 232, and service control point (SCP) 234.

In the SS7 network, the SSPs are the portions of the backbone switches providing SS7 functions. The SSPs can be, for example, a combination of a voice switch and an SS7 switch, or a computer connected to a voice switch. The SSPs communicate with the switches using primitives, and create packets for transmission over the SS7 network.

EOs 104a, 108a and ATs 206, 208 can be respectively represented in SS7 signaling network 114 as SSPs 236, 238, 240 and 242. Accordingly, the connections between EOs 104a, 108a and ATs 206, 208 (presented as dashed lines) can be represented by connections 254, 256, 258 and 268. The types of these links are described below.

The STPs act as routers in the SS7 network, typically being provided as adjuncts to in-place switches. The STPs route messages from originating SSPs to destination SSPs. Architecturally, STPs can and are typically provided in "mated pairs" to provide redundancy in the event of congestion or failure and to share resources (i.e., load sharing is done automatically). As illustrated in FIG. 2B, STPs can be arranged in hierarchical levels, to provide hierarchical routing of signaling messages. For example, mated STPs 222, 224 and mated STPs 226, 228 are at a first hierarchical level, while mated STPs 230, 232 are at a second hierarchical level.

SCPs provide database functions. SCPs can be used to provide advanced features in an SS7 network, including routing of special service numbers (e.g., 800 and 900 numbers), storing information regarding subscriber services, providing calling card validation and fraud protection, and offering advanced intelligent network (AIN) services. SCP 234 is connected to mated STPs 230 and 232.

In the SS7 network, there are unique links between the different network elements. Table 4 provides definitions for common SS7 links.

Referring to FIG. 2B, mated STP pairs are connected by C links. For example, STPs 222, 224, mated STPs 226, 228, and mated STPs 230, 232 are connected by C links (not labeled). SSPs 236, 238 and SSPs 240, 242 are connected by F links 262 and 264.

Mated STPs 222, 224 and mated STPs 226, 228, which are at the same hierarchical level, are connected by B links 270, 272, 244 and 282. Mated STPs 222, 224 and mated STPs 230, 232, which are at different hierarchical levels, are connected by D links 266, 268, 274 and 276. Similarly, mated STPs 226, 228 and mated STPs 230, 232, which are at different hierarchical levels, are connected by D links 278, 280, 246 and 248.

SSPs 236, 238 and mated STPs 222, 224 are connected by A links 254 and 256. SSPs 240, 242 and mated STPs 226, 228 are connected by A links 258 and 260.

SSPs 236, 238 can also be connected to mated STPs 230, 232 by E links (not shown). Finally, mated STPs 230, 232 are connected to SCP 234 by A links 250 and 252.

For a more elaborate description of SS7 network topology, the reader is referred to Russell, Travis, Signaling System #7, McGraw-Hill, New York, N.Y. 10020, ISBN 0-07-054991-5, which is incorporated herein by reference in its entirety.

TABLE 4

SS7 link terminology	Definitions
Access (A) links	A links connect SSPs to STPs, or SCPs to STPs, providing network access and database access through the STPs.
Bridge (B) links	B links connect mated STPs to other mated STPs.
Cross (C) links	C links connect the STPs in a mated pair to one another. During normal conditions, only network management messages are sent over C links.
Diagonal (D) links	D links connect the mated STPs at a primary hierarchical level to mated STPs at a secondary hierarchical level.
Extended (E) links	E links connect SSPs to remote mated STPs, and are used in the event that the A links to home mated STPs are congested.
Fully associated (F) links	F links provide direct connections between local SSPs (bypassing STPs) in the event there is much traffic between SSPs, or if a direct connection to an STP is not available. F links are used only for call setup and call teardown.

d. SS7 Signaled Call Flow

To initiate a call in an SS7 telecommunications network, a calling party using a telephone connected to an ingress EO switch, dials a telephone number of a called party. The telephone number is passed from the telephone to the SSP at the ingress EO of the calling party's local exchange carrier (LEC). First, the SSP can process triggers and internal route rules based on satisfaction of certain criteria. Second, the SSP can initiate further signaling messages to another EO or access tandem (AT), if necessary. The signaling information can be passed from the SSP to STPs, which route the signals between the ingress EO and the terminating end office, or egress EO. The egress EO has a port designated by the telephone number of the called party. The call is set up as a direct connection between the EOs through tandem switches if no direct trunking exists or if direct trunking is full. If the call is a long distance call, i.e., between a calling party and a called party located in different local access transport areas (LATAs), then the call is connected through an inter

exchange carrier (IXC) switch. Such a long distance call is commonly referred to as an inter-LATA call. LECs and IXCs are collectively referred to as the public switched telephone network (PSTN).

Passage of the Telecommunications Act of 1996, authorizing competition in the local phone service market, has permitted CLECs to compete with ILECs in providing local exchange services. This competition, however, has still not provided the bandwidth necessary to handle the large volume of voice and data communications. This is due to the limitations of circuit switching technology which limits the bandwidth of the equipment being used by the LECs, and to the high costs of adding additional equipment.

#### c. Circuit-Switching

Circuit switching dedicates a channel to a call for the duration of the call. Thus, using circuit switching, a large amount of switching bandwidth is required to handle the high volume of voice calls. This problem is compounded by the use of voice circuits to carry data communications over the same equipment that were designed to handle voice communications.

#### i. Time Division Multiplexed (TDM) Circuit Switching

TDM circuit switching creates a full-time connection or a dedicated circuit between any two attached devices for the duration of the connection. TDM divides the bandwidth down into fixed time slots in which there can be multiple time slots, each with its own fixed capacity, available. Each attached device on the TDM network is assigned a fixed portion of the bandwidth using one or more time slots depending on the need for speed. When the device is in transmit mode, the data is merely placed in this time slot without any extra overhead such as processing or translations. Therefore, TDM is protocol transparent to the traffic being carried. Unfortunately, however, when the device is not sending data, the time slots remain empty, thereby wasting the use of the bandwidth. A higher-speed device on the network can be slowed down or bottled up waiting to transmit data, but the capacity that sits idle cannot be allocated to this higher priority device for the duration of the transmission. TDM is not well suited for the bursts of data that are becoming the norm for the data needs in today's organization.

#### 2. Data Network

FIG. 1B depicts an example network 148 including workstations 144 and 146 coupled to data network 142. Data network 142 can act as a wide area network (WAN) for coupling a plurality of local area networks (LANs) together. Network 148 includes an example local area network including a plurality of host computers such as, e.g., client workstation 138 and server 136, coupled together by wiring including network interface cards (NICs) and a hub, such as, e.g., an Ethernet hub. The LAN is coupled to data network 142 by a network router 140 which permits data traffic to be routed to workstations 144 and 146 from client 138 and server 136.

#### a. Packet-Switching

Unlike voice networks 100 and 200 described above with reference to FIGS. 1A and 2A which transport traffic over circuit-switched connections, data network 148 transports traffic using packet switching.

Currently, internets, intranets, and similar public or private data networks that interconnect computers generally use packet switching technology. Packet switching provides for more efficient use of a communication channel than does circuit switching. Packet switched networks transport packets of information which can include various types of data such as, e.g., digitized voice, data, and video. With packet

switching, many different calls can share a communication channel rather than the channel being dedicated to a single call. During a voice call, for instance, digitized voice information might be transferred between the callers only 60% of the time, with silence being transferred the other 40% of the time. With a circuit switched connection, the voice call could tie-up a communications channel that could have 50% of its bandwidth, unused because of the silence. For a data call, information might be transferred between two computers only 10% of the time. With the data call, 90% of the channel's bandwidth may go unused. In contrast, a packet-switched connection would permit the voice call, the data call and possibly other call information to all be sent over the same channel.

Packet switching breaks a media stream into pieces known as, for example, packets, cells or frames. Each packet can then be encoded with address information for delivery to the proper destination and can be sent through the network. The packets can be received at the destination and the media stream is reassembled into its original form for delivery to the recipient. This process is made possible using an important family of communications protocols, commonly called the Internet Protocol (IP).

In a packet-switched network, there is no single, unbroken physical connection between sender and receiver. The packets from many different calls share network bandwidth with other transmissions. The packets can be sent over many different routes at the same time toward the destination, and can then be reassembled at the receiving end. The result is much more efficient use of a telecommunications network's bandwidth than could be achieved with circuit-switching.

#### b. Routers

Data network 142 can include a plurality of network routers 140. Network routers are used to route information between multiple networks. Routers act as an interface between two or more networks. Routers can find the best path between any two networks, even if there are several different networks between the two networks.

Network routers can include tables describing various network domains. A domain can be thought of as a local area network (LAN) or wide area network (WAN). Information can be transferred between a plurality of LANs and/or WANs via network routers. Routers look at a packet and determine from the destination address in the header of the packet, the destination domain of the packet. If the router is not directly connected to the destination domain, then the router can route the packet to the router's default router, i.e. a router higher in a hierarchy of routers. Since each router has a default router to which it is attached, a packet can be transmitted through a series of routers to the destination domain and to the destination host bearing the packet's final destination address.

#### C. Local Area Networks (LANs) and Wide Area Networks (WANs)

A local area network (LAN) can be thought of as a plurality of host computers interconnected via network interface cards (NICs) in the host computers. The NICs are connected via, for example, copper wires so as to permit communication between the host computers. Examples of LANs include an ethernet bus network, an ethernet switch network, a token ring network, a fiber digital data interconnect (FDDI) network, and an ATM network.

A wide area network (WAN) is a network connecting host computers over a wide area. In order for host computers on a particular LAN to communicate with a host computer on another LAN or on a WAN, network interfaces interconnecting the LANs and WANs must exist. An example of a network interface is a router discussed above.

A network designed to interconnect multiple LANs and/or WANs is known as an internet (with a lower case "i"). An internet can transfer data between any of a plurality of networks including both LANs and WANs. Communication occurs between host computers on one LAN and host computers on another LAN via, for example, an internet protocol (IP) protocol. The IP protocol is used to assign each host computer of a network, a unique IP address enabling packets to be transferred over the internet to other host computers on other LANs and/or WANs that are connected to the internet. An internet can comprise a router interconnecting two or more networks.

The "Internet" (with a capital "I") is a global internet interconnecting networks all over the world. The Internet includes a global network of computers which intercommunicate via the internet protocol (IP) family of protocols.

An "intranet" is an internet which is a private network that uses internet software and internet standards, such as the internet protocol (IP). An intranet can be reserved for use by parties who have been given the authority necessary to use that network.

#### d. Switching vs. Routing

Routing is done at the middle network architecture levels on such protocols as IPX or TCP/IP. Switching is done at a lower level, at layer 2 of the OSI model, i.e. the media access control (MAC) layer.

#### c. TCP/IP Packet-Centric vs. ATM Circuit-Centric Data Networks

Asynchronous Transfer Mode (ATM) is a fixed-size cell switched circuit-centric data network. ATM implements virtual circuits (VCS), virtual paths (VPs) and transmission paths (TPs). A circuit-centric network like ATM sets up virtual circuits between source and destination nodes which provide QoS by dedicating the virtual circuit to a specific traffic type.

Some networks are packet-centric networks. Unlike a circuit-centric network, a packet-centric network does not use dedicated circuits through which to transfer packets. TCP/IP performs a packetization of user data to be sent between and among the various systems on the IP network. When a large file is sent down the protocol stack, the IP function is responsible for segmentation and packetization of the data. Then a header is placed on the packet for delivery to the data link. The routing and switching of this data is handled at the IP (i.e. network) layer. IP is in a sense a dumb protocol. When a packet is prepared for transmission across the medium, IP does not specifically route the call across a specific channel. Instead, it places a header on the packet and lets the network deal with it. Therefore, the outward bound packets can take various routes to get from a source to a destination. This means that the packets are in a datagram form and not sequentially numbered as they are in other protocols. IP makes its best attempt to deliver the packets to the destination network interface; but it makes no assurances that data will arrive, that data will be free of errors, and that nodes along the way will concern themselves with the accuracy of the data and sequencing, or come back and alert the originator that something is wrong in the delivery mechanism. It is possible that in IP routing of a packet, the packet can be sent along the network in a loop, so IP has a mechanism in its header information to allow a certain number of "hops" or what is called "time to live" on the network. Rather than permit an undeliverable pack to loop around the network, IP has a counter mechanism that decrements every time the packet passes through a network node. If the counter expires, the node will discard the packet. Working together with IP is TCP which provides controls to

ensure that a reliable data stream is sent and delivered. At the sending end, TCP puts a byte count header on information that will be delivered to the IP protocol layer and encapsulates it as part of the packet. The receiving end, when it gets packets is responsible for resequencing the packets and ensuring its accuracy. If all of the IP flow is not received correctly, the byte count acknowledgment or nonacknowledgment message can be sent back to the sending end, prompting the sending end to resend the bytes necessary to fill in the remaining portions of the packet flow. TCP buffers additional packets until after resending the nonacknowledged packet.

#### 3. Video Network

FIG. 1C illustrates a conventional video network 150 such as, e.g., a cable television (CATV) network. Video network 150 can include video network 160 coupled to various video capture, distribution links and video output monitors. Video input devices can include, e.g., conference cameras 154 and 158. Video output devices can include, e.g., televisions 152 and 156. Video network 160 can include a variety of head end (i.e. the serving end of the cable) and distribution link equipment such as, e.g., coaxial cable television (CATV) and national television standard code (NTSC) tuner equipment for multiplexing various video signals. Standard cable systems have an immense amount of bandwidth available to them.

It is important to note that CATV is a wireless communication method. The frequencies of many video signals are distributed along the cable at the same time. A television tuner selects a particular channel by tuning into a specific frequency or a "frequency band."

Although a cable television CATV video network often includes only one physical cable, a number of channels can simultaneously be present on the cable. This accomplished by sharing the frequency spectrum of the cable and assigning different frequency ranges to different channels using frequency division multiplexing (FDM). A broadband cable communications system can operate exactly like a CATV system. A counter to this FDM technique is division of the cable not divided into frequency bands but into time slots using time-division multiplexing (TDM). With TDM, each transmitting video station can grab the entire bandwidth of the cable, but only for a very short period of time. The cable is currently capable of carrying up to 750 MHz. FDM techniques can be used to divide the channels into a number of dedicated logical channels. Innovations have allowed a time division multiple access (TDMA) within an FDM channel.

A cable system can allow multiplexing on two separate dimensions to achieve data channels over a cable. The channels can be separated by FDM, and in a frequency band the channel can then be shared via TDMA among multiple users. The most common of the TDMA access methods on broadband cable is CSMA/CD developed by XEROX for Ethernet.

Using a single cable, a midsplit arrangement can accommodate two-way simultaneous transmission. Another way to accommodate this is to use a dual cable system.

Broadband is inherently an analog signaling method. Because video cameras, e.g., are also analog devices, a signal from a video camera (or video recorder) can be directly transmitted onto a broadband cable channel in red/green/blue (RGB) format.

#### G. Convergence of Voice/Data/Video Networks

Recognizing the inherent efficiency of packet-switched data networks such as the Internet, attention has recently focused on the digitization and transmission of voice, data,

video and other information over converged packet-switched data networks. In order to deliver a high quality of service (QoS) end-user experience, the data networks attempt to provide mechanisms to deliver the different types of information timely and with appropriate bandwidth to provide an acceptable end-user experience.

FIG. 2C illustrates an example network 286 carrying voice, data and video traffic over a data network. Network 286 includes calling party 102b homed to EO 104b, where EO 104b is linked to a telephony gateway 288b. Network 286 also includes called party 110c homed to EO 108c, where EO 108c is linked to a telephony gateway 288c. EOs 104b and 108c and telephony gateways 288b and 288c can be linked to signaling network 114. Telephony gateways 288b and 288c can also be coupled to data network 142 via routers 140b and 140c, respectively.

Still referring to FIG. 2C, telephony gateways 288b and 288c can be used to packetize voice traffic and signaling information into a form appropriate for transport over data network 142. It would be apparent to those skilled in the art that telephony gateways 288b and 288c can include various computer devices designed for controlling, setting up and tearing down calls. Voice calls delivered over the data network can include, e.g., voice over packet (VoP), voice over data (VoD), voice over internet protocol (VoIP), voice over asynchronous transfer mode (VoATM), voice over frame (VoF). An example of a telephony gateway 288b and 288c is a media gateway control protocol (MGCP) compliant gateway available from various vendors such as, e.g., Lucent, of Parsippany, N.J., and CISCO of Palo Alto, Calif. It is important to note that other network devices such as a softswitch available from several member companies of the SoftSwitch Consortium, including Level 3 Communications of Louisville, Colo., could also be necessary to enable transport of, e.g., VoIP.

Network 286 is depicted to include other devices coupled to data network 142. First, an H.323 compliant video-conferencing system 289 is illustrated including a camera 154g and television 152g and router 140g. Second, a local area network (LAN) 128a including a client workstation 138a and a server 136a are coupled to data network 142 via network router 140a. Similarly, LAN 128f having a client workstation 138f and a server 136f are coupled via network router 140f to data network 142.

Data Network 142 can provide for routing of packets of information through network routing devices from source locations to destination locations coupled to data network 142. For example, data network 142 can route internet protocol (IP) packets for transmission of voice and data traffic from telephony gateway 288b to telephony gateway 288c. Data Network 142 represents any art-recognized packet centric data network. One well-known data network is the global Internet. Other examples include a private intranet, a packet-switched network, a frame relay network, and an asynchronous transfer mode (ATM) circuit-centric network.

In an example embodiment, data network 142 can be an IP packet-switched network. A packet-switched network such as, e.g., an IP network, unlike a circuit-switched network, does not require dedicated circuits between originating and terminating locations within the packet switched network. The packet-switched network instead breaks a message into pieces known as packets of information. Such packets can then be encapsulated with a header which designates a destination address to which the packet must be routed. The packet-switched network then takes the packets and routes them to the destination designated by the destination address contained in the header of the packet.

Routers 140a, 140b, 140c, 140d, 140e, 140f and 140g can be connected to one another via physical media such as, for example, optical fiber link connections, and copper wire connections. Routers 140a-g transfer information between one another and intercommunicate according to routing protocols.

Data network 142 could be implemented using any data network such as, e.g., IP networks, ATM virtual circuit-centric networks, frame relay networks, X.25 networks, and other kinds of LANs and WANs. Other data networks could be used interchangeably for data network 142 such as, for example, FDDI, Fast Ethernet, or an SMDS packet switched network. Frame relay and ATM are connection-oriented, circuit-centric services. Switched multi-megabyte data service (SMDS) is a connection-oriented mass packet service that offers speeds up to 45 Mbps.

#### 1. Example Data Networks

##### a. Asynchronous Transfer Mode (ATM)

ATM is a high-bandwidth, low-delay, fixed-sized cell-based multiplexing network technology. Bandwidth capacity is segmented into 53-byte cells, having a header and payload fields. ATM uses fixed-length cells with the belief that the fixed length cells can be switched more easily in hardware than variable size packets and thus should result in faster transmissions in certain environments.

The ATM environment sets up virtual circuits in a circuit-centric manner. Thus, ATM segments variable length IP packet flows into fixed size cells using a segmentation and resequencing algorithm (SAR).

Each ATM cell contains a 48-byte payload field and a 5-byte header that identifies the so-called "virtual circuit" of the cell. ATM is thought suitable for high-speed combinations of voice, data, and video services. Currently, ATM access can perform at speeds as high as 622 Mbps or higher. ATM has recently been doubling its maximum speed every year.

ATM is defined by a protocol standardized by the International Telecommunications Union (ITU-T), American National Standards Institute (ANSI), ETSI, and the ATM Forum. ATM comprises a number of building blocks, including transmission paths, virtual paths, and virtual channels. Asynchronous transfer mode (ATM) is a cell based switching and multiplexing technology designed to be a general purpose connection-oriented transfer mode for a wide range of telecommunications services. ATM can also be applied to LAN and private network technologies as specified by the ATM Forum.

ATM handles both connection-oriented traffic directly or through adaptation layers, or connectionless traffic through the use of adaptation layers. ATM virtual connections may operate at either a constant bit rate (CBR) or a variable bit rate (VBR). Each ATM cell sent into an ATM network contains a small header including information that establishes a virtual circuit-centric connection from origination to destination. All cells are transferred, in sequence, over this virtual connection. ATM provides either permanent or switched virtual connections (PVCs or SVCs). ATM is asynchronous because the transmitted cells need not be periodic as time slots of data are required to be in synchronous transfer mode (STM).

ATM uses an approach by which a header field prefixes each fixed-length payload. The ATM header identifies the virtual channel (VC). Therefore, time slots are available to any host which has data ready for transmission. If no hosts are ready to transmit, then an empty, or idle, cell is sent.

ATM permits standardization on one network architecture defining a multiplexing and a switching method. Synchron-

nous optical network (SONET) provides the basis for physical transmission at very high-speed rates. ATM can also support multiple quality of service (QoS) classes for differing application requirements by providing separate virtual circuits for different types of traffic, depending on delay and loss performance. ATM can also support LAN-like access to available bandwidth.

Cells are mapped into a physical transmission path, such as the North American DS1, DS3, and SONET; European, E1, E3, and E4; ITU-T STM standards; and various local fiber and electrical transmission payloads. All information is multiplexed and switched in an ATM network via these fixed-length cells.

The ATM cell header field identifies cell type, and priority, and includes six portions. An ATM cell header includes a generic flow control (GFC), a virtual path identifier (VPI), a virtual channel identifier (VCI), a payload type (PT), a call loss priority (CLP), and a header error check (HEC). VPI and VCI hold local significance only, and identify the destination. GFC allows a multiplexer to control the rate of an ATM terminal. PT indicates whether the cell contains user data, signaling data, or maintenance information. CLP indicates the relative priority of the cell, i.e., lower priority cells are discarded before higher priority cells during congested intervals. HEC detects and corrects errors in the header.

The ATM cell payload field is passed through the network intact, with no error checking or correction. ATM relies on higher-layer protocols to perform error checking and correction on the payload. For example, a transmission control protocol (TCP) can be used to perform error correction functions. The fixed cell size simplifies the implementation of ATM switches and multiplexers and enables implementations at high speeds.

When using ATM, longer packets cannot delay shorter packets as in other packet-switched networks, because long packets are separated into many fixed length cells. This feature enables ATM to carry CBR traffic, such as voice and video, in conjunction with VBR data traffic, potentially having very long packets, within the same network.

ATM switches take traffic and segment it into the fixed-length cells, and multiplex the cells into a single bit stream for transmission across a physical medium. As an example, different kinds of traffic can be transmitted over an ATM network including voice, video, and data traffic. Video and voice traffic are very time-sensitive, so delay cannot have significant variations. Data, on the other hand, can be sent in either connection-oriented or connectionless mode. In either case, data is not nearly as delay-sensitive as voice or video traffic. Data traffic, as e.g., spread sheet data requires accurate transmission. Therefore, ATM conventionally must discriminate between voice, video, and data traffic. Voice and video traffic requires priority and guaranteed delivery with bounded delay, while data traffic requires, simultaneously, assurance of low loss. In a converged data network, data traffic can also carry voice traffic, making it also time-dependent. Using ATM, in one embodiment, multiple types of traffic can be combined over a single ATM virtual path (VP), with virtual circuits (VCs) being assigned to separate data, voice, and video traffic.

A transmission path can include one or more VPs. Each VP can include one or more VCs. Thus, multiple VCs can be trunked over a single VP. Switching can be performed on a transmission path, VPs, or at the level of VCs.

The capability of ATM to switch to a virtual channel level is similar to the operation of a private or public branch exchange (PBX) or telephone switch in the telephone world. In a PBX switch, each channel within a trunk group can be

switched. Devices which perform VC connections are commonly called VC switches because of the analogy to telephone switches. ATM devices which connect VPs are commonly referred to as VP cross-connects, by analogy with the transmission network. The analogies are intended for explanatory reasons, but should not be taken literally. An ATM cell-switching machine need not be restricted to switching only VCs and cross-connection to only VPs.

At the ATM layer, users are provided a choice of either a virtual path connection (VPC) or a virtual channel connection (VCC). Virtual path connections (VPCs) are switched based upon the virtual path identifier (VPI) value only. Users of a VPC can assign VCCs within a VPI transparently, since they follow the same route. Virtual channel connections (VCCs) are switched upon a combined VPI and virtual channel identifier (VCI) value.

Both VPIs and VCIs are used to route calls through a network. Note that VPI and VCI values must be unique on a specific transmission path (TP).

It is important to note that data network 142 can be any of a number of other data-type networks, including various packet-switched data-type networks, in addition to an ATM network.

#### b. Frame Relay

Alternatively, data network 142 can be a frame relay network. It would be apparent to persons having ordinary skill in the art, that a frame relay network could be used as data network 142. Rather than transporting data in ATM cells, data could be transported in frames.

Frame relay is a packet-switching protocol used in WANs that has become popular for LAN-to-LAN connections between remote locations. Formerly frame relay access would top out at about 1.5 Mbps. Today, so-called "high-speed" frame relay offers around 45 Mbps. This speed is still relatively slow as compared with other technology such as ATM.

Frame relay services employ a form of packet-switching analogous to a streamlined version of X.25 networks. The packets are in the form of frames, which are variable in length. The key advantage to this approach is that a frame relay network can accommodate data packets of various sizes associated with virtually any native data protocol. A frame relay network is completely protocol independent. A frame relay network embodiment of data network 142 does not undertake a lengthy protocol conversion process, and therefore offers faster and less-expensive switching than some alternative networks. Frame relay also is faster than traditional X.25 networks because it was designed for the reliable circuits available today and performs less-rigorous error detection.

#### c. Internet Protocol (IP)

In an embodiment, data network 142 can be an internet protocol (IP) network over an ATM network. It would be apparent to those skilled in the art, that an internet protocol (IP) network over various other data link layer network such as, e.g., Ethernet, could be used as data network 142. Rather than transporting data in fixed length ATM circuit-centric cells, data could be transported in variable length IP datagram packet-centric packets as segmented by TCP. The IP data network can lie above any of a number of physical networks such as, for example, a SONET optical network.

#### 2. Virtual Private Networks (VPNs)

A virtual private network (VPN) is a wide area communications network operated by a telecommunications carrier that provides what appears to be dedicated lines when used, but that actually includes trunks shared among all customers as in a public network. Just as a VPN can be provided as a

service through a wireline network, a VPN can be provided in a wireless network. A VPN can allow a private network to be configured within a public network.

VPNs can be provided by telecommunications carriers to customers to provide secure, guaranteed, long-distance bandwidth for their WANs. These VPNs generally use frame relay or switched multi-megabyte data service (SMDS) as a protocol of choice because those protocols define groups of users logically on the network without regard to physical location. ATM has gained favor as a VPN protocol as companies require higher reliability and greater bandwidth to handle more complex applications. VPNs using ATM offer networks of companies with the same virtual security and QoS as WANs designed with dedicated circuits.

The Internet has created an alternative to VPNs, at a much lower cost, i.e. the virtual private Internet. The virtual private Internet (VPI) lets companies connect disparate LANs via the Internet. A user installs either a software-only or a hardware-software combination that creates a shared, secure intranet with VPN-style network authorizations and encryption capabilities. A VPI normally uses browser-based administration interfaces.

### 3. H.323 Video Conferencing

The H.323 Recommendation for video conferencing will now be briefly overviewed. The H.323 standard provides a foundation for, for example, audio, video, and data communications across IP-based networks, including the Internet. By complying with the H.323 Recommendation, multimedia products and applications from multiple vendors can interoperate, allowing users to communicate without concern for compatibility. H.323 promises to be the foundation of future LAN-based products multimedia applications.

H.323 is an umbrella recommendation from the International Telecommunications Union (ITU) that sets standards for multimedia communications over Local Area Networks (LANs) that do not provide a guaranteed Quality of Service (QoS). These networks dominate today's corporate desktops and include packet-switched TCP/IP and IPX over Ethernet, Fast Ethernet and Token Ring network technologies. Therefore, the H.323 standards are important building blocks for a broad new range of collaborative, LAN-based applications for multimedia communications.

The H.323 specification was approved in 1996 by the ITU's Study Group 16. Version 2 was approved in January 1998. The standard is broad in scope and includes both stand-alone devices and embedded personal computer technology as well as point-to-point and multipoint conferences. H.323 also addresses call control, multimedia management, and bandwidth management as well as interfaces between LANs and other networks.

H.323 is part of a series of communications standards that enable videoconferencing across a range of networks. Known as H.32X, this series includes H.320 and H.324, which address ISDN and PSTN communications, respectively.

The H.323 architecture defines four major components for network-based communications, including terminals, gateways, gatekeepers, and multipoint control units (MCUs).

Terminals are client endpoints on the LAN that provide real-time, two-way communications. All terminals support voice communications; video and data are optional. H.323 specifies the modes of operation required for different audio, video, and/or data terminals to work together. H.323 is the standard of next generation Internet phones, audio conferencing terminals, and video conferencing technologies.

All H.323 terminals also support H.245, which is used to negotiate channel usage and capabilities. Three other com-

ponents are required: Q.931 for call signaling and call setup, a component called Registration/Admission/Status (RAS), which is a protocol used to communicate with a gatekeeper; and support for RTP/RTCP for sequencing audio and video packets.

Optional components in an H.323 terminal are video codecs, T.120 data conferencing protocols, and MCU capabilities.

A gateway is an optional element in an H.323 conference. An H.323 gateway can provide many services, the most common being a translation function between H.323 conferencing endpoints and other terminal types. This function includes translation between transmission formats (i.e. H.225.0 to H.221) and between communications procedures (i.e. H.245 to H.242). In addition, a gateway also translates between audio and video codecs and performs call setup and clearing on both the LAN side and the switched-circuit network side.

In general, the purpose of the H.323 gateway is to reflect characteristics of a LAN endpoint to an SCN endpoint and vice versa. The primary applications of gateways are likely to be establishing links with analog PSTN terminals, establishing links with remote H.320 compliant terminals over ISDN-based switched-circuit networks, and establishing links with remote H.324-compliant terminals over PSTN networks.

Gateways are not required if connections to other networks are not needed, since endpoints may directly communicate with other endpoints on the same LAN. Terminals communicate with gateways using the H.245 and Q.931 protocols.

With the appropriate transcoders, H.323 gateways 5806 can support terminals that comply with H.310, H.321, H.322, and V.70.

Many gateway functions are left to the designer. For example, the actual number of H.323 terminals that can communicate through the gateway is not subject to standardization. Similarly, the number of SCN connections, the number of simultaneous independent conferences supported, the audio/video/data conversion functions, and inclusion of multipoint functions are left to the manufacturer. By incorporating H.323 gateway technology into the H.323 specification, the ITU has positioned H.323 as the means to hold standards-based conferencing endpoints together.

The gatekeeper is the most important component of an H.323 enabled network. It can act as the central point for all calls within its zone and provides call control services to registered endpoints. In many ways, an H.323 gatekeeper acts as a virtual switch.

Gatekeepers perform two important call control functions. The first is address translation from LAN aliases for terminals and gateways to IP or IPX addresses, as defined in the RAS specification. The second function is bandwidth management, which is also designated within RAS. For instance, if a network manager has specified a threshold for the number of simultaneous conferences on the LAN, the gatekeeper can refuse to make any more connections once the threshold is reached. The effect is to limit the total conferencing bandwidth to some fraction of the total available; the remaining capacity is left for e-mail, file transfers, and other LAN protocols. A collection of all terminals, gateways, and multipoint control units which can be managed by a single gatekeeper are known as an H.323 Zone.

An optional, but valuable feature of a gatekeeper is its ability to route H.323 calls. By routing a call through a gatekeeper, it can be controlled more effectively. Service

providers need this ability in order to bill for calls placed through their network. This service can also be used to re-route a call to another endpoint if a called endpoint is unavailable. In addition, a gatekeeper capable of routing H.323 calls can help make decisions involving balancing among multiple gateways. For instance, if a call is routed through a gatekeeper, that gatekeeper can then re-route the call to one of many gateways based on some proprietary routing logic.

While a gatekeeper is logically separate from H.323 endpoints, vendors can incorporate gatekeeper functionality into the physical implementation of gateways and MCUs.

A gatekeeper is not required in an H.323 system. However, if a gatekeeper is present, terminals must make use of the services offered by gatekeepers. RAS defines these as address translation, admissions control, bandwidth control, and zone management.

Gatekeepers can also play a role in multipoint connections. To support multipoint conferences, users would employ a gatekeeper to receive H.245 control channels from two terminals in a point-to-point conference. When the conference switches to multipoint, the gatekeeper can redirect the H.245 Control Channel to a multipoint controller, the MC. A gatekeeper need not process the H.245 signaling; it only needs to pass it between the terminals or between the terminals and the MC.

LANs which contain gateways could also contain a gatekeeper to translate incoming E.164 addresses into Transport Addresses. Because a Zone is defined by its gatekeeper, H.323 entities that contain an internal gatekeeper can require a mechanism to disable the internal function so that when there are multiple H.323 entities that contain a gatekeeper on a LAN, the entities can be configured into the same Zone.

The Multipoint Control Unit (MCU) supports conferences between three or more endpoints. Under H.323, an MCU consists of a Multipoint Controller (MC), which is required, and zero or more Multipoint Processors (MP). The MC handles H.245 negotiations between all terminals to determine common capabilities for audio and video processing. The MC also controls conference resources by determining which, if any, of the audio and video streams will be multicast.

The MC does not deal directly with any of the media streams. This is left to the MP, which mixes, switches, and processes audio, video, and/or data bits. MC and MP capabilities can exist in a dedicated component or be part of other H.323 components.

The present invention supports multicast for wireless base station 302, including providing: compatibility with RFC 1112, 1584; recognition and support of multicasting applications, including: multimedia, teleconferencing, database, distributed computing, real-time workgroups; support of broadcasting function over wireless link; preserves bandwidth, retains QoS latency performance; support of IPv6 IGMP and IPv4 IGMP multicast; group membership query, group membership report messages.

Approved in January of 1998, version 2 of the H.323 standard addresses deficiencies in version 1 and introduces new functionality within existing protocols, such as Q.931, H.245 and H.225, as well as entirely new protocols. The most significant advances were in security, fast call setup, supplementary services and T.120/H.323 integration.

G. Packet-Centric QoS-Aware Wireless Point-to-MultiPoint (PtMP) Telecommunications System  
1. Wireless Point-to-MultiPoint Telecommunications System

FIG. 2D depicts network 296 including a point-to-multipoint (PtMP) wireless network 298 coupled via router

140d to data network 142. It is important to note that network 296 includes network 286 from FIG. 2C, plus PtMP wireless network 298. PtMP wireless network 298 enables customer premise equipment (CPE) at a subscriber location to gain access to the various voice, data and video resources coupled to data network 142 by means of wireless connectivity over a shared bandwidth. The wireless PtMP network 298 is a packet switched network which is TCP/IP packet-centric (i.e. no dedicated circuit is created in delivering a communication IP flow) and QoS aware.

Specifically, PtMP wireless network 298 includes a wireless access point (WAP) 290d coupled to router 140d by, e.g., a wireline connection. A wireless access point 290e can be similarly coupled to router 140e by a wireline connection. WAP 290d is in wireless communication, such as, e.g., radio frequency (RF) communication, with one or more wireless transceiver subscriber antennae 292d and 292e. It would be apparent to those skilled in the art that various wireless communication methods could be used such as, e.g., microwave, cellular, spread spectrum, personal communications systems (PCS), and satellite.

In an alternative embodiment, RF communication is accomplished over cable television (CATV) coaxial cable. As those skilled in the relevant art will understand, a coaxial cable functions as a waveguide over which RF waves propagate. Accordingly, it is possible for the communications link between RF transceiver subscriber antenna 292d and WAP 290d to be a coaxial cable. Therefore, a coaxial cable connection is analogous to a wireless connection, and is referred to as an alternative form of wireless connection in the present invention.

In another alternative embodiment, RF communication is accomplished over a satellite connection, such as, e.g., a low earth orbit (LEO) satellite connection or a high earth orbit satellite. Taking the example of an LEO satellite connection, WAP 290d and RF transceiver subscriber antenna 292d function as satellite gateways, with the additional functionalities described in the present invention.

As would be apparent to those skilled in the art, although the present invention has been described in the context of a point-to-multi-point network, the invention is equally applicable to a point-to-point network environment.

Referring to FIG. 3A, in an embodiment of the invention, WAPs 290d and 290e can be coupled to a wireless base station 302 where "IP flow" traffic can be queued, analyzed, characterized, classified, prioritized and scheduled, as described more fully below with reference to the ensuing figures.

Referring to FIG. 3B, one embodiment of the invention, antennae 292d and 292e are coupled to subscriber customer premise equipment (CPE) stations 294d and 294e, respectively (also referred to as CPEs 294d, 294e). Subscriber CPE stations 294d and 294e are coupled to various other CPE equipment via wireline or wireless connections. For example, CPE stations 290d and 290e can be coupled to voice calling parties 124d, 124e, 126d and 126e, fax machines 116d and 116e, video conferencing equipment including video monitors 152d and 152e, and cameras 154d and 154e, host computers including client computers 120d and 120e and servers 122d and 122e. Various legacy devices such as PBXs can be coupled to CPEs 294d and 294e. In addition, next generation technologies such as Ethernet phones available from Selsius, a subsidiary of CISCO Systems from San Jose, Calif. and other Internet appliances can be coupled via LAN connections to CPEs 294d and 294e. Other video conferencing equipment as well as H.323 compliant conferencing equipment can also be coupled to CPEs 294d and 294e.

In an embodiment of the invention, either of antennae 292d and 292e can communicate with both WAPs 290d and 290e for alternate or backup wireless communications paths.

Returning to FIG. 3A, it depicts an example perspective diagram 300 of a PIMP network of the present invention. Diagram 300 includes a wireless base station 302 shown in wireless communication with subscriber locations 306a, 306b, 306c, 306d, 306e, 306f, 306g, 306h, 306i and 306j. Specifically, wireless base station 302 communicates via wireless access point 290d to subscriber antennae 292a-j of subscriber locations 306a-j.

Wireless base station 302 is coupled at interface 320 to network router 140d by, e.g., a wireline connection. Network router 140d is coupled to data network 142 which includes various other network routers 140b for routing traffic to other nodes on data network 142 such as, e.g., telephony gateway 288b.

Returning to FIG. 3B, it depicts block diagram 310 further illustrating the wireless PIMP of the present invention. Diagram 310 includes wireless base station 302 coupled at interface 320 to data network 142. Also coupled to data network 142 are router 140d and telephony gateway 288b which is in turn coupled to a class central office (CO) switch at EO 104b. IP telephony gateway 288b can terminate telephony traffic to PSTN facilities by, e.g., translating packets into time domain multiplexed (TDM) standard telephone signals. Wireless base station 302 is in communication with wireless CPE 294d at subscriber location 306d via antenna WAP 290d and 292d. It would be apparent to those skilled in the art that other configurations of CPE 294d are possible, such as, e.g., one or more host computers with no telephone devices, one or more telephones with no host computers, one or more host computers and one or more telephone devices, and one or more H.323 capable video-conferencing platforms which could include a host computer with monitor and camera.

CPE 294d is shown with several telephone devices 124d and 126d, e.g., analog phones, and host computers, client 120d and server 122d. Client 120d and server 122d can be coupled to CPE 294d via a LAN connection such as, e.g., an Ethernet LAN, or via a legacy V.35 device 322d providing a high speed data connection. Other Internet appliances capable of attachment to a data network can also be coupled to CPE 294d.

## 2. Networking Protocol Stack Architecture—Wireless IP Network Access Architecture (WINAAR)

FIG. 4 depicts the wireless IP network access architecture (WINAAR) 400 of the present invention. Architecture 400 illustrates the networking protocol stack which is a version of a TCP/IP protocol stack enhanced to support IP-centric, QoS over a packet switched, shared bandwidth, wireless PIMP connection. The networking protocol stack will be described in terms of the Open Systems Interconnect (OSI) 7 layer networking protocol stack standard which includes physical layer (OSI layer 1) 402, data link layer (OSI layer 2) 404, network layer (OSI layer 7) 406 and 408, transport layer (OSI layer 4) 410 and applications layer (OSI layer 7) 412.

### a. Physical Layer

In an example embodiment, physical layer 402 can be implemented using several wireless application specific integrated circuits (wASICs), an off-the-shelf 16QAM/QPSK 416 ASIC, an Interference Mitigation and Multipath Negation (IMMUNE)/RF 418 algorithm ASIC for minimizing and/or eliminating harmful interference; and a frequency hopping (FH) 419 ASIC for providing dynamic and adaptive multi-channel transmission that optimizes data link integrity

by changing frequency levels depending on the noise level of a given frequency. Physical layer 402 can include the radio frequency (RF) signal 415.

### b. Data Link Layer

Data link layer 404 lies on top of physical layer 402. Data link layer 404 can include a media access control (MAC) layer 414 which is depicted graphically in diagram 400 as MAC layer portion 414a and proactive reservation-based intelligent multi-media access (PRIMMA) technology portions 414b and 414c. Arrows 426, 428 and 430, respectively, illustrate that MAC layer 414 can read header information from data and multimedia applications 425, TCP/UDP 427 and IP 429 layers to analyze and schedule an IP packet of an "IP flow." IP packets of the IP flow are identified by analyzing the header information to determine QoS requirements of the IP flow, so that the IP flow can be characterized, classified, presented, prioritized and scheduled.

### c. Network Layer

#### 1. Internet Protocol (IP)

Network layer 408 is the Internet protocol (IP) 429. As will be discussed further below and as already discussed above with reference to data network 142, IP is a standard protocol for addressing packets of information. Referring now to FIG. 7, IP header fields 702 can include, e.g., source and destination IP addresses, IP type of service (TOS), IP time to live (TTL), and protocol fields. IP is a datagram protocol that is highly resilient to network failures, but does not guarantee sequence delivery. Routers send error and control messages to other routers using the Internet control message protocol (ICMP). ICMP can also provide a function in which a user can send a "ping" (echo packet) to verify reachability and round trip delay of an IP-addressee host. Another OSI layer 3 protocol is address resolution protocol (ARP) which can directly interface to the data link layer. ARP maps a physical address, e.g., an Ethernet MAC address, to an IP address.

#### 2. Internet Protocol (IP)v4 and IPv6

IP 429 of network layer 408 can be, e.g., an IP version 4 (IPv4) or an IP version 6 (IPv6). IPv6 (sometimes called next-generation internet protocol or IPng) is a backward-compatible extension of the current version of the Internet protocol, IPv4. IPv6 is designed to solve problems brought on by the success of the Internet (such as running out of address space and router tables). IPv6 also adds needed features, including circuiting security, auto-configuration, and real-time services similar to QoS. Increased Internet usage and the allocation of many of the available IP addresses has created an urgent need for increased addressing capacity. IPv4 uses a 32-byte number to form an address, which can offer about 4 billion distinct network addresses. In comparison, IPv6 uses 128-bytes per address, which provides for a much larger number of available addresses.

#### 3. Resource Reservation Protocol (RSVP)

IP 429 of network layer 408 can have RSVP enhancement. Developed to enhance IPv4 with QoS features, RSVP is supposed to let network managers allocate bandwidth based on the bandwidth requirements of an application. Basically, RSVP is an emerging communications protocol that is hoped to signal a router to reserve bandwidth for real-time transmission of data, video, and audio traffic.

Resource reservation protocols that operate on a per-connection basis can be used in a network to elevate the priority of a given user temporarily. RSVP runs end to end to communicate application requirements for special handling. RSVP identifies a session between a client and a server and asks the routers handling the session to give its communications a priority in accessing resources. When the



session is completed, the resources reserved for the session are freed for the use of others.

RSVP unfortunately offers only two levels of priority in its signaling scheme. Packets are identified at each router hop as either low or high priority. However, in crowded networks, two-level classification may not be sufficient. In addition, packets prioritized at one router hop might be rejected at the next.

Accepted as an IETF standard in 1997, RSVP does not attempt to govern who should receive bandwidth, and questions remain about what will happen when several users all demand a large block of bandwidth at the same time. Currently, the technology outlines a first-come, first-served response to this situation. The IETF has formed a task force to consider the issue.

Because RSVP provides a special level of service, many people equate QoS with the protocol. For example, Cisco currently uses RSVP in its IPv4-based internetwork router operating system to deliver IPv6-type QoS features. However, RSVP is only a small part of the QoS picture because it is effective only as far as it is supported within a given client/server connection. Although RSVP allows an application to request latency and bandwidth, RSVP does not provide for congestion control or network-wide priority with the traffic flow management needed to integrate QoS across an enterprise. Further, RSVP does not address the particular challenges related to delivering packets over a wireless medium.

The present invention supports RSVP by providing: (1) compatibility with RFC 2205; (2) recognition and support of RSVP messages, including: Path messages, Reservation (Resv), Path teardown messages, Resv teardown messages, Path error messages, Resv error messages, and Confirmation messages; (3) recognition and support of RSVP objects, including: Null, Session, RSVP\_Hop, Time\_Values, Style, Flowspec, Sender\_Template, Sender\_Spec, Adspec, Error\_Spec, Policy\_Data, Integrity, and Scope, Resv\_Confirm; (4) configurable translation of RSVP Flowspecs for QoS resource allocation in wireless base station 302.

The present invention provides support of DiffServ and RSVP/int-serv by providing: (1) support of RFC 2474 and 2475; (2) DiffServ in the core of Internet; (3) RSVP/int-serv for hosts and edge networks; (4) admission control capability for DiffServ compatibility; (5) differentiated services (DSs) (a field marking supported for use by DiffServ, and translation into a wireless base station 302 resource allocation); and (6) support for binding of multiple end-to-end sessions to one tunnel session.

4. Real-time Transport Protocol (RTP) and Real-time Control Protocol (RTCP)

TCP of transport layer 410 can have a RTP and RTCP enhancement. Real-time transport protocol (RTP) is an emerging protocol for the Internet championed by the audio/video transport workgroup of the IETF. Referring to FIG. 7, RTP and RTCP header fields 708 can include several subfields of information. RTP supports real-time transmission of interactive voice and video over packet-switched networks. RTP is a thin protocol that provides content identification, packet sequencing, timing reconstruction, loss detection, and security. With RTP, data can be delivered to one or more destinations, with a limit on delay.

RTP and other Internet real-time protocols, such as the Internet stream protocol version 2 (SI2), focus on the efficiency of data transport. RTP and other Internet real-time protocols like RTCP are designed for communications sessions that are persistent and that exchange large amounts of data. RTP does not handle resource reservation or QoS

control. Instead, RTP relies on resource reservation protocols such as RSVP, communicating dynamically to allocate appropriate bandwidth.

RTP adds a time stamp and a header that distinguishes whether an IP packet is data or voice, allowing prioritization of voice packets, while RSVP allows networking devices to reserve bandwidth for carrying unbroken multimedia data streams.

Real-time Control Protocol (RTCP) is a companion protocol to RTP that analyzes network conditions. RTCP operates in a multi-cast fashion to provide feedback to RTP data sources as well as all session participants. RTCP can be adopted to circumvent datagram transport of voice-over-IP in private IP networks. With RTCP, software can adjust to changing network loads by notifying applications of spikes, or variations, in network transmissions. Using RTCP network feedback, telephony software can switch compression algorithms in response to degraded connections.

5. IP Multi-Casting Protocols

IP 429 of network layer 408 can also support multi-casting protocols. Digital voice and video comprise of large quantities of data that, when broken up into packets, must be delivered in a timely fashion and in the right order to preserve the qualities of the original content. Protocol developments have been focused on providing efficient ways to send content to multiple recipients, transmission referred to as multi-casting. Multi-casting involves the broadcasting of a message from one host to many hosts in a one-to-many relationship. A network device broadcasts a message to a select group of other devices such as PCS or workstations on a LAN, WAN, or the Internet. For example, a router might send information about a routing table update to other routers in a network.

Several protocols are being implemented for IP multi-casting, including upgrades to the Internet protocol itself. For example, some of the changes in the newest version of IP, IPv6, will support different forms of addressing for uni-cast (point-to-point communications), any cast (communications with the closest member of a device group), and multi-cast. Support for IP multi-casting comes from several protocols, including the Internet group management protocol (IGMP), protocol-independent multi-cast (PIM) and distance vector multi-cast routing protocol (DVMRP). Queuing algorithms can also be used to ensure that video or other multi-cast data types arrive when they are supposed to without visible or audible distortion.

Real-time transport protocol (RTP) is currently an IETF draft, designed for end-to-end, real-time delivery of data such as video and voice. RTP works over the user datagram protocol (UDP), providing no guarantee of in-time delivery, quality of service (QoS), delivery, or order of delivery. RTP works in conjunction with a mixer and translator and supports encryption and security. The real-time control protocol (RTCP) is a part of the RTP definition that analyzes network conditions. RTCP provides mandatory monitoring of services and collects information on participants. RTP communicates with RSVP dynamically to allocate appropriate bandwidth.

Internet packets typically move on a first-come, first-serve basis. When the network becomes congested, Resource Reservation Protocol (RSVP) can enable certain types of traffic, such as video conferences, to be delivered before less time-sensitive traffic such as E-mail for potentially a premium price. RSVP could change the Internet's pricing structure by offering different QoS at different prices. Using SLAs, different QoS levels can be provided to users at CPE location stations depending on SLA subscription level.

The RSVP protocol can be used by a host, on behalf of an application, to request a specific QoS from the network for particular data streams or flows. Routers can use the RSVP protocol to deliver QoS control requests to all necessary network nodes to establish and maintain the state necessary to provide the requested service. RSVP requests can generally, although not necessarily, result in resources being reserved in each node along the data path.

RSVP is not itself a routing protocol. RSVP is designed to operate with current and future uni-cast and multi-cast routing protocols. An RSVP process consults the local routing database to obtain routes. In the multi-cast case for example, the host sends IGMP messages to join a multi-cast group and then sends RSVP messages to reserve resources along the delivery paths of that group. Routing protocols determine where packets are forwarded. RSVP is concerned with only the QoS of those packets as they are forwarded in accordance with that routing. The present invention delivers QoS-aware wireless PtMP access to users over a shared wireless bandwidth, and can take into account priority information provided within packet headers of packets in IP flows received for transmission over the wireless base station's bandwidth.

d. VPN Networks (Example Optional Protocols) at Network Layer

Also at network layer 406 are depicted example optional virtual private network (VPN) protocols point to point protocol (PPP) 420 and IPsec 422, discussed below.

A plurality of protocol standards exist today for VPNs. For example, IP security (IPsec), point-to-point tunneling protocol (PPTP), layer 2 forwarding protocol (L2F) and layer 2 tunneling protocol (L2TP). The IETF has proposed a security architecture for the Internet protocol (IP) that can be used for securing Internet-based VPNs. IPsec facilitates secure private sessions across the Internet between organizational firewalls by encrypting traffic as it enters the Internet and decrypting it at the other end, while allowing vendors to use many encryption algorithms, key lengths and key escrow techniques. The goal of IPsec is to let companies mix-and-match the best firewall, encryption, and TCP/IP protocol products.

IPsec is designed to link two LANs together via an encrypted data stream across the Internet.

#### 1. Point-to-Point Tunneling Protocol (PPTP)

Point-to-point tunneling protocol (PPTP) provides an alternate approach to VPN security than the use of IPsec. Unlike IPsec, which is designed to link two LANs together via an encrypted data stream across the Internet, PPTP allows users to connect to a network of an organization via the Internet by a PPTP server or by an ISP that supports PPTP. PPTP was proposed as a standard to the IETF in early 1996. Firewall vendors are expected to support PPTP.

PPTP was developed by Microsoft along with 3Com, Ascend and US Robotics and is currently implemented in WINDOWS NT SERVER 4.0, WINDOWS NT WORKSTATION 4.0, WINDOWS 95 via an upgrade and WINDOWS 98, available from Microsoft Corporation of Redmond, Wash.

The "tunneling" in PPTP refers to encapsulating a message so that the message can be encrypted and then transmitted over the Internet. PPTP, by creating a tunnel between the server and the client, can tie up processing resources.

#### 2. Layer 2 Forwarding (L2F) Protocol

Developed by Cisco, layer 2 forwarding protocol (L2F) resembles PPTP in that it also encapsulates other protocols inside a TCP/IP packet for transport across the Internet, or any other TCP/IP network, such as data network 112. Unlike

PPTP, L2F requires a special L2F-compliant router (which can require changes to a LAN or WAN infrastructure), runs at a lower level of the network protocol stack and does not require TCP/IP routing to function. L2F also provides additional security for user names and passwords beyond that found in PPTP.

#### 3. Layer 2 Tunneling Protocol (L2TP)

The layer 2 tunneling protocol (L2TP) combines specifications from L2F with PPTP. In November 1997, the IETF approved the L2TP standard. Cisco is putting L2TP into its Internet operating system software and Microsoft is incorporating it into WINDOWS NT 5.0. A key advantage of L2TP over IPsec, which covers only TCP/IP communications, is that L2TP can carry multiple protocols. L2TP also offers transmission capability over non-IP networks. L2TP however ignores data encryption, an important security feature for network administrators to employ VPNs with confidence.

#### 4. IPsec

IP flows using the security encryption features of IPsec 422 are supported by the present invention. The integration of IPsec 422 flows of WINAAR architecture 400 are described below in the downlink and uplink directions with reference to FIGS. 17A and 17B, respectively. Wireless base station 302 supports prioritization of IPsec encrypted streams by placing the iS firewall at the wireless base station and unencrypting the datastream and packet header information prior to identification analysis. Through the wireless transmission medium, the frame stream already includes encryption of the frame data and implements frequency hopping.

IPsec provides for secure data transmission for, e.g., VPNs and eCommerce security. IPsec is compatible with RFC 2401-2407. IPsec is supported with IPv4 and IPv6, and also IPsec tunnel mode. Wireless base station 302 security protocol support includes authentication header (AH) and encapsulating security payload (ESP). Wireless base station 302 supports IPsec authentication (MD5), encryption algorithms, and automatic key management (IKE and ISAKMP/Oakley). Wireless base station 302 provides for a choice of transport mode or tunnel mode and selectable granularity of security service, such as, e.g., providing a single encrypted tunnel for all traffic between two hosts, or providing separate encrypted tunnel for each TCP connection between hosts.

#### c. Transport Layer

##### 1. Transmission Control Protocol/Internet Protocol (TCP/IP) and User Datagram Protocol/Internet Protocol (UDP/IP)

As already discussed, internet protocol (IP) has become the primary networking protocol used today. This success is largely a part of the Internet, which is based on the transmission control protocol/internet protocol (TCP/IP) family of protocols. TCP/IP is the most common method of connecting PCs, workstations, and servers. TCP/IP is included as part of many software products, including desktop operating systems (e.g., Microsoft's Windows 95 or Windows NT) and LAN operating systems.

The most pervasive LAN protocol to date, has been IPX/SPX from Novell's NetWare network operating system (NOS). However, IPX/SPX is losing ground to TCP/IP. Novell now incorporates native IP support into NetWare, ending NetWare's need to encapsulate IPX packets when carrying them over TCP/IP connections. Both UNIX and Windows NT servers can use TCP/IP. Banyan's VINES, IBM's OS/2 and other LAN server operating systems can also use TCP/IP.

Transport layer four 410 can include transmission control protocol (TCP) or user datagram protocol (UDP) 427 part of

the standard TCP/UDP/IP protocol family suite of networking protocols. As will be discussed further below and as already mentioned briefly above with reference to data network 142, TCP is a standard protocol for segmenting traffic into packets, transmitting, reassembling and retransmitting packets of information between a source and destination IP address. Referring now to FIG. 7, TCP header fields 706 can include, e.g., source and destination port numbers, window size, urgent pointer, flags (SYN, ISN, PSH, RST, FIN), and maximum segment size (MSS). Both TCP and UDP provide a capability for the TCP/IP host to distinguish among multiple applications through port numbers. TCP can provide for a reliable, sequenced delivery of data to applications. TCP can also provide adaptive flow control, segmentation, and reassembly, and prioritization of data flows. UDP only provides unacknowledged datagram capability. The recently defined real time protocol (RTP), RFC 1889, can provide real time capabilities in support of multimedia applications, for example.

TCP uses a window-based flow control. Each TCP source has a dynamically changing transmit window that determines how many packets it can transmit during each successive round-trip time (RTT). The TCP source can continue increasing its transmit window if no packets were lost within the last RTT. Once congestion is detected, the source TCP throttles back its transmission, i.e. it "backs-off," via a multiplicative decrease. An increasing width of the so-called TCP window versus time corresponds to increasingly longer bursts of packets. TCP's window flow-controlled protocol exhibits this effect of increasing throughput and buffer utilization until terminated by loss, followed by a period of rapid backoff.

TCP works over IP to provide end-to-end reliable transmission of data across data network 142. TCP controls the amount of unacknowledged data in transit by dynamically reducing either window size or segment size. The reverse is also true in that increased window or segment size values achieve higher throughput if all intervening network elements have low error rates, support the larger packets, and have sufficient buffering to support larger window sizes.

#### f. Application Layer

Applications layer seven 412 can include applications 426 such as, e.g., over TCP, hypertext transport protocol (HTTP), file transfer protocol (FTP), TELNET remote terminal login, and simple mail transfer protocol (SMTP); and over UDP, simple network management protocol (SNMP), RPC, NFS, and TFTP. Other applications can also run over the network stack such as, e.g., a world wide web browser such as NETSCAPE NAVIGATOR available from AOL of Reston, Va., a spreadsheet application program such as LOTUS 123 available from IBM of Armonk, N.Y. or a video teleconferencing program such as MS NetMeeting available from MICROSOFT of Redmond, Wash. Packets transmitted from such applications could require special handling and prioritization to achieve an appropriate end-user QoS.

### 3. PRIMMA-System IP Flow Prioritization

#### a. Scheduling of Mixed IP Flows

FIG. 6 illustrates block diagram 600 representing scheduling of mixed IP flows. Block diagram 600 shows the scheduling of wireless base station 302. The functionality of block diagram 600 includes PRIMMA management of Internet, VPN, and realtime IP flows. Referring back to FIG. 3A, wireless IP flows are coming from data network 142 via network router 140d to interface 320 of wireless base station 302. IP flows are then scheduled for transmission from wireless base station 302 via antenna 290d through subscriber location 306d via antenna 292d.

Referring back to block diagram 600 of FIG. 6, illustrated therein are the downlink and uplink flows between interface 320 and wireless base station antenna 290d. An IP flow, as described herein, refers to a series of related packets of data transmitted from a source to a destination post computer. IP flow 630 from data network 142 (over interface 320) comprises Internet IP flows 608, VPN IP flows 610, and realtime IP flows 612. IP flow 630 is in the downlink direction.

Downlink IP flow analyzer 602 (hereinafter downlink flow analyzer 602) analyzes Internet IP flow 608, VPN IP flow 610 and realtime IP flow 612. IP flow analyzer 602 is described further below with reference to FIGS. 8A and 15A. IP flow analyzer 602 receives packets and analyzes packet header fields to identify new or existing IP flows. IP flow analyzer 602 can also characterize QoS requirements for the IP flow depending on packet header field contents. IP flow analyzer 602 can classify the IP flow and associate a given packet with other packets from an existing IP flow and can group together IP flows with similar QoS requirements. IP flow analyzer 602 can also present the IP flows to a flow scheduler.

Downlink PRIMMA MAC IP flow scheduler 604 (hereinafter downlink flow scheduler 604) schedules received IP flows 608, 610, and 612 for transmission in the downlink direction. Downlink flow scheduler 604 can prioritize the different classes of IP flows. For example, scheduler 604 can reserve slots in downlink frames for latency sensitive IP flows; for FTP type IP flows 608, scheduler 604 can allocate large amounts of bandwidth for file transfer; and for e-mail type IP flows 608, a lower priority can be given to packets. In prioritizing allocation of wireless bandwidth frame slots, downlink flow scheduler 604 can take into account the fact that an IP flow 630 is a VPN IP flow 610 from a virtual private network (VPN), such as, e.g., a remote branch office tying into a corporate network. All traffic from a VPN can be given a higher priority or specific types of VPN traffic can request particular service levels. Downlink flow scheduler 604 can prioritize realtime IP flows 612 such that their arrival at CPEs 294 at CPE subscriber locations 306 will occur as required.

Downlink PRIMMA MAC segmentation and resequencing (SAR) and framer 606 (hereinafter downlink SAR and framer 606) segments and frames the data packets of received IP flows into frames for transmission over the wireless medium to CPEs 294 at CPE subscriber locations 306. For example IP flow 616, 624 can be transmitted to CPE 294d at CPE subscriber location 306d, via base station antenna 290d over a wireless medium to subscriber antenna 292d and CPE 294d at CPE subscriber location 306d. In the present invention, the term wireless medium is used to broadly encompass not only propagation of RF transmissions over cellular communications, but also RF transmissions over satellite communications and cable (e.g., coaxial cable) communications.

In the uplink direction, IP flow 626 from CPE 294d at CPE subscriber station 306d is received at wireless base station antenna 290d. IP flow 626 can include Internet IP flow 618, VPN IP flow 620 and realtime IP flow 622. Uplink IP flow analyzer 632 (hereinafter uplink flow analyzer 632) analyzes Internet IP flow 618, VPN IP flow 620 and realtime IP flow 622. Uplink flow analyzer 632 is described further below with reference to FIGS. 8B and 15B. In one embodiment, the functionality of IP flow analyzer 632 occurs at the CPE 294d at subscriber CPE location 306d and sends a request to transmit data up to wireless base station 302, including information about an IP flow for which CPE 294d would like to schedule an uplink slot.

Uplink PRIMMA MAC IP flow scheduler 634 (hereinafter uplink flow scheduler 634) can schedule the requested IP flow. In one embodiment, the functionality of scheduler 634 can be performed at CPE 294d at subscriber CPE location 306d. In another embodiment, the functionality of scheduler 634 can be performed at the wireless base station 302. An advantage of placing uplink flow scheduler 634 at the wireless base station is that this provides efficiencies particularly in a point-to-multi-point architecture. It is more efficient to have one centralized scheduler at the base station 302 rather than to place multiple uplink flow schedulers 634 at CPEs 294 of subscriber CPE locations 306.

Uplink PRIMMA MAC segmentation and resequencing (SAR) and framer 636 (hereinafter SAR and framer 636) can segment and frame the data packets of IP flows into frames for transmission over the wireless medium from CPE 294 at CPE subscriber locations 306 to wireless base station 302 for further transmission over data network 142. IP flow 626 from CPE 294d at CPE subscriber location 306d can be transmitted to base station antenna 290d over a wireless medium such as, e.g., RF communication, cable modem and satellite communication, from subscriber antenna 292d coupled to CPE 294d at CPE subscriber location 306d.

b. Summary of Downlink and Uplink SubFrame Prioritization

Block diagram 800 of FIG. 8A summarizes an exemplary downlink analysis, prioritization and scheduling function. Similarly, block diagram 830 of FIG. 8B summarizes an exemplary uplink analysis prioritization and scheduling function. Block diagram 800 and 830 are more detailed views of the function of block diagram 600 of FIG. 6.

Beginning with block diagram 800 (of FIG. 8A), it depicts how IP flow prioritization and scheduling of a shared wireless bandwidth is performed in the downlink path, from data network 142—to router 140d—to interface 320—to wireless base station 302—WAP 290d—over a wireless medium—to wireless transceiver subscriber antenna 292d—to subscriber CPE station 294d at subscriber CPE location 306d.

IP flow analyzer 602 performs the function of identifying, characterizing, classifying, and presenting data packets to a downlink frame scheduler. The functions of identifying, characterizing, classifying and presenting the data packets are described with respect to FIG. 15A.

During identification, it is determined whether a data packet of an incoming IP data flow is known to the system, i.e. is an "existing IP flow", or rather is the first data packet of a new IP data flow, based on fields in a packet header section. Identification can also include, e.g., determining the source of the packet in order to extrapolate the type of information in the packet payload.

During characterization, a new data packet (of a new IP data flow) previously unknown to the system is characterized based on the packet header information to determine the QoS requirements for the IP data flow, and to identify the subscriber CPE station that will receive the IP data flow.

During classification, the new IP data flow is classified into a communications priority class. Classification can also include grouping together packets from different IP flows having similar characteristics into a single class. Example class groupings of IP flows 630 are illustrated as IP classes 810a-810g.

During presentation, the new IP data flow is initialized and presented to a downlink flow scheduler 604.

Downlink flow scheduler places the data packets of an IP data flow into a class queue based on class queue priorities, and using a set of rules, schedules the data packets for

transmission over a wireless medium to a subscriber CPE station 294 at subscriber CPE location 306 with an advanced reservation algorithm. The rules are determined by inputs to the downlink flow scheduler based on, e.g., a hierarchical class-based prioritization, a virtual private network (VPN) directory enabled data priority (such as, for example, directory enabled networking (DEN)), and a service level agreement priority. The advanced reservation algorithm for use in scheduling, e.g., isochronous traffic, is described with respect to FIG. 14 below.

SAR and framer 606 breaks up, sequences, and frames the data packets for wireless transmission from WAP 290d over the wireless medium to a wireless transceiver subscriber antenna 292. Illustrated in block diagram 800 are a number of subscriber applications 820a-820e running on devices such as, e.g., subscriber workstation 120d (not shown), connected to subscriber CPE stations 294a-e (not shown) located at subscriber CPE locations 306a-306e. Each subscriber CPE location 306 can house one or more subscriber CPE stations 294, and each subscriber CPE station 294 can receive and transmit one or more IP data flows to and from one or more subscriber workstations 120. In fact, each application connected to a single CPE station can receive or transmit multiple IP data flows.

Referring to subscriber CPE location 306a of FIG. 8A, a CPE SAR and framer 814a resequences the received data and transmits it through CPE flow scheduler 816a, and CPE IP flow analyzer 818a, to subscriber application 820a. CPE IP flow schedulers 816a-816e can perform the same function as downlink flow scheduler 604 for uplink traffic. Similarly, CPE IP flow analyzers 818a-818e perform the same function as downlink flow analyzer 602.

In an embodiment of the invention, in downlink mode, CPE IP flow schedulers 816a-816e and CPE IP flow analyzers 818a-818e perform no function.

Block diagram 800 illustrates the logical functions performed on the downlink path, not necessarily the physical locations of these functions.

The functions of subscriber applications 820a-820e, and CPE SAR and framers 814a-814e can be performed in the actual subscriber CPE stations 294 connected over a wireless connection to wireless base station 302.

Block diagram 800 lists an exemplary set of priorities 812 used by downlink flow scheduler 604 to place received data packets into priority class queues. Listed are the following set of example priorities: latency-sensitive UDP priority 812a, high priority 812b, intermediate priority 812c, initial hypertext transfer protocol (HTTP) screens priority 812d, latency-neutral priority 812e, file transfer protocol (FTP), simple mail transfer protocol (SMTP) and other e-mail traffic priority 812f and low priority 812g. Persons skilled in the art will recognize that many different priority classes are possible, depending upon the QoS requirements of the end-users. Latency-sensitive UDP priority data can refer to data that has the highest priority because it is sensitive to jitter (i.e., time synchronization is important) and latency (i.e., the amount of time passage between IP data flows in reverse directions). High priority 812b can refer to, e.g., premium VPN service, and a high priority SLA service. Intermediate priority 812c can refer to, e.g., a value VPN service level and an intermediate level SLA service. HTTP screens priority 812d can refer to the download of HTTP data, for example, an initial HTTP screen, which is important for making an Internet user feel as if he has a great deal of bandwidth available for his Internet session. Latency-neutral priority 812e can refer to data that is neutral to latency, such as, e.g., e-mail traffic. FTP, SMTP priority 812f

data includes data that is insensitive to latency and jitter, but requires a large amount of bandwidth to be downloaded accurately because of the size of a transmission. Finally, low priority data 812g can refer to data that can be transmitted over a long period of time, as when one network device transmits its status information to another network device on a 24 hour basis.

Block diagram 830 (of FIG. 8B) depicts how IP flow analysis, prioritization and scheduling of the shared wireless bandwidth is performed in the uplink path, from subscriber CPE station 294d—to wireless transceiver subscriber antenna 292d—over the wireless medium—to WAP 290d—to wireless base station 302—to interface 320—to router 140d—to data network 140.

Block diagram 830 includes uplink flow analyzer 632, uplink flow scheduler 634 and uplink SAR and framer 636. These components are similar in function to downlink flow analyzer 602, downlink flow scheduler 604 and downlink SAR and framer 606, but instead analyze, schedule and sequence and frame data packets being transmitted from subscriber workstations 120 of subscriber CPE stations 294 (at subscriber CPE locations 306a–306e) over the wireless medium, and transmit the data packets to interface 320 for transmission to data network 142.

Illustrated in FIG. 8B are subscriber applications 820a–820e, which are the same applications shown in FIG. 8A. Also shown therein are CPE IP flow analyzers 819a–819e, CPE IP flow schedulers 817a–817e, and CPE SAR and framers 815a–815e. These components function analogously to subscriber applications 820a–820e, CPE IP flow analyzers 818a–818e, CPE IP flow schedulers 816a–816e, and CPE SAR and framers 814a–814e. However, these components function to analyze, schedule and transmit IP flows in the uplink path, from subscriber CPE stations (at subscriber CPE locations 306a–306e) to wireless base station 302 for routing to destination host workstations 136 (not shown).

As noted, multiple applications can be connected to one or more subscriber CPE stations at subscriber CPE locations 306a–306e. To prevent collisions between multiple applications contending for a fixed number of bandwidth allocations for uplink communication, in one embodiment of the present invention a reservation scheduling system is used. The bandwidth allocations for data packets are called frame slots, and are described below with respect to FIGS. 12A–12Q, 14, 16A and 16B.

Block diagram 830 illustrates the logical functions performed on the uplink path, not necessarily the physical locations of these functions.

For example, in one embodiment, the analysis function of IP flow analyzer 632 which identifies a packet for uplink, characterizes and classifies the packet, can occur in a preferred embodiment in CPE IP flow analyzers 819a–819e at the CPE subscriber stations 294a–294e (not shown) at subscriber locations 306a–306e.

Also, one embodiment, the functions of CPE IP flow schedulers 817a–817f for scheduling uplinks subframe slots can be performed in wireless base station 302 for each of the subscriber CPE stations 294 connected over the wireless connection to wireless base station 302.

In this embodiment, the scheduling function is performed at uplink flow scheduler 634 at wireless base station 302 based on classification information provided to the wireless base station 302 through an uplink IP flow reservation request from the CPE station. By placing all scheduling function at the wireless base station 302, overall system quality of service can be optimized by centralizing the control of scheduling.

In another embodiment, however, their respective functions can be performed in the actual subscriber CPE stations.

In the reservation scheduling function of this embodiment, each subscriber CPE station requests the reservation of frame slots for its uplink transmissions using a reservation request block (RRB) of the TDMA airframe, described further below with reference to FIGS. 12A–12O, before it is permitted to communicate in the uplink path with interface 320. After the reservation request, uplink flow scheduler 634 transmits, as indicated by line 640, to the requesting subscriber CPE station 294 a description of one or more slots which the CPE station 294 can use to transmit its uplink data packets from source subscriber workstations 120, over the wireless medium, which are directed toward destination host workstations 136, over data network 142.

c. Service Level Requests  
FIG. 9 illustrates how PRIMMA MAC IP flow scheduler 604 can also take into account a Service Level Agreement in prioritizing frame slot scheduling and resource allocation. FIG. 9 depicts SLA-mediated IP flow management diagram 900 including prioritization of uplink traffic being transmitted to wireless base station 302 from CPE subscriber locations 306a, 306b, 306c and 306d. For example, suppose subscribers of telecommunications services have subscribed to one of four SLA levels, P1 902a, P2 904a, P3 906a and P4 908a. In the illustrated example, suppose IP flows 902b are being sent to a subscriber at CPE location 306a and have an SLA priority level of P1 902a. Similarly, IP flows 904b, 906b and 908b are being sent to subscribers at CPE locations 306b, 306c and 306d and have SLA priority levels of P2 904a, 906a and 908a, respectively. PRIMMA MAC scheduler 604, 634 of wireless base station 302 can take into account SLA-based priorities in allocating available bandwidth to the subscriber CPE IP flows 902b, 904b, 906b and 908b. In the example illustration, IP flow 902b can be allocated frame slot 902c based on SLA priority 902a. Frame slots 904c, 906c and 908c can be similarly scheduled taking into account SLA priorities. Uplinked IP flow traffic can then be transmitted on to data network 142.

SLA-based prioritization can provide a valuable means for a telecommunications provider to provide differentiated services to a variety of customers. For example, it is possible that low priority traffic from a subscriber who has purchased a premium SLA service agreement, can be scheduled at a higher priority than high priority traffic from a subscriber which has only signed up for a value level or low cost SLA service priority.

#### d. Identification of Headers

FIG. 7 illustrates packet header field information 700 which can be used to identify IP flows and the QoS requirements of the IP flows. Specifically, IP header fields 702 can include, e.g., source and destination IP addresses, helpful in providing application aware preferential resource allocation; IP type of service (TOS), a useful field for assisting PRIMMA MAC in classifying a packet or IP flow; IP time to live (TTL), a useful field for anticipating application packet discards; and protocol fields which can be used in identifying IP flows.

Packet header information 700 also includes UDP header fields 704. Included in UDP packet header fields 704 are source and destination port numbers.

Packet header information 700 also includes TCP header fields 706. Included in TCP packet header fields 706 are source and destination port numbers; TCP sliding window size; urgent pointer; SYN, ISN, PSH, RST and FIN flags; and maximum segment size (MSS).

Packet header information 700 also includes realtime protocol RTP and RTCP header fields 708.

It would be apparent to those skilled in the art that other packet header fields could be useful in identifying an IP flow. The fields have been given by way of example and are not intended to be an exhaustive list of useful packet header fields. Other fields, such as, e.g., fields from IP v6 relating to differentiated services (DIFF SERV) could also be useful to IP flow analyzer 602 and 632 of wireless base station 302.

e. TDMA MAC Air Frame

FIGS. 12A-12O illustrate an exemplary time domain multiple access (TDMA) media access control (MAC) transmission air frame. The fields described herein merely refer to one embodiment for the present invention, and are not limiting to the numerous implementations of the present invention.

FIG. 12A illustrates an entire TDMA MAC transmission air frame. Air frame 1202 includes downstream transmission subframe 1202 and upstream transmission subframe 1204.

The TDMA MAC air frame of FIG. 12A includes upstream acknowledgment block (UAB) 1206, acknowledgment request block (ARB) 1208, frame descriptor block (FDB) 1210, data slot (DS)<sub>1</sub> 1212a, DS<sub>2</sub> 1212b, DS<sub>3</sub> 1212c, DS<sub>4</sub> 1212d, DS<sub>5</sub> 1212e, DS<sub>6</sub> 1212f, DS<sub>7</sub> 1212g, DS<sub>8</sub> 1212h, DS<sub>9</sub> 1212i, DS<sub>10</sub> 1212j, DS<sub>11</sub> 1212k, DS<sub>m</sub> 1212l, downstream acknowledgment block (DAB) 1214, reservation request block (RRB) 1216, UA<sub>1</sub> 1218a, UA<sub>2</sub> 1218b, UA<sub>3</sub> 1218c, UA<sub>4</sub> 1218d, UA<sub>5</sub> 1218e, UA<sub>6</sub> 1218f, UA<sub>7</sub> 1218g, UA<sub>8</sub> 1218h, UA<sub>9</sub> 1218i, UA<sub>10</sub> 1218j, UA<sub>11</sub> 1218k, UA<sub>12</sub> 1218l, and UA<sub>n</sub> 1218m.

In the embodiment described herein, the type of TDMA used is TDMA/time division duplex (TDMA/TDD). In TDMA/TDD, for one interval of time, transmission is from a CPE station 294 to a wireless base station 302, and in another instance of time, it is from a wireless base station 302 to a CPE station 194. Any number of slots can be used for the uplink or for the downlink. The number of slots is dynamically assigned for both the uplink and the downlink. However, because the downlink data rate is usually higher than the uplink data rate, more slots are assigned to the downlink. Although distribution of slots between the downlink and uplink is dynamically assigned, the total number of slots for a frame is fixed in this embodiment.

TABLE 5

MAC Air Frame	Slots	Block/ SubFrame	Name	Description
0	1-8	DAB/ Upstream	Downstream Acknowledgment Request Block	Acknowledgments from subscribers CPE stations to wireless base station of receipt of downstream slots in previous downstream subframe
0	1-8	RRB/ Upstream	Reservation Request Block	Requests from subscriber CPE stations for transmission reservations in later frames with dynamically adjustable number of contentions slots
0	up to 16	US <sub>1</sub> -US <sub>n</sub> / Upstream	Upstream Slot Transmissions	Data slots in the upstream subframe, which is a variable number per frame (up to 16 in one embodiment)

TABLE 5-continued

MAC Air Frame	Slots	Block/ SubFrame	Name	Description
0	1-3	ODB/ Upstream	Operations Data Block	OA&MP data from subscribers sequenced by a subscriber CPE station per frame
0	0	UAB/ Downstream	Upstream Acknowledgment Block	Acknowledgments from wireless base station to subscriber CPE stations of receipt of upstream slots in a previous subframe
0	0	ARB/ Downstream	Acknowledgment Request Block	Acknowledgments of subscriber CPE requests of having received reservation requests in a previous subframe
0	0	FD/ Downstream	Frame Descriptor Block for current frame	Describes the contents of the downstream transmission subframe
0	up to 16	DS <sub>1</sub> -DS <sub>n</sub> / Downstream	Downstream Slot Transmission	Data slots in the downstream subframe, which is variable per frame (up to 16 in one embodiment)
0	0	CCB/ Downstream	Command and Control Block	OA&MP commands sequenced by subscribers per frame and frame synchronization

FIG. 12B is a symbolic illustration of an exemplary TDMA/TDD air frame 1220 of the present invention. TDMA/TDD air frame structure 1220 depicts a frame of frame size 1228, which can be, e.g., 16 slots or 32 slots. It would be apparent to those skilled in the art that frame structures 1220 having other numbers of slots could be used without departing from the spirit and scope of the invention. Frame structure 1220 includes, e.g., various TDMA slots 1222a, 1222b, 1222c and 1222d. Within each TDMA slot 1222a-c, can be included a data slot 1224a, 1224b, 1224c and 1224d which in turn can contain a control packet 1226a, or a data packet 1226b-d, respectively.

In the present embodiment the sum of all TDMA slots 1222 within a frame of frame size 1228 is fixed. However, as noted, using the resource allocation methodologies of the present invention it is possible to dynamically allocate a subset of the entire number of TDMA slots 1222 to an uplink direction, where all the uplink TDMA slots are known collectively as an uplink subframe or an upstream transmission subframe 1204, and to dynamically allocate a subset of the entire number of TDMA slots 1222 to a downlink direction, where all the downlink TDMA slots are known collectively as a downlink subframe or an downlink transmission subframe 1202. Using the resource allocation method of the present invention, it is possible to allocate all TDMA slots 1222 to a given upstream or downstream direction. It is further possible to allocate all data slots 1224 to a single CPE station. The wireless base station 302 has a state machine, and knows the state of each CPE station 294 having a connection therewith (i.e., having an IP flow recognized by the wireless base station 294).

Downstream transmission subframe 1202 and upstream transmission subframe 1204 are described in detail below.

1. Downstream Transmission Subframe  
 FIG. 12C depicts an exemplary downstream transmission subframe 1202. The downstream transmission subframe of

FIG. 12C includes transmitter turnaround time 1230, UAB 1206, ARB 1208, FDB 1210, a variable number of DSs per frame (e.g., 16) 1212, and command and control block (CCB) 1232. The DS transmissions 1212 include DS<sub>1</sub> 1212a, DS<sub>2</sub> 1212b, DS<sub>3</sub> 1212c, DS<sub>4</sub> 1212d, DS<sub>5</sub> 1212e, DS<sub>6</sub> 1212f, DS<sub>7</sub> 1212g, DS<sub>8</sub> 1212h, DS<sub>9</sub> 1212i, DS<sub>10</sub> 1212j, DS<sub>11</sub> 1212k, and DS<sub>n</sub> 1212l.

FIG. 12D depicts an exemplary UAB 1206 of a downstream transmission subframe 1202. The downstream transmission subframe of FIG. 12D includes UAB 1206, ARB 1208, FDB 1210, DS<sub>1</sub> 1212a, DS<sub>2</sub> 1212b, DS<sub>3</sub> 1212c, DS<sub>4</sub> 1212d, DS<sub>5</sub> 1212e, DS<sub>6</sub> 1212f, DS<sub>7</sub> 1212g, DS<sub>8</sub> 1212h, DS<sub>9</sub> 1212i, DS<sub>10</sub> 1212j, DS<sub>11</sub> 1212k, DS<sub>n</sub> 1212l, and CCB 1232.

UAB 1206 includes subslots UAB<sub>1</sub> 1206a, UAB<sub>2</sub> 1206b, UAB<sub>3</sub> 1206c, UAB<sub>4</sub> 1206d, UAB<sub>5</sub> 1206e, UAB<sub>6</sub> 1206f, UAB<sub>7</sub> 1206g, and UAB<sub>n</sub> 1206h. UAB<sub>1</sub> 1206a includes a preamble 1234a, subscriber ID 1234b, IP-flow identifier 1234c, slot sequence number 1234d, and cyclical redundancy check (CRC) 1234e.

The UAB field is an acknowledgment by a wireless base station 302 to a CPE station 294 that the slots (e.g., US<sub>1</sub>-US<sub>16</sub>) of an upstream transmission subframe have been received. The reader is referred to the discussion of the upstream transmission subframe below.

In subslot UAB<sub>1</sub> 1206a of ARB 1206: preamble 1234a includes data used for link integrity purposes; subscriber ID 1234b identifies which CPE station 294 is making the reservation request; IP-flow identifier 1234c identifies the IP data flow; quality of service data class 1234d identifies the priority class of the IP data flow, if known to the CPE station 294; IP-flow priority and type 1234b is an indicator of a new IP data flow; and CRC 1234e, which stands for cyclic redundancy code, provides error checking bits for subslot RRB<sub>1</sub> 1216a.

FIG. 12E depicts an exemplary ARB 1208 of a downstream transmission subframe 1202. The downstream transmission subframe of FIG. 12E includes UAB 1206, ARB 1208, FDB 1210, DS<sub>1</sub> 1212a, DS<sub>2</sub> 1212b, DS<sub>3</sub> 1212c, DS<sub>4</sub> 1212d, DS<sub>5</sub> 1212e, DS<sub>6</sub> 1212f, DS<sub>7</sub> 1212g, DS<sub>8</sub> 1212h, DS<sub>9</sub> 1212i, DS<sub>10</sub> 1212j, DS<sub>11</sub> 1212k, DS<sub>n</sub> 1212l, and CCB 1232.

ARB 1208 includes subslots ARB<sub>1</sub> 1208a, ARB<sub>2</sub> 1208b, ARB<sub>3</sub> 1208c, ARB<sub>4</sub> 1208d, ARB<sub>5</sub> 1208e, ARB<sub>6</sub> 1208f, ARB<sub>7</sub> 1208g, and ARB<sub>n</sub> 1208h. ARB<sub>1</sub> 1208a includes a preamble 1234a, subscriber ID 1234b, IP-flow identifier 1234c, slot sequence number 1234d, and CRC 1234e.

The ARB field is an acknowledgment by a wireless base station 302 to a CPE station 294 that the wireless base station 302 has received an upstream reservation request from the CPE station 294. The reader is referred to the discussion of the upstream transmission subframe below.

In subslot ARB<sub>1</sub> 1208a of ARB 1208: preamble 1234a includes data used for link integrity purposes; subscriber ID 1234b identifies which CPE station 294 is making the reservation request; IP-flow identifier 1234c identifies the IP data flow; quality of service data class 1234d identifies the priority class of the IP data flow, if known to the CPE station 294; IP-flow priority and type 1234b is an indicator of a new IP data flow; and CRC 1234e, which stands for cyclic redundancy code, provides error checking bits for subslot RRB<sub>1</sub> 1216a.

FIG. 12F depicts an exemplary FDB 1210 of a downstream transmission subframe 1202. The downstream transmission subframe of FIG. 12F includes UAB 1206, ARB 1208, FDB 1210, DS<sub>1</sub> 1212a, DS<sub>2</sub> 1212b, DS<sub>3</sub> 1212c, DS<sub>4</sub> 1212d, DS<sub>5</sub> 1212e, DS<sub>6</sub> 1212f, DS<sub>7</sub> 1212g, DS<sub>8</sub> 1212h, DS<sub>9</sub> 1212i, DS<sub>10</sub> 1212j, DS<sub>11</sub> 1212k, DS<sub>n</sub> 1212l, and CCB 1232.

The FDB includes detailed information pertaining to the slots (e.g., DS<sub>2</sub>-DS<sub>16</sub>) of the downstream transmission subframe.

FDB 1210 includes a preamble subslot 1236a, number of downstream slots subslot 1236b, IP-flow ID for upstream reservation 1 subslot 1236c, IP-flow ID for upstream reservation 2 subslot 1236d, IP-flow ID for upstream reservation n subslot 1236e, and contention slot count for next upstream subframe subslot 1236f.

In FDB 1210, the fields are defined as follows: preamble subslot 1236a includes data used for link integrity purposes; number of downstream slots subslot 1236b includes the number of downstream slots (DSs), IP-flow ID for downstream reservation subslot 1236c includes an IP flow identification for DS<sub>1</sub>; IP-flow ID for downstream reservation subslot 1236d includes a second IP flow identification for DS<sub>2</sub>; IP-flow ID for downstream reservation n subslot 1236e includes another IP flow identification for DS<sub>n</sub>; contention slot count for next upstream subframe subslot 1236f provides a count for the next available upstream subframe.

FIG. 12G depicts an exemplary downstream MAC payload data unit (PDU). The downstream MAC PDU includes information regarding the actual structure of the payload. The downstream MAC PDU of FIG. 12G includes MAC linked list sequence number 1238a (the sequence number of the MAC linked list), reservation request index number 1238b (an index to the downstream IP flow), compressed IP-flow identifier 1238c, compressed IP-flow priority and type 1238d (identifying the priority and type of a compressed IP flow), slot payload 1238e (the amount of data in a downstream data slot), and CRC 1234e (error checking information).

FIG. 12H depicts an exemplary CCB of a downstream transmission subframe 1202. The CCB comprises OAM&P commands sequenced by subscriber CPE station 294 per frame and frame synchronization. CCB 1232 includes a mode command subslot 1240a (includes options of what mode the CPE station is to take), profile command subslot 1240b (includes specific system commands, such as a patch for a module), control data index subslot 1240c (including download locations and memory requirements or other information needed by the CPE stations to download data), datablock 1 subslot 1240d (includes specific system data), datablock 2 subslot 1240e (same), datablock n subslot 1240f (same), and CRC subslot 1234e (error checking information).

## 2. Upstream Transmission Subframe

FIG. 12I depicts an exemplary upstream transmission subframe 1204. The upstream transmission subframe of FIG. 12I includes transmitter turnaround time 1230, DAB 1214, RRB 1216, a variable number of USs per frame, e.g., 16, 1218, and operations data block (ODB) 1242, consisting of OAM&P data from subscribers, sequenced by subscriber per frame. The US transmissions 1218 include US<sub>1</sub> 1218a, US<sub>2</sub> 1218b, US<sub>3</sub> 1218c, US<sub>4</sub> 1218d, US<sub>5</sub> 1218e, US<sub>6</sub> 1218f, US<sub>7</sub> 1218g, US<sub>8</sub> 1218h, US<sub>9</sub> 1218i, US<sub>10</sub> 1218j, US<sub>11</sub> 1218k, US<sub>12</sub> 1218l, and US<sub>n</sub> 1218m.

FIG. 12K depicts an exemplary RRB 1216 of an upstream transmission subframe 1204. The upstream transmission subframe of FIG. 12K also shows DAB 1214, RRB 1216, US<sub>1</sub> 1218a, US<sub>2</sub> 1218b, US<sub>3</sub> 1218c, US<sub>4</sub> 1218d, US<sub>5</sub> 1218e, US<sub>6</sub> 1218f, US<sub>7</sub> 1218g, US<sub>8</sub> 1218h, US<sub>9</sub> 1218i, US<sub>10</sub> 1218j, US<sub>11</sub> 1218k, US<sub>12</sub> 1218l, US<sub>n</sub> 1218m, and ODB 1242.

RRB 1216 includes subslots RRB<sub>1</sub> 1216a, RRB<sub>2</sub> 1216b, RRB<sub>3</sub> 1216c, RRB<sub>4</sub> 1216d, RRB<sub>5</sub> 1216e, RRB<sub>6</sub> 1216f, RRB<sub>7</sub> 1216g, and RRB<sub>n</sub> 1216h. RRB<sub>1</sub> 1216a includes a preamble 1234a, subscriber ID 1234b, IP-flow identifier 1234c, quality of service data class 1244a, IP-flow priority and type 1244b, and CRC 1234e.

A CPE station 294 uses one of the subslots (RRB<sub>1</sub> 1216a, RRB<sub>2</sub> 1216b, RRB<sub>3</sub> 1216c, RRB<sub>4</sub> 1216d, RRB<sub>5</sub> 1216e,

RRB<sub>6</sub> 1216f, RRB<sub>7</sub> 1216g, and RRB<sub>n</sub> 1216h) of RRB 1216 to make a reservation request, which is a request by the CPE station 294 for bandwidth in a future uplink transmission subframe. If two CPE stations 294d, 294e attempt to access the same subslot in RRB 1216, which can occur because their pseudorandom number generators select the same subslot, then a "collision" occurs and the data is not readable by wireless base station 302. The two CPE stations 294d, 294e are required to try again.

Reservation request slots can be provided on an IP flow basis. Rather than allocate a reservation request slot to every CPE subscriber station, a default number (e.g., 5) are made available as contention slots. If collisions are detected by a greater number of requesting subscribers than the number of reservation request slots, then the slots allocated can be dynamically varied to provide additional RRB slots. (Collisions are analogous to CSMA/CD collisions in Ethernet, where colliding devices on an Ethernet network attempt to retransmit over the bus architecture by retrying at a random time.)

The radio contention method of the present invention builds upon aspects of the "Slotted Aloha" method developed by L. Roberts in 1972, as a refinement of the "Aloha" method developed by N. Abramson in the early 1970's, and so-called bit-mapped reservation protocols. Like the Slotted Aloha method, the present invention provides for discrete slots for transmission of data, rather than allowing the transmission of data at any point. However, instead of transmitting the actual "payload" of data, the present invention advantageously transmits only a "reservation request" describing the actual data payload contents. Also, the number of slots for reservation requests can advantageously be dynamically altered according to the frequency of detected collisions in the recent past.

Unlike various Carrier Sense Multiple Access (CSMA) techniques previously used in wireless, both persistent and non-persistent, the present method advantageously does not require that subscriber CPE station 294d "sense" the carrier (the radio channel) before transmission. Instead, a subscriber CPE station 294d selects a "subslot" to transmit through a pseudo-random number selection, without a prior carrier sense. If a collision is detected, the subscriber CPE station 294d will try again in the next frame using the pseudo-random number process.

Instead of using a bit-map protocol for the resolution of contention, as is used in some reservation protocols, the wireless base station can explicitly grant reservation requests. The standard bit-map protocol can require that all stations can receive signals from all other stations so that the subsequent order of transmission can be implicitly determined from the resulting bit-map pattern. The present method advantageously does not require the receipt of reservation request signals from other CPE subscriber stations 294d. This is advantageous because, at higher frequencies (such as, e.g., 2 GHz to 30 GHz) where there may be line-of-sight and distance constraints, the requirement for receipt of the transmissions of other CPE subscriber stations 294d could unduly constrain the topology, locations and distances of CPE subscriber stations.

Advantageously, by allowing the wireless base station 302 to explicitly grant the requested reservation, other factors such as relative or dynamic CPE subscriber station 294d (or IP-flow) priority factors can be considered. Therefore, the present invention's reservation protocol with a dynamically adjustable number of contention subslots and an explicit wireless base station reservation grants, allows a more optimal means of providing for the allocation of

wireless, such as, e.g., radio, bandwidth in response to QoS requirements of IP-flows than any prior method.

As noted, RRB<sub>1</sub> 1216a includes the following fields: a preamble 1234a, subscriber ID 1234b, IP-flow identifier 1234c, quality of service data class 1244a, IP-flow priority and type 1244b, and CRC 1234e. In subslot RRB<sub>1</sub> 1216a of RRB 1216: preamble 1234a includes data used for link integrity purposes; subscriber ID 1234b identifies which CPE station 294 is making the reservation request; IP-flow identifier 1234c identifies the IP data flow; quality of service data class 1234a identifies the priority class of the IP data flow, if known to the CPE station 294; IP-flow priority and type 1234b is an indicator of a new IP data flow; and CRC 1234e, which stands for cyclic redundancy code, provides error checking bits for subslot RRB<sub>1</sub> 1216a. Optionally, an additional field can be provided in subslot RRB<sub>1</sub> 1216a which includes the number of data packets CPE station 294 will transmit in its IP data flow.

FIG. 12J depicts an exemplary DAB 1214 of an upstream transmission subframe 1204, where a CPE acknowledges receipt of a slot from base. The DAB is an acknowledgment from a subscriber CPE station 294 to the wireless base station that downstream slots have been received in a previous subframe.

The DAB 1214 includes subslots DAB<sub>1</sub> 1214a, DAB<sub>2</sub> 1214b, DAB<sub>3</sub> 1214c, DAB<sub>4</sub> 1214d, DAB<sub>5</sub> 1214e, DAB<sub>6</sub> 1214f, DAB<sub>7</sub> 1214g, and DAB<sub>n</sub> 1214h. Subslot DAB<sub>1</sub> 1214a includes a preamble 1234a, subscriber ID 1234b, IP-flow identifier 1234c, slot sequence number 1234d, and CRC 1234e. (These fields have the same information as described with respect to the RRB.)

FIG. 12L depicts an exemplary MAC PDU upstream slot. The MAC PDU upstream slot of FIG. 12L includes a CPE linked-list sequence number 1246, reservation request index number 1236b, compressed IP-flow identifier 1238c, compressed IP-flow priority and type 1238d, slot payload 1238e, and CRC 1234e. The upstream MAC PDU is similar to the downstream MAC PDU, but is used instead for upstream subframe payload information.

FIGS. 12M, 12N and 12O depict an exemplary ODB 1242 in detail. This field is used to store information regarding the connection between the wireless base station 302 and the CPE station 294. ODB 1242 includes preamble 1234a (including link integrity data), subscriber ID 1234b (identifies which CPE station 294 is making the reservation request), system state 1248a (information about the status of the CPE station 294), performance data 1248b (how full the buffer statistics, cpe processor performance statistics, system state), antenna data 1248c (information pertaining to the antenna), CRC 1234e (error checking information) and synchronization pattern 1248d (error checking information).

Referring to FIG. 12M, system state subslot 1248a comprises system mode 1250a (the mode of the CPE station, e.g., command mode, operations mode, or initialization mode of the system), system status 1250b (the status of the CPE station), system resources 1250a (the mode of the CPE station), system power 1250b (the mode of the CPE station), system temperature 1250a (the temperature of the CPE station). The CPE stations 294 are required to take turns using ODB 1242 to transmit their information.

Referring to FIG. 12N, performance data 1248a comprises the number of comrepeats 1252a (the number of repeats of communication attempts), number of frameslips 1252b (the number of frames that have slipped), waitstate index 1252c (an index to the waiting state).

f. Exemplary Class-based Frame Prioritization

FIG. 13 shows block diagram 1300, illustrating how an exemplary flow scheduler for the present invention functions



to schedule packets. Block diagram 1300 includes: flow scheduler 604, 634 (which is a combination of downlink flow scheduler 604 and uplink flow scheduler 634), downlink transmission subframe 1202 (i.e., the next MAC downstream subframe), uplink transmission subframe 1204 (i.e., the current MAC upstream subframe). Block diagram 1300 also includes the following downstream components: downstream reservation first-in-first-out queue 1322, class 1 downstream queue 1302, class 2 downstream queue 1304, and class 3 downstream queue 1306. Block diagram 1300 also includes the following upstream reservation components: current upstream subframe 1344 (with the current upstream subframe 1204 about to be stored in it), previous upstream subframes 1346, 1348, 1350, class 1 upstream reservation request queue 1308, class 2 upstream reservation request queue 1310, and class 3 upstream reservation request queue 1312.

In the downlink path, an IP flow QoS class queuing processor (described below with respect to FIGS. 15A and 15B) queues the received data packets into class 1 packet flow queues 1324, 1326 and 1328, class 2 packet flow queues 1330, 1332, 1334, and class 3 packet flow queues 1336, 1338, 1340 and 1342.

Based on inputs from a hierarchical class-based priority processor, a virtual private network (VPN) directory enabled (DEN) data table and a service level agreement (SLA) priority data table (described below with respect to FIGS. 15A and 15B), the class 1, class 2, and class 3 packet flow queues are respectively assigned to class 1 downstream queue 1302, class 2 downstream queue 1304, and class 3 downstream queue 1306. Flow scheduler 604, 634 schedules these downlink data packets onto the downlink transmission subframe 1202.

In one embodiment, additional processing is used to minimize latency and jitter. For example, suppose the data packets of class 1 packet flow queue 1324 require jitter-free and latency-free delivery, i.e., delivery of packets must be at constant time intervals and in real-time. Packet flow queue 1324 creates, e.g., 4 equal time spaced slot reservations in future frames, as shown in class 1 downstream queue 1302 and described with respect to FIG. 14 below. The reservations are fed to downstream reservation first-in-first-out queue 1322, and are scheduled onto a future downstream frame 1202 by flow scheduler 604, 634.

In the uplink path, reservation requests for future upstream slots arrive at wireless base station 302 as part of the current upstream subframe 1204 received from CPE subscriber stations 294 over the wireless medium. Current upstream subframe 1344 can temporarily store reservation requests for analysis and scheduling of uplink packets in accordance with the description of FIG. 8B above. Previous upstream subframes 1346, 1348, 1350 include upstream reservation requests awaiting upstream frame slot allocations in future upstream subframes 1204. Reservation request blocks (RRBs), described further above with reference to FIG. 12, include a request for a number of slots for a single IP flow with an IP flow identifier # and class of service. The upstream reservation requests (by IP flow and class) are queued onto class 1 upstream reservation request queue 1308, class 2 upstream reservation request queue 1310, and class 3 upstream reservation request queue 1312. An IP flow QoS class queuing processor (described below with respect to FIGS. 16A and 16B). Flow scheduler 604 and 634 and 1666, uses these downstream reservations and upstream reservation requests to assign slots to data packets in the next downstream transmission subframe 1202 and upstream transmission subframe 1204, respectively.

FIG. 14 is an exemplary two-dimensional block diagram 1400 of the advanced reservation algorithm. FIG. 14 includes MAC subframe scheduler 1566, 1666, frames current frame,  $n$  1402, and future frames,  $n+1$  1404,  $n+2$  1406,  $n+3$  1408,  $n+4$  1410,  $n+5$  1412,  $n+6$  1414 . . .  $n+x$  1416, representing frames of data packets to be transmitted at times  $n$ ,  $n+1$ ,  $n+2$  . . .  $n+x$ . Each frame is divided into a variable length downlink subframe 1202 and a variable length uplink subframe 1204. The lengths of downlink subframe 1202 and uplink subframe 1204 together comprise the length of an entire frame.

Each frame  $n$  1402 includes a number of slots (1418-1478). Slots 1418-1446 comprise the downlink subframe 1202, and slots 1448-1478 comprise the uplink subframe 1204. In one embodiment, the slots are fixed in length, with each slot capable of storing a single data packet. The total number of frame slots in a frame remains constant. For example, if a given frame includes 64 frame slots, the slots can be allocated dynamically in either the uplink or downlink directions, such as, e.g., 32 up and 32 down, 64 up and 0 down, 0 up and 64 down. Block diagram 1400 can be thought of as a two dimensional matrix with each slot having a time value (i.e., a slot-to-slot time interval), e.g., 0.01 ms, and each frame having a total frame interval time value (i.e., a frame-to-frame time interval), e.g., 0.5 ms.

In the present invention, an advanced reservation algorithm assigns future slots to data packets based on the priority of the IP data flow with which the packet is associated. Exemplary priorities are described above with respect to FIGS. 8A and 8B. For calls that are sensitive to jitter, meaning calls that are time sensitive, it is important to maintain an isochronous (i.e., in phase with respect to time) connection. With such signals, it is important that the data be dispersed in the same slot between frames, or in slots having a periodic variation between frames. For example, vertical reservation 1480 shows a jitter sensitive signal receiving the same slot for downlink communications in each frame. Specifically, the signal is assigned slot 1422 in frames 1402-1416. If the frame-to-frame interval is 0.5 ms, then a slot will be provided to the IP flow every 0.5 ms. As another example, diagonal reservation 1482 shows a jitter sensitive signal receiving a slot varying by a period of one between sequential frames. Specifically, the signal is assigned slot 1440 in frame 1402, slot 1438 in slot 1404, . . . slot 1426 in frame 1416, to create a "diagonal." If the frame-to-frame interval is 0.5 ms and the slot-to-slot interval is 0.01 ms, then a slot can be provided to the IP flow every 0.5 minus 0.01, equals 0.49 mms. Thus, to decrease the frame interval, a diagonal reservation of positive slope can be used. To obtain an increased frame interval, a diagonal of negative slope such as, e.g., negative slope diagonal uplink reservation 1486. The diagonal reservation 1482 can also be more pronounced (i.e., using a greater or lesser slope), depending on the period between sequential frames desired. Reservation patterns 1480, 1482, 1484 and 1486 are useful patterns for jitter sensitive communications. Also illustrated is a vertical reservation 1486, similar to vertical reservation 1480, useful for a jitter sensitive communication in the uplink direction.

For latency sensitivity, one or more slots can be guaranteed in each frame. For example, for a call that is latency sensitive, but not jitter sensitive, each frame can be assigned one (or more) slots for communications. However, the slot(s) need not be periodic between frames, as with jitter sensitive calls. The greater the number of slots allocated per frame to an IP flow, the greater total bandwidth per frame rate for the IP flow.

For calls that are less latency sensitive, fewer slots per frame can be assigned for the communication. For example, a communication that is less latency sensitive can receive a guaranteed bandwidth of one slot every four frames. A call that is even less latency sensitive can receive, e.g., a single slot every ten frames.

Using these principles, the advanced reservation algorithm can assign the slots from highest priority to lowest priority, exhausting the number of available slots in future frames. IP data flows that are both jitter and latency sensitive can be assigned slots with periodic patterns first (e.g., patterns 1480, 1482, 1484 and 1486), followed by flows that are highly latency sensitive (but not jitter sensitive), et cetera, until the flows of lowest latency sensitivity are assigned to slots. Prioritization of different classes of IP flows by scheduler 604, 634, 1566, 1666 is described further below with reference to FIGS. 15A, 15B, 16A and 16B.

g. Downlink SubFrame Prioritization

#### 1. Overview

FIGS. 15A and 15B are exemplary logical flow diagrams for analysis and scheduling of the shared wireless bandwidth for the downlink direction. The logical flow pertains to IP packet flows arriving from data network 140, at the wireless base station 302, for transmission down to a subscriber CPE station 294d over the wireless medium. FIG. 15A is an exemplary logical flow diagram 1500 for downlink IP analyzer 602. FIG. 15B is an exemplary logical flow diagram 1560 for the downlink flow scheduler 604.

The functional components for FIGS. 15A and 15B are explained by way of method modules, which can be viewed as physical units (e.g., comprising software, hardware, or a combination thereof) or logical vehicles (e.g., used for explanatory purposes only). Those skilled in the art will recognize that the modules are used only to explain an exemplary embodiment, and are not to be considered limiting.

The exemplary logical flow diagram 1500 for downlink IP flow analyzer of FIG. 15A includes packet header identification component 1502, packet characterization component 1504, packet classification component 1506, and IP flow presentation component 1508. The functions of these components are explained in detail below.

In one embodiment, downlink IP flow analyzer 602 is physically located in wireless base station 302, although those skilled in the art will recognize that the same functionality can be located remotely from wireless base station 302.

FIGS. 2D, 3A and 3B are helpful to the reader for an understanding of the downlink IP flow analyzer.

#### 2. Introduction

IP flow analyzer 602 performs the function of identifying, characterizing, classifying, and presenting data packets to a downlink frame scheduler 604. The functions of identifying, characterizing, classifying and presenting the data packets are respectively performed by packet header identification component 1502, packet characterization component 1504, packet classification component 1506 and IP flow presentation component 1508 of downlink IP flow analyzer 602.

Packet header identification component 1502 determines whether a data packet of an incoming IP data flow is part of an IP flow that is known to the system, or is the first data packet of a new IP data flow, based on the contents of fields of the packet header section. Packet header identification component 1502 also identifies, e.g., the source of the packet using the packet header field contents. Packet characterization component 1504 characterizes a new data packet (of a new IP data flow) to determine the QoS requirements for the

IP data flow, and identifies the subscriber CPE station associated with the subscriber workstation that will receive the IP data flow. Packet classification component 1506 classifies the new IP data flow into a communications priority class, grouping the packet together with similar type IP flows. IP data flow presentation 1508 initializes the new IP data flow and presents it to downlink flow scheduler 604.

Downlink flow scheduler 604 places the data packets of an IP data flow into a class queue, and based on a set of rules, schedules the data packets for transmission over the wireless medium to a subscriber CPE station using, e.g., an advanced reservation algorithm. The rules can be determined by inputs to the downlink flow scheduler from a hierarchical class-based priority processor module 1574, a virtual private network (VPN) directory enabled (DEN) data table 1572, and a service level agreement (SLA) priority data table 1570. The advanced reservation algorithm is described further above with respect to FIG. 14.

#### 3. Identification

Packet header identification component 1502 identifies the IP flow received from data network 142 at data interface 320 based on the packet header.

An IP flow packet stream from data network 142, including packets from various IP flows (where each IP flow is associated with a single data "call") is received at packet header identification component 1502. An IP flow can include packetized data including any type of digital information such as, e.g., packetized voice, video, audio, data, IP flows, VPN flows, and real time flows. The IP flow is transmitted over data network 142 from, e.g., a host workstation 136d and arrives at interface 302 of wireless base station 320. Interface 302 transmits the packets of the IP flow to packet header identification component 1502. At module 1510, the received packets are buffered into a storage area. At module 1520, the contents of the packet header fields are extracted and parsed.

For IP flows known to the system, so-called "existing IP flows," there are entries in a table 1526. An IP flow is in the system if there is an existing characterized IP data call. In module 1522, it is determined if there is a match between the incoming packet and an existing IP flow call in an entry in existing IP flow identification table 1526. If so, then the IP flow is known to the system, and control passes to module 1530 of the packet characterization component 1504.

If not, meaning that the IP flow is a new IP data flow, then control passes to module 1524, where the packet header fields are analyzed. Module 1524 analyzes the packet header source field and determines from source application packet header data table 1528 the type of source application making the data call or transmitting the IP packet. The application can be any of the applications described with respect to FIG. 2D or known to those skilled in the art. Examples include a file transfer protocol (FTP) download from another client workstation 138f, an IP voice telephony call (over telephony gateway 288b), a voice telephony call from a caller 124d (connected over a modem), an e-mail from a LAN 128a attached host workstation 136a, a fax machine call, and a conference call from multiple callers 124d and 126d (connected over a modem), to name a few. If the IP flow is not known to the system, then the IP flow is given an IP flow identifier number, and control passes to module 1526 where the IP flow identifier number is added to the existing IP flow identification table 1526.

Once the type source application has been determined by packet header information or by another means, such as direct application identification, then control passes from module 1524 to module 1532 of the packet characterization

component 1504. In order to identify the type of source application of the IP flow, any type of service (TOS) or differentiated service (DiffServ) field can also be analyzed.

#### 4. Characterization

Packet characterization component 1504 characterizes new IP flows and passes them to packet classification component 1506 for classification.

For an existing IP flow, control passes to module 1530 from module 1522 of the packet header identification component 1502. If in module 1522 it is determined that the IP data flow is known to the system, in module 1530 it is determined whether the packet is old (i.e., stale). This can include, e.g., determining from a time-to-live field (a field in the IP packet header) the age of the packet, and comparing the field to a threshold age value. If the packet is determined to be stale, it can be discarded. Based on the age of the packet, client application discards can be anticipated. Otherwise, control can pass to module 1540 of the packet classification component 1506.

For a new IP flow, control passes to module 1532 from module 1524 of the packet header identification component 1502. If in module 1524 it is determined that the IP flow is not known to the system, in module 1532 the QoS requirements for the application are determined using the source application information identified in modules 1524 and 1528. Module 1532 performs this operation by looking up the QoS requirements for the identified source application in the QoS requirement table 1534. Different applications have different QoS requirements in order to provide an acceptable end-user experience. For example, bandwidth allocation (i.e., allocating an appropriate amount of bandwidth) is important to an application performing FTP file transfer downloads, and not jitter (i.e., time synchronizing the received data) and latency (i.e., the amount of time passage between responses). On the other hand, jitter and latency are important to voice telephony and conference calls, while bandwidth allocation is not.

After processing by module 1532, in module 1536 a destination CPE subscriber station ID lookup from subscriber CPE IP address table 1538, is performed for the IP flow. Each subscriber CPE station 294d can have one or more applications, running on one or more subscriber workstations 120d, homed to it. Accordingly, the IP flows can be directed to one or more applications on one or more subscriber workstations of one or more CPE stations 294d. A subscriber workstation can be any device coupled to a subscriber CPE station 294d. Module 1536 looks up the IP flow in table 1538, to determine the identity of the subscriber CPE station 294d that will receive the packets of the new IP flow from data network 142. Control then passes from module 1536 to module 1542 of the packet classification component 1506.

#### 5. Classification

Packet classification component 1506 classifies the IP flow and passes it to IP flow presentation component 1508 for presentation.

For an existing IP flow, control passes to module 1540 from module 1530 of the packet characterization component 1504. If in module 1530 it is determined that the packet is not stale, then in module 1540 the packet is associated with its existing IP flow. As illustrated in FIG. 15A, the packet processed herein was determined to be a portion of an IP flow known to the system. Therefore, the QoS processing of modules 1532, 1536 and 1542 are unnecessary, because the QoS requirements of the present packet are assumed to be the same as for its IP flow. In another embodiment, all packets are characterized and classified. From module 1540, control can continue with module 1546 of IP flow presentation 1508.

For the new IP flow, control passes to module 1542 from module 1536 of the packet characterization component 1504. In module 1542 the packet is classified into a QoS class by performing a table lookup into IP flow QoS class table module 1544, where the types of QoS classes are stored depending on the QoS requirements for packets. Similar IP flows, (i.e., IP flows having similar QoS requirements) can be grouped together in module 1542. In classifying packets and IP flows, QoS class groupings, any DiffServ priority markings, and any TOS priority markings can be taken into account. From the module 1542, control passes to module 1548 of IP flow presentation component 1508.

#### 6. IP Flow Presentation

IP flow presentation component 1508 prepares and presents the IP flow packets to downlink flow scheduler 604.

For existing IP flows, control passes to module 1546 from module 1540 of the packet classification component 1506. In module 1546 the packet is added to the associated existing IP flow queue, which is the queue for the current IP flow. From module 1546, control passes to IP flow QoS class queuing processor module 1562 of downlink flow scheduler 604.

For the new IP flow, control passes to module 1548 from module 1542 of the packet classification component 1506. In module 1548, this new IP flow can be initialized for presentation to module 1552. In module 1550, the IP flow QoS class is presented to frame scheduler 604 to be placed in an appropriate class queue. Module 1552 presents the IP flow (in particular, the data packet) and IP flow identifier to IP flow QoS class queuing processor module 1562 of downlink flow scheduler 604.

#### 7. Downlink Flow Scheduler

The exemplary logical flow diagram 1560 for the downlink flow scheduler 604 of FIG. 15B comprises IP flow QoS class queuing processor module 1562, MAC downlink subframe scheduler module 1566, hierarchical class-based priority processor module 1574, VPN DEN data table module 1572, SLA priority data table 1570, CPE IP flow queue depth status processor 1582 and link layer acknowledgment processor module 1578.

Downlink flow scheduler 604 of FIG. 15B also includes QoS class queues as follows: class 1, 1564a; class 2, 1564b; class 3, 1564c; class 4, 1564d; class 5, 1564e; and class 6, 1564f; and MAC downlink subframes: frame n, 1568a; frame n+1, 1568b; frame n+2, 1568c; frame n+3, 1568d; . . . frame n+p, 1568k.

In one embodiment, downlink flow scheduler 604 is physically located in wireless base station 302, although those skilled in the art will recognize that the same functionality can be located remotely from wireless base station 302.

Downlink flow scheduler 604 is used to schedule the downlink subframe. An entire frame can be divided into an uplink portion (called an uplink subframe) for transmitting uplink frames, and a downlink portion (called a downlink subframe) for transmitting downlink frames.

Also illustrated on FIG. 15B are WAP antenna, the wireless medium, 290d, RF transceiver subscriber antenna 292d, subscriber CPE station 294d and subscriber workstation 120d. WAP antenna 290d and RF transceiver subscriber antenna 292d respectively provide a wireless connection between wireless base station 302 (where downlink flow scheduler 604 resides in one embodiment) and subscriber CPE station 294d, which can transmit an IP flow to an application running on subscriber workstation 120d. WAP antenna 290d serves as a wireless gateway for data network

142, and RF transceiver subscriber antenna serves as a wireless gateway for subscriber CPE station 294d. The connection is also illustrated in FIGS. 2D and 3B.

IP flow QoS class queuing processor module 1562 receives the packets from IP flow presentation component 1508. Module 1562 then creates class queues 1564a-1564f, which is a variable number of queues, and places the packets in these class queues. How packets are placed in class queues 1564a-1564f is determined by the inputs to module 1562.

Module 1562 can receive inputs from hierarchical class-based priority processor module 1574, VPN DEN data table 1572 and service level agreement (SLA) priority data table 1570. The queuing function of module 1562 can be based on these inputs.

SLA priority data table 1570 can use predetermined service level agreements for particular customers to affect the queuing function. A customer can be provided a higher quality of telecommunications service by, for example, paying additional money to receive such premium service. An algorithm running on module 1562 can increase the queuing priority for messages transmitted to such customers.

Virtual private network (VPN) directory enabled networking (DEN) data table 1572 can provide prioritization for a predetermined quality of service for a VPN for a company that pays for the VPN function. A VPN is understood by those skilled in the relevant art to be a private network, including a guaranteed allocation of bandwidth on the network, provided by the telecommunications service provider. VPN DEN data table 1572 permits module 1562 to provide higher quality of service for customer-purchased VPNs. As with SLA priority data table 1570, the queuing priority can be increased for such VPNs. For example, a platinum level VPN's lowest priority IP flow classes could also be given a higher priority than a high priority brass level VPN.

Both SLA priority data table 1570 and VPN DEN data table 1572 receive input from operations, administration, maintenance and provisioning (OAM&P) module 1108. This is a module that is kept off-line, and includes storage and revision of administrative information regarding new customers, or updates of information pertaining to existing customers. For example, the SLA priority of the customers and VPN information is updated from OAM&P module 1108.

Hierarchical class-based priority processor module 1574 is a module that operates under the principles of hierarchical class-based queuing. Hierarchical class-based queuing was created by Sally Floyd and Van Jacobson, considered early architects of the Internet.

Hierarchical class-based queuing classifies different types of IP flows using a tree structure at the edge access device routers. Each branch of the tree signifies a different class of IP flows, and each class is dedicated a set limited amount of bandwidth. In this manner, different classes of flows are guaranteed minimum bandwidth, so that no single IP data flow within a class, and no single class of IP flows, can use up all available bandwidth. The present invention adds a prioritization feature enabling class based priority reservations to be made using the hierarchical class queue concept, as discussed above with respect to FIGS. 13 and 14.

MAC downlink subframe scheduler 1566 is a processor module that takes the packets queued in class queues 1564a-1564f, and can make frame slot reservations to fill up subframes 1568a-1568k based on priorities 1570, 1572 and 1574, which is a variable number of frames. In one embodiment, each subframe is scheduled (filled) with up to

a predetermined number of packets from each of the classes 1564a-1564f according to priorities 1570, 1572 and 1574. In another embodiment, the subframes are scheduled according to the inventive advanced reservation algorithm method described with respect to FIGS. 13 and 14 for isochronous reservations. In yet another embodiment, the subframes are scheduled according to a combination of known methods and the advanced reservation algorithm method of the present invention.

The subframes can then be sent to WAP antenna 290d for wireless transmission over the wireless medium to RF transceiver subscriber antenna 292d coupled to subscriber CPE station 294d, which in turn can send the packets contained in the subframes to subscriber workstation 120d at CPE subscriber location 306d. The subframes can be scheduled from highest priority to lowest priority.

Hierarchical class-based priority (HCBP) processor module 1574 receives as input the subframes that have been scheduled and transmitted from WAP antenna 290d. By maintaining awareness of the status of the packets (i.e., by knowing which packets have been sent out), HCBP processor module 1574 knows which packets from which class queues 1564a-1564f must yet be scheduled.

Every once in a while, a packet is lost through, e.g., noise. When this situation arises, the subscriber CPE station 294d sends a retransmit request 1576 to WAP 290d, which transmits the request to link layer acknowledgment (ARQ) processor 1578. ARQ processor 1578 informs MAC downlink subframe scheduler 1566 of this condition, which in turn reschedules the requested packets from the appropriate class queues 1564a-1564f for retransmission. Link layer acknowledgment ARQ processor 1578 also awaits positive acknowledgments from subscriber CPE station 294d, to determine that the data packets have been properly received. Only after receiving a positive receipt acknowledgment does MAC downlink subframe scheduler 1566 remove the packet from class queues 1564a-1564f.

Each subscriber CPE station 294d has a limited amount of memory available for received data packets in an IP flow. When, for example, the devices coupled to the subscriber CPE station 294d (e.g., subscriber workstation 120d) stop receiving IP data flows (e.g., subscriber workstation 120d goes down), the CPE data packet queues in CPE subscriber station 294d are quickly filled up. In this scenario, subscriber CPE station 294d transmits a CPE IP flow queue depth message 1580 indicating that the queue is filled up, which can be received by CPE IP flow queue depth status processor 1582. CPE queue depth processor 1582 informs MAC downlink subframe scheduler 1566 of this condition, which stops scheduling downlink subframes directed to subscriber CPE station 294d. Processor 1582 can also send messages to MAC downlink subframe scheduler 1566 to flush particular IP flows from class queues 1564a-1564f.

#### h. Uplink SubFrame Prioritization

##### 1. Overview

FIGS. 16A and 16B are exemplary logical flow diagrams for the uplink. The logical flow pertains to analysis and scheduling of shared wireless bandwidth to IP packet flows from a subscriber workstation 120d coupled to a subscriber CPE station 294d, being transmitted over the wireless medium up to the wireless base station 302, and on to data network 142 for transmission to a destination host workstation 136a. FIG. 16A is an exemplary logical flow diagram 1600 for uplink IP flow analyzer 632. FIG. 16B is an exemplary logical flow diagram 1660 for the uplink flow scheduler 634.

The functional components for FIGS. 16A and 16B are explained by way of method modules, which can be viewed

as physical units (e.g., comprising software, hardware, or a combination thereof) or logical vehicles (e.g., used for explanatory purposes only). Those skilled in the art will recognize that the modules are used only to explain an exemplary embodiment, and are not to be considered limiting.

The exemplary logical flow diagram 1600 for uplink IP flow analyzer 632 of FIG. 16A includes packet header identification component 1602, packet characterization component 1604, packet classification component 1606, and IP flow presentation component 1608. The functions of these components are explained in detail below.

In one embodiment, uplink IP flow analyzer 632 is physically located in wireless base station 302, although those skilled in the art will recognize that the same functionality can be located remotely from wireless base station 302. In a preferred embodiment of the present invention, the function of IP flow analyzer 632 is performed at a subscriber CPE station 294d desiring an uplink reservation slot for uplinking a packet/IP flow up to base station 302. A reservation request block (RRB) request detailing the IP flow identifier, number of packets and classification of the IP flow can be created then by IP flow analyzer 632 and can be uplinked via preferably a contention RRB slot for scheduling by uplink frame scheduler 634 in future uplink subframe slots up at wireless base station 302.

FIGS. 2D, 3A and 3B are helpful to the reader for an understanding of the uplink IP flow analyzer.

## 2. Introduction

IP flow analyzer 632 performs the function of identifying, characterizing, classifying, and presenting data packets to an uplink frame scheduler 634. The functions of identifying, characterizing, classifying and presenting the data packets can be respectively performed by packet header identification component 1602, packet characterization component 1604, packet classification component 1606 and IP flow presentation component 1608 of uplink IP flow analyzer 632.

Packet header identification component 1602 determines whether a packet of an incoming IP flow is known to the system (i.e. is an existing IP flow), or if it is the first data packet of a new IP data flow, and determines the source application based on fields in the header section of the packet. Identification 1602 can include buffering packets and extracting and parsing the header contents. Packet characterization component 1604 characterizes a new data packet (of a new IP flow) to determine the QoS requirements for the IP flow based on the source application, and to identify the subscriber CPE station that will receive the IP flow. Packet classification component 1606 classifies the new IP data flow into one of several priority classes. Classification 1606 can include, e.g., grouping packets having similar QoS requirements. IP data flow presentation component 1608 initializes the new IP data flow and presents it to uplink flow scheduler 634.

Each time a subscriber CPE station 294d attempts to communicate in the uplink direction with wireless base station 302, it requests a reservation by inserting an RRB in the uplink subframe. Uplink frame scheduler 634 then schedules the reservation request in a future uplink subframe and notifies the CPE station 294d of the reservation. In a downlink signal, uplink flow scheduler 634 located preferably at wireless base station 302, transmits a reservation slot in a particular future frame for the requesting subscriber CPE station 294d to transmit its uplink data. Uplink flow scheduler 634 assigns the reservation based on the same parameters as the downlink flow scheduler 604 uses in the

downlink. In other words, uplink flow scheduler 634 determines the reservation slots based on the queue class priority and based on a set of rules, schedules the reservations for uplink transmissions from subscriber CPE station 294d using, e.g., an advanced reservation algorithm. The rules are determined by inputs to the uplink flow scheduler 634 from a hierarchical class-based priority processor module 1674, a virtual private network (VPN) directory enabled (DEN) data table 1672, and a service level agreement (SLA) priority data table 1670. The advanced reservation algorithm is described with respect to FIG. 14.

## 3. Identification

Packet header identification component 1602 identifies the IP flow received from a subscriber CPE station 294d based on the packet's header contents.

A stream of packets, also known as packets from several IP flows (i.e. each IP flow is associated with a single "call") is received at packet header identification component 1602. The IP flow in one embodiment is transmitted to subscriber CPE station 294d from one or more subscriber workstations 120d for uplink to host computers 136a coupled to wireless base station 302 by data network 142. Subscriber CPE station 294d can transmit the data packets of the IP flow to packet buffer module 1610 of packet header identification component 1602. In one embodiment, packet header identification component is within CPE subscriber station 294d. At module 1610, the received packets are buffered in a storage area for transfer to header extraction module 1620. At module 1620, the packet header files are extracted and parsed to obtain the contents of the packet header fields.

Relevant fields can include, e.g., source, destination, type of service (TOS) and differentiated service (DiffServ) markings, if any exist.

For IP flows known to the system, there are entries in existing IP flow identification table 1626. An IP flow is in the system if a previous packet of the IP flow of the existing IP data call has already been identified. In module 1622, it is determined if there is a match between the incoming IP flow and an entry in table 1626. If so, then the IP flow is known to the system, and control passes to module 1630 of the packet characterization component 1604.

If the IP flow is not an existing flow known to the system, meaning that the IP flow is a new IP flow, then control passes to module 1624, where the packet header fields are analyzed to identify the source application of the IP flow.

Packet header analysis module 1624 determines from source application packet header table 1628 the type of source application making the IP flow. The application can be any of the types of applications described with respect to FIG. 2D or known to those skilled in the art. Examples include a file transfer protocol (FTP) download from another client workstation 138f, a voice telephony call from a caller 124d (connected over a modem), a fax machine call, and a conference call from multiple callers 124d and 126d (connected over a modem), to name a few. If the IP flow is a new IP flow, then the identification information about the new IP flow is added to table 1626, and control passes from analysis module 1624 to module 1632 of the packet characterization component 1604.

## 4. Characterization

Packet characterization component 1604 characterizes the IP flow and passes it to packet classification component 1606 for classification.

If the IP flow is an existing IP flow, control passes to module 1630 from module 1622 of the packet header identification component 1602. If in module 1622 it is determined that the IP data flow is known to the system, in

module 1630 it is determined whether the packet is old (i.e., stale). This can include determining from a time-to-live field (a field in the IP packet header) the age of the packet, and comparing the field to a threshold age value. If the packet is determined to be stale, it is discarded. Module 1630 can anticipate application packet discards. From module 1630, control passes to module 1640 of the packet classification component 1606.

If the IP flow is new, control passes to module 1632 from module 1624 of the packet header identification component 1602. If in module 1624 it is determined that the application associated with the IP flow application is not known to the system, in IP flow QoS requirements lookup module 1632 the QoS requirements for the application associated with the IP flow are determined. Module 1632 performs this operation by looking up the application in IP flow QoS requirement table 1634. Different applications have different requirements. For example, bandwidth allocation (i.e., allocating an appropriate amount of bandwidth) is important to an application performing FTP downloads, and not jitter (i.e., time synchronizing the received data) and latency (i.e., the amount of time passage between responses). On the other hand, jitter and latency are important to voice telephony and conference calls, and bandwidth allocation is not.

After processing by module 1632, control passes to module 163b. In CPE subscriber station identifier (ID) lookup module 1636 a subscriber CPE ID lookup is performed for the new IP data flow. Each subscriber CPE station 294d can have one or more applications, running on one or more subscriber workstations 120d, homed to it. Accordingly, one or many subscribers can generate or receive an IP flow directed from or at a subscriber CPE station 294d. A subscriber workstation 120d can be any device coupled to a subscriber CPE station 294d. Module 1636 looks up the CPE station identifier for the IP flow in table 1638, to provide the CPE ID in the reservation request block (RRB). Control then passes from module 1636 to module 1648 of the packet classification component 1606.

#### 5. Classification

Packet classification component 1606 classifies the IP flow and passes it to IP flow presentation component 1608 for presentation.

For existing IP flows, control passes to module 1640 from module 1630 of the packet characterization component 1604. If in module 1630 it is determined that the packet is not stale, then in module 1640 the packet is associated with its IP flow. As illustrated in FIG. 16A, the packet processed herein was determined to be a portion of an IP flow known to the system. Therefore, the QoS processing of modules 1632, 1636 and 1642 are unnecessary, because the QoS requirements of the present packet are the same as for its IP flow.

For new IP flows, control passes to module 1642 from module 1636 of the packet characterization component 1604. In module 1642 the packet is classified or grouped into a QoS class by performing an IP flow QoS requirement table 1644 lookup where the QoS classes are stored depending on the QoS requirements for packets. From module 1642, control passes to module 1648 of IP flow presentation component 1608.

#### 6. IP Flow Presentation

IP flow presentation component 1608 prepares and presents the IP data flow packets to flow scheduler 634. In one embodiment of the uplink direction, a reservation request block (RRB) is created and uplinked via a contention slot to the wireless base station 302 for scheduling by IP flow scheduler 634. In another embodiment, the scheduler is located at the CPE station 294d so no reservation request is needed.

For existing IP flows, control passes to module 1646 from module 1640 of the packet classification component 1640. In module 1646, the packet is added to the IP flow queue, which is the queue for the current existing IP flow. In one embodiment, this can include preparation of a RRB. From module 1646, control passes to module 1662 of uplink flow scheduler 634. In one embodiment, this can include uplink of the RRB from CPE 294d to wireless base station 302.

For a new IP flow, control passes to module 1648 from module 1642 of the packet classification component 1606. In initialize IP flow module 1648, this new IP flow is initialized for presentation to module 1652. Module 1652 presents the IP data flow (in particular, the reservation request block data packet) to module 1662 of uplink flow scheduler 634. In module 1650, the QoS class for the IP flow is presented to scheduler 634, preferably by inclusion in a RRB.

#### 7. Uplink Flow Scheduler

The exemplary logical flow diagram for the uplink flow scheduler 634 of FIG. 16B comprises IP flow QoS class queuing processor module 1662, MAC uplink subframe scheduler module 1666, hierarchical class-based priority processor module 1674, VPN DEN data table module 1672, SLA priority data table 1670, CPE IP flow queue depth status processor 1682 and link layer acknowledgment processor module 1678.

Uplink flow scheduler 634 of FIG. 16B also includes QoS class queues for class 1, 1664a; class 2, 1664b; class 3, 1664c; class 4, 1664d; class 5, 1664e; and class 6, 1664f; and

MAC uplink subframes: frame n 1668a; frame n+1, 1668b; frame n+2, 1668c; frame n+3, 1668d, . . . frame n+p, 1668k.

In one embodiment, uplink flow scheduler 634 is physically located in wireless base station 302, although those skilled in the art will recognize that the same functionality can be located remotely from wireless base station 302. For example, in another embodiment, uplink flow scheduler 634 can be located at CPE station 294d and is in communication with other CPE stations 294 and the wireless base station 302.

Uplink flow scheduler 634 is used to schedule the uplink subframe. The entire frame is divided into an uplink portion (called an uplink subframe) for transmitting uplink frames, and a downlink portion (called a downlink subframe) for transmitting downlink frames.

Illustrated in FIG. 16B are WAP antenna 290d, the wireless medium, RF transceiver subscriber antenna 292d, subscriber CPE station 294d and subscriber workstation 120d. WAP 290d and RF transceiver subscriber antenna 292d respectively provide a wireless connection between wireless base station 302 (where uplink flow scheduler 634 resides in one embodiment) and subscriber CPE station 294d, which can transmit upstream an IP flow from an application running on client computer 120d. WAP 290d serves as a wireless gateway for data network 142, and RF transceiver subscriber antenna 292d serves as a wireless gateway for subscriber CPE station 294d to uplink the IP flow packet data.

Also illustrated in FIG. 16B is data interface 320, which provides a connection from uplink flow scheduler 634 for sending uplinked IP flow packets on to data router 140d of data network 142 and on to a destination host computer 136a. These connections are also illustrated in FIGS. 2D and 3B.

The previous frame includes an uplink reservation request which is received by the wireless base station from a

subscriber CPE station 294d. At this point, the reservation request block has been identified, characterized, classified, and presented, preferably at the CPE station 294d, and has been transmitted to uplink flow scheduler 634 from uplink flow analyzer 632 at the CPE 294d. In particular, the reservation request block is presented to IP flow QoS class queuing processor module 1662 from module 1650. Module 1662 informs MAC uplink subframe scheduler 1666 of the reservation.

In turn, MAC uplink subframe scheduler 1666 uses a slot in the subframe to acknowledge receipt of the request called the acknowledgment request block (ARB). An exemplary slot used to convey the frame, slot, and IP flow identifier for this reservation is described with respect to FIG. 12. Scheduler 1666 transmits in this reservation slot the CPE identification data, along with which future slot(s) and frame(s) the requesting subscriber CPE station 294d is permitted to use for uplink of the requested data packet IP flow transmissions.

The future slot(s) in the future frame(s) are assigned, e.g., based on inputs from hierarchical class-based priority processor module 1674, VPN DEN data table 1672 and service level agreement (SLA) priority data table 1670. These components function in a similar manner to hierarchical class-based priority processor module 1574, VPN DEN data table 1572 and service level agreement (SLA) priority data table 1570, described with respect to the downlink flow scheduler 604.

When IP flow QoS class queuing processor module 1662 receives packets of an existing or new IP flow from IP flow presentation module 1608, it then creates class queues 1664a-1664f, which is a variable number of queues, and places the packets in these class queues. In a preferred embodiment there are between 3 and 10 classes. These queues hold reservation request packets for scheduling. Packets are placed in class queues 1664a-1664f according to the contents of the reservation request block for input to module 1662.

Module 1662 receives inputs from hierarchical class-based priority processor module 1674, VPN DEN data table 1672 and service level agreement (SLA) priority data table 1670. The queuing function of module 1662 is based on these inputs. These components function analogously to their counterparts in the downlink flow scheduling method. SLA priority data table 1670 and VPN DEN data table 1672 receive input from operations, administration, maintenance and provisioning (OAM&P) module 1108. OAM&P module 1108 provides updates to priorities when, e.g., a subscriber modifies its service level agreement or a VPN subscription is changed.

MAC uplink subframe scheduler 1666 takes the requests queued in class queues 1664a-1664f, and schedules reservations of slots in frames 1668a-1668k, which is a variable number of frames. In one embodiment, each frame is scheduled with up to a predetermined number limit or percentage limit of packets from each of the classes 1664a-1664f. The requests can be scheduled as shown in FIG. 13, taking into account certain priorities. In another embodiment, the frames are scheduled according to the inventive advanced reservation algorithm method for scheduling isochronous type traffic described with respect to FIG. 14. In yet another embodiment, the frames are scheduled according to a combination of known methods and the advanced reservation algorithm method of the present invention.

The reservation slot schedule can then be sent down to the CPE stations 294 using, e.g., FDB slots such as 1236g and

1236h of FIG. 12F. The uplink slots can then be inserted by CPE station 294d into the uplink subframe as scheduled. The frame slots are then transmitted up from CPE station 294d to wireless base station 302 and are then sent on as packets to their destination addresses. For example, from wireless base station 302 the packets can be transmitted over data network 142 to a host computer 136a.

After the uplink packets are received by the wireless base station 302, the wireless base station 302 sends an upstream acknowledgment data block (UAB) message back down to the transmitting subscriber CPE station 294d, to acknowledge receipt of the transmitted data packets.

Every once in a while, a packet is lost through noise or other interference in the wireless medium. When this situation arises, the subscriber CPE station 294d determines that it has not received a UAB data acknowledgment, so it sends a retransmit request requesting another uplink reservation slot to wireless base station 302 via WAP 290d, which transmits the request to link layer acknowledgment (ARQ) processor 1678. ARQ processor 1678 informs MAC uplink subframe scheduler 1666 of the need of retransmission (i.e. the need of a frame slot reservation for resending the uplink packet). CPE subscriber station 294d can also send to ARQ processor 1678, other data messages about nonreceipt of uplink transmission acknowledgments. The ARQ 1678 can forward such messages on to the uplink subframe scheduler 1666. The uplink subframe scheduler 1666 in turn reschedules the requested uplink reservation from the appropriate class queues 1664a-1664f. Alternatively, in another embodiment, link layer acknowledgment processor 1678 can also send a positive UAB acknowledgment to the subscriber CPE station 294d, to indicate that the data packets have been properly received. Thus uplink scheduler 1666 in addition to scheduling first time reservations, also can schedule repeat reservations for lost packets.

Each subscriber CPE station 294d has a limited amount of memory space available for queuing packets received from subscriber workstations 120d awaiting reservation slots of uplink from the CPE 294d to wireless base station 302. When, for example, the the queue of subscriber CPE station 294d becomes full from a backup of packets awaiting upstream reservations, IP data flows can potentially be lost, or packets may become stale. In this scenario, subscriber CPE station 294d transmits a CPE IP flow queue depth message 1680 to the wireless base station 302 indicating that the queue is filled up, which can be received by CPE IP flow queue depth status processor 1682. Processor 1682 can inform MAC uplink subframe scheduler 1666 of this condition, which can, e.g., increase temporarily the priority of IP flows at subscriber CPE station 294d to overcome the backlog or can, e.g., stop transmitting additional downlink packets to the CPE station 294d until the queue depth backlog is decreased to an acceptable level again. Processor 1682 can also send messages to MAC uplink subframe scheduler 1666 to flush reservation requests from the subscriber CPE station 294d in class queues 1664a-1664f.

#### 4. TCP Adjunct Agent

TCP is a reliable transport protocol tuned to perform well in traditional networks where congestion is the primary cause of packet loss. However, networks with wireless links incur significant losses due to bit-errors. The wireless environment violates many assumptions made by TCP, causing degraded end-to-end performance. See for example, Balakrishnan, H., Seshan, S. and Katz, R. H., "Improving Reliable Transport and Handoff Performance in Cellular Wireless Networks," University of California at Berkeley, Berkeley, Calif., accessible over the Internet at URL, <http://>

www.cs.berkeley.edu/~ss/papers/winet/html/winet.html, dealing more directly with handoffs and bit errors in a narrowband wireless environment, the contents of which are incorporated by reference. Attempts to address this problem have modified TCP in order to overcome it. However, this is not a commercially feasible means of overcoming this challenge. It is impracticable to implement any solution that requires a change to the standard operation of TCP.

The present invention uses an enhanced MAC layer which interfaces with a TCP adjunct agent to intercept TCP layer requests to manipulate the TCP layers at either a source or destination end of a transmission, to modify TCP behavior at the source and destination of the TCP/IP transmission which includes an intermediary wireless link. Packets can be queued at the wireless base station awaiting receipt acknowledgment and the base station can perform local retransmissions across the wireless link to overcome packet loss caused by high bit-error rates. Communication over wireless links is characterized by limited bandwidth, high latencies, sporadic high bit-error rates and temporary disconnections which must be dealt with by network protocols and applications.

Reliable transport protocols such as TCP have been tuned for traditional wired line networks. TCP performs very well on such networks by adapting to end-to-end delays and packet losses caused by congestion. TCP provides reliability by maintaining a running average of estimated round-trip delay and mean deviation, and by retransmitting any packet whose acknowledgment is not received within four times the deviation from the average. Due to the relatively low bit-error rates over wired networks, all packet losses are correctly assumed to be caused by congestion.

In the presence of the high bit-error rates characteristic of wireless environments, TCP reacts to packet losses as it would in the wired environment, i.e. it drops its transmission window size before retransmitting packets, initiates congestion control or avoidance mechanisms (e.g., slow start) and resets its retransmission timer. These measures result in an unnecessary reduction in the link's bandwidth utilization, thereby causing a significant degradation in performance in the form of poor throughput and very high interactive delays.

The present invention maintains packets in class queues awaiting acknowledgment of receipt from the subscriber CPE stations. Unacknowledged data slots can then be resent by having the wireless base station perform local retransmissions to the subscriber CPE station. By using duplicate acknowledgments to identify a packet loss and performing local retransmissions as soon as the loss is detected, the wireless base station can shield the sender from the inherently high bit error rate of the wireless link. In particular, transient situations of very low communication quality and temporary disconnectivity can be hidden from the sender.

For transfer of data from a CPE subscriber host to a wireless base station host, missing packets are detected at the wireless base station and negative acknowledgments can be generated for them. The negative acknowledgments can request that the packet be resent from the CPE subscriber host (the sender). The CPE subscriber host can then process the negative acknowledgment and retransmit corresponding missing packets. Advantageously, no modifications to the sender TCP or receiver TCP is necessary, since the present invention places TCP aware functionality in the MAC layer.

FIG. 5A illustrates flow 500 depicting IP flows from a source TCP at a subscriber host, down a protocol stack for transmission through a CPE subscriber station, through a wireless medium to a wireless base station, up and through

a protocol stack at the wireless base station having an example TCP adjunct agent, then through a wireline connection and through a protocol stack to a destination host. The adjunct TCP agent modifies operation of a TCP sliding window algorithm at the transmitting TCP and in cooperation with proactive reservation-based intelligent multimedia access technology (PRIMMA) media access control (MAC) enables local retransmission over the wireless medium in accord with the present invention.

Specifically, flow 500 illustrates IP packet flow from subscriber workstation 120d, through CPE subscriber station 294d at CPE subscriber location 306d, then over a wireless transmission medium to wireless base station 302, and eventually over a wireline link over data network 142 to host workstation 136a.

TCP adjunct agent 510e makes sure transport is reliable by modifying operation of the TCP sliding window algorithm at the transmitting TCP in a manner that optimizes the window for the wireless medium. TCP adjunct agent 510e advantageously is transparent to industry standard protocols as agent 510e does not require modification of the standard TCP/UDP layer of client subscriber workstation 120d or host workstation 136a.

Flow 500 includes IP flows from application layer 512a, down the protocol stack through TCP/UDP layer 510a, through IP layer 508a, then through point-to-point (PPP) layer 520a, then through data link Ethernet layer 504a, then through 10BaseT Ethernet network interface card (NIC) physical layer 502a, over a wire line connection to 10BaseT Ethernet NIC physical layer 502b of subscriber CPE 294d.

Subscriber CPE 294d flows packets coming in from NIC 502b, back up its protocol stack through Ethernet layer 504b, through PPP layers 520b and 520c, back down through PRIMMA MAC 504c to wireless physical layer 502c including antenna 292d, then over the wireless medium to antenna 290d of wireless base station 302.

Wireless base station 302 flows packet IP flows up from antenna 290d at physical layer 502d through PRIMMA MAC layer 504d, through PPP layer 520a, through IP layer 508d to TCP adjunct agent 510e, which can flow IP flows down through IP layer 508e, through PPP layer 520e, through wide area network (WAN) layer 504e, through wireline physical layer 502e, through interface 320, over routers 140d, through data network 142, via wireline connections to wireline layer 502f of WAN host workstation 136a.

Host workstation 136a flows IP flows from wireline layer 502f, up through its protocol stack through WAN layer 504f, through PPP layer 520f, through IP layer 508f, to TCP/UDP layer 510f and on to application layer 512f.

TCP/UDP layers 510a and 510f act to provide such transport functions as, e.g., segmentation, managing a transmission window, resequencing, and requesting retransmission of lost packet flows. Normally TCP layers 510a and 510f would send a window of packets and then await acknowledgment or requests for retransmission. A TCP sliding window algorithm is normally used to vary the transmission flow to provide optimized transport and to back off when congestion is detected by receipt of requests for retransmission. Unfortunately in the wireless environment, due to high bit error rates, not all packets may reach the destination address, not because of congestion, but rather because of high bit error rates, so as to prompt a retransmission request from the destination IP host to the source. Rather than slow transport, TCP adjunct agent 510e modifies operation of the TCP sliding window algorithm to optimize operation over wireless. PRIMMA MAC layer 504d inter-



acts with TCP adjunct agent 510e permitting the agent to intercept, e.g., retransmission requests, from TCP layer 510a of subscriber workstation 120d intended for host 136a, and allowing the wireless base station to retransmit the desired packets or flows to subscriber workstation 120d rather than forwarding on the retransmission request to host 136a, since the packets could still be stored in the queue of PRIMMA 504d and would not be discarded until an acknowledgment of receipt is received from the subscriber CPE. Since retransmission can be performed according to the present invention at the PRIMMA MAC data link layer, i.e. layer 2, retransmission can occur from the base station to the CPE subscriber, rather than requiring a retransmission from all the way over at the transmitting source TCP which would cause TCP to backoff its sliding window algorithm. Thus, by having wireless base station 302 retransmit until receipt is acknowledged over the wireless link, the inherently high bit error rate can be overcome, while maintaining an optimal TCP window.

Recall, a TCP transmitter transmits a TCP sliding window block of packets and alters the size of the window upon detection of congestion. The TCP transmitter transports a block of packets in a window, and then awaits acknowledgment from the receiver. If transmission is going smoothly, i.e. no congestion or lost packets occur, then the transmitter TCP ramps up the transmission rate. This increased transmission rate continues until the transmitting TCP detects congestion or packet loss. When notified of congestion, the transmitting TCP stops transmitting, backs off and sends a smaller block (i.e. a smaller window) of packets.

TCP adjunct agent modifies normal TCP operation by tricking the transmitting TCP and its transmitting window algorithm. The TCP adjunct agent prevents the transmitter from being notified of loss, i.e. receiving congestion notification, from the receiving TCP by, e.g., preventing duplicate retransmission requests. Since the transmitting TCP does not receive such notification, it does not modify the TCP sliding window and transmission continues at the higher rate.

In the event that real congestion occurs, i.e. if the TCP adjunct agent recognizes packets really were lost, then the TCP adjunct agent can let the retransmission request go through to the transmitting TCP. This is advantageously accomplished because the MAC link layer of the present invention is in communication with the higher protocol layers, it is application aware, transport aware and network aware. In this case, because the MAC layer is transport layer aware, PRIMMA MAC layer 504d communicates with the TCP adjunct agent 510e at layer 4. Since the MAC requires acknowledgment of receipt of wireless transmissions sent to the CPE subscriber station 294d for every packet sent from the wireless base station 302, the MAC layer 504d knows whether an inter-TCP layer communication, e.g., a request for retransmission, is sent from a client computer TCP at the CPE station is created because the lost packet was lost in wireless transmission, or because of real congestion.

If PRIMMA MAC 504d does not receive an acknowledgment from 504c, then the PRIMMA MAC 504d of wireless base station 302 can retransmit the contents of the lost packet to the subscriber CPE station 294d. If the PRIMMA MAC 504c of the subscriber CPE station 294d acknowledges receipt and still requests a retransmission, then real congestion could have occurred and the PRIMMA MAC 504d of the wireless base station 302 can let the TCP adjunct agent 510e know that it should allow the retransmission request to be sent to the transmitting TCP 510f of host workstation 136a.

Thus, TCP adjunct agent 510e of the present invention can modify operation of the TCP sliding window algorithm in a manner that is optimal for the wireless medium, without requiring any change to commercially available TCP layers 510a and 510f at the receiver and sender hosts. In an embodiment, TCP adjunct agent 510e obviates the need for any modification of the TCP layers at either the sending (i.e. transmitting) host or client. In another embodiment the host and client TCP layers are unaware of the modification of operation by the TCP adjunct agent, i.e. it is transparent to source and destination TCP layers. In another embodiment, TCP adjunct agent 510e intercepts retransmission requests between a TCP layer of the client computer coupled to the subscriber CPE station and the TCP layer of the host workstation coupled to the data network.

FIG. 5B illustrates functional flow diagram 522 including an example functional description of TCP adjunct agent 510e performing an outgoing TCP spoof function. Referring to FIGS. 5B and 5A, diagram 522 assumes that a TCP layer 510f at a transmitting host 136a has transmitted a windowful of packet data to subscriber workstation 120d, and awaits acknowledgment. Diagram 522 illustrates receipt of an outgoing TCP message 524 in TCP adjunct agent 510e at wireless base station 302 which has been sent from subscriber workstation 120d via subscriber CPE station 294d.

In step 526, the TCP header contents of outgoing TCP message 524 is parsed in order to reveal the contents of the message being sent from subscriber workstation 120d through the wireless network toward the transmitting host 136a.

In step 528, it is determined whether the TCP header contents includes a duplicate acknowledgment message from the CPE station. Receiving a duplicate acknowledgment request from the CPE subscriber location could be indicative of a lost message in the wireless medium, or a real congestion problem. If in step 528 the TCP packet is determined to be a duplicate acknowledgment message, then processing can continue with step 532, if not, then processing can continue with step 530.

In step 530, it is determined that there was real congestion, i.e., this was not a duplicate acknowledgment message caused by retransmission attempts at the wireless link layer. Thus, in step 530, the TCP message is permitted to pass through TCP adjunct 510e without modification, and can continue through flow 500 to TCP layer 510f of FIG. 5A.

In step 532, since there was a duplicate acknowledgment detected in step 528, it is determined whether the packet was successfully transmitted, or not. Step 532 is performed via intercommunication between TCP adjunct agent 510e and PRIMMA MAC layer 504d. This is an example of the interactivity between PRIMMA MAC and higher layer protocols illustrated as line 428 in FIG. 4. PRIMMA MAC layer 504d can identify whether a packet was successfully sent from wireless base station 302 to CPE station 294d since, as illustrated in FIG. 15B, requests for retransmission 1576 are received from CPE station 294d at link layer acknowledgment (ARQ) processor 1578 to MAC downlink subframe scheduler 1566 alerting the scheduler 1566 to retransmit the lost packet in a future frame 1568. If in step 532, it is determined that the packet was successfully transmitted, then processing can continue with step 530, as described above. If however it is determined that the packet was not successfully transmitted, then processing continues with step 534.

In step 534, since the packet was not successfully transmitted, TCP adjunct agent 510e can suppress transmission of TCP message 524 since it can be assumed that the

packet was lost in the wireless medium. Processing can continue with step 536.

In step 536, TCP adjunct agent 510e can wait for notification from PRIMMA MAC 504d that a successful link layer retransmission of the lost packet was received at link layer acknowledgment processor 1578. From step 536, processing can continue with step 538.

In step 538, upon receipt of acknowledgment of a successful PRIMMA MAC 504d link layer retransmission, then normal TCP messages can be resumed.

In another step (not shown), TCP adjunct agent and PRIMMA MAC layers can set a limit of a threshold number of retransmission attempts, and if that threshold is reached, then processing can continue with step 530 to permit the TCP message to pass without modification.

FIG. 5C illustrates functional flow diagram 540 including an example functional description of TCP adjunct agent 510e performing an incoming TCP spoof function. Referring to FIGS. 5C and 5A, diagram 540 assumes that a TCP layer 510a at a transmitting subscriber workstation 120d has transmitted a windowful of packet data to host 136a, and awaits acknowledgment. Diagram 544 illustrates receipt of an incoming TCP message 542 in TCP adjunct agent 510e at wireless base station 302 which has been sent from host workstation 136a via data network 142 for transmission over the wireless medium to subscriber CPE 294d to subscriber workstation 120d.

In step 544, the TCP header contents of ingoing TCP message 542 is parsed in order to reveal the contents of the message being sent from host 136a through the wireless network toward the transmitting subscriber workstation 120d.

In step 546, it is determined whether the TCP header contents includes a duplicate acknowledgment message from host 136a. Receiving a duplicate acknowledgment request from the host could be indicative of a lost message in the wireless medium, or a real congestion problem. If in step 546 the TCP packet is determined to be a duplicate acknowledgment message, then processing can continue with step 550, if not, then processing can continue with step 548.

In step 548, it is determined that there was real congestion, i.e., this was not a duplicate acknowledgment message caused by retransmission attempts at the wireless link layer. Thus, in step 548, the TCP message is permitted to pass through TCP adjunct 510e without modification, and can continue through flow 500 to TCP layer 510a of FIG. 5A.

In step 550, since there was a duplicate acknowledgment detected in step 546, it can be determined whether the packet was successfully transmitted, or not. Step 550 can be performed via intercommunication between TCP adjunct agent 510e and PRIMMA MAC layer 504d. This is an example of the interactivity between PRIMMA MAC and higher layer protocols illustrated as line 428 in FIG. 4. PRIMMA MAC layer 504d can identify whether a packet was successfully sent from CPE station 294d to wireless base station 302, as illustrated in FIG. 16B, requests for retransmission 1676 are received from CPE station 294d at link layer acknowledgment (ARQ) processor 1678 to MAC downlink subframe scheduler 1666 alerting the scheduler 1666 to retransmit the lost packet in a future frame 1668. If in step 550, it is determined that the packet was successfully transmitted, then processing can continue with step 548, as described above. If however it is determined that the packet was not successfully transmitted, then processing continues with step 552.

In step 552, since the packet was not successfully transmitted, TCP adjunct agent 510e can suppress transmission of TCP message 542 since it can be assumed that the packet was lost in the wireless medium. Processing can continue with step 554.

In step 554, TCP adjunct agent 510e can wait for notification from PRIMMA MAC 504d that a successful link layer retransmission of the lost packet was received at link layer acknowledgment processor 1678. From step 554, processing can continue with step 556.

In step 556, upon receipt of acknowledgment of a successful PRIMMA MAC 504d link layer retransmission, then normal TCP messages can be resumed.

In another step (not shown), TCP adjunct agent and PRIMMA MAC layers can set a limit of a threshold number of retransmission attempts, and if that threshold is reached, then processing can continue with step 548 to permit the TCP message to pass without modification.

#### 5. Wireless QoS Aware PRIMMA Media Access Control (MAC) Hardware Architecture

FIG. 10 illustratively depicts an embodiment of PRIMMA MAC hardware architecture 1000. Architecture 1000 shows data network 142 coupled by a wireline bidirectional connection to WAN interface 320.

WAN interface 320 is bidirectionally linked to a bidirectional data frame FIFO 1002 which is bidirectionally coupled to both segmentation and resequencing (SAR) 1004 and QoS/SLA rules engine and processor 1008.

QoS/SLA rules engine and processor 1008 is also bidirectionally coupled to IP flow buffers 1014 and flash random access memory (RAM) 1010.

SAR 1004 is bidirectionally coupled to IP flow buffers 1014, flash RAM 1010, QoS/SLA rules engine and processor 1008 and PRIMA MAC scheduler ASIC 1012.

PRIMA MAC scheduler ASIC 1012 is also bidirectionally coupled to an RF interface 290, a static RAM (SRAM) radio cell buffer 1018 and IP blow buffer 1014.

#### 6. Wireless Base Station Software Organization

FIG. 11 is an exemplary software organization for a packet-centric wireless point to multi-point telecommunications system. The software organization of FIG. 11 includes wireless transceiver and RF application specific integrated circuit (ASIC) module 290, IP flow control component 1102, WAN interface management component 1104, QoS and SLA administration component 1106, system and OAM&P component 1108, customer billing and logging component 1110, directory enabled networking (DEN) component 1112, and wireless base station 320.

IP flow control module 1102 includes transmission queuing control module 1102a, TCP rate control and class of service module 1102b, wireless PRIMMA MAC layer engine 1102c and IP flow identification and analysis module 1102d.

WAN interface management component 1104 includes WAN ingress/egress queuing control module 1104a, WAN interface ports (e.g., for T1, T3, OC3 ports) 1104b, firewall and security module 1104c, and WAN traffic shaping module 1104d.

The IP Flow control component 1102 and WAN interface management component 1104 represent the "core" of the system, where the packet processing, MAC layer scheduling, TCP proxy agent, and WAN I/F control functions are located. Much of the activities of the "non-core" components described above support and control these core components.

QoS and SLA administration component 1106 includes QoS performance monitoring and control module

1106a, service level agreements module 1106b, policy manager module 1106c and encryption administration module 1106d.

The QoS and SLA administration component 1106 provides the static data needed by the system in order to properly group particular IP-flows into QoS classes. Typically, during the provisioning phase of installing the system, the service provider will (remotely) download pertinent information about the subscriber CPE station 294, including the subscriber CPE stations's SLA, any policy-based information (such as hours of operation or peak data transmission rate allowance.). Encryption keys or "strengths" can also be downloaded, which may be subscriber CPE station or service provider specific.

System OAM&P component 1108 includes SNMP proxy client for WAP module 1108a, SNMP proxy clients for CPE module 1108b, and system operations, administration, management and provisioning module 1108c.

The OAM&P component 1108 allows remote service personnel and equipment to monitor, control, service, modify and repair the system. System performance levels can be automatically monitored, and system traps and traces can be set. Subscriber complaints can be addressed with the use of remote test and debug services controlled by OAM&P component 1108. System capacity limits can be monitored, and proactive provisioning of additional WAN connectivity can occur, as the result of automatic trend analysis functions in OAM&P component 1108.

Customer billing and logging module 1110 includes account logging and database management module 1110a, transaction query and processing control module 1110b, billing and account control module 1110c, and user authentication module 1110d.

The customer billing and logging component 1110 allows the service provider to receive account, billing and transaction information pertaining to subscribers in the system. For service providers who bill on the basis of usage, cumulative system resource utilization data can be gathered. For specific types of activities (eg. video conferencing, multi-casting, etc.) there may be special billing data that is collected and transmitted to the service provider. This component also controls the availability of the system to subscribers through the operation of the subscriber authentication function. Once a subscriber is authorized to use the system, a new subscriber authentication entry is made (remotely) by the service provider. Likewise, a subscriber can be denied further access to the system for delinquent payment for services, or for other reasons. The service provider can also remotely query the system for specific account-related transactions.

Directory Enabled Networking (DEN) component 1112 includes DEN QoS 1112a module, DEN management and provisioning 1112b module, DEN IPSEC module 1112c and IP-based VPN control and administration module 1112d.

The DEN component 1112 allows the service provider the means to input into the system relevant information regarding the operation of DEN-based VPN's of subscribers. Subscriber VPNs need to be "initialized" and "provisioned" so that the system properly allocates system resources to subscribers with these VPNs, and provides for the recognition and operation of these VPNs. Data from DEN component 1112 are utilized by the system to apply the appropriate priorities to IP-flows of the subject subscribers.

The invention's packet-centric wireless base station supports directory enabled networking (DEN), a MICROSOFT, INTEL and CISCO standard for providing a standard structure for how distributed sites manage IP flows. The present invention prioritizes VPN traffic in a lightweight directory

access protocol (LDAP)-compliant (LDAP is available from MICROSOFT of Redmond, Wash.) manner which allows remote administration, provisioning and management. The present invention is also LDAP version 2 compliant. The present invention also complies with the X.500 standard promulgated by the international telecommunications union/ telecommunications section (ITU/T), and with the RFC 1777.

In one embodiment, DEN provides policy-based network management, IPsec compatible network security, and IPsec based VPNs. The DEN of the wireless base station 302 is planned to be common information model (CIM) 3.0 compatible (once the specification is finalized). The wireless base station 302 can provide native DEN support and supports directory based DEN QoS mechanisms including reservation model (i.e. RSVP, per-flow queuing), and precedence/priority/differentiated model (i.e. packet marking). Wireless base station 302 can plan support of DEN network policy QoS, and until DEN is complete, can support internal QoS and network extensions.

#### 6. IPsec Support

IPsec is introduced above with reference to FIG. 4. IPsec provides a standard method of encrypting packets. In VPN tunnel mode, an entire header can be encoded, i.e. encrypted. In order for the present invention to be able to implement its packet-centric, QoS aware prioritization, during identification of a packet/IP flow, the wireless base station needs to be able to analyze the contents of header fields of the packets. Therefore, analysis of unencrypted packets is desirable.

The present invention already encrypts the data stream prior to transmitting frames over the wireless medium, so IPsec does not really need to be used over the wireless link to provide for encrypted transmission. Where a service provider finds it desirable to use IPsec, IPsec can be used for authentication and secure encapsulation of the header and payload, or just the payload data. IPsec is normally integrated at a firewall. If a service provider desires to implement the present invention and IPsec, then the present invention should be implemented behind the firewall, i.e. the firewall can be moved to the wireless base station. This permits ending the IPsec stream at the base station which can provide the base station access to packet header fields.

FIG. 17 illustrates IP flow in the downlink direction including IPsec encryption. Similarly, FIG. 18 illustratively depicts an uplink direction of IPsec support of the present invention.

FIG. 17 illustrates downlink flow 1700 depicting downlink direction IP flows from a source host workstation 136a, down a protocol stack which supports IPsec, for transmission up and through wireless base station 302 which is coupled to data network 142, through encryption layers, then through the wireless link to subscriber CPE 294d, up and through a protocol stack at the subscriber CPE 294d, then through a wireline connection to data network 142 and up through the protocol stack to the destination subscriber workstation 120d at subscriber location 306d.

Specifically, flow 1700 illustrates IP packet flow from host workstation 136a, through wireless base station 302, then over a wireless transmission link to subscriber CPE 294d, and over a wireline link to subscriber workstation 120d.

Host workstation 136a flows IP flows down from application layer 1712h, down through TCP/UDP layer 1710h, through IP layer 1708h, through optional PPP layer 1706h, through Ethernet layer 1705h, down through 10BaseT layer 1702h, over data network 142 to 10BaseT layer 1702g, then up through Ethernet 1704g, up its protocol stack through

nal PPP layer 1706g to IP layer 1708g and 1708h, back through Internet firewall and IPsec security gateway 1704f, down through WAN layer 1704f, to wireline layer to data network 142 to wireline physical layer 1702e. 5  
 wireline physical layer 1702e of wireless base station flows IP flows up the protocol stack through WAN layer through IPsec security gateway 1706e and firewall to work layer 1708e and 1708d and then down through option layer 1706d, PRIMMA MAC layer 1704d and to wireless link to subscriber CPE 294d.

Subscriber CPE 294d flows packet IP flows up from 292d at physical wireless layer 1702c up through layer 1704c, through encryption layer 1706c, through 1708b and 1708c, then down through optional 1706b to Ethernet layer 1704b to 10BaseT connection 15 to 10BaseT connection.

Subscriber workstation 120d flows IP flows up from T layer 1702a up through its protocol stack through layer 1704a, through optional PPP layer 1706a, and IP layer 1708a, to TCP/UDP layer 1710a and on up 20 to application layer 1712a.

FIG. 18 illustrates uplink flow 1800 depicting uplink IP flows from a source TCP at subscriber workstation 120d at CPE location 306d, down a protocol stack for 25 transmission through Ethernet coupled CPE subscriber station through wireless medium to wireless base station and through a protocol stack at the wireless base station 302 which supports IPsec, then through a wireline connection to data network 142 and through a protocol stack to destination host.

Specifically, flow 1800 illustrates IP packet flow from subscriber workstation 120d, through subscriber CPE 294d, through a wireless transmission medium to wireless base station 302, and eventually over a wireline link to host workstation 136a.

Flow 1800 includes IP flows from application layer down the protocol stack through TCP/UDP layer through IP layer 1808a, then through optional point-to-point (PPP) layer 1806a, then through data link Ethernet layer 1804a, then through 10BaseT Ethernet network interface (NIC) physical layer 1802a, over a wire line connection to 10BaseT Ethernet NIC physical layer 1802b of subscriber CPE 294d.

Subscriber CPE 294d flows packets coming in from NIC 1802b up its protocol stack through Ethernet layer through optional PPP layer 1806b to IP layer 1808b and back down through an Internet firewall and IPsec security gateway 1806c, down through PRIMMA MAC layer 1806c, down through PRIMMA MAC layer 1802c including antenna 302 over the wireless medium, such as, e.g., RF transmission, cable RF, and satellite link, to antenna 290d of wireless base station 302 at wireless physical layer 1802d. 30  
 Wireless base station 302 flows packet IP flows up from antenna 290d at physical wireless layer 1802d up through Ethernet layer 1804d, through IPsec layers 1806d and 1806e, encapsulate packets and encrypt them. From antenna 290d, IP flows can flow down through WAN layer 1806e and through wireline physical layer 1802e over wireline physical layer 142.

Subscriber workstation 120d flows IP flows up the protocol stack through WAN layer 1804f through IPsec security gateway 1806f and firewall to IP network layer 1808g and then down through optional PPP layer 1806f, Ethernet layer 1804h and down through 10BaseT Ethernet layer 1804h and down through 10BaseT Ethernet layer 1804h, over routers 140d, through interface 320, over routers 140d, to data network 142, via wireline connections to wireline physical layer 1802h of host workstation 136a. 65

Host workstation 136a flows IP flows up from 10BaseT layer 1802h up through its protocol stack through Ethernet layer 1805h, through optional PPP layer 1806h, through IP layer 1808h, to TCP/UDP layer 1810h and on to application layer 1812h.

#### IV. Conclusion

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. An IP flow classification system that groups IP flows in a packet-centric wireless point to multi-point telecommunications system, said classification system comprising:

a wireless base station coupled to a first data network; one or more host workstations coupled to said first data network;

one or more subscriber customer premise equipment (CPE) stations in wireless communication with said wireless base station over a shared bandwidth using a packet-centric protocol; and

one or more subscriber workstations coupled to each of said subscriber CPE stations over a second network; resource allocation means optimizing end-user quality of service (QoS) and allocating shared bandwidth among said subscriber CPE stations; and

analyzing and scheduling an internet protocol (IP) flow over said shared wireless bandwidth, wherein said analyzing means comprises:

a classifier that classifies said IP flow.

2. The system of claim 1, wherein said classifier comprises:

means for associating a packet of an existing IP flow with said IP flow.

3. The system of claim 1, wherein said classifier comprises:

QoS grouping device that groups a packet of a new IP flow into a QoS class grouping.

4. The system of claim 3, wherein said QoS grouping device comprises:

determining device that determines and takes into account QoS class groupings for said IP flow.

5. The system of claim 4, wherein said QoS grouping device comprises:

optional differentiated services (Diff Serv) device that takes into account an optional Diff Servs field priority marking for said IP flow.

6. The system of claim 4, wherein said QoS grouping device comprises:

optional type of service (TOS) device that takes into account any optional type of service field priority marking for said IP flow.

7. The system according to claim 1, wherein said packet-centric protocol is transmission control protocol/internet protocol (TCP/IP).

8. The system according to claim 1, wherein said packet-centric protocol is user datagram protocol/internet protocol (UDP/IP).

9. The system according to claim 1, wherein said shared wireless bandwidth comprises a wireless communication medium comprising at least one of:

a radio frequency (RF) communications medium;

a cable communications medium; and  
 a satellite communications medium.

10. The system according to claim 9, wherein said wireless communication medium further comprises, a telecommunications access method including at least one of:

- a time division multiple access (TDMA) access method;
- a time division multiple access/time division duplex (TDMA/TDD) access method;
- a code division multiple access (CDMA) access method; and
- a frequency division multiple access (FDMA) access method.

11. The system according to claim 1, wherein said first data network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

12. The system according to claim 1, wherein said second network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

13. The system according to claim 1, wherein said resource allocation means optimizes end-user internet protocol (IP) quality of service (QoS).

14. The system according to claim 1, wherein said resource allocation means is application aware.

15. The system according to claim 1, wherein said IP flow includes at least one of:

- a transmission control protocol/internet protocol (TCP/IP) flow, and
- a user datagram protocol/internet protocol (UDP/IP) flow.

16. The system according to claim 1, wherein said analyzing and scheduling means further comprises at least one of:

- an identifier operative to identify said IP flow,
- a characterizer operative to characterize said IP flow, and
- a prioritizer device operative to prioritize said IP flow.

17. The system according to claim 16, wherein said identifier comprises:

- an analyzer device operative to analyze one or more header and payload packet fields; and
- an identifier device operative to identify a new and an existing IP flow.

18. The system according to claim 17, wherein said analyzer device comprises:

- a buffer operative to buffer packets of a plurality of IP flows;
- a data extraction device operative to extract data from said one or more header and payload packet fields of each of said packets; and
- a packet field analyzer device operative to analyze said header and payload packet fields.

19. The system according to claim 18, wherein said data extraction device comprises:

- means for determining whether a packet of said IP flow is of version IPv4 or IPv6; and
- means for parsing said packet of said IP flow.

20. The system according to claim 18, wherein said packet field analyzer comprises:

determining means for determining a source application type.

21. The system according to claim 18, wherein said data extraction device comprises:

- an IP version determiner; and
- a parser operative to parse said packets.

22. The system according to claim 18, wherein said packet field analyzer comprises:

- a source application type determiner operative to determine a source application type of said packets.

23. The system according to claim 20, wherein said determining means comprises at least one of:

- means for storing and retrieving a source application for a source address from a source application table;
- means for determining a source application from a type of service (TOS) packet field; and
- means for determining a source application from a differentiated services (DiffServ) header field.

24. The system according to claim 17, wherein said identifier device comprises:

- means for storing and retrieving an existing IP flow to and from an IP flow identification data table.

25. The system according to claim 16, wherein said characterizer comprises:

- older determining means for determining whether an age of a packet is older than a threshold age;
- means for anticipating client application IP flow discards based on said age of said packet;
- QoS determining means for determining a QoS requirement for said IP flow; and
- means for determining a subscriber identification for one of said one or more subscriber CPE stations associated with said IP flow.

26. The system according to claim 25, wherein said older determining means comprises:

- means for analyzing a time to live (TTL) packet field for determining said age of said packet.

27. The system according to claim 25, wherein said QoS determining means determines said QoS requirement based on at least one of:

- a source address;
- a destination address; and
- a UDP port number,

wherein said QoS determining means comprises:

- means for storing and retrieving a QoS requirement for an IP flow from an IP flow QoS requirement table.

28. The system according to claim 1, wherein said classifier comprises:

- classifying means for classifying a packet of a new IP flow into a QoS class grouping of a previously classified IP flow.

29. The system according to claim 28, wherein said classifying means comprises:

- means for determining and taking into account QoS class groupings of said previously classified IP flow.

30. The system according to claim 29, wherein said classifying means comprises:

- means for taking into account any optional differentiated services (Diff Serv) field priority marking for said previously classified IP flow.

31. The system according to claim 29, wherein said classifying means comprises:

- means for taking into account any optional type of service (TOS) field priority marking for said previously classified IP flow.

32. The system according to claim 16, wherein said prioritizer device comprises:

means for taking into account hierarchical class based priorities (HCBPs) for said IP flow.

33. The system according to claim 16, wherein said prioritizer device comprises:

means for taking into account virtual private network (VPN) priorities for said IP flow.

34. The system according to claim 16, wherein said prioritizer device comprises:

means for taking into account service level agreement (SLA) based priorities for said IP flow.

35. The system according to claim 16, wherein said prioritizer device comprises:

means for taking into account any type of service (TOS) priorities for said IP flow.

36. The system according to claim 16, wherein said prioritizer device comprises:

means for taking into account any differentiated services (DiffServ) priorities for said IP flow.

37. The system according to claim 16, wherein said identifier comprises:

packet analyzing means for analyzing one or more header and payload packet fields in said IP flow; and

distinguishing means for distinguishing between a new and an existing IP flow.

38. The system according to claim 37, wherein said packet analyzing means is located at each of said one or more subscriber CPE stations for an uplink wireless communication from said each of said one or more subscriber CPE stations to said wireless base station.

39. The system according to claim 37, wherein said distinguishing means is located at each of said one or more subscriber CPE stations for an uplink wireless communication from said each of said one or more subscriber CPE stations to said wireless base station.

40. The system according to claim 37, wherein said packet analyzing means is located at said wireless base station for a downlink wireless communication from said wireless base station to each of said one or more subscriber CPE stations.

41. The system according to claim 37, wherein said distinguishing means is located at said wireless base station for a downlink wireless communication from said wireless base station to each of said one or more subscriber CPE stations.

42. The system according to claim 37, wherein said packet analyzing means comprises:

means for buffering packets of a plurality of IP flows;

extracting means for extracting data from said packet fields of each of said packets; and

second analyzing means for analyzing said packet fields.

43. The system according to claim 42, wherein said extracting means comprises:

means for determining whether said packets are a packet version LPv.4 or IPv.6; and

means for parsing said packet fields of said plurality of IP flows.

44. The system according to claim 42, wherein said second analyzing means comprises:

determining means for determining a source application type.

45. The system according to claim 44, wherein said determining means comprises:

means for storing and retrieving a source application type to and from a source application table.

46. The system according to claim 44, wherein said determining means comprises:

means for determining a source application from a type of service (TOS) packet field.

47. The system according to claim 44, wherein said determining means comprises:

means for determining a source application from a differentiated services (DiffServ) packet field.

48. The system according to claim 44, wherein said determining means comprises:

means for determining a source application from information provided by a direct application conduit.

49. The system according to claim 37, wherein said distinguishing means comprises:

means for storing and retrieving identification information for an existing IP flow to and from an IP flow identification data table.

50. The system according to claim 16, wherein said identifier comprises:

determining means for determining whether said IP flow is known to the system based on a packet received over said shared wireless bandwidth; and

source identifying means for identifying a source application having transmitted said received packet.

51. The system according to claim 50, wherein said determining means is located at said wireless base station for a downlink wireless communication from said wireless base station to said one or more subscriber CPE stations.

52. The system according to claim 50, wherein said determining means is located at each of said one or more subscriber CPE stations for an uplink wireless communication from said each of said one or more subscriber CPE stations to said wireless base station.

53. The system according to claim 50, wherein said identifying means is located at said wireless base station for a downlink wireless communication from said wireless base station to said one or more subscriber CPE stations.

54. The system according to claim 50, wherein said identifying means is located at each of said one or more subscriber CPE stations for an uplink wireless communication from said each of said one or more subscriber CPE stations to said wireless base station.

55. The system according to claim 50, wherein said determining means comprises:

means for buffering said packet;

means for extracting identification information from one or more header and payload packet fields of said packet;

means for performing a lookup of an existing IP flow identifier using said identification information in an existing IP flow data table to determine whether the IP flow is known to the system.

56. The system according to claim 50, wherein said source identifying means comprises:

means for buffering said packet;

means for extracting information from one or more header and payload packet fields of said packet;

means for performing a lookup of a source application type using said information in a source application data table to identify said source application.

57. The system according to claim 16, wherein said characterizer comprises:

age determining means for determining whether an age of a packet is older than a threshold age.

58. The system according to claim 57, wherein said age determining means comprises:

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means for analyzing a time to live (TTL) packet field for determining said age of said packet.

59. The system according to claim 57, wherein said age determining means comprises:

means for anticipating application IP flow discards based on said age of said packet.

60. The system according to claim 16, wherein said characterizer comprises:

QoS determining means for determining a QoS requirement for said IP flow if said IP flow is a new IP flow.

61. The system according to claim 16, wherein said characterizer comprises:

means for determining a subscriber CPE identification for said one or more subscriber CPE stations associated with said IP flow if said IP flow is a new IP flow.

62. The system according to claim 60, wherein said QoS determining means comprises:

means for determining QoS requirements based on at least one of:

- a source address,
- a destination address, and
- a UDP port number.

63. The system according to claim 60, wherein said QoS determining means comprises:

means for storing and retrieving a QoS requirement for an IP flow from an IP flow QoS requirement table.

64. The system according to claim 16, wherein said classifier comprises:

means for associating a packet of an existing IP flow with said IP flow.

65. The system according to claim 16, wherein said classifier comprises:

a QoS grouping device operative to group a packet of a new IP flow into a QoS class grouping.

66. The system according to claim 3, wherein said QoS grouping device comprises:

a determining device operative to determine and take into account QoS class groupings for said IP flow.

67. The system according to claim 66, wherein said QoS grouping device comprises:

an optional differentiated services (Diff Serv) device operative to take into account an optional Diff Servs field priority marking for said IP flow.

68. The system according to claim 66, wherein said QoS grouping device comprises:

an optional type of service (TOS) device operative to take into account any optional type of service (TOS) field priority marking for said IP flow.

69. The system according to claim 16, wherein said prioritizer comprises:

a hierarchical class based priority (HCBP) prioritizer operative to prioritize said IP flow based on a HCBP priority of said IP flow.

70. The system according to claim 69, wherein said HCBP prioritizer comprises:

a class based priority limits operative to establish limits for each of said HCBP priorities.

71. The system according to claim 16, wherein said prioritizer device comprises:

a virtual private network (VPN) prioritizer operative to prioritize a plurality of IP flows based on their source being a VPN.

72. The system according to claim 71, wherein said virtual private network (VPN) prioritizer grants preferential priority to said plurality of IP flows associated with said VPN.

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73. The system according to claim 71, wherein said virtual private network (VPN) prioritizer grants preferential priority to at least one of:

- said VPN IP flows of a particular IP flow type, and
- said VPN IP flows from a type of VPN.

74. The system according to claim 73, wherein said type of VPN comprises:

a directory enabled networking (DEN) table management scheme type.

75. The system according to claim 16, wherein said prioritizer device comprises:

a service level agreement (SLA) based prioritizer operative to prioritize said IP flow based on an SLA level of a subscriber source of said IP flow.

76. The system according to claim 75, wherein said SLA level comprises at least one of a premium level, a standard level and a value level.

77. The system according to claim 16, wherein said prioritizer device comprises:

a type of service (TOS) prioritizer that prioritizes said IP flow based on a TOS marking of a packet of said IP flow.

78. The system according to claim 16, wherein said prioritizer device comprises:

a differentiated services (DiffServ) prioritizer that prioritizes said IP flow based on a DiffServ marking of a packet of said IP flow.

79. The system according to claim 16, wherein said prioritizer device comprises:

a weighted fair priority (WFP) prioritizer that ensures fair distribution of said shared bandwidth, that sets reservation policy limits based on IP flow priorities.

80. The system according to claim 75, wherein said SLA based prioritizer comprises:

means for analyzing said SLA level for said IP flow.

81. The system according to claim 80, comprising:

means for prioritizing said IP flow based on one or more subscriber-defined parameters.

82. The system according to claim 75, wherein said SLA level comprises at least one of:

- a premium service level;
- a normal service level; and
- a value service level.

83. The system according to claim 75, wherein said SLA level is used to provide at least one of:

- differing traffic rates between SLA subscribers;
- network availability for said SLA subscribers;
- increased bandwidth for said SLA subscribers;
- decreased error rates for said SLA subscribers;
- latency guarantees for said SLA subscribers; and
- jitter guarantees for said SLA subscribers.

84. The system according to claim 1, wherein said resource allocation means comprises:

assigning means for assigning future slots of a transmission frame to a data packet in the transmission frame for transmission over said wireless medium.

85. The system according to claim 84, wherein said assigning means comprises:

- means for applying an advanced reservation algorithm;
- first reserving means for reserving a first slot for a first data packet of said IP flow in a future transmission frame based on said advanced reservation algorithm;
- and

second reserving means for reserving a second slot for a second data packet of said IP flow in a transmission frame subsequent in time to said future transmission frame based on said advanced reservation algorithm, wherein said second data packet is placed in said second slot in an isochronous manner to the placement of said first data packet in said first slot.

86. The system according to claim 85, wherein there is a periodic variation between the placement of said first data packet in said first slot and the placement of said second data packet in said second slot.

87. The system according to claim 85, wherein there is an aperiodic variation between the placement of said first data packet in said first slot and the placement of said second data packet in said second slot.

88. The system according to claim 85, wherein said advanced reservation algorithm determines whether said IP flow is jitter-sensitive.

89. The system according to claim 1, wherein said resource allocation means comprises:  
means for accounting for hierarchical class based priorities (HCBPs) for said IP flow.

90. The system according to claim 1, wherein said resource allocation means comprises:  
means for accounting for virtual private network (VPN) priorities for said IP flow.

91. The system according to claim 1, wherein said resource allocation means comprises:  
means for accounting for service level agreement (SLA) based priorities for said IP flow.

92. The system according to claim 1, wherein said resource allocation means comprises:  
means for accounting for any type of service (TOS) priorities for said IP flow.

93. The system according to claim 1, wherein said resource allocation means comprises:  
means for accounting for any differentiated services (DiffServ) priorities for said IP flow.

94. The system according to claim 85, further comprising:  
means for providing a periodic variation between the placement of said first data packet in said first slot and the placement of second data packet in said second slot.

95. The system according to claim 85, further comprising:  
means for providing an aperiodic variation between the placement of said first data packet in said first slot and the placement of second data packet in said second slot.

96. The system according to claim 85, wherein said advanced reservation algorithm comprises:  
means for determining whether said IP flow is jitter-sensitive.

97. The system according to claim 85, comprising: means for providing no periodic variation between successive reservations of succeeding slots.

98. The system according to claim 85, comprising:  
means for providing a periodic variation between successive reservations of succeeding slots.

99. The system according to claim 85, wherein said advanced reservation algorithm comprises:  
means for determining whether said IP flow is jitter-sensitive.

100. The system according to claim 16, wherein said analyzing and scheduling means comprises an analyzer and scheduler,  
wherein said analyzer is operative to identify IP-priority packet IP flow identification information and to classify said IP flow, and

said scheduler is operative to prioritize said IP flow and operative to take into account said IP priority header identification information.

101. The system according to claim 100, wherein said IP-priority packet IP flow identification information comprises a determiner operative to determine and to take into account QoS class groupings for said IP flow.

102. The system according to claim 100, wherein said IP-priority packet IP flow identification information comprises a TOS prioritizer operative to account for any optional type of service (TOS) field priority marking.

103. The system according to claim 102, wherein said type of service (TOS) field priority marking is compatible with Internet Engineering Task Force (IETF) RFC 1992b.

104. The system according to claim 103, wherein said type of service (TOS) field priority marking is compatible with IETF RFC 1349.

105. The system according to claim 104, wherein said marking comprises:

- a minimize delay marking;
- a maximize throughput marking;
- a maximize reliability marking;
- a minimize monetary cost marking; and
- a normal service marking.

106. The system according to claim 100, wherein said IP-priority packet header IP flow identification information comprises a DiffServ prioritizer operative to account for any optional differential service (Diff Serv) field priority marking.

107. The system according to claim 106, wherein said Diff Serv field priority marking is compatible with Internet Engineering Task Force (IETF) RFC 2474.

108. The system according to claim 106, wherein said Diff Serv field priority marking is compatible with IETF RFC 2475.

109. The system according to claim 100, wherein said IP-priority packet header IP flow identification information comprises means for taking into account any resource reservation protocol (RSVP) messages and objects.

110. The system according to claim 109, wherein said RSVP protocol messages include any of the following:

- path messages;
- reservation (Resv);
- path teardown messages;
- resv teardown messages;
- path error messages; and
- confirmation messages.

111. The system according to claim 109, wherein said RSVP protocol objects include any of the following:

- null;
- session;
- RSVP\_hop;
- time\_values;
- style;
- flowspec;
- sender\_template;
- sender\_Tspec;
- Adspec;
- Error\_Spec;
- Policy\_data;
- Integrity;
- Scope; and
- Resv\_Confirm.



112. The system according to claim 106, wherein said RSVP marking is compatible with Internet Engineering Task Force (IETF) RFC 2205.

113. The system according to claim 33, comprising: means for analyzing said virtual private network (VPN) priorities for said IP flow.

114. The system according to claim 113, comprising: means for prioritizing all VPN IP flows.

115. The system according to claim 113, comprising: means for prioritizing said IP flow based on one or more subscriber-defined parameters.

116. The system according to claim 33, wherein said VPN comprises a directory enabled networking (DEN) table management scheme.

117. The system according to claim 33, wherein said VPN is implemented using a point-to-point tunneling protocol (PPTP).

118. The system according to claim 1, wherein said system is used in a point to point (PtP) telecommunications system.

119. The system according to claim 118, wherein said shared wireless bandwidth comprises a wireless communication medium comprising at least one of:

- a radio frequency (RF) communications medium;
- a cable communications medium; and
- a satellite communications medium.

120. The system according to claim 119, wherein said wireless communication medium further comprises, a telecommunications access method including at least one of:

- a time division multiple access (TDMA) access method;
- a time division multiple access/time division duplex (TDMA/TDD) access method;
- a code division multiple access (CDMA) access method; and
- a frequency division multiple access (FDMA) access method.

121. The system according to claim 118, wherein said first data network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

122. The system according to claim 118, wherein said second network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

123. The system according to claim 118, said resource allocation means comprises a resource allocator that allocates shared bandwidth between said wireless base station and one of said subscriber CPE stations.

124. The system according to claim 123, wherein said resource allocator optimizes end-user internet protocol (IP) quality of service (QoS).

125. The system according to claim 123, wherein said resource allocator is application aware.

126. The system according to claim 1, wherein said system is a broadband coaxial cable telecommunications system wherein said wireless medium comprises a coaxial cable communications medium.

127. The system according to claim 1, wherein the system is a wireless local area network (LAN) point to multi-point (PMP) system.

128. The system according to claim 1, wherein said wireless base station is a wireless access point.

129. The system according to claim 126, wherein said resource allocation means comprises a coaxial cable resource allocator for allocating shared bandwidth between said wireless base station and said subscriber CPE stations.

130. The system according to claim 129, wherein said coaxial cable resource allocator optimizes end-user internet protocol (IP) quality of service (QoS).

131. The system according to claim 126, wherein said coaxial cable communications medium comprises a radio frequency data communication over a coaxial cable, wherein one or more cable modems modulate and demodulate signals transmitted over said coaxial cable communications medium.

132. The system according to claim 131, wherein said cable modem is DOC/SYS compliant.

133. The system according to claim 130, wherein said end-user IP QoS optimized coaxial cable resource allocator system comprises:

- an IP flow identifier;
- an IP flow characterizer;
- an IP flow classifier; and
- an IP flow prioritizer.

134. The system according to claim 129, wherein said coaxial cable communications medium comprises, a telecommunications access method including at least one of:

- a time division multiple access (TDMA) access method;
- a time division multiple access/time division duplex (TDMA/TDD) access method;
- a code division multiple access (CDMA) access method; and
- frequency division multiple access (FDMA) access method.

135. The system according to claim 126, wherein said first data network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

136. The system according to claim 126, wherein said second network comprises at least one of:

- a wireline network;
- a wireless network;
- a local area network (LAN); and
- a wide area network (WAN).

137. The system according to claim 129, wherein said coaxial cable resource allocator is application aware.

138. The system according to claim 129, wherein the system is used in a point to point (PtP) network.

139. The system according to claim 1, wherein said resource allocation means is a part of a media access control (MAC) layer.

140. The system according to claim 9, wherein said wireless communication medium further comprises a telecommunications access method comprising a time division multiple access/time division duplex (TDMA/TDD) access method and wherein the system further comprises a TDMA/TDD media access control (MAC) transmission frame, comprising:

- one or more dynamically allocatable IP flow control slots for providing IP flow control information over a wireless medium between said wireless base station and said one or more subscriber customer premises equipment (CPE) stations; and

one or more dynamically allocatable IP flow data slots for providing IP flow data information over said wireless communication medium between said wireless base station and said one or more subscriber customer premises equipment (CPE) stations.

141. The system according to claim 140, wherein said control slots comprise at least one of:

- a downstream acknowledgment slot;
- a reservation request slot;
- an operations data slot;
- an upstream acknowledgment slot;
- an acknowledgment request slot;
- a frame descriptor slot; and
- a command and control slot.

142. The system according to claim 140, wherein said data slots comprise at least one of:

- uplink data slots for transmission in an uplink direction from each of said one or more subscriber CPE stations to said wireless base station; and
- downlink data slots for transmission in a downlink direction from said wireless base station to each of said one or more subscriber CPE stations.

143. The system according to claim 140, wherein said time division multiple access/time division duplex (TDMA/TDD) transmission media access method involves:

- a downlink subframe for use over said wireless medium from said wireless base station and said one or more subscriber customer premises equipment (CPE) stations; and
- an uplink subframe for use over said wireless medium from said subscriber CPE stations to said wireless base station,

wherein a bandwidth is dynamically allocated between said downlink subframe and said uplink subframe for transmission of Internet protocol (IP) flow information so as to optimize end-user IP quality of service (QoS).

144. The system according to claim 143, wherein multiple slots in said downlink subframe are scheduled for one of said one or more subscriber CPE stations for a single internet protocol (IP) flow.

145. The system according to claim 143, wherein multiple slots in said downlink subframe are scheduled for one of said one or more subscriber CPE stations for a plurality of Internet protocol (IP) flows.

146. The system according to claim 143, wherein multiple slots in said uplink subframe are scheduled for one of said one or more subscriber CPE stations for a single internet protocol (IP) flow.

147. The system according to claim 143, wherein multiple slots in said uplink subframe are scheduled for one of said one or more subscriber CPE stations for a plurality of internet protocol (IP) flows.

148. The system according to claim 143, further comprising:

- one or more dynamically allocatable reservation request contention slots for addressing contentions between reservation requests for available slots in said uplink subframe between said wireless base station and each of said one or more subscriber CPE stations for transmission of IP flows.

149. The system according to claim 143, wherein said contention slots are dynamically allocated according to the frequency of detected collisions between said reservation requests.

150. The system according to claim 143, further comprising:

a frame descriptor block for transmitting one or more reservation slots in said downlink subframe defining where each of said one or more subscriber CPE stations requesting a reservation will place uplink data thereof.

151. The system according to claim 140, wherein said IP flow control slots comprise at least one of:

- a downstream acknowledgment slot;
- an operations data slot;
- an upstream acknowledgment slot;
- an acknowledgment request slot; and
- a frame descriptor slot.

152. The system of claim 1, further comprising a TCP adjunct system that prevents operation of a transmission control program (TCP) sliding window algorithm that controls a TCP transmission rate in said packet-centric wireless point to multi-point telecommunications system, said TCP adjunct system comprising:

- a TCP adjunct agent that takes into account application awareness, guarantees enduser quality of service (QoS), and prevents operation of a TCP sliding window algorithm that controls a TCP transmission rate in a manner that optimizes for a wireless communication medium.

153. The system of claim 152, wherein said TCP adjunct agent obviates modification of a source TCP layer at a first of said one or more host workstations and a destination TCP layer at one of said one or more subscriber workstations.

154. The system of claim 153, wherein said source and destination TCP layers are unaware of operation modification by said TCP adjunct agent.

155. The system of claim 152, wherein said TCP adjunct agent is configured to intercept retransmission requests between a TCP layer of one of said subscriber workstations coupled to a first subscriber CPE station and a TCP layer of at least one of a host workstation and said wireless base station.

156. An IP flow classification system that groups IP flows in a packet-centric wireless point to multi-point telecommunications system, said classification system comprising:

- a wireless base station coupled to a first data network;
- one or more host workstations coupled to said first data network;
- one or more subscriber customer premise equipment (CPE) stations in wireless communication with said wireless base station over a shared wireless bandwidth using a packet-centric protocol over a wireless communication medium;
- one or more subscriber workstations coupled to each of said subscriber CPE stations over a second network;
- a resource allocator operative to optimize end-user quality of service (QoS) and allocating shared bandwidth among said subscriber CPE stations; and
- an analyzer and scheduler operative to analyze and schedule an internet protocol (IP) flow over said shared wireless bandwidth, wherein said analyzer and scheduler comprises:
  - a classifier that classifies said IP flow.

157. The system of claim 156, wherein said classifier comprises:

- an association device that associates a packet of an existing IP flow with said IP flow.

158. The system of claim 156, wherein said classifier comprises:

- QoS grouping device that groups a packet of a new IP flow into a QoS class grouping.

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159. The system of claim 158, wherein said QoS grouping device comprises:

determining device that determines and takes into account QoS class groupings for said IP flow.

160. The system of claim 159, wherein said QoS grouping device comprises:

optional differentiated services (Diff Serv) device that takes into account an optional Diff Servs field priority marking for said IP flow.

161. The system of claim 159, wherein said QoS grouping device comprises:

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optional type of service (TOS) device that takes into account any optional type of service (TOS) field priority marking for said IP flow.

162. The system according to claim 156, wherein the wireless point to multi-point telecommunications system is a wireless local area network (LAN) system.

163. The system according to claim 156, wherein the wireless point to multi-point telecommunications system is a wireless wide area network (WAN) system.

\* \* \* \* \*



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Goyal et al.

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(45) Date of Patent: **Oct. 15, 2002**

(54) **METHOD AND APPARATUS FOR PROVIDING QUALITY OF SERVICE USING THE INTERNET PROTOCOL**

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(57) **ABSTRACT**

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

A method and apparatus for communicating information in a network is described. A packet for the information is generated at a first network device. The first network device assigns a flow label to the packet. The flow label indicates that the packet is part of a particular sequence of packets. The first network device also assigns a direction to the packet by, for example, setting a bit in the flow label. The packet is then sent to a second network device through at least one intermediate network device. This process is continued for the entire sequence of packets. The intermediate network device actually routes the packets to the second network device. The intermediate network device receives the packets at an input port. A flow label is identified for each packet. The intermediate network device determines whether a flow table has an entry for the flow label. If there is no present entry for the flow label in the flow table, an entry for the flow label is created. If there is an entry for the flow label, an output port associated with the flow label is obtained. The intermediate network device then sends the packet to the output port. This continues at each intermediate network device until each packet reaches the second network device.

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**Related U.S. Application Data**

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(51) Int. Cl.<sup>7</sup> ..... **G06F 13/00**

(52) U.S. Cl. .... **709/238; 709/236; 709/246; 370/236**

(58) Field of Search ..... **709/230, 232, 709/234, 235, 236, 237, 238, 245, 246, 250, 311; 370/230, 231, 235, 236**

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**15 Claims, 2 Drawing Sheets**

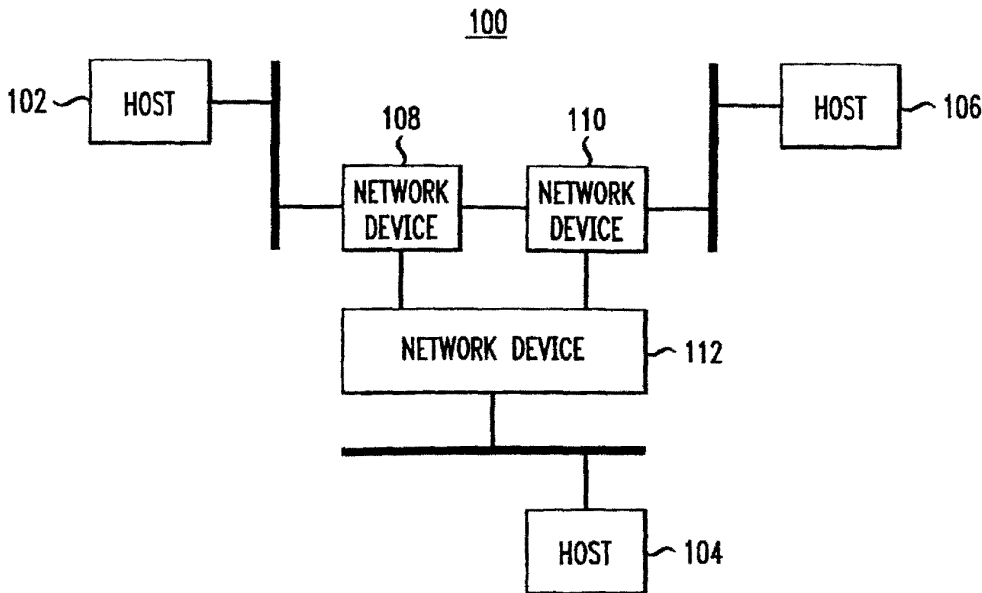


FIG. 1  
100

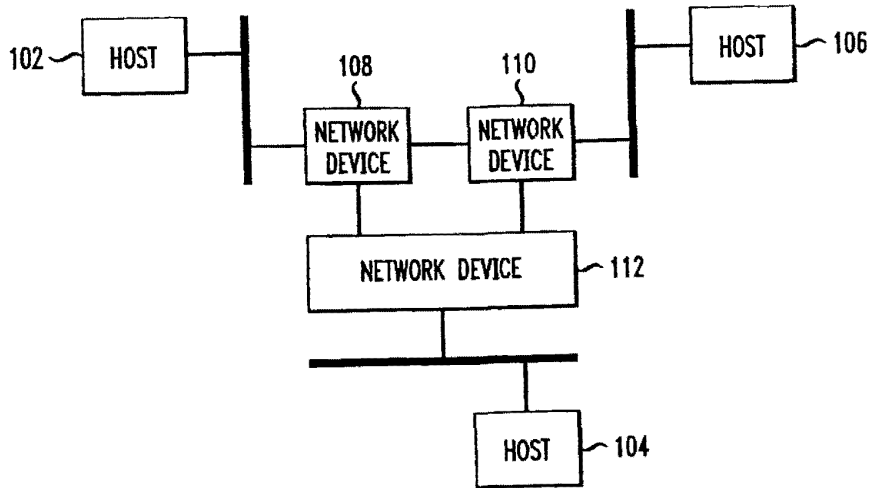
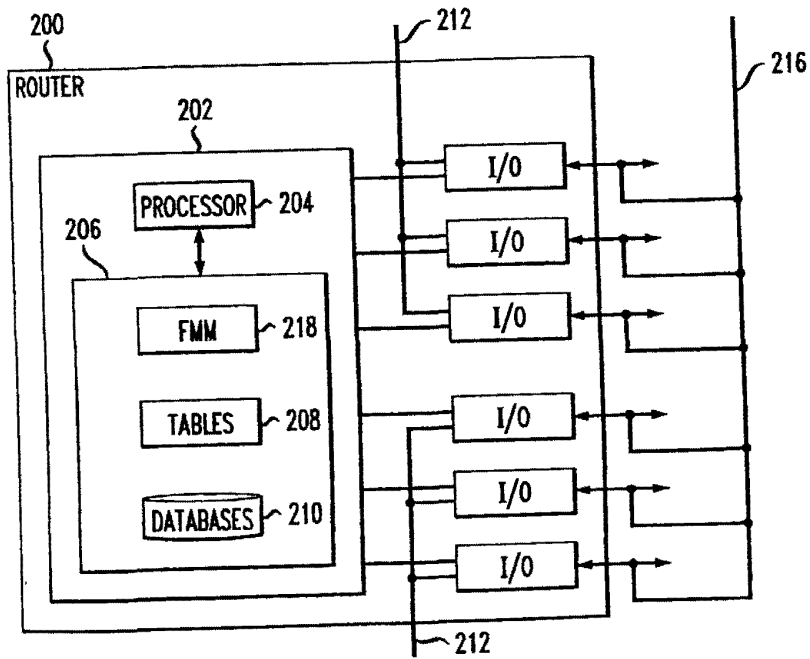


FIG. 2



## METHOD AND APPARATUS FOR PROVIDING QUALITY OF SERVICE USING THE INTERNET PROTOCOL

### CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/081,479, filed Apr. 10, 1998, entitled "Provision of Quality Services Using the Internet Protocol," the entire disclosure of which is hereby incorporated by reference.

### FIELD OF THE INVENTION

The embodiments of the invention relate to communications in general. In particular, the embodiments of the invention relate to a method and apparatus for providing quality of service using the Internet Protocol (IP).

### BACKGROUND OF THE INVENTION

With the explosive growth of the Internet and new network applications almost exclusively written for the Internet Protocol (IP), it has become essential to optimize protocols and network management for the IP. Originally designed for data networking, the Internet is increasingly being used for audio and video applications. Whereas using a single network level technology may potentially simplify network management, providing sufficient service quality for multimedia applications over the Internet remains a significant challenge. After almost a decade of emphasis on resource reservations and end-to-end Quality of Service (QoS), as part of both the design of Asynchronous Transfer Mode (ATM) networks and standardization of the Resource Reservation Protocol (RSVP), there is now a significant backlash against these state rich, fine grained QoS models. This is in part based on the observation that rather than unavailability of bandwidth, service instability is causing problems to multimedia applications. Current efforts on differentiated services are an attempt to develop a service model that improves the service quality of the Internet while acting at aggregate levels. However ensuring stable service level requires richer traffic management facilities than currently available in the Internet.

The two most essential characteristics of the IP that have contributed to its success and distinguish it from connection oriented networks are the softness of state inside the network, and the aggregation properties of this state. Apart from the routing database, for best effort destination based routing, (cached) state is used purely for performance enhancement, but is not essential for correctly delivering packets to destination. In particular this state can be lost, or removed at routers discretion without affecting the validity of state elsewhere in the network. With single class destination based routing, prefix matching effectively aggregates the forwarding information for multiple destinations into a single entry per prefix. Even with nodal service differentiation (ToS bits) this property is retained.

In contrast, the strengths of the state rich telephony network, and derived connection-oriented models (e.g., ATM), are their service quality assurances. In part, the quality assurances are achieved through resource reservations and tight channel scheduling, based on declared or inferred user objectives. In part, the consistent quality is achieved through network management; exploiting intra-domain knowledge about network load and conditions. In addition connection oriented models enhance stability, as the

time-scale of (load) change becomes that of connection duration, rather than that of routing updates and packet interarrivals. Whereas traditional methods exploit mechanisms for connectivity and reservations to achieve quality of service and implement traffic management, the coupling of these distinct mechanisms has contributed to the perceived complexity of connection oriented networks.

In view of the foregoing, it can be appreciated that a substantial need exists for introducing the QoS advantages of connection-oriented networks into connectionless networks (e.g., using IP) without losing the advantages given by connectionless networks.

### SUMMARY OF THE INVENTION

One embodiment of the invention comprises a method and apparatus for communicating information in a network. A packet for the information is generated at a first network device such as an end system. The first network device assigns a flow label to the packet. The flow label indicates that the packet is part of a particular sequence of packets. The first network device also assigns a direction to the packet by, for example, setting a bit in the flow label. The packet is then sent to a second network device (e.g., another end system) through at least one intermediate network device (e.g., a router or switch). This process is continued for the entire sequence of packets for a given flow.

The intermediate network device actually routes the packets to the second network device. The intermediate network device receives the packets at an input port. A flow label is identified for each packet. The intermediate network device determines whether a flow table has an entry for the flow label. If there is no present entry for the flow label in the flow table, an entry for the flow label is created. If there is an entry for the flow label, an output port associated with the flow label is obtained. The intermediate network device then sends the packet to the output port. This continues at each intermediate network device until each packet of a given flow reaches the second network device.

With these and other advantages and features of the invention that will become hereinafter apparent, the nature of the invention may be more clearly understood by reference to the following detailed description of the invention, the appended claims and to the several drawings attached herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a network suitable for practicing one embodiment of the invention.

FIG. 2 is a block diagram of a router suitable for practicing one embodiment of the invention.

FIG. 3 is a block flow diagram of the steps performed by a first network device in accordance with one embodiment of the invention.

FIG. 4 is a block flow diagram of the steps performed by an intermediate network device in accordance with one embodiment of the invention.

### DETAILED DESCRIPTION

The embodiments of the invention are directed to enhancing the consistency in service quality on the Internet. Whereas the soft-state and scalability have been key to the success of the Internet, its service quality is wanting. The embodiments borrow some of the concepts from connection-oriented networks, without compromising on the essential characteristics of IP. The embodiments are optimized for

carrying IP "flows," and may be implemented as part of lower level (layer 2) protocols, including ATM or Multiprotocol Label Switching (MPLS). One particular advantageous embodiment of the invention creates the capability of running the IP directly on top of the optical layer of a network.

The embodiments of the invention provide QoS capability using the IP, particularly as set forth in Request For Comments (RFC) 1883 titled "Internet Protocol, Version 6 (IPv6) Specification," dated December 1995 ("IPv6"), which is incorporated by reference herein. By introducing QoS characteristics using the IP, the need for carrying IP datagrams in lower layer protocol units (ATM cells) is avoided. This reduces network complexity by removing a network layer, which in turn simplifies network and service management. Furthermore, using IP also avoids the complexity of mapping customer requests (at the network interface) onto requests on the physical backbone infrastructure that may have conflicting service models.

The embodiments of the invention explicitly identify a group of IP packets as belonging to a "flow," and ensures that packets of a flow traverse the same sequence of routers. This creates some unique advantages, such as load balancing, enhanced management and accountability, the ability to assign attributes to a flow, amortizing costly (in terms of bandwidth) operations over a sequence of packets, and providing symmetric and reverse path routing.

A first advantage is load balancing. In current IP, all the packets from a source intended for a given destination traverse the same path. This technique does not optimally utilize the network resources. Furthermore, if a link on the path gets overloaded, a router may reroute either all or part of the traffic to a given destination. This leads to either routing instability or route flapping, neither of which is desirable for a large class of applications. This can be overcome using "route pinning." Route pinning involves ensuring that packets for a particular flow traverse the same sequence of intermediate network devices (e.g., routers). Route pinning enables the network to better utilize its resources and avoid the route-flapping problem while ameliorating routing instability.

A second advantage is that the embodiments of the invention enhance management and accountability within the network. Recording of network usage, whether for billing or off-line diagnostic analysis, is an important part of providing network services. This is particularly important in a network that provides some assurance regarding quality. Labeled flows traversing a fixed path enable this functionality.

A third advantage is that certain attributes, such as QoS attributes, can be assigned to designated flows. For a number of reasons, it may be desirable to assign attributes to distinguished flows, for example to reserve resources along the path. This requires a mechanism to declare a path as "special" and then to describe (and possibly negotiate) the path attributes. RSVP is designed for this purpose. The use of RSVP with the current IP (e.g., IPv4), however, is particularly complex without some mechanism to declare a path as "special." This problem is overcome somewhat using the flow label already defined for IPv6.

A fourth advantage is that costly operations in terms of bandwidth can be amortized over a sequence of packets. Assignment of flow attributes (for example, reservations), requires some mechanism to establish state and share that state across sequence of datagrams. State sharing fails if the forwarding path is not stable across multiple packets. Installing state is expensive, both in latency (end-to-end

consistency) and in processing (admission control, and negotiations). Thus, it is desirable that forwarding path of a flow be stable. Stable forwarding paths also enable other optimizations. For example, though explicit routes can be specified in every IPv6 packet, significant bandwidth savings can be accrued when stability of a flow path can be assumed, as with using, for example, the concept of route pinning. The same concept applies more generally to extension headers.

In addition, the embodiments of the invention offer the advantage of symmetric and reverse path routing. Symmetric routing is desirable because it simplifies algorithms and provides benefits to some services. Reverse path routing is necessary for flow level control where it must be possible to send control messages on the reverse forwarding path. Part of the complexity of RSVP is due to mechanisms to provide a control path on the reverse data path. Explicit labeling of flows will enable routing symmetry.

The embodiments of the invention provide the fundamental strengths of connections while retaining the softness of state and aggregation properties of connectionless networks. The embodiments of the invention makes use of flows that can be designated as "special" or "distinguished" through the use of a unique identifier or label for each flow. A distinguished flow can then be pinned to a route, support reverse path routing, and may have associated (QoS) attributes.

A new flow can be established by using a previously undeclared flow name. Assignment of a name declares the intent to use this flow for something special, and enables the end-system to refer to the flow for later attribute assignment. An unknown flow name is interpreted as a request for a new flow.

In addition to the flow name, the first packet of a flow (effectively the flow-request) contains a datagram of a network level protocol for which the network node can do routing (e.g., IPv6). Although subsequent packets may contain arbitrary datagrams, softness of state is achieved when all the transferred packets are of such "known" protocol. In that case, if the state is lost, the next packet of the named flow is processed as if it were the first packet of a new flow. To optimize the transport network for IPv6, the network nodes simply support IPv6 routing. The flows defined herein incur no call setup delay. Moreover, adopting (or assuming) a "use it or lose it" state invalidation policy, there is no need for explicit tear-down. A flow may be uni- or bidirectional.

There are four aspects of constructing a flow: (1) declaring a name; (2) pinning the route, (3) enabling reverse path routing, and (4) assigning attributes (such as QoS). Abstractly, current network nodes maintain two tables, a routing table and a forwarding table. In the case of a traditional router the forwarding table corresponds to the routing cache. On an ATM switch or an MPLS Label Switch Router (LSR), the forwarding table is respectively the Virtual Channel (VC) lookup table or the label lookup table. To support the flows used in the embodiments of the invention, a traditional router would be augmented with an additional forwarding table for mapping flow names to flow state (including the output port), as discussed in more detail with reference to FIG. 2.

A flow request may be interpreted as an implicit request for route pinning. If not, route pinning may be requested subsequently in a separate message. Without route pinning, the entry in the flow cache simply points to the corresponding entry (in the regular cache) for the destination address. When route pinning is requested this entry is copied and thus becomes independent of changes in the default destination based route.

Reverse path routing on a flow requires the node to record the incoming port as a part of the flow forwarding state. In addition this information must be conveyed to the output port. This given, however, reverse path routing may be achieved either by constructing a new path in the reverse direction (i.e., a path association) or by a naming convention allowing a name to be resolved in the reverse path name space.

Other flow attributes are signaled separately, and can be processed with specialized software using a conventional processor, or by a dedicated attribute control processor. Flows maintain a control mapping separate from the forwarding map, thus supporting control paradigms allowing service specific controllers, potentially installed on demand, to process the attribute messages.

To aggregate state, a node (e.g., a backbone border node) may aggregate smaller flows and tunnel the aggregate flow to a particular node in the network (an egress router for example). After exiting the tunnel, the data packets would then be routed to their respective destinations as if they had originated at the tunnel end. To construct the tunnel, the router precedes the user packets with a "tunnel request" packet, a datagram of the "known" protocol, distinguished as a tunnel request. In the case of the IP as the known protocol, explicit routing could be specified using the source routing option (extension header for IPv6). Of course this is complementary to the use of normal tunneling, which themselves might exploit flows as well.

The IPv6 flow label can be used to implement a flow in an IPv6 network. To define a name an end-system sets a locally unique flow label on a packet intended for that flow. Hop-by-hop extension headers are used to assign attributes to the route. For example, the hop-by-hop router alert extension can be used, although additional extension headers are possible as well.

For network centric flows in IPv6, a router may identify a sequence of packets whose flow label is not set and aggregate them into a tunneled flow. The tunnel request packet is an IPv6 datagram carrying the assigned flow label. The router then sets the flow label of subsequent packets, which are then nullified on exit from the tunnel. To aggregate labeled flows we use traditional IP tunneling with flows.

The embodiments of the invention modify the current definition of the IPv6 flow label for reverse path forwarding. The first bit of the flow label specifies whether it is source or destination unique, with a zero (0) implying a destination unique flow label, and a one (1) declaring a source unique flow label. To send on the reverse path, the receiver flips the first bit of the flow label. Since the source and destination are also swapped (as compared to the received packet), the same address is used with the flow label to uniquely identify the flow.

Implementing the flow concept in MPLS is similar to that for IPv6. A sender uses a label to define a flow name. As labels are "link local" this amounts to upstream label allocation. Flow pinning is implemented as with IPv6. Attributes are signaled using hop-by-hop router alerts. Reverse path is accomplished in a manner similar to IPv6, that is, dividing the namespace on each link into two, with a direction distinguished by the leading bit. It is also possible, however, to use a separate flow name to associate the reverse path to the corresponding label path. Furthermore, this flow association might be maintained only at the higher level, and not be explicit at the label path level. This could for example be the case if running IPv6 over MPLS.

The embodiments of the invention aggregate separate flows to a tunnel in MPLS by using a label stack. A label is

pushed on the stack at the entry of the tunnel, and popped off on exit. As the tunnel end may in effect be a multiplexing point (i.e., a virtual termination of many tunnels) the tunnel label must be assigned by the tunnel termination node (downstream allocation), to ensure that the enclosed labels further down on the stack are uniquely resolved. To avoid subsequent round trip delays, however, the first request may yield two labels, allowing the entry point node to maintain a cache one label for subsequent tunnel construction.

Referring now in detail to the drawings wherein like parts are designated by like reference numerals throughout, there is illustrated in FIG. 1 a network suitable for practicing one embodiment of the invention. FIG. 1 illustrates an exemplary network 100 having multiple hosts and multiple intermediate network devices connected as shown. Network 100 shown in FIG. 1 represents one possible network configuration and will be used to describe the operation of the invention. Specifically, three intermediate network devices 108, 110 and 112 are coupled to one another as shown. FIG. 1 also illustrates three host devices 102, 104 and 106. Each host is coupled to a particular intermediate network device using an interface 120 (not shown). Interface 120 may be any type of interface circuit, including a network, capable of coupling one or more hosts to an intermediate network device. Alternatively, interface 120 may be omitted, and the host (or hosts) coupled directly to the intermediate network device. To simplify the illustration, only one host device is shown coupled to each intermediate network device. Those skilled in the art will appreciate that multiple hosts may be coupled to a single intermediate network device and a single host may be coupled to multiple intermediate network devices.

It can be appreciated that the particular configuration shown in FIG. 1 is chosen as an example only and is not limitive of the type of network on which the present invention can work. The number of configurations that networks can take are virtually limitless and techniques for setting up these configurations are well known to those skilled in the art. The embodiments of the present invention can operate on any of these possible configurations.

Furthermore, both the host device and intermediate network device can represent several types of devices. An example of a host device would be an end system (ES). An ES is a device attached to a network or subnetwork that is used to support end-user applications or services (e.g., a personal computer). An example of an intermediate network device would be a router, ATM switch or LSR. In this embodiment of the invention, a router is used as an example to demonstrate the principles described herein. Furthermore, the router utilizes IPv6 to route individual packets between hosts or end systems.

FIG. 2 is a block schematic diagram of a router suitable for practicing one embodiment of the invention. A router 200 is capable of incorporating the teachings of the present invention and includes a routing engine 202 having a processor 204 and a storage device 206. Storage device 206 may be any suitable computer readable memory device, such as one or more dynamic random access memory (DRAM) devices, disk drives, or other mechanism for storing data.

Routing engine 202 includes in storage device 206 various computer program segments that when executed by a processor (e.g., processor 204) performs the functionality for the various embodiments of the invention. In one embodiment of the invention, the computer program segments are combined into a single flow management module



(FMM) 218. It can be appreciated, however, that the functions performed by this module can be separated into more modules, or be distributed throughout the system, and still fall within the scope of the invention. Furthermore, although this embodiment of the invention implements the functionality of this module in software, it can be appreciated that the functionality of this module may be implemented in hardware, software, or a combination of hardware and software, using well-known signal processing techniques.

Routing engine 202 includes also includes various tables 208 and databases 210 contained within storage device 206. Tables 208 and databases 210 maintain information necessary for router 200 to properly forward data. Tables 208 may include a Routing Table and a Flow Table. Databases 210 may include a Link State Database and a Forwarding Database. Routing engine 202 is capable of calculating paths through a network based on information contained in tables 208 and databases 210, as well as the functionality provided by FMM 218.

Input/Output (I/O) interfaces 212 are coupled to routing engine 202 and provide a physical connection to one or more network links 216. I/O interfaces 212 may be any suitable means for controlling communication signals between objects using a desired set of protocols, services and operating procedures, such as IPv6. In this embodiment of the invention, I/O interfaces 212 are bidirectional, that is, signals can be sent and received using any particular I/O interface. Those skilled in the art, however, will recognize that uni-directional interfaces can also be used and fall within the scope of the invention. Furthermore, those skilled in the art will understand that the communication signals may be received over any suitable medium such as twisted-pair wire, co-axial cable, fiber optics, radio-frequencies, and so forth.

Processor 204 may be any general purpose microprocessor having sufficient speed to implement the functionality described herein, such as the Pentium®, Pentium Pro, or Pentium II processors made by Intel Corporation.

It can be appreciated that although router 200 is used as an example to describe this embodiment of the invention, those skilled in the art will appreciate that various types of routers and other intermediary network devices may be used with the invention described herein.

FIG. 3 is a block flow diagram of the steps performed by a first network device in accordance with one embodiment of the invention. As shown in FIG. 3, a packet for the information is generated at a first network device at step 302. A flow label is assigned to the packet at step 304. A direction is assigned to the packet using the flow label at step 306. The packet is sent to a second network device through the network at step 308.

With respect to step 306, an example of assigning a direction includes a flow label having a plurality of bits. The first network device would indicate the direction for the packet by modifying the flow label. The first bit of the flow label specifies whether it is source or destination unique, with a zero (0) implying a destination unique flow label, and a one (1) declaring a source unique flow label. To send on the reverse path, the receiving network device flips the first bit of the flow label. Since the source and destination are also swapped (as compared to the received packet), the same address is used with the flow label to uniquely identify the flow.

FIG. 4 is a block flow diagram of the steps performed by an intermediate network device in accordance with one embodiment of the invention. As shown in FIG. 4, a first

packet is received at a first input port of an intermediate network device at step 402. A flow label for the first packet is identified at step 404. Whether a flow table has an entry for the flow label is determined at step 406. An entry for the flow label is created if no present entry at step 408. An output port associated with the flow label is obtained from the table at step 410. The first packet is sent to the output port at step 412.

An entry for the flow label is added to the flow table if there is no present entry at step 408. Whether the flow label has an associated routing attribute is determined. A pointer associated with the flow label is stored in the flow table, the pointer pointing to an output port in a routing table for the intermediate network device, if the flow label does not have a routing attribute associated with it. An output port from the routing table is stored in the flow table associated with the flow label, if the flow label does have a routing attribute associated with it.

The steps described with reference to FIG. 4 may be better understood using the following example. In this embodiment of the invention, the intermediate network device is router 200. Router 200 receives a first packet at a first input port. FMM 218 of router 200 identifies a flow label for the first packet. FMM 218 searches a flow table stored with tables 208 to determine whether the flow table has an entry for the flow label. FMM 218 creates an entry for the flow label if no entry is currently in the flow table for the flow label. FMM 218 then obtains an output port associated with the flow label from the table. Routing engine 202 sends the first packet to the output port.

Router 200 performs the above steps with each packet that it receives. Packets received subsequent to the first packet and having the same flow label would be processed more efficiently since an entry for the flow label will already be present. If a packet does not have a flow label, FMM 218 can be programmed to ignore the packet in terms of processing it for flow control, or to assign a flow label if needed for more efficient routing (e.g., such as for tunneling).

If there is no entry for the flow label present in the flow table, FMM 218 creates an entry. FMM 218 determines whether any attributes have been assigned to the flow label, such as route pinning. If a route pinning attribute has not been assigned to the flow label, a pointer associated with the flow label is stored in the flow table. The pointer points to an output port in the routing table for router 200. If a route pinning attribute has been assigned to the flow label, by FMM 218 or the first network device, FMM 218 copies the output port stored in the routing table having the same destination as the first packet in the flow table. The output port is associated with the flow label. In this manner, subsequent packets sharing the same flow label will traverse the path designated by the routing table if route pinning is not set, or will traverse the same path as the first packet if route pinning is set. In the latter case, a stable forwarding path is maintained since each packet within a flow will traverse the same sequence of routers.

To enable reverse path forwarding, the first input port where the first packet was received must also be stored in the flow table in association with the flow label for the first packet. If router 200 receives a second packet, FMM 218 identifies a flow label for the second packet. Further, FMM 218 also determines a direction for the second packet by examining the first bit of the flow label. If the first bit of the flow label indicates that the second packet is from the second network device back to the first network device, then routing engine 202 sends the packet to the I/O interface port where

the first packet was initially received. This can be accomplished since I/O interfaces 212 are bidirectional. Those skilled in the art could appreciate that reverse path routing could also be implemented using unidirectional ports if necessary.

The embodiments of the invention can also apply the aggregation properties already currently used in IPv4 and IPv6 for individual packets to the concept of flows. For example, if router 200 receives a second packet at an input port, it first identifies its flow label. Then it determines whether the first packet and the second packet should be aggregated based on their flow labels and either associated attributes or intelligence of routing engine 202. If the first and second packets should be aggregated, they are aggregated using conventional tunneling techniques.

The use of flows in MPLS is similar to IPv6, with specific modifications to take advantage of the underlying mechanisms for MPLS. This embodiment of the invention assumes a "neighbor discover protocol" that can (be augmented to) carry capability information such as label space. It also assumes that the network can do routing on demand inside the label network (this is virtually implied by on demand routes).

There are two types of allocations in this embodiment of the invention. The first is upstream allocated on-demand label paths of three sub-types: (1) without any acknowledgments (acks); (2) with hop-by-hop ack's; and for tunnels. The second general allocation type is downstream allocated on-demand label paths. These are allocated using, for example, the methods and apparatus set forth in U.S. patent application Ser. No. 09/015,496, filed on Jan. 29, 1998, entitled "An Architecture For Lightweight Signaling In ATM Networks", the entire disclosure of which is hereby incorporated by reference. One of the down sides of downstream allocation as compared to upstream allocation is that with tunnels the hop-by-hop latency (over the tunnel) may be O (end-to-end) latency. One solution could be to place an IPv4 header into a single ATM cell.

In both the upstream allocation and downstream allocation, the label path setup can be accomplished in the following steps: (1) the end system initiates path setup; (2) the path (channel, featherweight flow); (3) can subsequently assign additional parameters to the flow. One solution is to use a higher level protocol for routing and forwarding of non-switched packets

As part of boot strapping nodes exchange capabilities and setup a default path that is subsequently used for out of band signaling. If a node understands multiple higher level protocols (i.e., can route using the rules of many protocols) e.g., IPv4, IPv6, ATM UNI, a different signaling path can be established for each of these protocols.

The label distribution protocol uses a short label, which is valid for a limited time and created on demand. This provides manageability, as the forwarding map can be customized based on network conditions, the need of the flow, and so forth. Softness of state is maintained for those protocol types for which a default path (and/or a signaling channel) is defined, and whose protocol data units carry enough information to establish (recover) the forwarding state. This follows as the default paths per protocol assume that the LSR per protocol processing is sufficient to reach inside the MPLS encapsulation and parse the (header) information needed to (re)create the state. As a consequence, no explicit signaling is needed. The soft state is relatively efficient, as it is "use it or loose it," thus averting the need for keep-alive messages to maintain the state.

As part of neighborhood discovery each node informs its upstream neighbor of the label space it is willing to accept. It is assumed that by standardization some small number of labels may be taken for granted (say 1 or 10). The upstream node may subsequently ask for the namespace to be expanded (this is done on signaling connections from controller, to controller).

Labels are assigned for one-way connections by default. New extensions allow for bidirectional label assignment. This can be done either by mechanisms to make a label valid both ways, or alternatively by associating a new label path going on a reverse route with a particular existing forward path.

To create a new label path from a source (S) to a destination (D), S creates a datagram (or otherwise the protocol transfer unit of the protocol used on the default (signaling) path), allocates a new label and issues a path-request communicating a path request, the new label and the datagram.

The path request could be a new router alert option (an extension header in IPv6), or could be communicated implicitly either on a signaling channel, or by interpreting a new (unknown) label as a path request. The last one offers particular advantages and is described in more detail below.

With respect to the new label, potentially more than a single label will be pushed on the stack, for example when constructing a tunnel. The new label(s) may be pushed on top of already existing labels.

The datagram may encode information about routes (e.g., explicit routes), type of service, or desired service quality as the richness of the protocol on the default path allows.

An intermediate node receiving a path-request processes the message as follows. First, a new label entry is created in its forwarding table(s) unique on the pair (input port, label). This could be achieved by having a separate forwarding table per input port. Note that input port here may be an abstract input port, e., an end of a tunnel. The forwarding function on the enclosed datagram is then performed, yielding an output port determination. A new label is allocated on the outgoing port. The label forwarding table is then updated, recording the outgoing port and outgoing label. The request is then forwarded to the appropriate output port. If an acknowledgment is requested, then the intermediate node replies with an ack. If ack's are requested, the information could be a semi-static and negotiated as part of neighbor discovery. This could also, however, be done on demand by having the datagrams carry path construction attribute objects.

If a bidirectional path is requested then instead of replying with an just an ack, a label is allocated a label on the reverse path, the forwarding table is updated, the reverse label is recorded, and an ack is sent using the new upstream label.

Some of the possible errors include "Reject—sent on a well-known (signaling) channel." This would also include a reason code.

To implement flows with a soft state, label paths can be created for arbitrary data streams. For example, an access node from a frame-relay network to a LSR network capable of routing IP datagrams only, would simply create a label path by creating and sending an IP datagram as a path request, and encapsulating the frame-relay packets. When new (unknown) labels are interpreted as label requests, however, the state constituting labels paths used by well know protocols (i.e., one for which the LSR cloud can do routing) becomes soft. This happens because the state may be locally managed, and in particular lost, as the next

datagram arriving with a label that is no longer recognized will serve as a path request and effectively reconstruct the state. In this case there is no call setup delay. Moreover, by adopting (or assuming) a "use it or lose it" state invalidation policy, there is no need for explicit tear-down.

RSVP is designed to support reservations for individual end-to-end flows on the Internet, in particular IPv4. An RSVP session is identified by a destination address and transport level protocol, and optionally the destination ("generalized") port. A session is further classified into flows by receiver specified filters. Whereas in principle these filters may be applied to any fields in the IP- or protocol level header (even potentially application level headers), current specifications and implementations of RSVP limit filters to a source address, and optionally the source port. Reservations are on simplex streams and are exclusively receiver initiated.

A destination address may be a multicast address, with the multicast session having multiple senders and receivers (multipoint-to-multipoint). Receiver initiated reservations may result in different reservations in different segments of the distribution of the multicast (variegated multicast trees). Moreover, in multicast sessions with multiple senders, receivers may use the three different reservation "styles" (one of wild-card, fixed, or shared exclusive) to make reservations at even a finer level of the flow than specified by the filters.

The two principal messages of QoS management in RSVP are the path message, sent from senders towards receivers, and the reservation messages, sent from receivers towards senders. Path messages establish flow identification state along the downstream path. This state includes filters and the traffic description (T-spec). Messages are processed at each hop before forwarding. Reservations messages carry reservation requests (R-specs), and styles. Significant complexity is incorporated into RSVP to ensure that the RSVP signaling messages are forwarded to the same path (forward and reverse) as data is being forwarded. To make the RSVP state "soft" and to cope with route changes and changes in the topology of multicase distribution trees, path state and reservation state must be refreshed periodically.

Implementing RSVP using this embodiment of the invention simplifies RSVP in several ways. First, this embodiment of the invention already does a flow classification, thus subsuming most of the filtering mechanisms of RSVP. In addition to the benefit of separation of mechanisms, using this embodiment of the invention allows for rich filtering at the edge of the network (to classify the incoming data-stream into flows), but very simple flow identification (explicit, or very trivial) inside the network. Filtering of finer grained subflows and RSVP reservation styles that apply on subflows (fixed, or shared exclusive) could be implemented by performing a nodal classification, or by defining a new flow for each of the subflows. This embodiment of the invention supports variegated trees similar to that of RSVP.

RSVP messages are effectively signaled in-band on the established flow, distinguished with router alert option (hop-by-hop extension header). Whereas this could be the standard router alert options, the new "CC" extension header could also be used, further improving efficiency by allowing the RSVP messages to be forwarded on the output ports before nodal processing takes place. The latter is a departure from current RSVP semantics. Using this embodiment of the invention, the RSVP path message serves to advertise the T-spec, and possibly a filter for subflow classification. The previous hop information is not needed. As the message is

forwarded without processing the "Adspec" does not serve a useful purpose in this case. The reserve messages, however, must be processed at every branch point of a multicast flow. This is achieved using bidirectional flows and a blocking router alert option. Point-to-point connections, however, can exploit the in-band signaling for reservation messages, thus allowing the reservations to be processed in parallel. Other RSVP messages, for errors, tear-down, and confirmation are processed by the RSVP processor in a standard manner, but are transmitted in-band on the established flow. The RSVP processor must in addition process a tear-down commands from the forwarding engine, to invalidate reservation state for flows that have become invalid (at the forwarding level).

Using the support for bidirectional flows, forwarding on the reverse path may be moved out of the RSVP control process, and handled at forwarding level. To allow for softness of the reservation state and to allow for adjustments in reservations in multicast flows as membership (and thus topology) changes, state refresh may still be needed. The stability of the connections, however, can be exploited and therefore the need for frequent state refresh may be reduced. In particular, it is feasible to have the data traffic refresh the state, limiting refresh only to "keep-alives" during extended inactivity. This is particularly true for point-to-point flows. The need for state refresh is further reduced if the route of the flow is pinned. Therefore, removing the connectivity issues from the RSVP processing, and benefiting from the stability caused by connections, RSVP is simplified and may be more optimized for common cases (e.g., point-to-point flows) while retaining the essential qualities of RSVP.

It is worthy to note that any reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Although various embodiments are specifically illustrated and described herein, it will be appreciated that modifications and variations of the present invention are covered by the above teachings and within the purview of the appended claims without departing from the spirit and intended scope of the invention. For example, although a router was used in certain embodiments of the invention, those skilled in the art will appreciate that the principles described herein can also be applied to other network devices such as ATM switches or LSRs.

What is claimed is:

1. A method for communicating information in a network, comprising:
  - generating a packet for the information at a first network device;
  - assigning a flow label to said packet;
  - assigning a direction to said packet using said flow label, and wherein said flow label is reverse path forwarding enabled; and
  - sending said packet to a second network device through the network.
2. The method of claim 1, wherein said flow label is comprised of a plurality of bits, and wherein said step of assigning said direction comprises the step of setting one of said bits in said flow label.
3. A method for communicating information in a network, comprising:
  - receiving a first packet at a first input port of an intermediate network device;

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identifying a flow label for said first packet;  
 determining whether a flow table has an entry for said flow label;  
 creating an entry for said flow label if no entry is present;  
 obtaining an output port associated with said flow label from said table; and  
 sending said first packet to said output port.  
 4. The method of claim 3, wherein said step of creating an entry comprises the steps of:  
 adding an entry for said flow label to said flow table;  
 determining whether said flow label has an associated routing attribute;  
 storing a pointer associated with said flow label in said flow table, said pointer pointing to an output port in a routing table for said intermediate network device, if said flow label does not have a routing attribute associated with it; and  
 storing said output port from said routing table in said flow table associated with said flow label, if said flow label does have a routing attribute associated with it.  
 5. The method of claim 3, further comprising the step of storing said first input port in said flow table associated with said flow label.  
 6. The method of claim 5, wherein said input and output ports for said intermediate network device are bidirectional, further comprising the steps of:  
 receiving a second packet at a second input port of said intermediate network device;  
 identifying a flow label for said second packet;  
 determining a direction for said second packet using said flow label; and  
 obtaining said first input port associated with said flow label from said flow table; and  
 sending said first packet to said first input port.  
 7. The method of claim 3, further comprising the steps of:  
 receiving a second packet at an input port of said intermediate network device;  
 identifying a flow label for said first packet;  
 determining whether said first and second packets should be aggregated; and  
 aggregating said first and second packets in accordance with said determination.  
 8. A method for requesting a connection-oriented packet flow between a first network device and a second network device in a packet network, comprising  
 allocating a flow label to the packet flow that has not been previously declared;  
 assigning the flow label to a header in a first packet of the packet flow;

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adding any desired flow attributes to the header, and  
 sending the packet to the second network device through the network, where in the flow label that has not been previously declared is interpreted by the second network device as a request for a new packet flow and the second network device can utilize the flow attributes in establishing state for the packet flow, and wherein the flow label includes an indication of direction for the flow.  
 9. The method of claim 8 wherein the second network device treats the flow label as a request to pin the route between the first network device and the second network device.  
 10. The method of claim 8 wherein the second network device may send another packet in a reverse path by using a second flow label including a different indication of direction for the flow.  
 11. The method of claim 10 wherein the flow attributes reflect quality of service attributes for the packet flow.  
 12. A network router comprising:  
 a processor;  
 a plurality of input/output (I/O) interfaces connected to the processor; and  
 one or more storage devices, connected to the processor, further comprising a routing table, a flow table, and a computer program which when executed by the processor performs a method of establishing a packet flow between the network router and a second network router comprising the steps of:  
 receiving a packet from the second network router with a flow label that has not been previously declare;  
 interpreting the flow label as a request for a new packet flow between the network router and the second network router; and  
 creating an entry for the flow label in the flow table, and wherein the flow label includes an indication of direction for the flow.  
 13. The network router of claim 12 wherein the request for a new packet flow is treated by the network router as an implicit request for route pinning between the network router and the second network router.  
 14. The network router of claim 12 wherein the network router may send another packet in a reverse path to the second network router by using a second flow label including a different indication of direction for the flow.  
 15. The network router of claim 14 wherein the packet includes quality of service attributes for the packet flow and wherein the network router can establish state based on the quality of service attributes.

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US006453360B1

(12) **United States Patent**  
Muller et al.

(10) **Patent No.:** US 6,453,360 B1  
(45) **Date of Patent:** Sep. 17, 2002

- (54) **HIGH PERFORMANCE NETWORK INTERFACE**
- (75) **Inventors:** Shimon Muller, Sunnyvale, CA (US); Denton E. Gentry, Jr., Fremont, CA (US); John E. Watkins, Sunnyvale, CA (US); Linda T. Cheng, San Jose, CA (US)
- (73) **Assignee:** Sun Microsystems, Inc., Santa Clara, CA (US)
- (\*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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*Primary Examiner*—Viet D. Vu  
(74) *Attorney, Agent, or Firm*—Park, Vaughan & Fleming LLP

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- (22) **Filed:** Mar. 1, 1999
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- (52) **U.S. Cl.:** 709/250; 709/232; 709/236; 709/238; 370/235; 370/392; 370/401
- (58) **Field of Search:** 709/106, 201, 709/230, 232, 235, 236, 238, 245, 246, 250, 249; 370/231, 235, 389, 392, 396, 401

(57) **ABSTRACT**

A high performance network interface is provided for receiving a packet from a network and transferring it to a host computer system. A header portion of a received packet is parsed by a parser module to determine the packet's compatibility with, or conformance to, one or more pre-selected protocols. If compatible, a number of processing functions may be performed to increase the efficiency with which the packet is handled. In one function, a re-assembly engine re-assembles, in a re-assembly buffer, data portions of multiple packets in a single communication flow or connection. Header portions of such packets are stored in a header buffer. An incompatible packet may be stored in another buffer. In another function, a packet batching module determines when multiple packets in one flow are transferred to the host computer system, so that their header portions are processed collectively rather than being interspersed with headers of other flows' packets. In yet another function, the processing of packets through their protocol stacks is distributed among multiple processors by a load distributor, based on their communication flows. A flow database is maintained by a flow database manager to reflect the creation, termination and activity of flows. A packet queue stores packets to await transfer to the host computer system, and a control queue stores information concerning the waiting packets. If the packet queue becomes saturated with packets, a random packet may be discarded. An interrupt modulator may modulate the rate at which interrupts associated with packet arrival events are issued to the host computer system.

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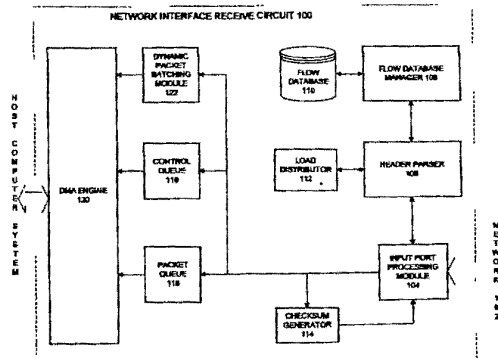
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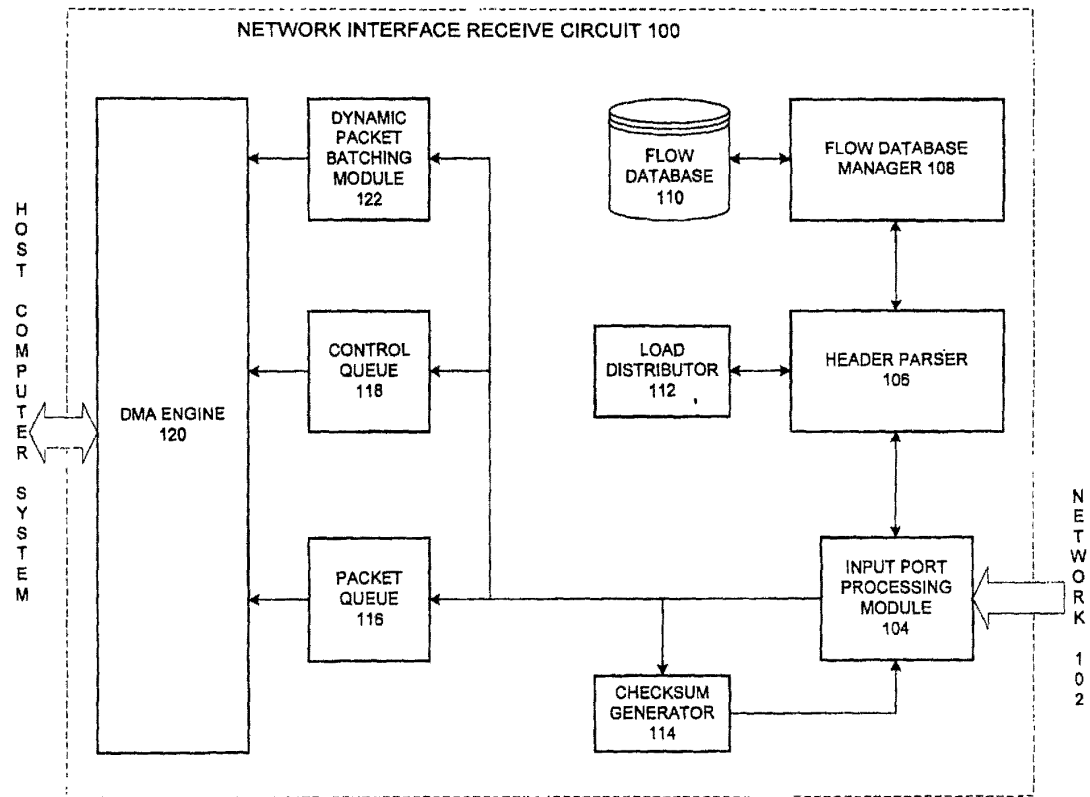


FIG. 1A

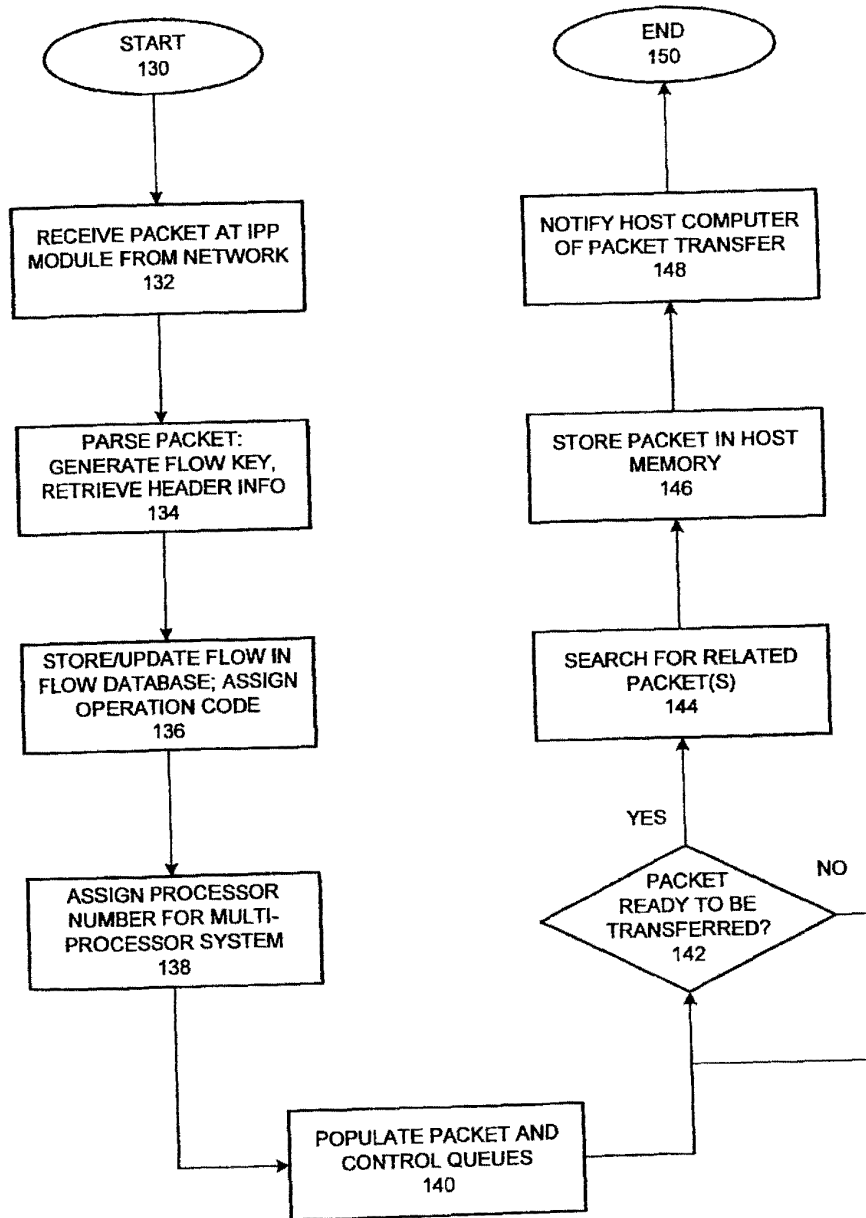


FIG. 1B



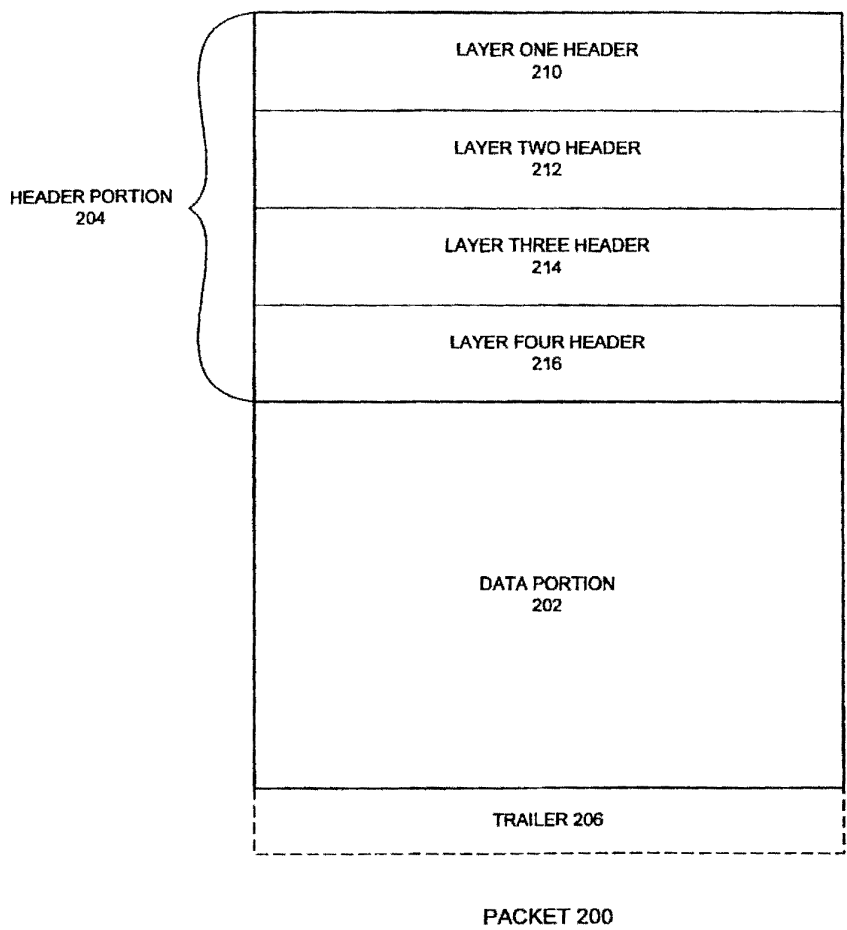


FIG. 2

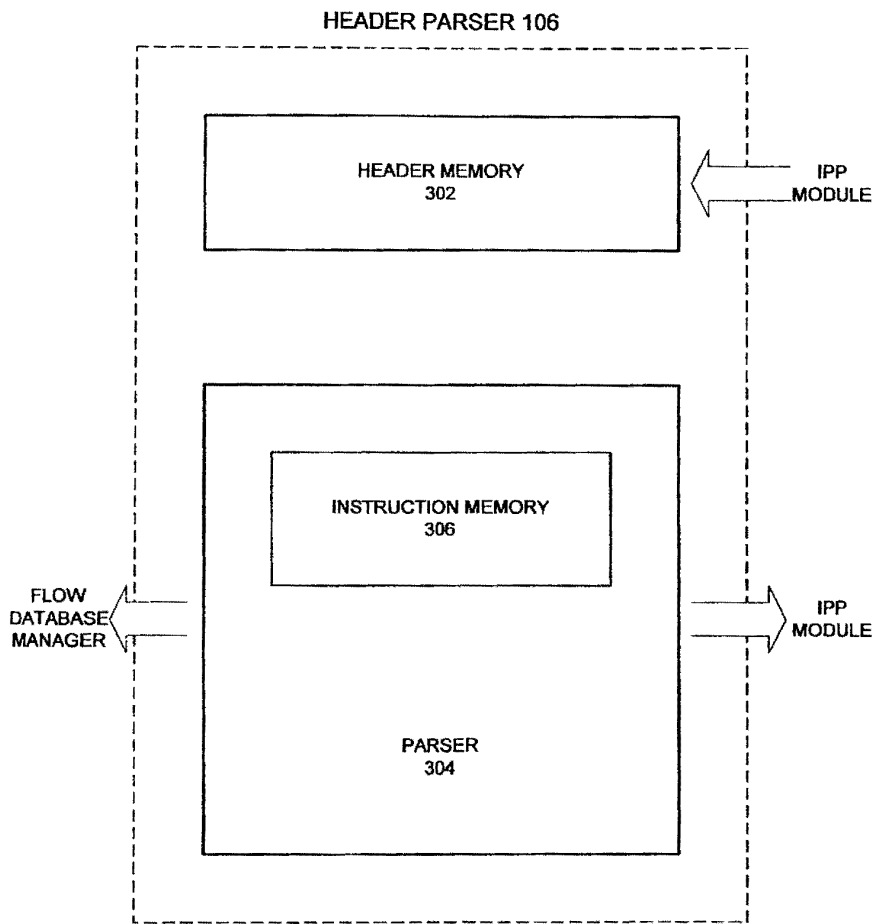


FIG. 3

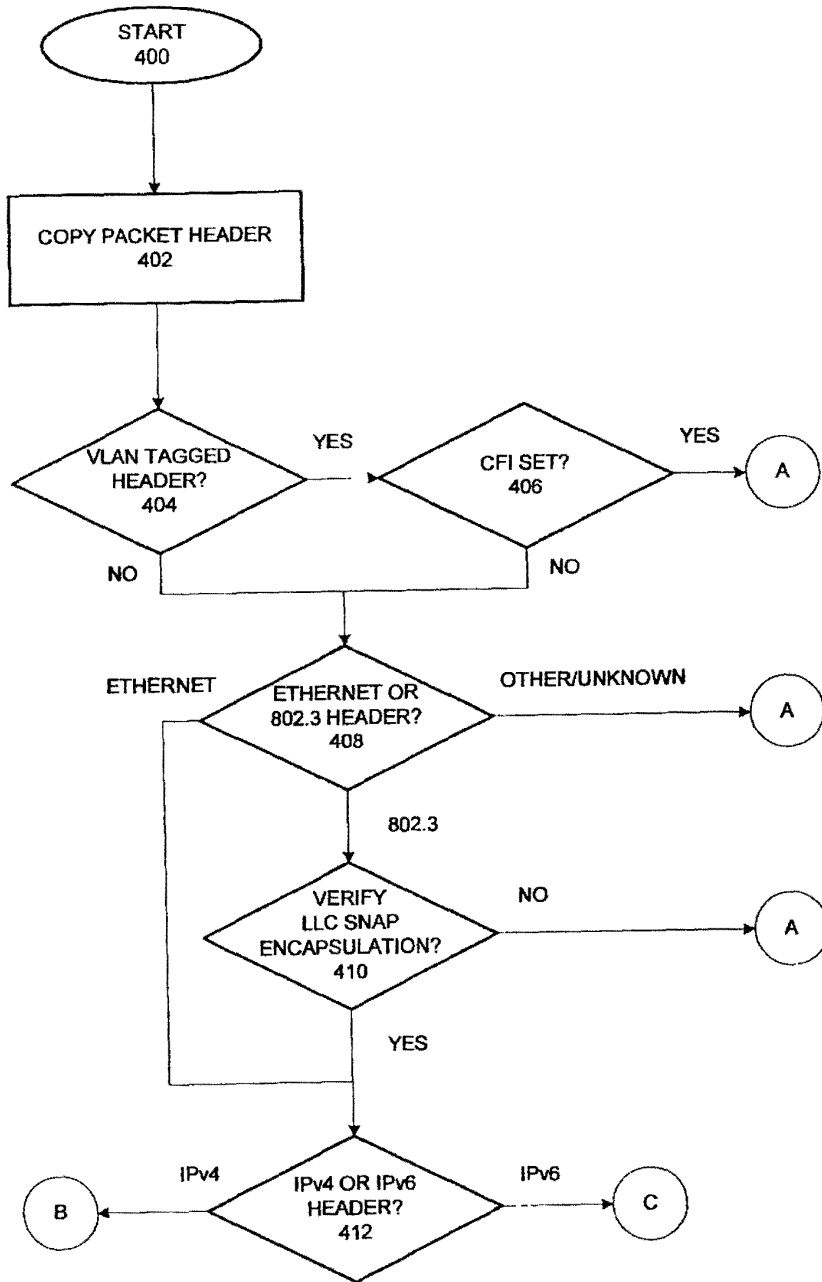


FIG. 4A

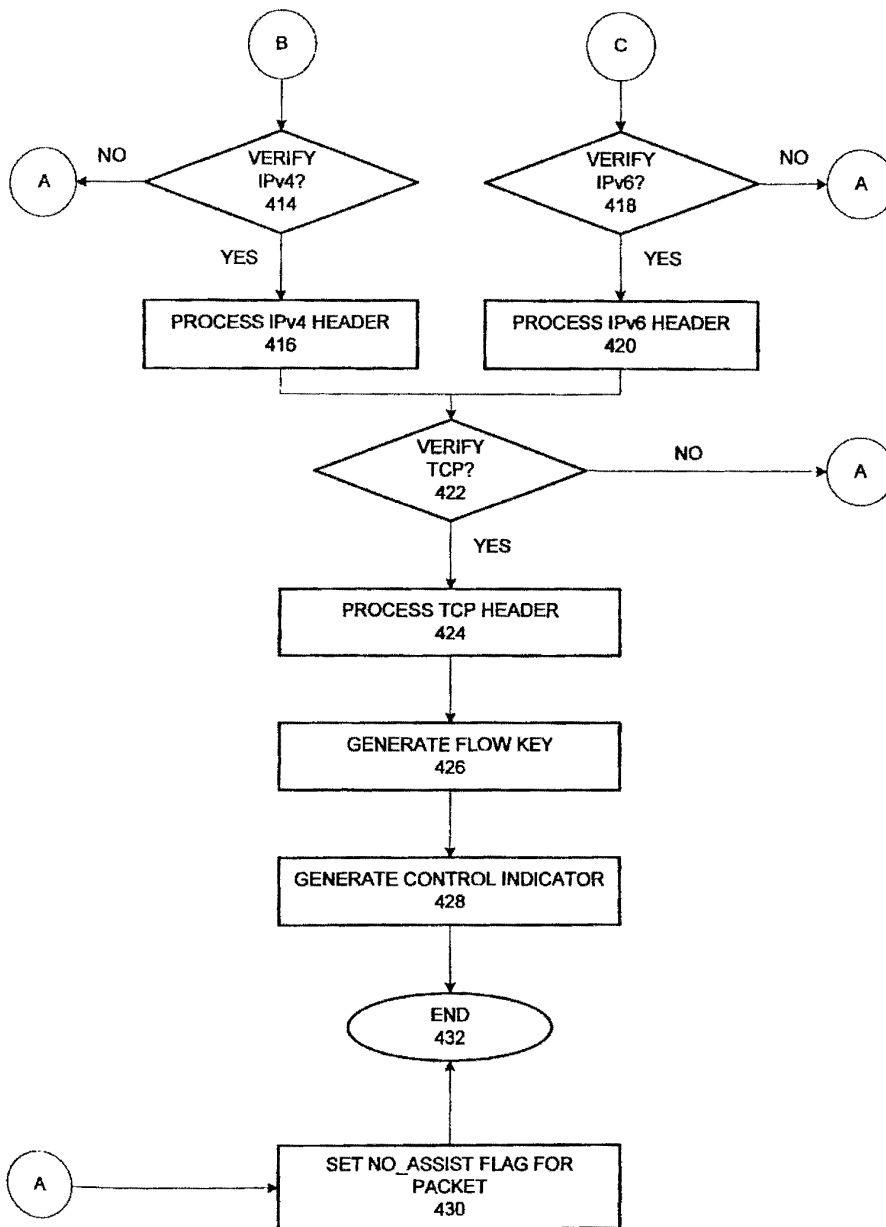


FIG. 4B

FLOW DATABASE 110

ASSOCIATIVE PORTION 502				FLOW#	ASSOCIATED PORTION 504		
IP SOURCE ADDRESS 510	IP DESTINATION ADDRESS 512	TCP SOURCE PORT 514	TCP DESTINATION PORT 516		FLOW VALIDITY INDICATOR 520	FLOW SEQUENCE # 522	FLOW ACTIVITY INDICATOR 524
				0			
				1			
				...			
				N			

FIG. 5

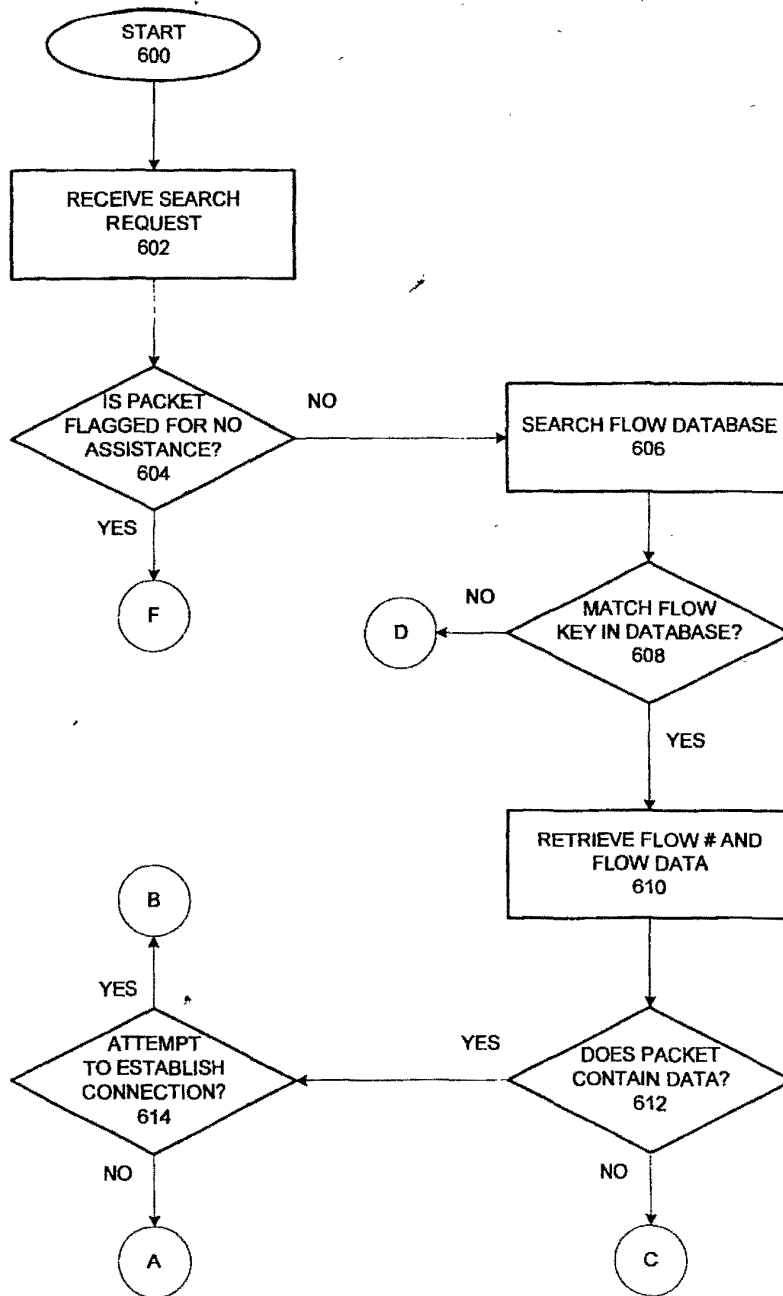


FIG. 6A

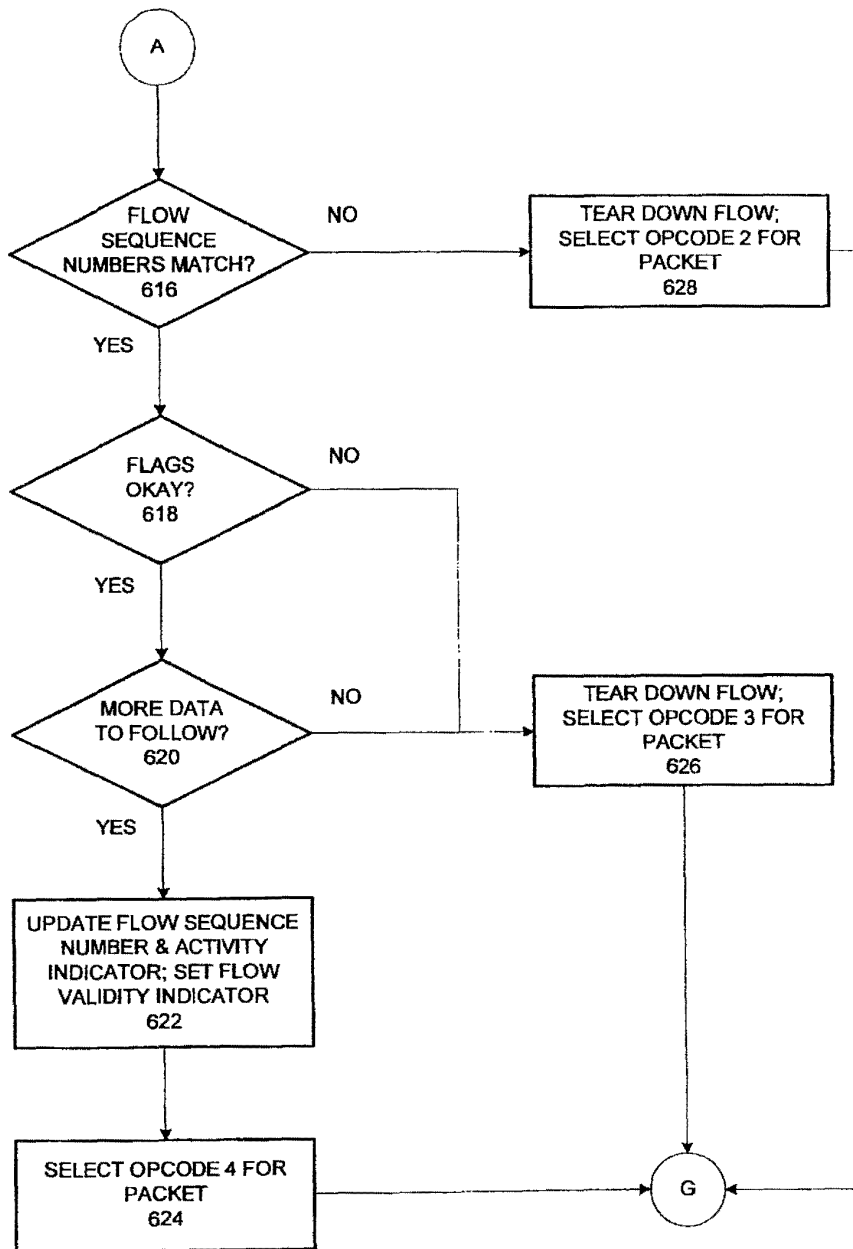


FIG. 6B

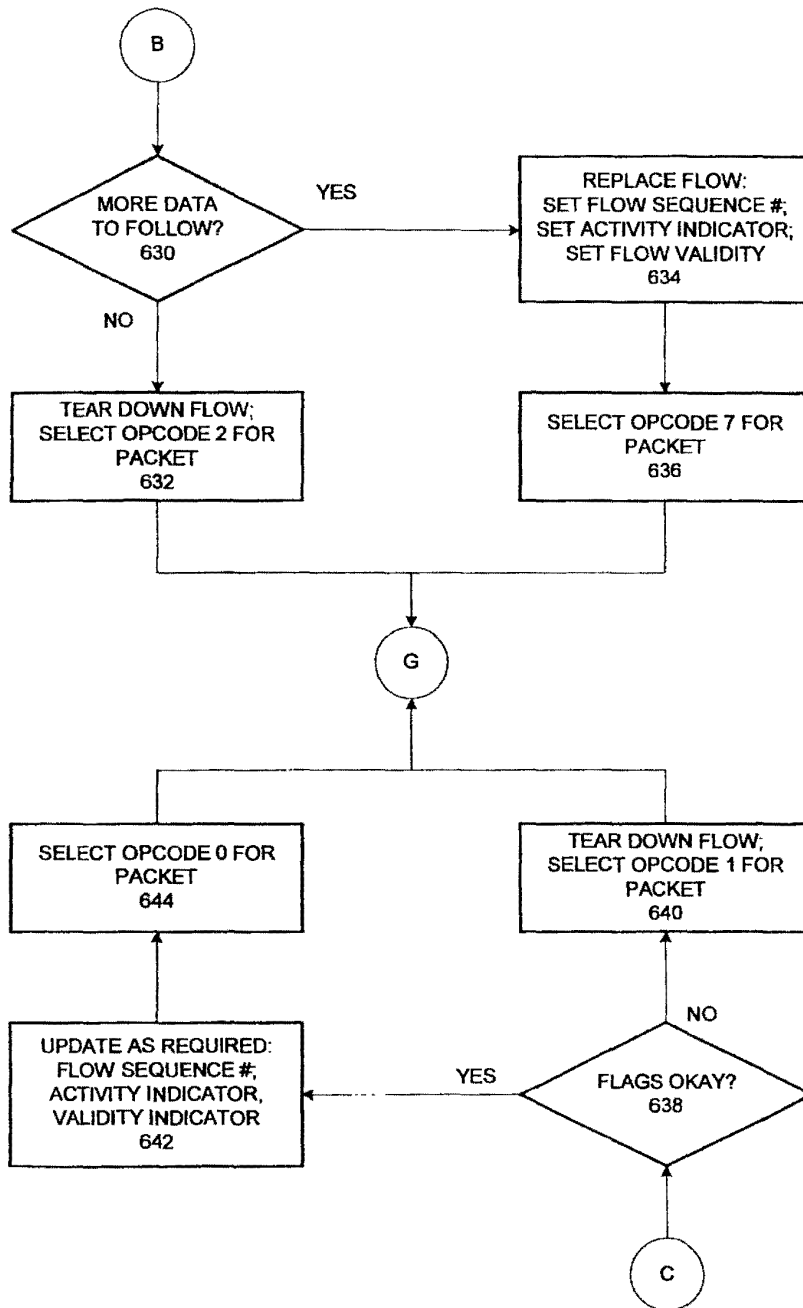


FIG. 6C



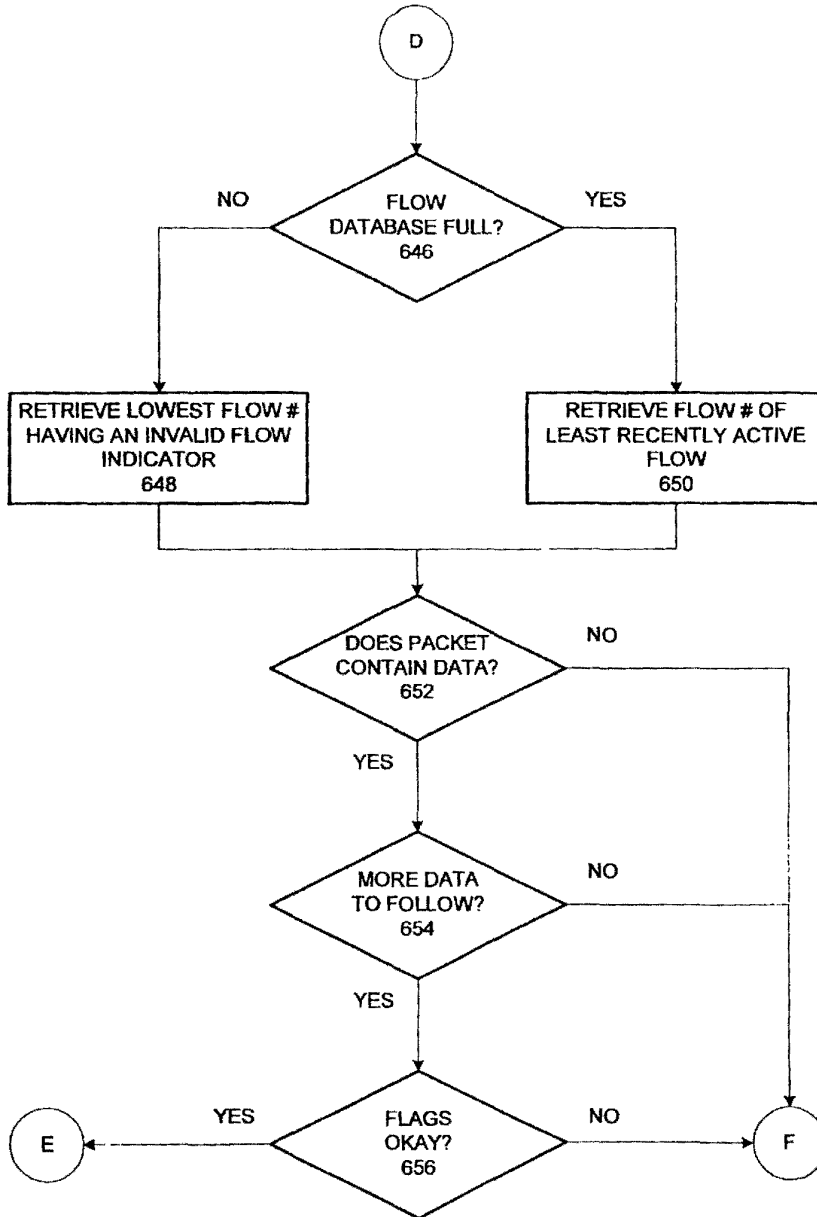


FIG. 6D

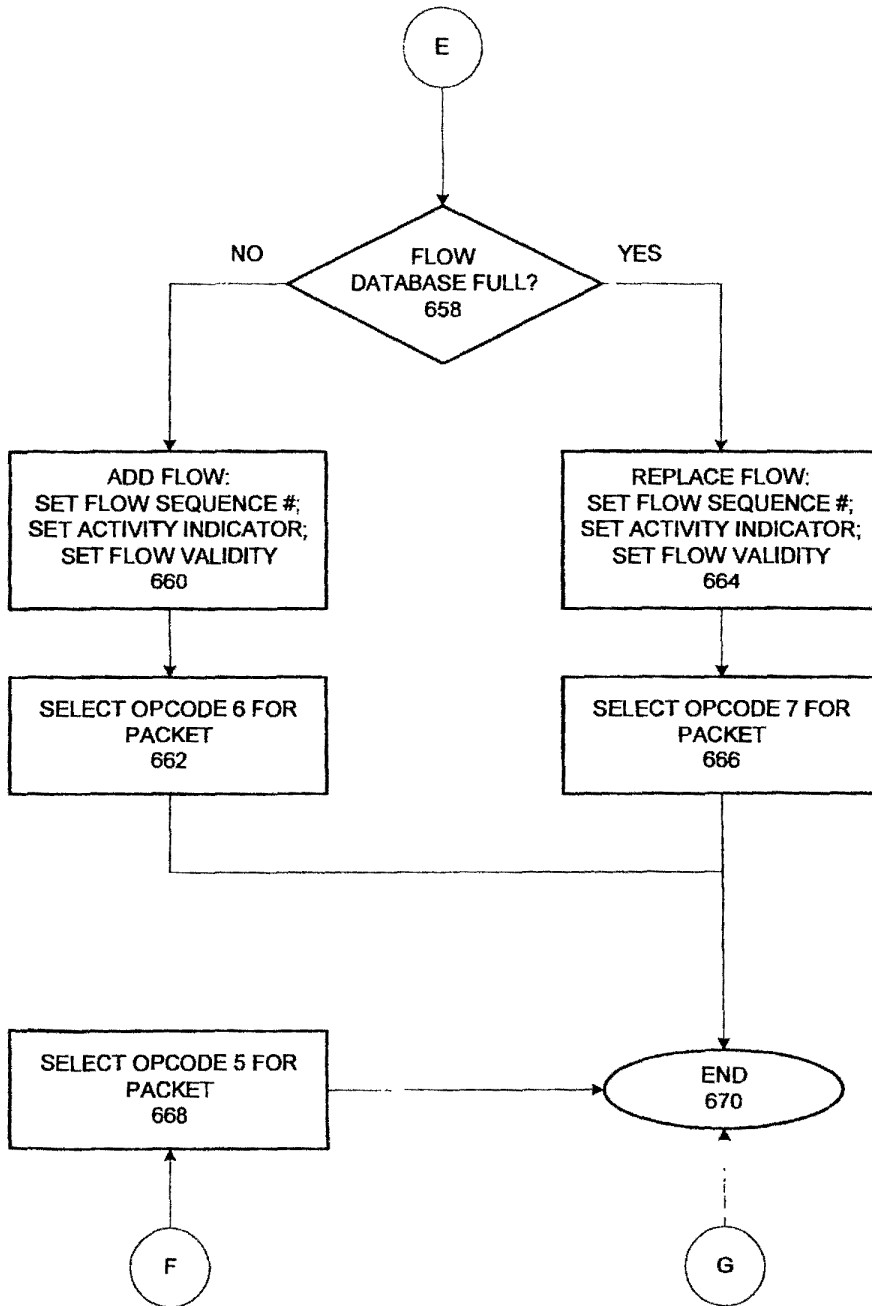


FIG. 6E

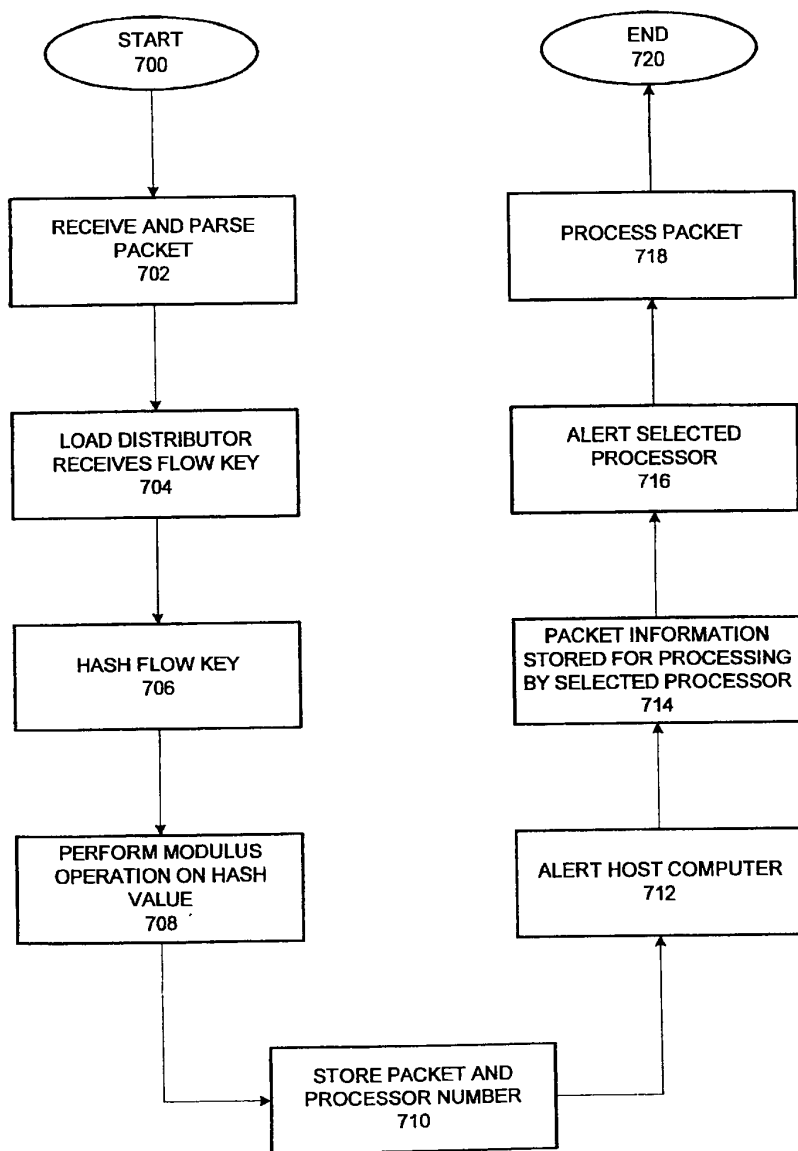


FIG. 7

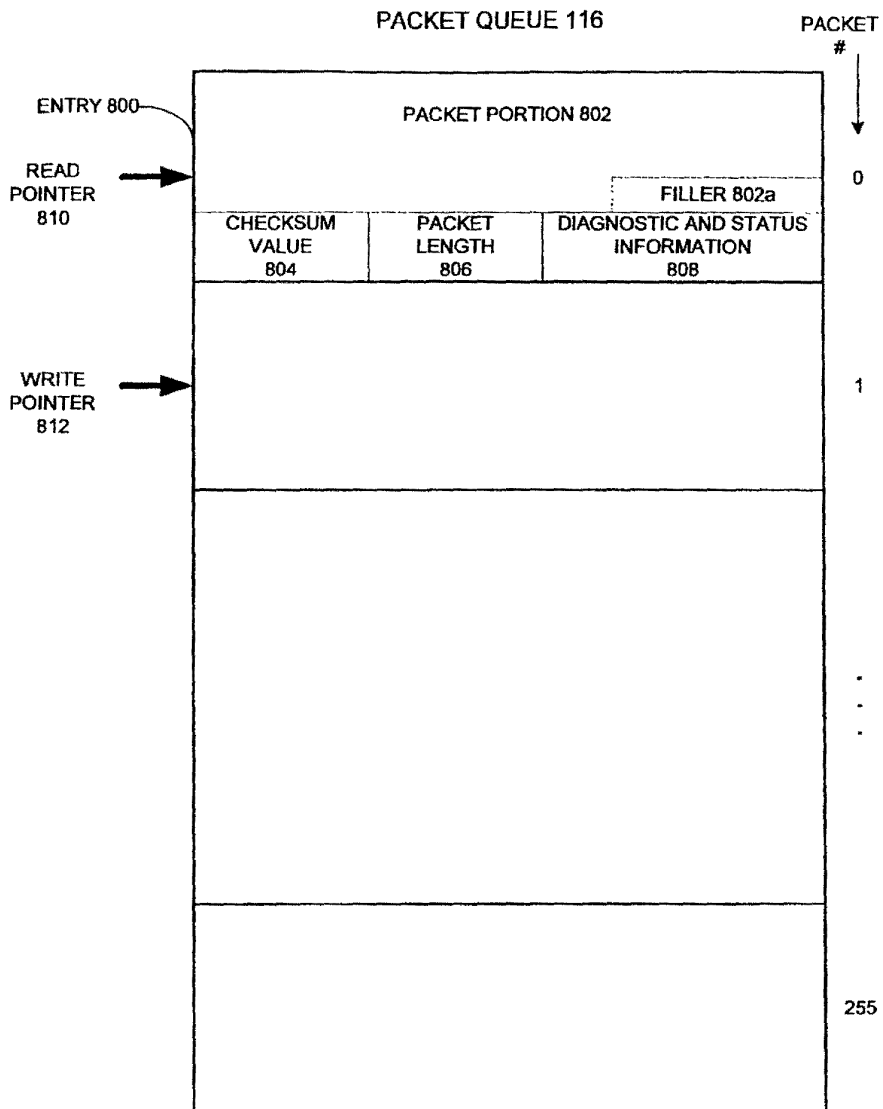


FIG. 8

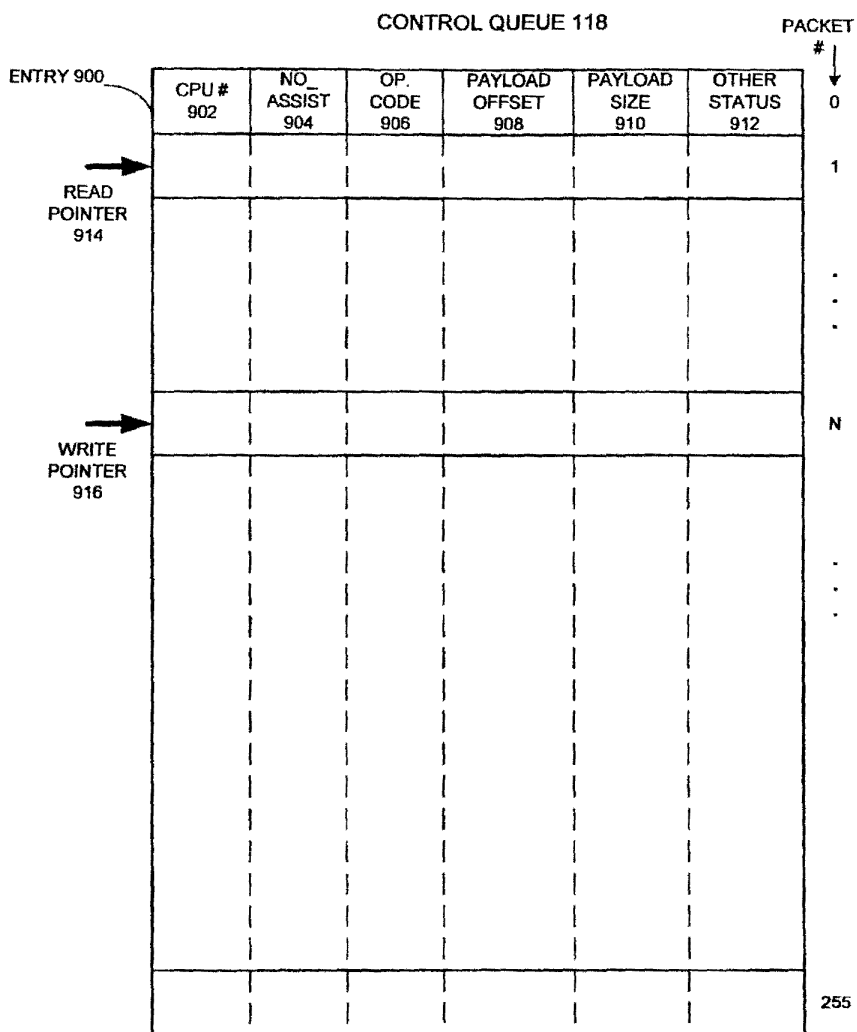


FIG. 9

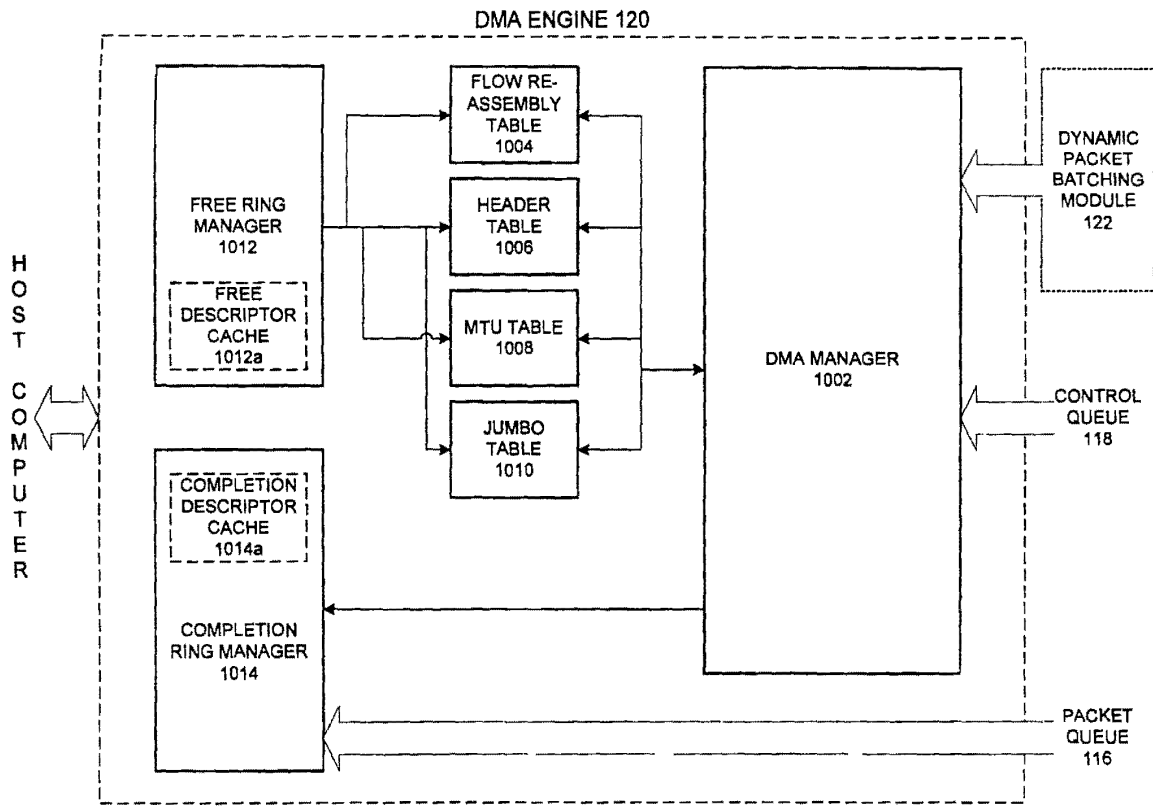


FIG. 10

FLOW RE-ASSEMBLY TABLE 1004

VALIDITY INDICATOR 1106	NEXT ADDRESS 1104	FLOW RE-ASSEMBLY BUFFER INDEX 1102	PACKET # ↓
			0
			.
			.
			.
			63

HEADER TABLE 1006

VALIDITY INDICATOR 1116	NEXT ADDRESS 1114	HEADER BUFFER INDEX 1112

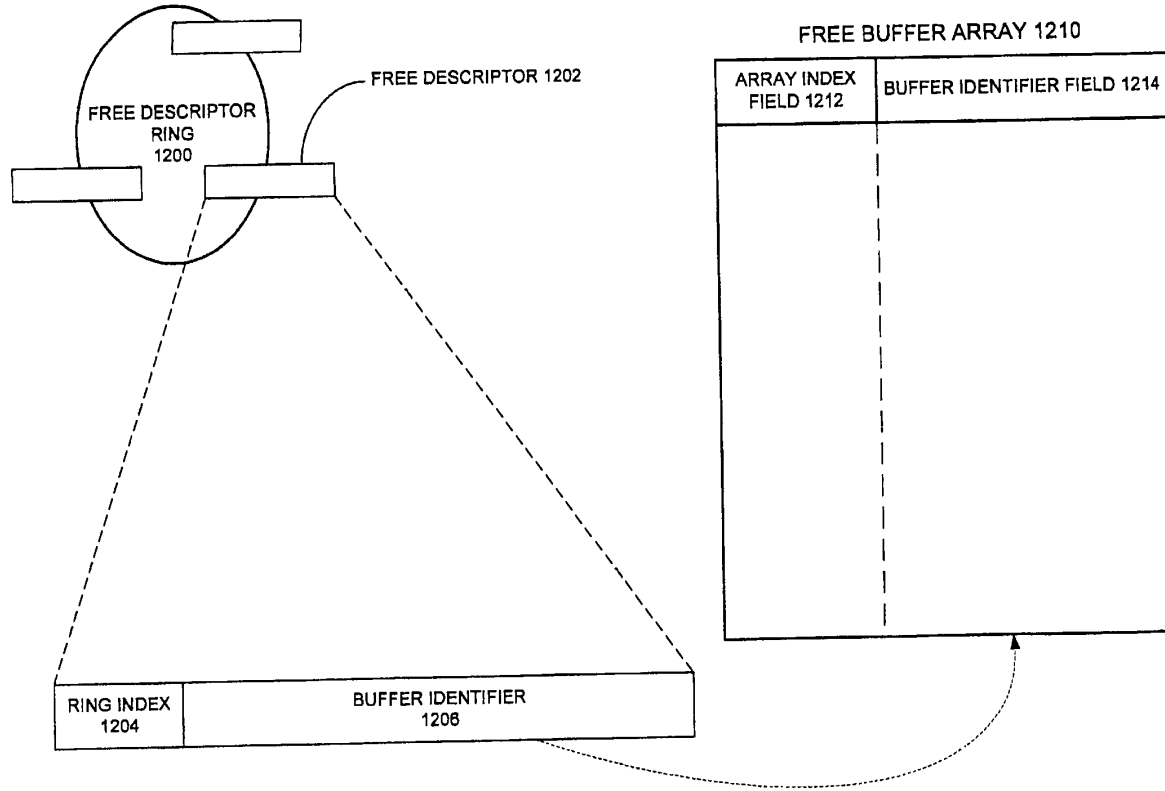
MTU TABLE 1008

VALIDITY INDICATOR 1126	NEXT ADDRESS 1124	MTU BUFFER INDEX 1122

JUMBO TABLE 1010

VALIDITY INDICATOR 1136	NEXT ADDRESS 1134	JUMBO BUFFER INDEX 1132

FIG. 11



**FIG. 12A**



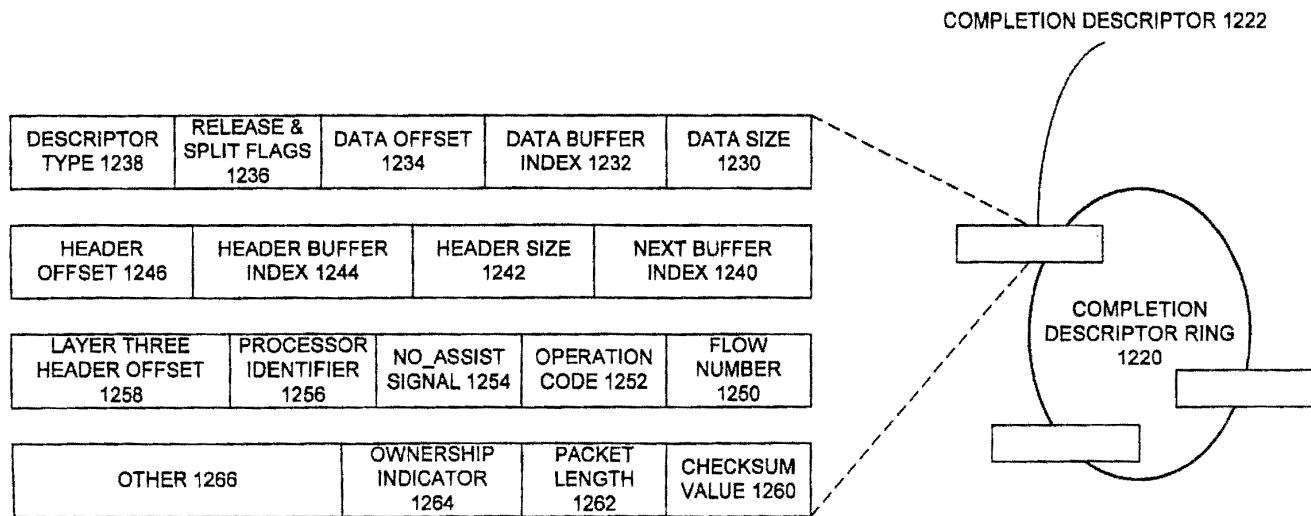


FIG. 12B

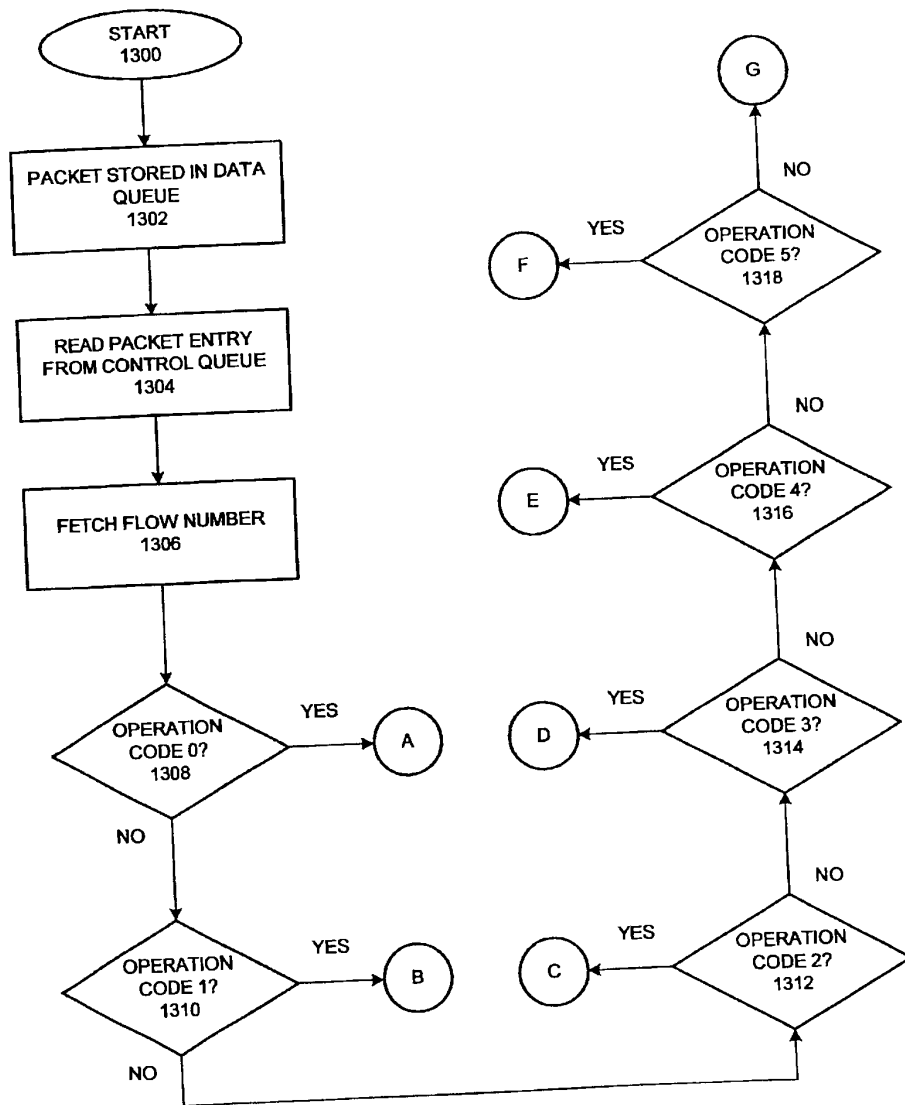


FIG. 13

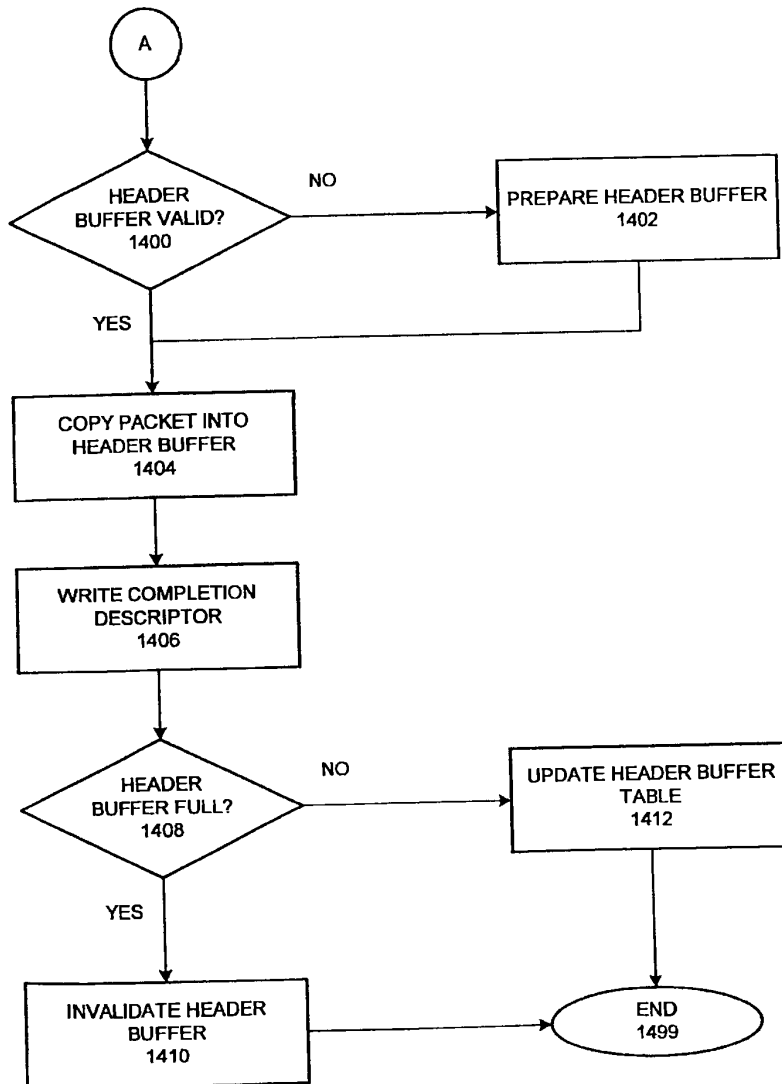


FIG. 14

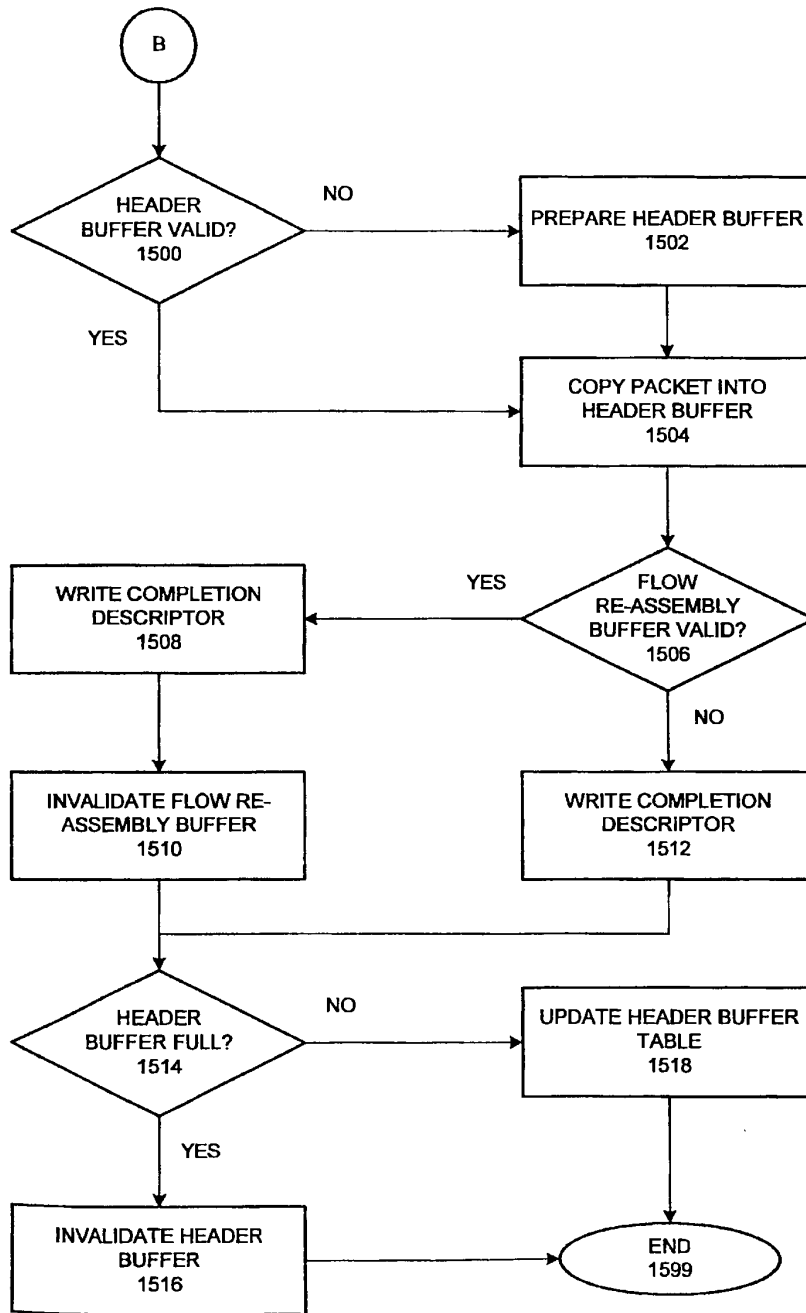


FIG. 15

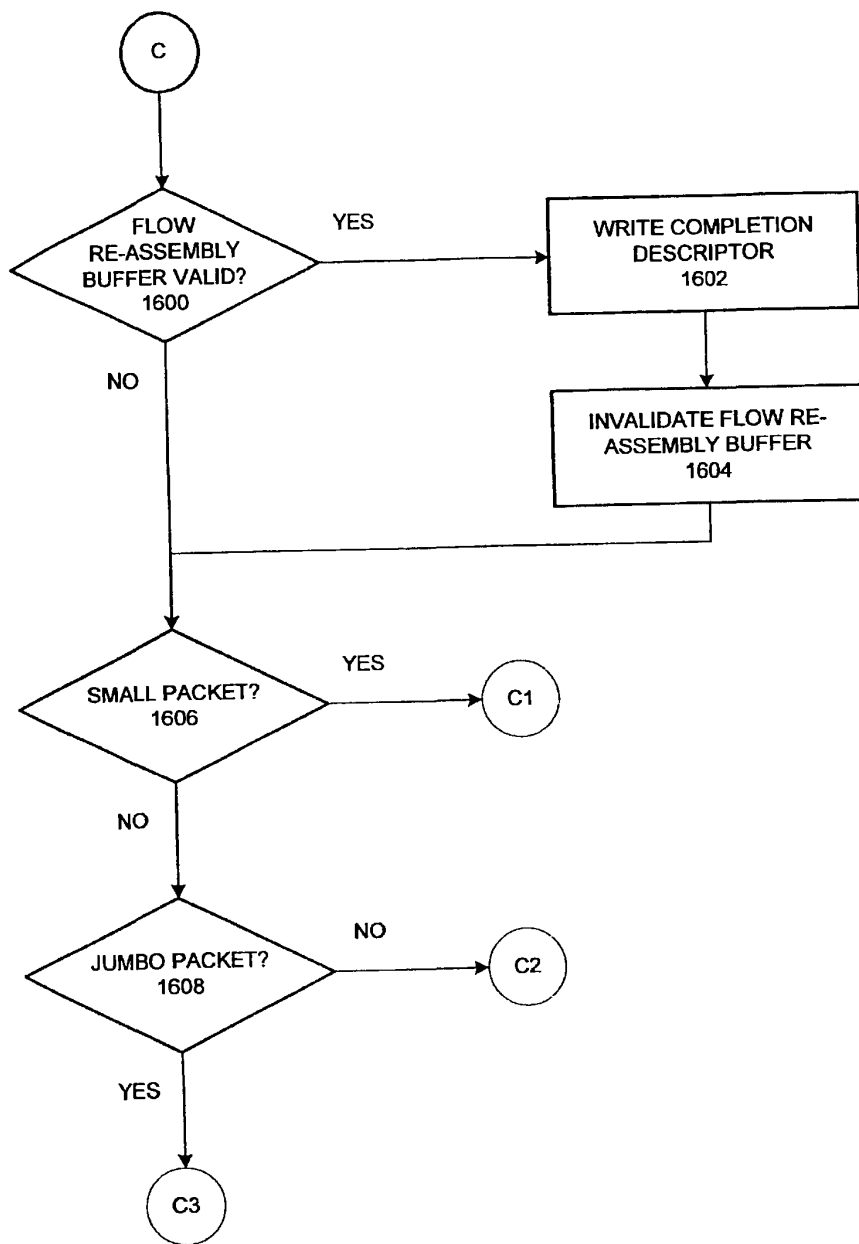


FIG. 16A

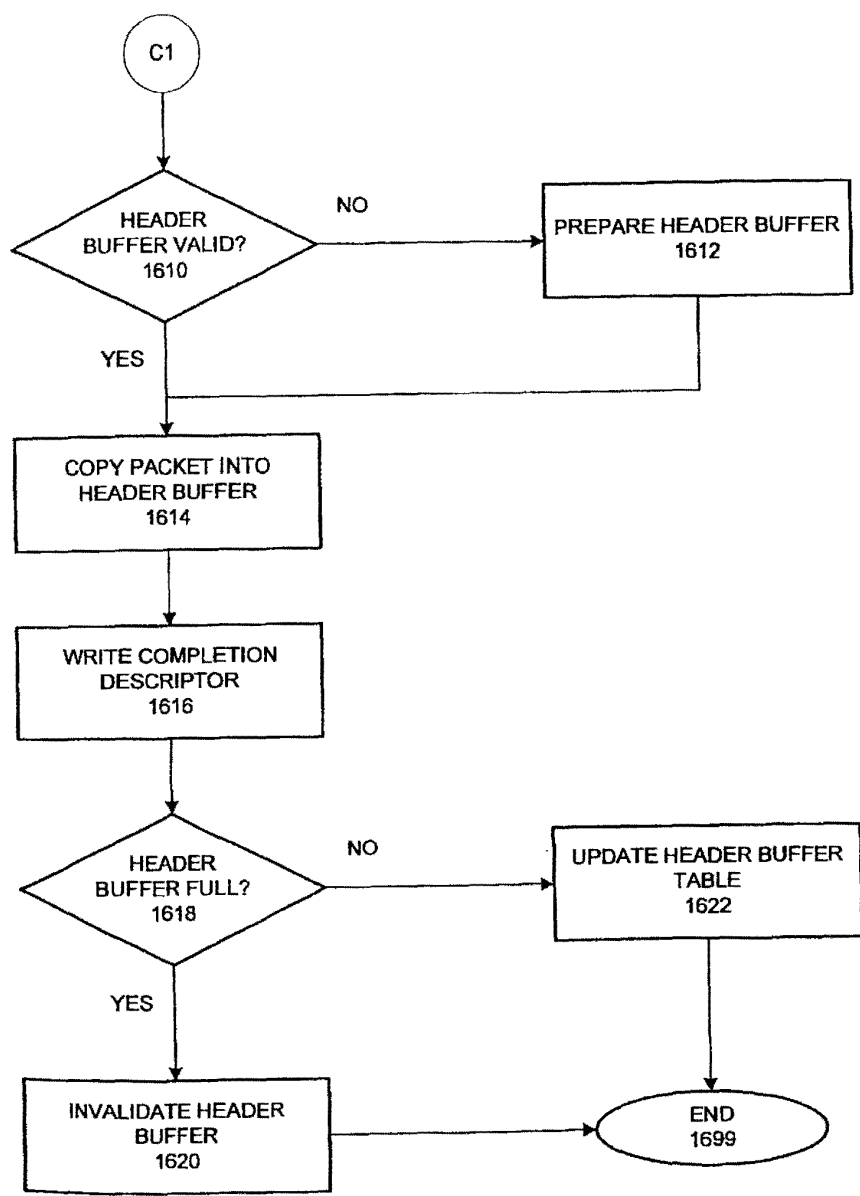


FIG. 16B

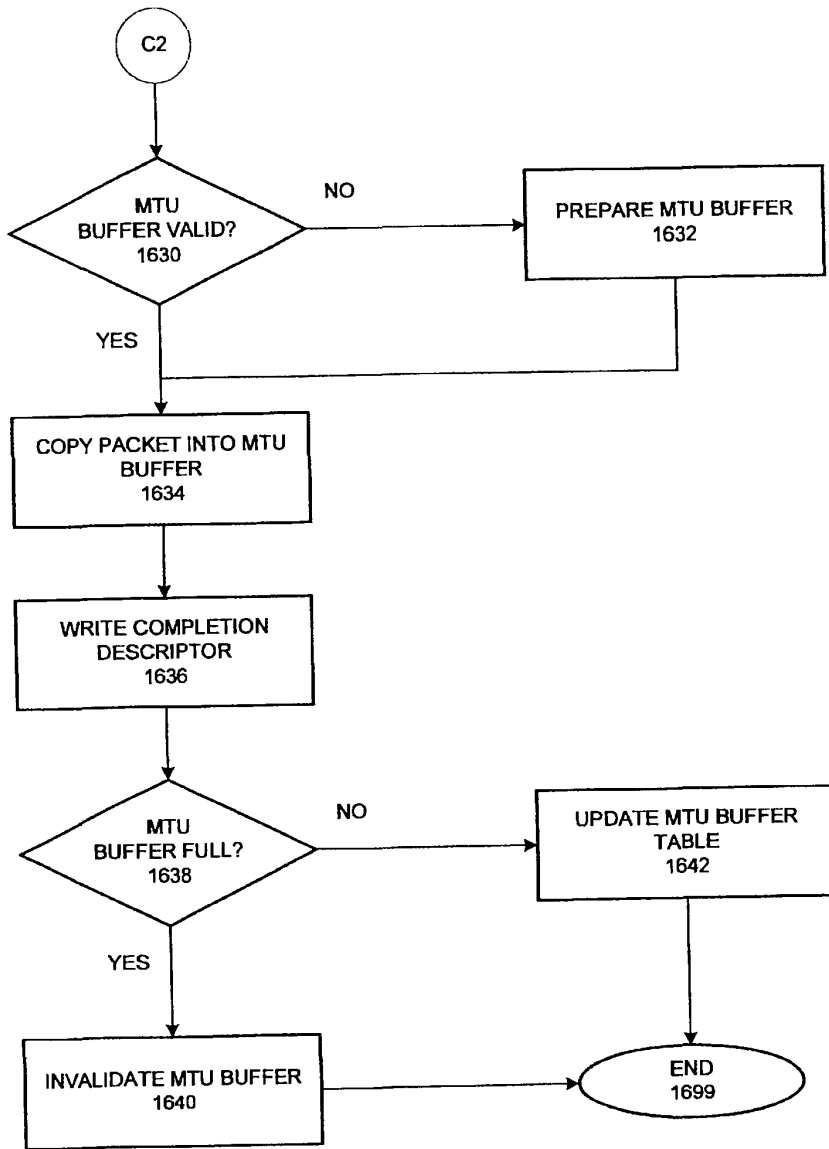


FIG. 16C

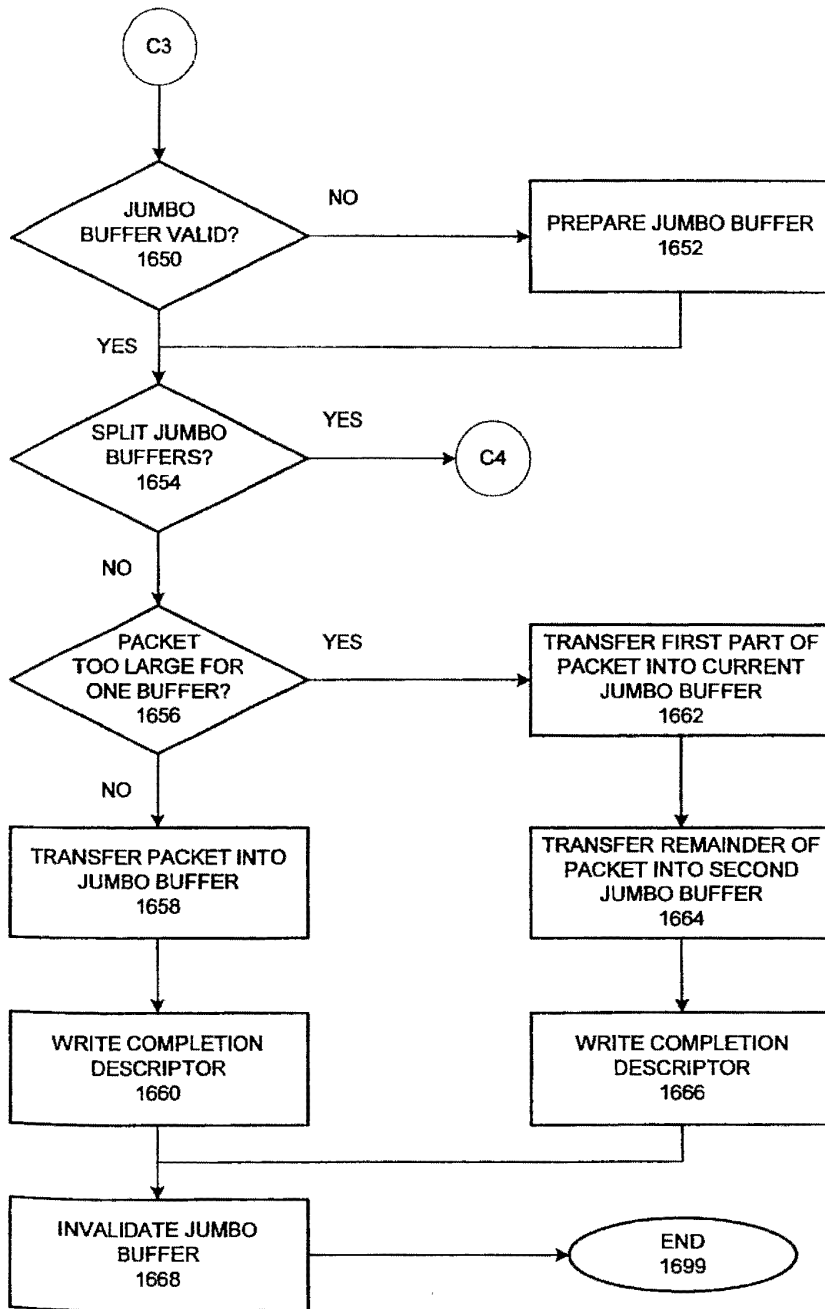


FIG. 16D



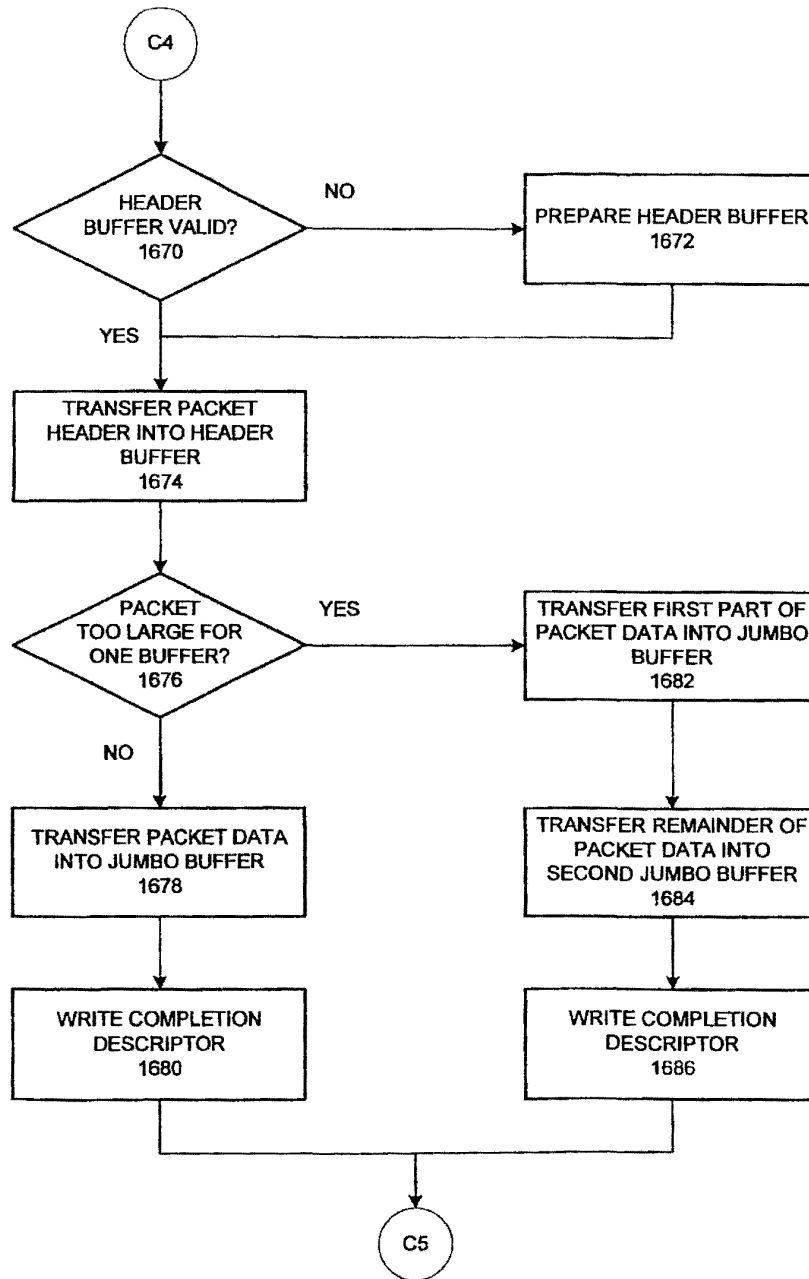


FIG. 16E

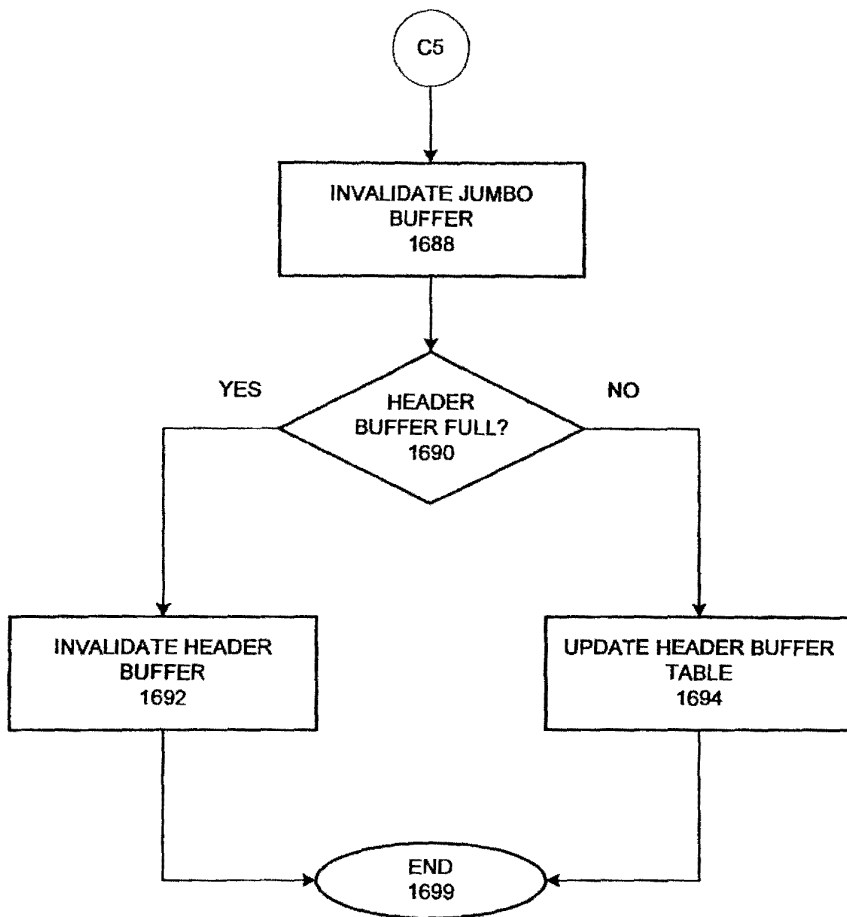


FIG. 16F

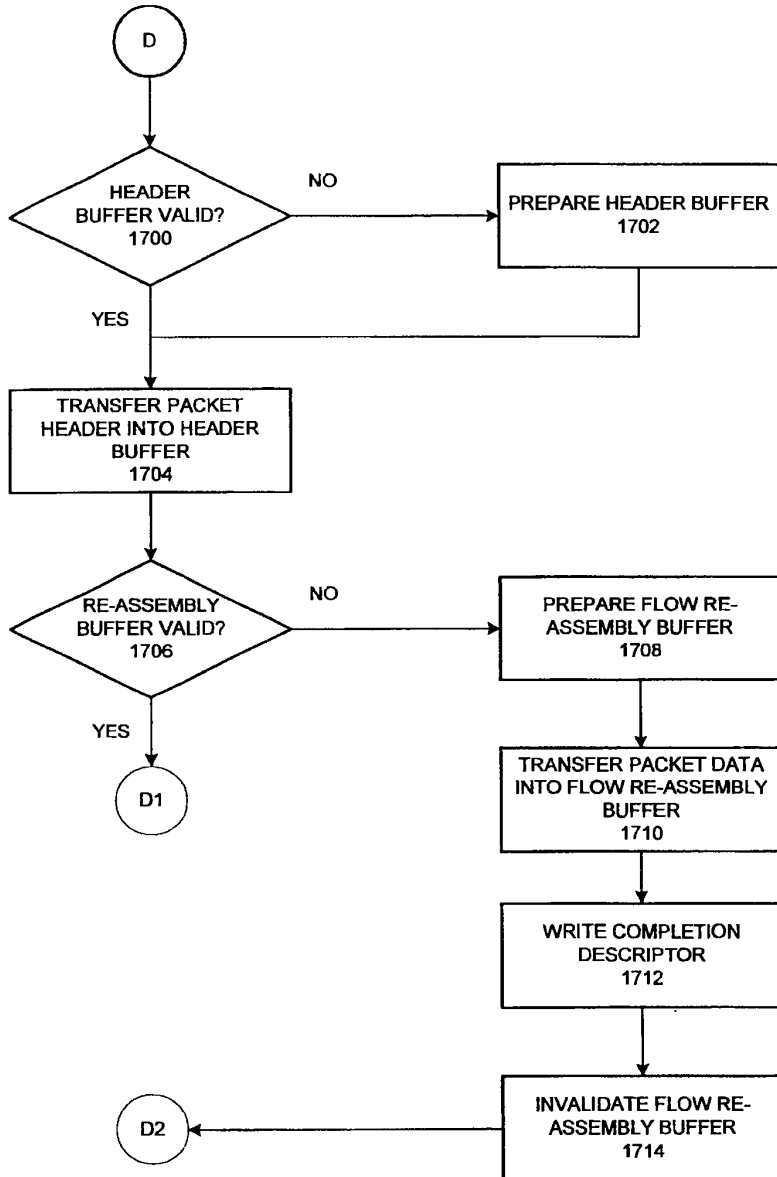


FIG. 17A

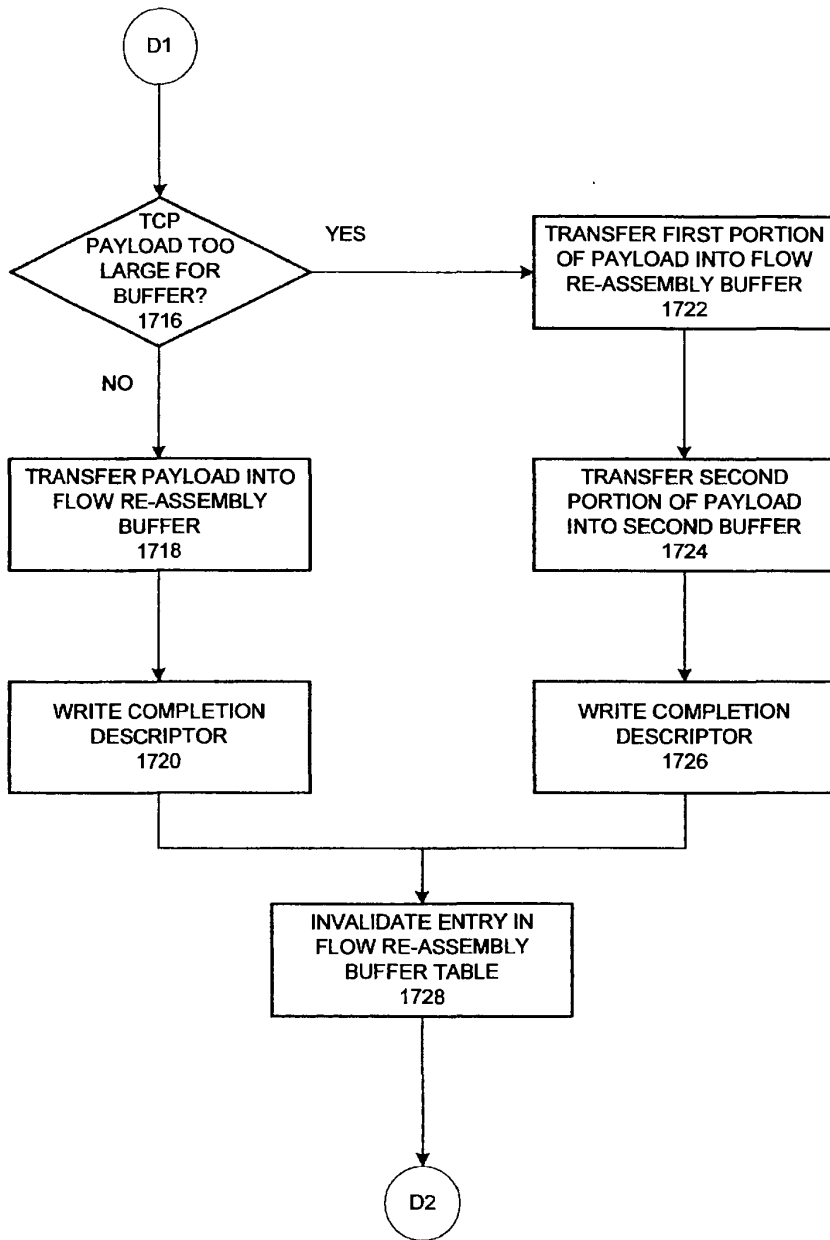


FIG. 17B

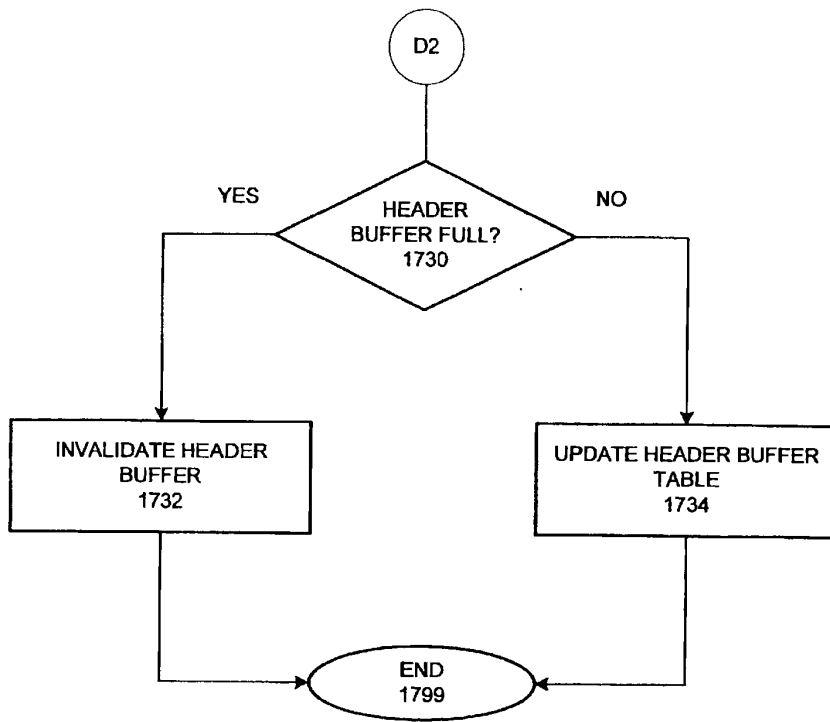


FIG. 17C

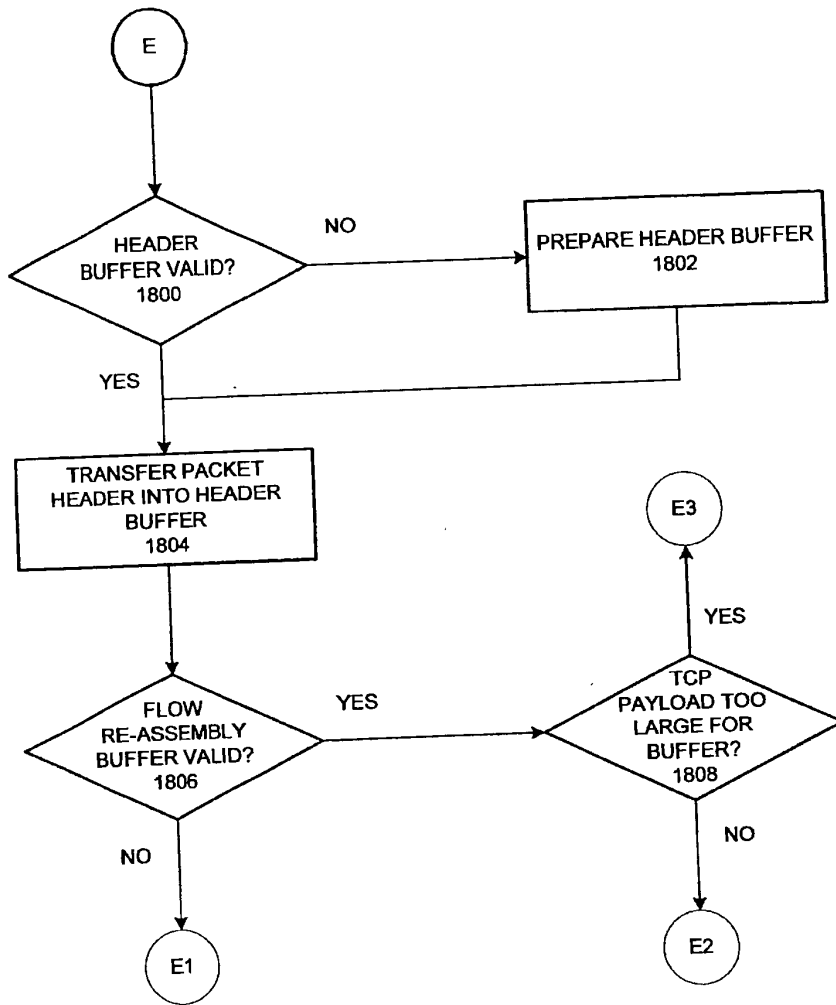


FIG. 18A

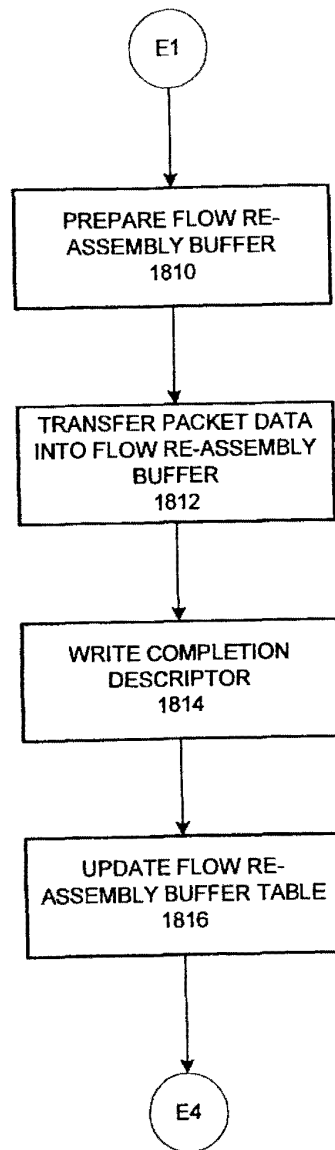


FIG. 18B

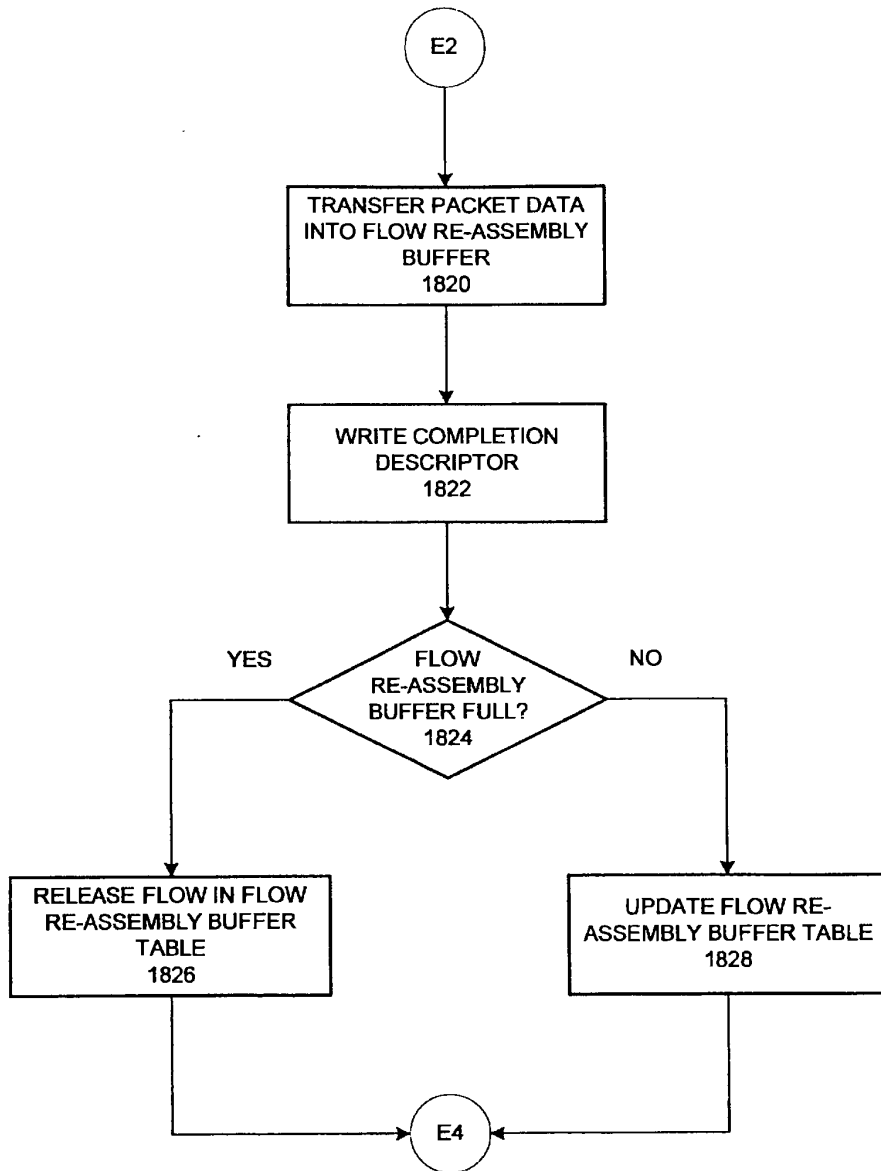


FIG. 18C



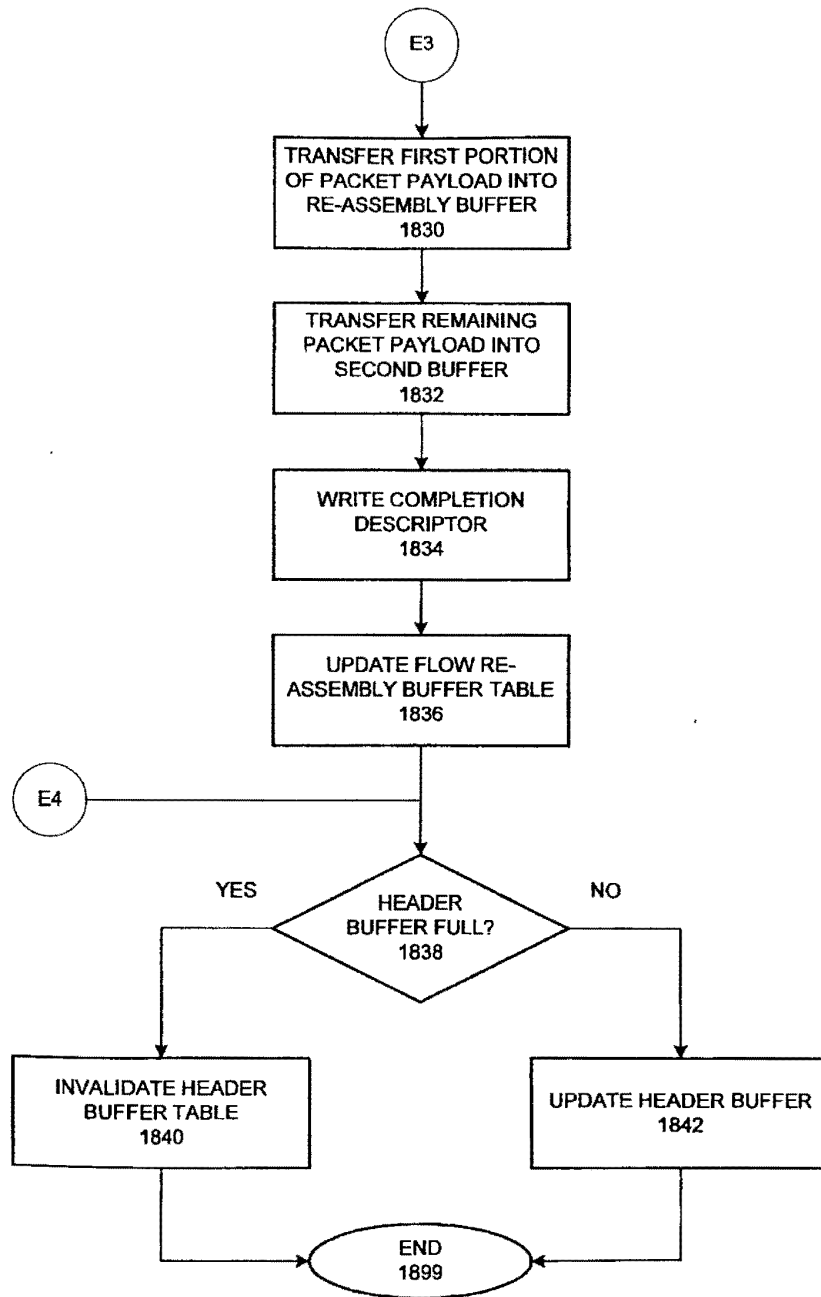


FIG. 18D

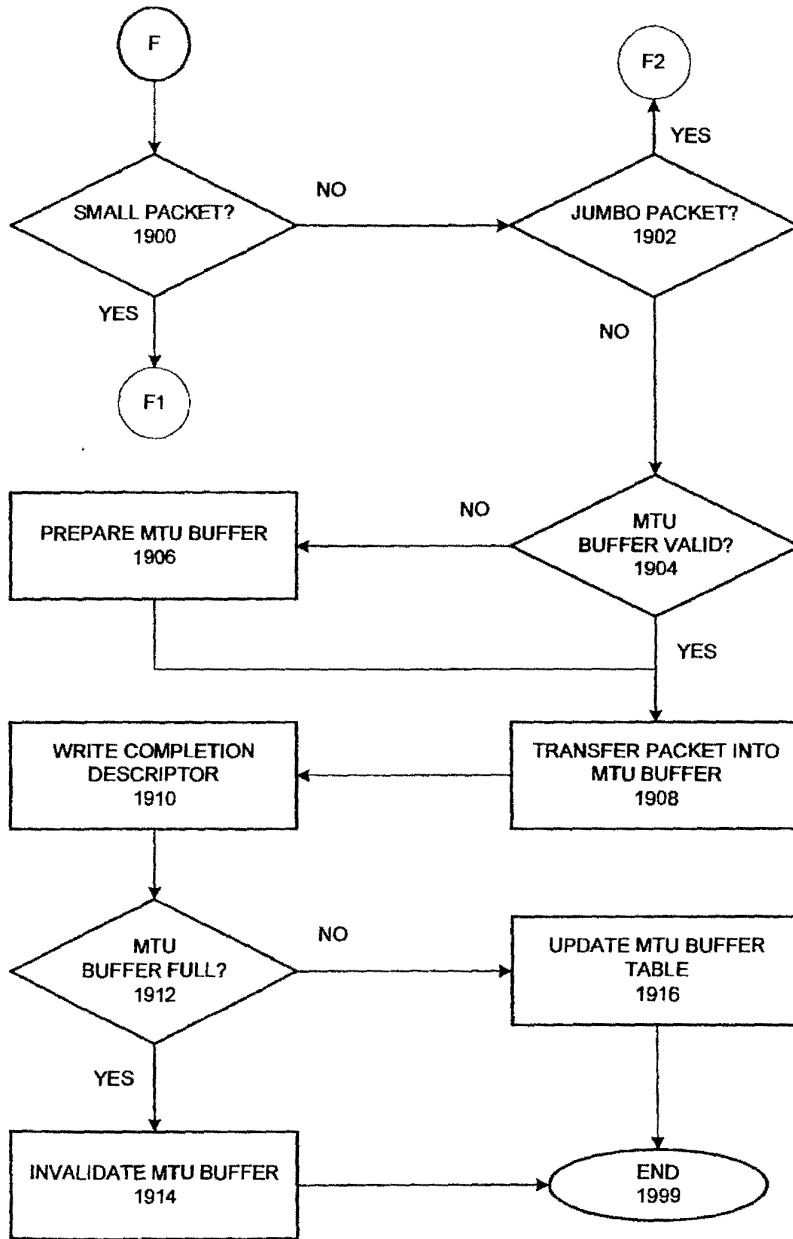


FIG. 19A

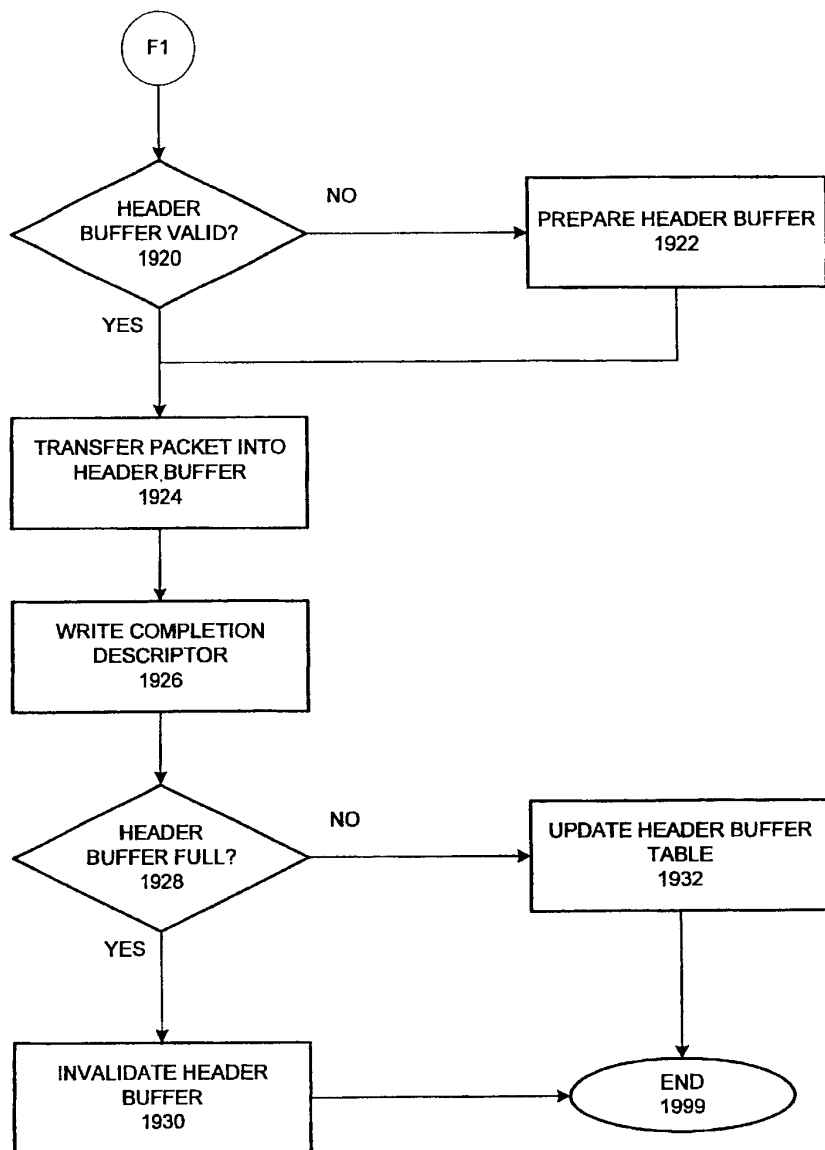


FIG. 19B

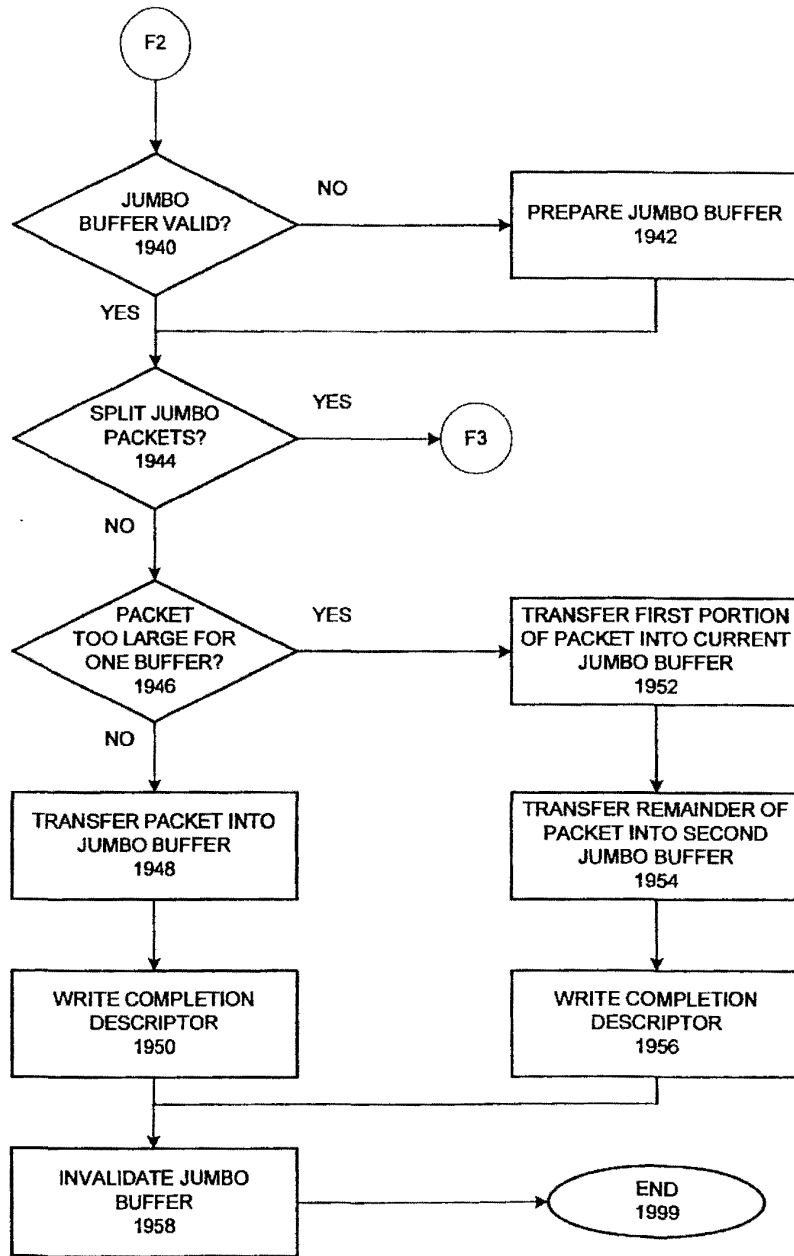


FIG. 19C

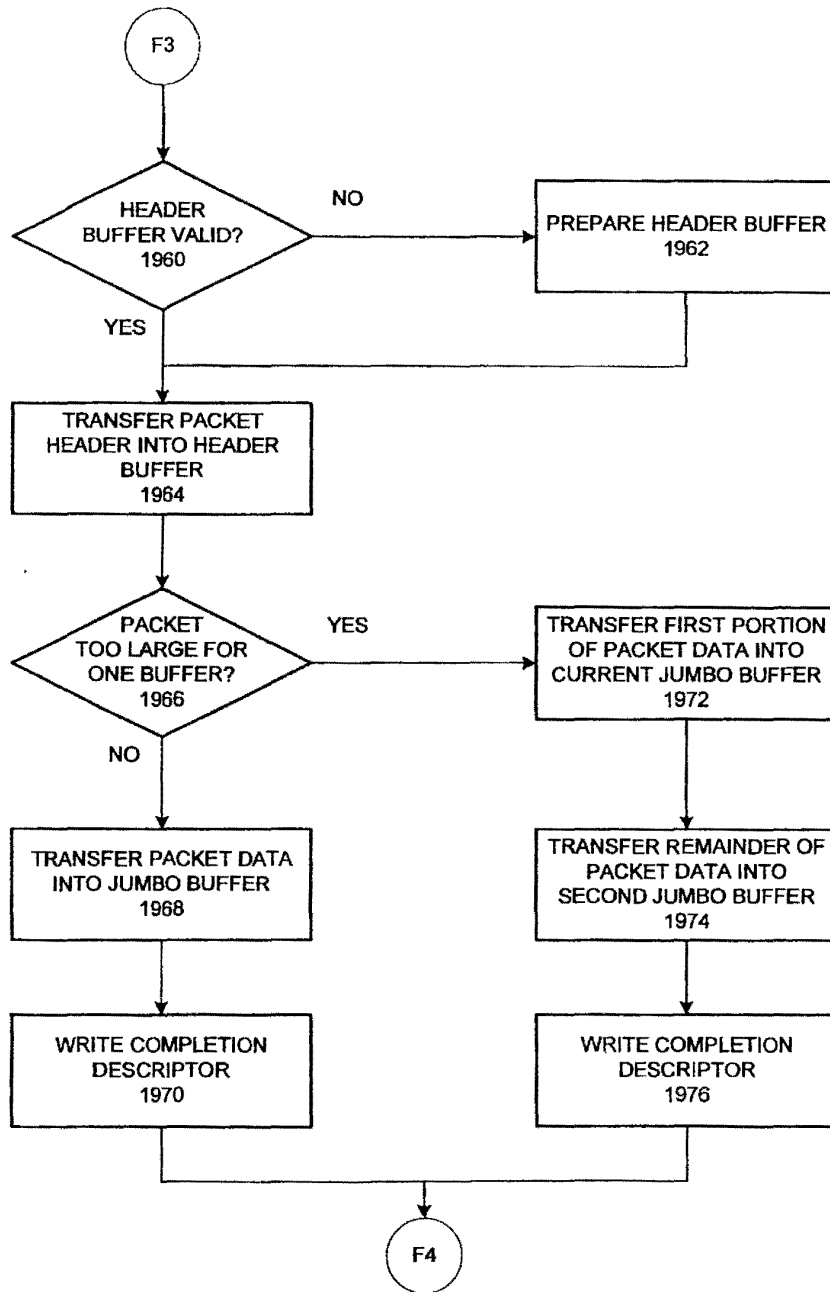


FIG. 19D

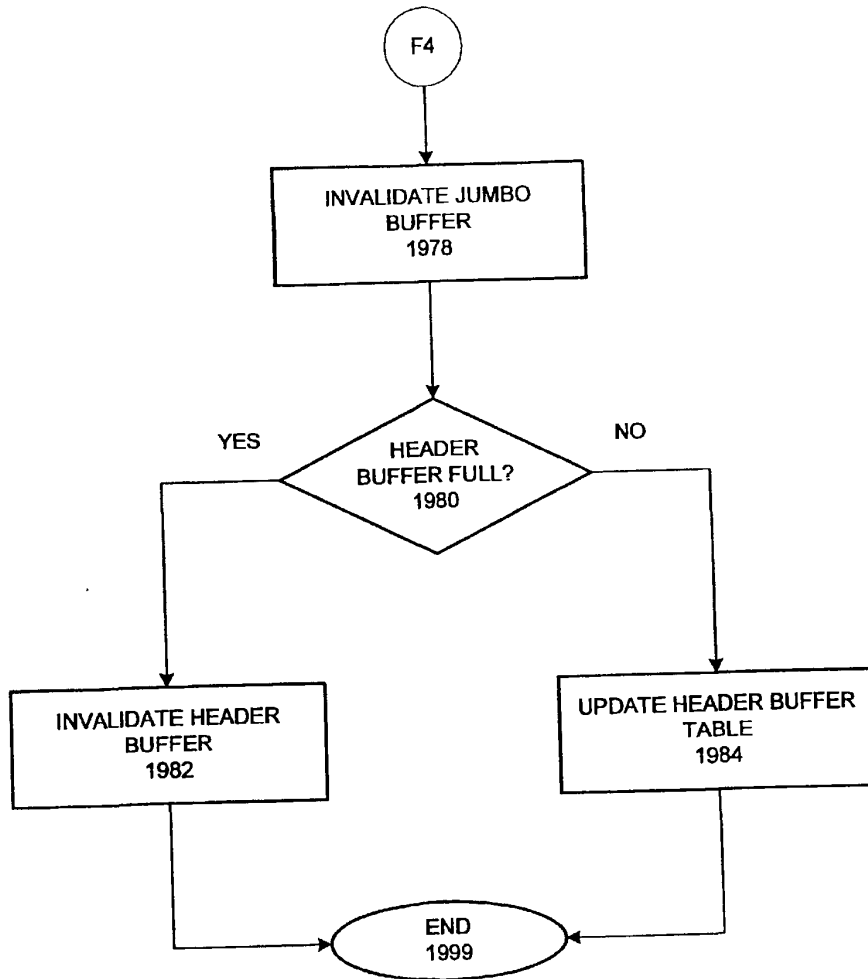


FIG. 19E

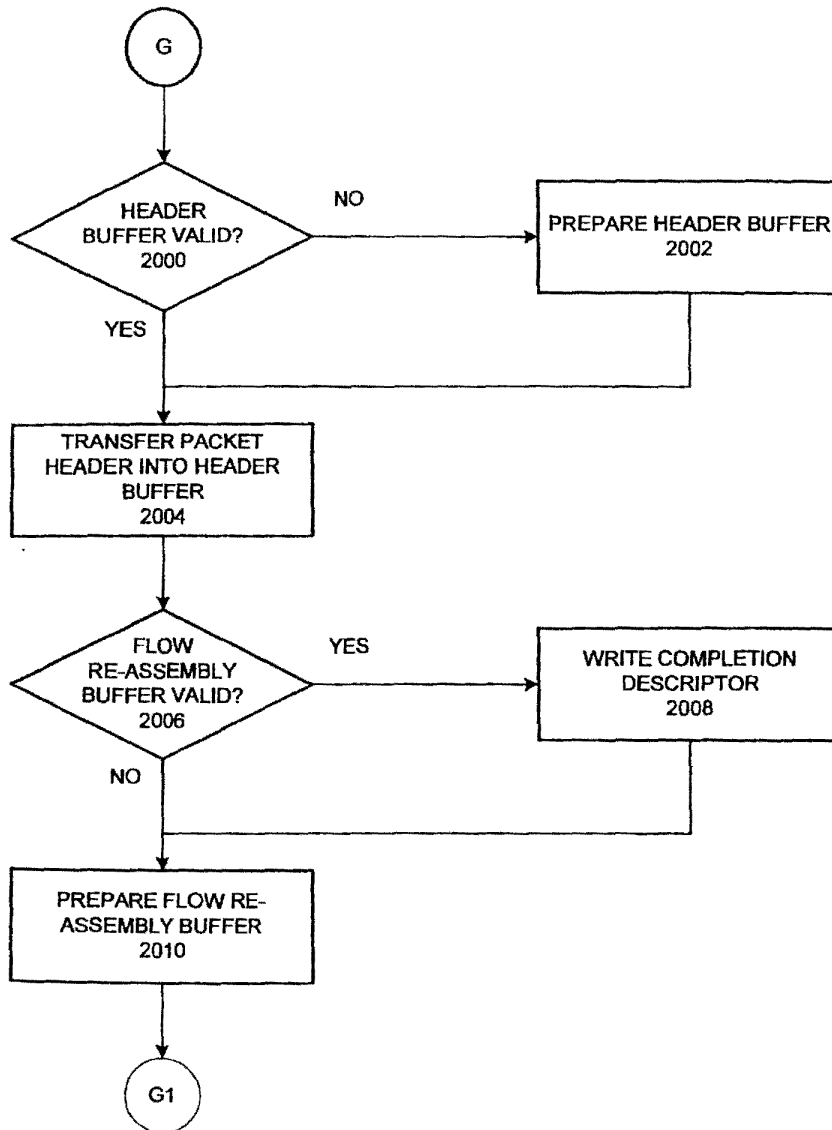


FIG. 20A

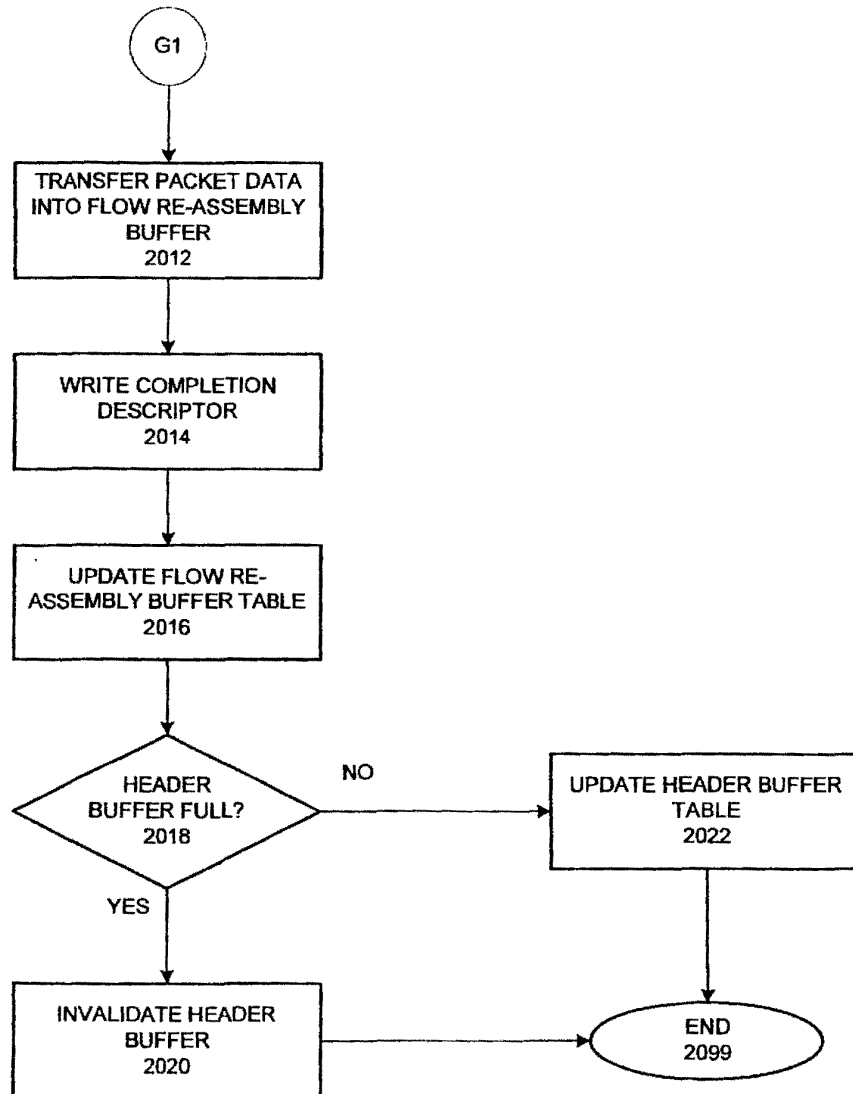


FIG. 20B



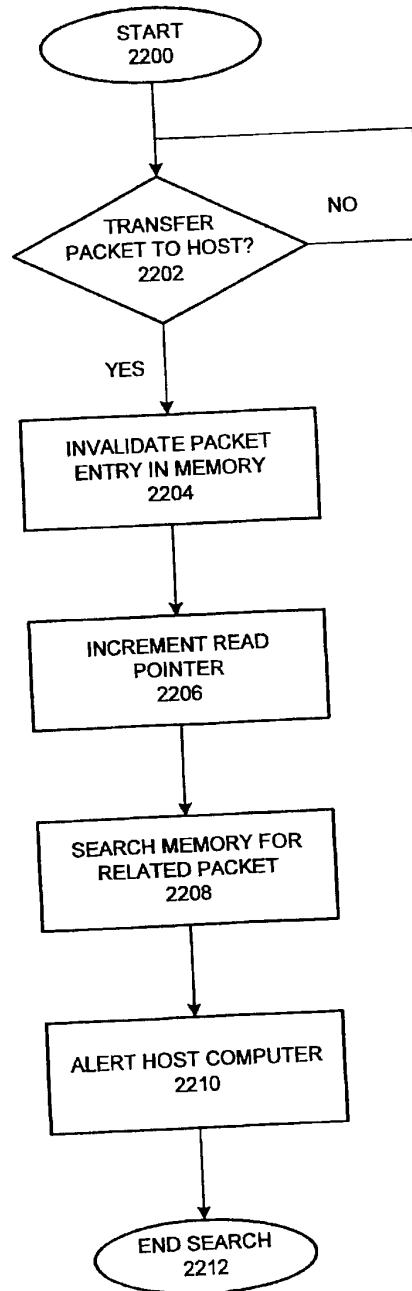


FIG. 22A

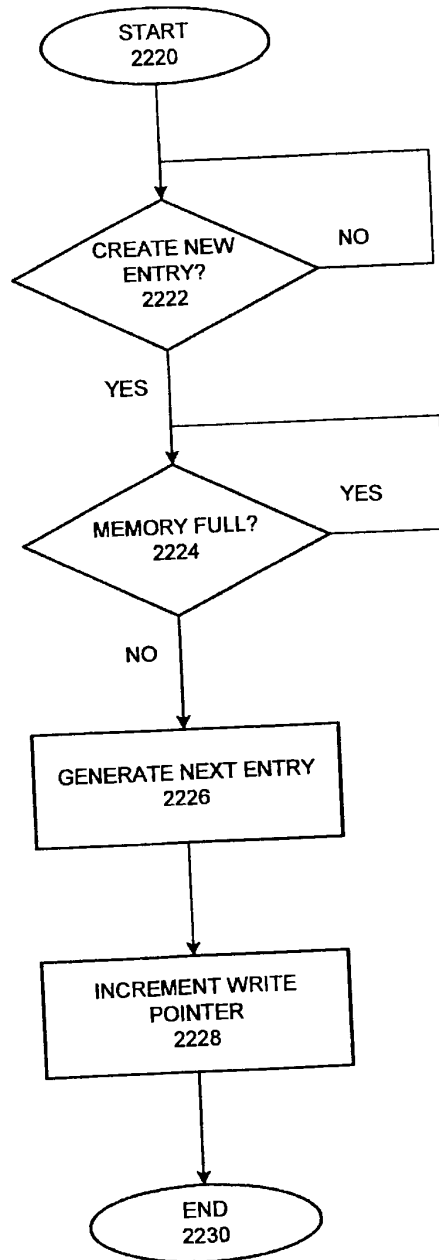


FIG. 22B

INSTR. NO. 2302	INSTR. NAME 2304	INSTRUCTION CONTENT 2306 (EXTRACTION MASK, COMPARE VALUE, OPERATOR, SUCCESS OFFSET, SUCCESS INSTRUCTION, FAILURE OFFSET, FAILURE INSTRUCTION, OUTPUT OPERATION, OPERATION ARGUMENT, OPERATION ENABLER, SHIFT, OUTPUT MASK)
-----------------------	------------------------	--

0	WAIT	0xFFFF, 0x0000, NP, 6, VLAN, 0, WAIT, CLR_REG, 0x3FF, 1, 0, 0x0000
1	VLAN	0xFFFF, 0x8100, EQ, 1, CFI, 0, 802.3, IM_CTL, 0x00A, 3, 0, 0xFFFF
2	CFI	0x1000, 0x1000, EQ, 0, DONE, 1, 802.3, NONE, 0x000, 0, 0, 0x0000
3	802.3	0xFFFF, 0x0600, LT, 1, LLC_1, 0, IPV4_1, NONE, 0x000, 0, 0, 0x0000
4	LLC_1	0xFFFF, 0xAAAA, EQ, 1, LLC_2, 0, DONE, NONE, 0x000, 0, 0, 0x0000
5	LLC_2	0xFF00, 0x0300, EQ, 2, IPV4_1, 0, DONE, NONE, 0x000, 0, 0, 0x0000
6	IPV4_1	0xFFFF, 0x0800, EQ, 1, IPV4_2, 0, IPV6_1, LD_SAP, 0x100, 3, 0, 0xFFFF
7	IPV4_2	0xFF00, 0x4500, EQ, 3, IPV4_3, 0, DONE, LD_SUM, 0x00A, 1, 0, 0x0000
8	IPV4_3	0x3FFF, 0x0000, EQ, 1, IPV4_4, 0, DONE, LD_LEN, 0x03E, 1, 0, 0xFFFF
9	IPV4_4	0x00FF, 0x0006, EQ, 7, TCP_1, 0, DONE, LD_FID, 0x182, 1, 0, 0xFFFF
10	IPV6_1	0xFFFF, 0x86DD, EQ, 1, IPV6_2, 0, DONE, LD_SUM, 0x015, 1, 0x0000
11	IPV6_2	0xF000, 0x6000, EQ, 0, IPV6_3, 0, DONE, IM_R1, 0x114, 1, 0, 0xFFFF
12	IPV6_3	0x0000, 0x0000, EQ, 3, IPV6_4, 0, DONE, LD_FID, 0x484, 1, 0, 0xFFFF
13	IPV6_4	0xFF00, 0x0600, EQ, 18, TCP_1, 0, DONE, LD_LEN, 0x03F, 1, 0xFFFF
14	TCP_1	0x0000, 0x0000, EQ, 0, TCP_2, 4, TCP_2, LD_SEQ, 0x081, 3, 0, 0xFFFF
15	TCP_2	0x0000, 0x0000, EQ, 0, TCP_3, 0, TCP_3, ST_FLAG, 0x145, 3, 0, 0x002F
16	TCP_3	0x0000, 0x0000, EQ, 0, TCP_4, 0, TCP_4, LD_R1, 0x205, 3, 0xB, 0xF000
17	TCP_4	0x0000, 0x0000, EQ, 0, WAIT, 0, WAIT, LD_HDR, 0x0FF, 3, 0, 0xFFFF
18	DONE	0x0000, 0x0000, EQ, 0, WAIT, 0, WAIT, IM_CTL, 0x001, 3, 0x0000

PROGRAM 2300

FIG. 23

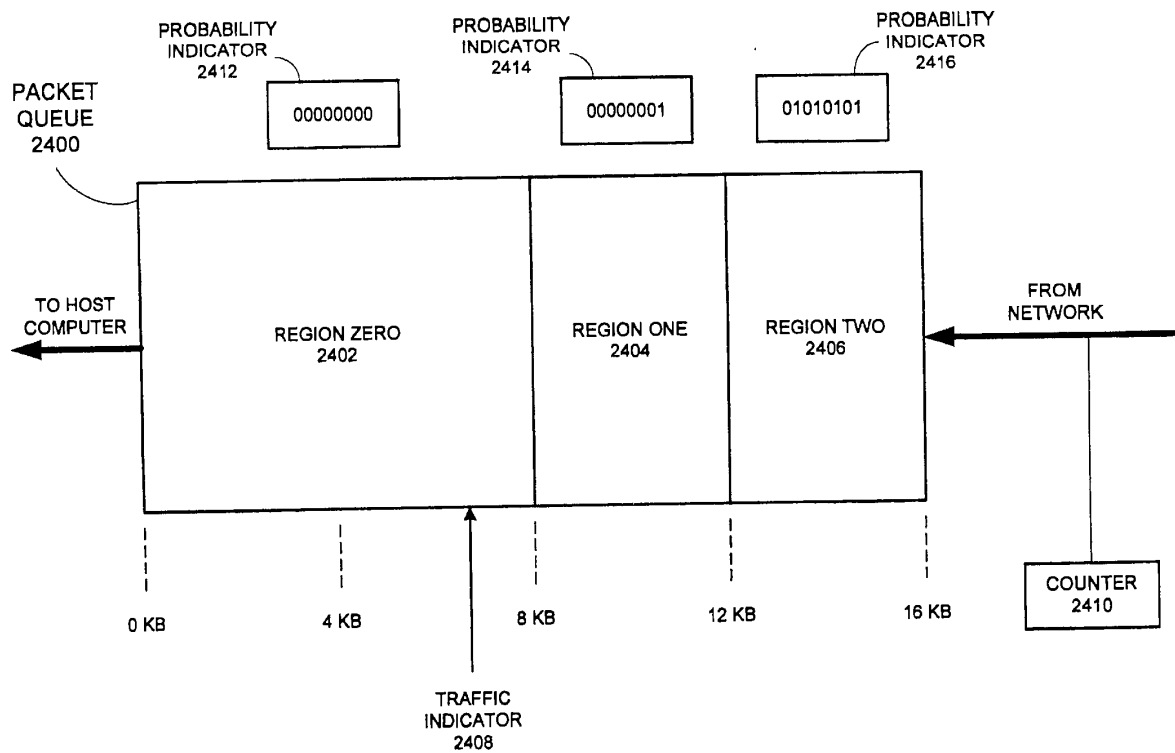


FIG. 24

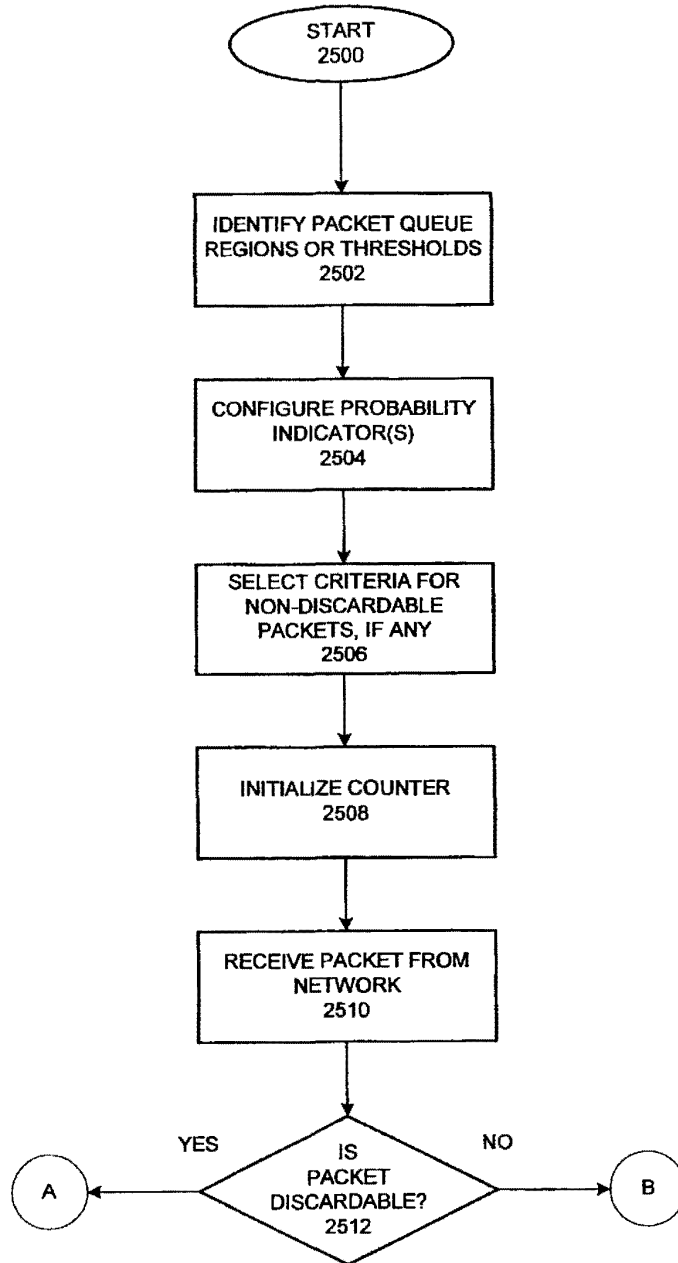


FIG. 25A

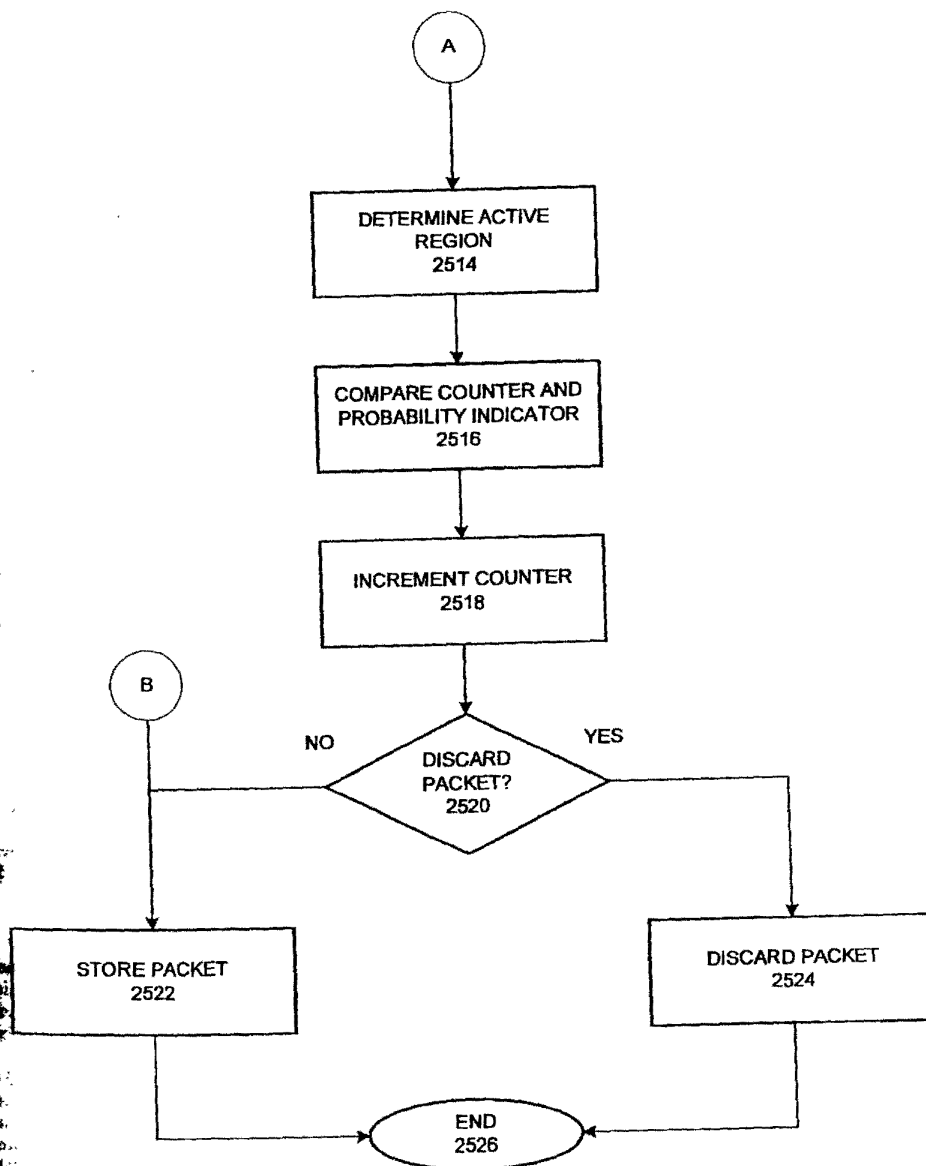


FIG. 25B

**HIGH PERFORMANCE NETWORK  
INTERFACE**

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5  
A Method of Transferring a Packet with Operation Code  
6 or 7  
One Embodiment of a Dynamic Packet Batching Module  
Early Random Packet Discard in One Embodiment of the  
Invention  
CLAIMS

**BACKGROUND**

This invention relates to the fields of computer systems and computer networks. In particular, the present invention relates to a Network Interface Circuit (NIC) for processing communication packets exchanged between a computer network and a host computer system.

The interface between a computer and a network is often a bottleneck for communications passing between the computer and the network. While computer performance (e.g., processor speed) has increased exponentially over the years and computer network transmission speeds have undergone similar increases, inefficiencies in the way network interface circuits handle communications have become more and more evident. With each incremental increase in computer or network speed, it becomes ever more apparent that the interface between the computer and the network cannot keep pace. These inefficiencies involve several basic problems in the way communications between a network and a computer are handled.

Today's most popular forms of networks tend to be packet-based. These types of networks, including the Internet and many local area networks, transmit information in the form of packets. Each packet is separately created and

transmitted by an originating endstation and is separately received and processed by a destination endstation. In addition, each packet may, in a bus topology network for example, be received and processed by numerous stations located between the originating and destination endstations.

One basic problem with packet networks is that each packet must be processed through multiple protocols or protocol levels (known collectively as a "protocol stack") on both the origination and destination endstations. When data transmitted between stations is longer than a certain minimal length, the data is divided into multiple portions, and each portion is carried by a separate packet. The amount of data that a packet can carry is generally limited by the network that conveys the packet and is often expressed as a maximum transfer unit (MTU). The original aggregation of data is sometimes known as a "datagram," and each packet carrying part of a single datagram is processed very similarly to the other packets of the datagram.

Communication packets are generally processed as follows. In the origination endstation, each separate data portion of a datagram is processed through a protocol stack. During this processing multiple protocol headers (e.g., TCP, IP, Ethernet) are added to the data portion to form a packet that can be transmitted across the network. The packet is received by a network interface circuit, which transfers the packet to the destination endstation or a host computer that serves the destination endstation. In the destination endstation, the packet is processed through the protocol stack in the opposite direction as in the origination endstation. During this processing the protocol headers are removed in the opposite order in which they were applied. The data portion is thus recovered and can be made available to a user, an application program, etc.

Several related packets (e.g., packets carrying data from one datagram) thus undergo substantially the same process in a serial manner (i.e., one packet at a time). The more data that must be transmitted, the more packets must be sent, with each one being separately handled and processed through the protocol stack in each direction. Naturally, the more packets that must be processed, the greater the demand placed upon an endstation's processor. The number of packets that must be processed is affected by factors other than just the amount of data being sent in a datagram. For example, as the amount of data that can be encapsulated in a packet increases, fewer packets need to be sent. As stated above, however, a packet may have a maximum allowable size, depending on the type of network in use (e.g., the maximum transfer unit for standard Ethernet traffic is approximately 1,500 bytes). The speed of the network also affects the number of packets that a NIC may handle in a given period of time. For example, a gigabit Ethernet network operating at peak capacity may require a NIC to receive approximately 1.48 million packets per second. Thus, the number of packets to be processed through a protocol stack may place a significant burden upon a computer's processor. The situation is exacerbated by the need to process each packet separately even though each one will be processed in a substantially similar manner.

A related problem to the disjoint processing of packets is the manner in which data is moved between "user space" (e.g., an application program's data storage) and "system space" (e.g., system memory) during data transmission and receipt. Presently, data is simply copied from one area of memory assigned to a user or application program into another area of memory dedicated to the processor's use. Because each portion of a datagram that is transmitted in a packet may be copied separately (e.g., one byte at a time),

there is a nontrivial amount of processor time required and frequent transfers can consume a large amount of the memory bus' bandwidth. Illustratively, each byte of data in a packet received from the network may be read from the system space and written to the user space in a separate copy operation, and vice versa for data transmitted over the network. Although system space generally provides a protected memory area (e.g., protected from manipulation by user programs), the copy operation does nothing of value when seen from the point of view of a network interface circuit. Instead, it risks over-burdening the host processor and retarding its ability to rapidly accept additional network traffic from the NIC. Copying each packet's data separately can therefore be very inefficient, particularly in a high-speed network environment.

In addition to the inefficient transfer of data (e.g., one packet's data at a time), the processing of headers from packets received from a network is also inefficient. Each packet carrying part of a single datagram generally has the same protocol headers (e.g., Ethernet, IP and TCP), although there may be some variation in the values within the packets' headers for a particular protocol. Each packet, however, is individually processed through the same protocol stack, thus requiring multiple repetitions of identical operations for related packets. Successively processing unrelated packets through different protocol stacks will likely be much less efficient than progressively processing a number of related packets through one protocol stack at a time.

Another basic problem concerning the interaction between present network interface circuits and host computer systems is that the combination often fails to capitalize on the increased processor resources that are available in multi-processor computer systems. In other words, present attempts to distribute the processing of network packets (e.g., through a protocol stack) among a number of processors in an efficient manner are generally ineffective. In particular, the performance of present NICs does not come close to the expected or desired linear performance gains one may expect to realize from the availability of multiple processors. In some multi-processor systems, little improvement in the processing of network traffic is realized from the use of more than 4-6 processors, for example.

In addition, the rate at which packets are transferred from a network interface circuit to a host computer or other communication device may fail to keep pace with the rate of packet arrival at the network interface. One element or another of the host computer (e.g., a memory bus, a processor) may be over-burdened or otherwise unable to accept packets with sufficient alacrity. In this event one or more packets may be dropped or discarded. Dropping packets may cause a network entity to re-transmit some traffic and, if too many packets are dropped, a network connection may require re-initialization. Further, dropping one packet or type of packet instead of another may make a significant difference in overall network traffic. If, for example, a control packet is dropped, the corresponding network connection may be severely affected and may do little to alleviate the packet saturation of the network interface circuit because of the typically small size of a control packet. Therefore, unless the dropping of packets is performed in a manner that distributes the effect among many network connections or that makes allowance for certain types of packets, network traffic may be degraded more than necessary.

Thus, present NICs fail to provide adequate performance to interconnect today's high-end computer systems and high-speed networks. In addition, a network interface circuit

that cannot make allowance for an over-burdened host computer may degrade the computer's performance.

#### SUMMARY

A high performance network interface is provided for receiving a packet from a network and transferring it to a host computer system. In various embodiments of the invention, the high performance network interface is configured to implement one or more enhanced operations in order to efficiently handle a range of packet arrival rates without unduly burdening the host computer system.

One such operation is the re-assembly of data from multiple packets in one communication flow, circuit or connection. In particular, data portions of such packets may be re-assembled by transferring or copying them into a single host memory area, or buffer, that is of a predetermined size (e.g., one memory page). The re-assembled data may then be provided to the destination entity in an efficient manner, such as a single copy or memory transfer.

Another operation for increasing the efficiency of handling network traffic in an embodiment of the invention is the batch processing of packet headers through an appropriate protocol stack. In this operation, a host computer system is alerted to the transfer, into host memory, of two or more packets from the same communication flow. When so alerted, the host computer may delay processing a first packet in the flow in order to await receipt of a second. The packets' headers may then be processed collectively, or in rapid sequence, rather than interspersing the processing of the packets with packets from other flows.

In yet another operation, the processing of packets or packet headers through their protocol stacks may be distributed among two or more processors in a multi-processor host computer system. In a load distribution operation in one embodiment of the invention, an identifier of the processor that is to process a packet is generated from a packet's flow key. In this embodiment, a flow key is assembled from identifiers of the packet's source and destination entities extracted from the packet's header portion. By using the packet's flow key, which uniquely identifies a particular communication flow all packets in the same flow will be sent to the same processor. One method of generating the processor identifier is to perform a hashing function on the flow key and then take the modulus of that result over the number of processors in the host computer system.

In one embodiment of the invention a high performance network interface includes a header parser module. When a packet is received from a network, the header parser module parses a header portion of the packet. The header parser module executes a series of parsing instructions configured in accordance with a set of selected communication protocols for conveying packets across the network. While parsing the packet, the header parser module compares a value extracted from a header field with an expected value in order to test the received packet for compatibility with the selected protocols. Instructions for operating the header parser module may be stored in a rewriteable memory so that the module may be reconfigured to parse packets conforming to virtually any communication protocol.

Besides parsing a packet to determine its compatibility with a set of protocols, a header parser module in one embodiment of the invention retrieves values from one or more fields in the packet's headers. The extracted values may be used to enable or assist one of the enhanced operations. In particular, in this embodiment a header parser module extracts identifiers of the packet's source and des-



mination entities. These identifiers may be combined to form a flow key for the purpose of identifying the communication flow, circuit or connection in which the packet was sent. In this embodiment, each separate datagram sent from a source entity to a destination entity may comprise a separate flow.

After a header parser module parses a packet received from a network, the header parser module passes the packet's flow key and, possibly, other information extracted from the packet, to a flow database manager. The flow database manager maintains a flow database to manage the communication flows received at the network interface. Within a flow database, a number of flow keys may be stored and indexed by flow numbers. The database is updated accordingly as flows are initiated and terminated and as flow packets are received.

From information received from a header parser module in this embodiment, the flow database manager assigns an operation code to the packet. Other modules of the network interface may use the operation code to determine the suitability of the packet for one or more of the enhanced operations described above or to identify a method of performing an operation. For example, the received packet's operation code may reveal whether the packet is compatible with the set of selected protocols, whether the packet contains data, whether the packet's data can be re-assembled with other flow packets, whether a flow is to be set up or torn down, etc.

In one embodiment of the invention, the high performance network interface includes a packet queue in which to store a packet received from a network prior to its transfer to a host computer system. The network interface may also include a control queue or other data structures (e.g., registers) in which to store data extracted from a packet and/or information concerning the extracted data, such as an operation code or flow number. Information stored in one or both of the packet and control queues may also include a checksum generated by a checksum module, a processor identifier generated by a load distributor module, offsets to specific portions of the packet, flags concerning statuses or conditions of the packet, etc.

In another embodiment of the invention, a DMA engine is provided for transferring a packet from a packet queue into a host memory area, such as a buffer, in the host computer system. The DMA engine may draw upon information in the packet queue or a control queue, such as an operation code, to determine which buffer or buffers to store a packet in. For example, a packet's header may be stored in a header buffer while its data portion is stored in a re-assembly buffer. Packets less than a specified size may also be stored in a header buffer. A packet that is not compatible with the selected protocols may be stored, intact, in a non-re-assembly buffer. In one embodiment, buffers are of a predetermined size that increases the efficiency of memory transfers or copies, such as one memory page.

In yet another embodiment of the invention, a high performance network interface includes a dynamic packet batching module for notifying a host computer when multiple packets in one communication are being transferred to the computer. In this embodiment, a packet batching module includes a memory for storing flow numbers or flow keys of multiple packets to be transferred to the host computer. When a packet is transferred or about to be transferred, the packet batching module searches its memory for other packets having the same flow number or flow key as the transferred packet. The host computer is notified accordingly and may delay processing one packet in a flow in order to process it in conjunction with another packet in the same flow.

The network interface may notify the host computer system of the arrival or transfer of a packet by configuring and releasing a descriptor that identifies where the packet is stored. In another embodiment, a high performance network interface issues an alert, such as an interrupt, to the host computer system. Interrupts issued by the network interface may be modulated, particularly as the rate of packets arriving from a network increases, so as to limit the number of interrupts or the frequency with which they are issued. In one method of modulating interrupts, after a first interrupt is issued further interrupts may be disabled until a specified number of packets have been received and/or a predetermined period of time elapses. In another method of modulating interrupts, interrupts may be disabled while software operating on the host computer polls the network interface to determine if a packet has been received or transferred. Packet and time counters may also be used in this method in order to allow interrupts to be generated in the event that the polling software is blocked or fails.

In one embodiment of the invention, if the rate at which a host computer accepts packets from a high-speed network interface does not keep pace with the rate at which packets are received at the network interface, a packet may be dropped. In this embodiment a method is provided for randomly selecting a packet to be discarded, before or after the packet is stored in a packet queue. A packet queue in this embodiment is logically separated into multiple regions or divisions, which may overlap. A probability indicator is associated with each region to indicate the probability of dropping a packet when the level of traffic stored in the queue is within the region. When the level of traffic is within a particular region, the probability indicator for that region is applied each time a discardable packet is to be stored in the packet queue. The region's probability indicator thus indicates whether to discard the packet or allow it to be stored in the queue. All packets may be considered discardable, or some packets (e.g., control packets, packets in a certain flow, packets adhering to a particular protocol) may be considered non-discardable. In one embodiment of the invention, the network interface includes a counter that is incremented through a limited range of values as discardable packets are received for storage in the queue. In this embodiment, a probability indicator consists of a set of numbers (e.g., a mask) to indicate, for each value in the range of counter values, whether or not to discard a packet.

#### DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram depicting a network interface circuit (NIC) for receiving a packet from a network in accordance with an embodiment of the present invention.

FIG. 1B is a flow chart demonstrating one method of operating the NIC of FIG. 1A to transfer a packet received from a network to a host computer in accordance with an embodiment of the invention.

FIG. 2 is a diagram of a packet transmitted over a network and received at a network interface circuit in one embodiment of the invention.

FIG. 3 is a block diagram depicting a header parser of a network interface circuit for parsing a packet in accordance with an embodiment of the invention.

FIGS. 4A-4B comprise a flow chart demonstrating one method of parsing a packet received from a network at a network interface circuit in accordance with an embodiment of the present invention.

FIG. 5 is a block diagram depicting a network interface circuit flow database in accordance with an embodiment of the invention.

FIGS. 6A-6E comprise a flowchart illustrating one method of managing a network interface circuit flow database in accordance with an embodiment of the invention.

FIG. 7 is a flow chart demonstrating one method of distributing the processing of network packets among multiple processors on a host computer in accordance with an embodiment of the invention.

FIG. 8 is a diagram of a packet queue for a network interface circuit in accordance with an embodiment of the invention.

FIG. 9 is a diagram of a control queue for a network interface circuit in accordance with an embodiment of the invention.

FIG. 10 is a block diagram of a DMA engine for transferring a packet received from a network to a host computer in accordance with an embodiment of the invention.

FIG. 11 includes diagrams of data structures for managing the storage of network packets in host memory buffers in accordance with an embodiment of the invention.

FIGS. 12A-12B are diagrams of a free descriptor, a completion descriptor and a free buffer array in accordance with an embodiment of the invention.

FIGS. 13-20 are flow charts demonstrating methods of transferring a packet received from a network to a buffer in a host computer memory in accordance with an embodiment of the invention.

FIG. 21 is a diagram of a dynamic packet batching module in accordance with an embodiment of the invention.

FIGS. 22A-22B comprise a flow chart demonstrating one method of dynamically searching a memory containing information concerning packets awaiting transfer to a host computer in order to locate a packet in the same communication flow as a packet being transferred, in accordance with an embodiment of the invention.

FIG. 23 depicts one set of dynamic instructions for parsing a packet in accordance with an embodiment of the invention.

FIG. 24 depicts a system for randomly discarding a packet from a network interface in accordance with an embodiment of the invention.

FIGS. 25A-25B comprise a flow chart demonstrating one method of discarding a packet from a network interface in accordance with an embodiment of the invention.

#### DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of particular applications of the invention and their requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

In particular, embodiments of the invention are described below in the form of a network interface circuit (NIC) receiving communication packets formatted in accordance with certain communication protocols compatible with the Internet. One skilled in the art will recognize, however, that the present invention is not limited to communication protocols compatible with the Internet and may be readily

adapted for use with other protocols and in communication devices other than a NIC.

The program environment in which a present embodiment of the invention is executed illustratively incorporates a general-purpose computer or a special purpose device such as a hand-held computer. Details of such devices (e.g., processor, memory, data storage, input/output ports and display) are well known and are omitted for the sake of clarity.

It should also be understood that the techniques of the present invention might be implemented using a variety of technologies. For example, the methods described herein may be implemented in software running on a programmable microprocessor, or implemented in hardware utilizing either a combination of microprocessors or other specially designed application specific integrated circuits, programmable logic devices, or various combinations thereof. In particular, the methods described herein may be implemented by a series of computer-executable instructions residing on a storage medium such as a carrier wave, disk drive, or other computer-readable medium.

#### Introduction

In one embodiment of the present invention, a network interface circuit (NIC) is configured to receive and process communication packets exchanged between a host computer system and a network such as the Internet. In particular, the NIC is configured to receive and manipulate packets formatted in accordance with a protocol stack (e.g., a combination of communication protocols) supported by a network coupled to the NIC.

A protocol stack may be described with reference to the seven-layer ISO-OSI (International Standards Organization-Open Systems Interconnection) model framework. Thus, one illustrative protocol stack includes the Transport Control Protocol (TCP) at layer four, Internet Protocol (IP) at layer three and Ethernet at layer two. For purposes of discussion, the term "Ethernet" may be used herein to refer collectively to the standardized IEEE (Institute of Electrical and Electronics Engineers) 802.3 specification as well as version two of the non-standardized form of the protocol. Where different forms of the protocol need to be distinguished, the standard form may be identified by including the "802.3" designation.

Other embodiments of the invention are configured to work with communications adhering to other protocols, both known (e.g., AppleTalk, IPX (Internetwork Packet Exchange), etc.) and unknown at the present time. One skilled in the art will recognize that the methods provided by this invention are easily adaptable for new communication protocols.

In addition, the processing of packets described below may be performed on communication devices other than a NIC. For example, a modem, switch, router or other communication port or device (e.g., serial, parallel, USB, SCSI) may be similarly configured and operated.

In embodiments of the invention described below, a NIC receives a packet from a network on behalf of a host computer system or other communication device. The NIC analyzes the packet (e.g., by retrieving certain fields from one or more of its protocol headers) and takes action to increase the efficiency with which the packet is transferred or provided to its destination entity. Equipment and methods discussed below for increasing the efficiency of processing or transferring packets received from a network may also be used for packets moving in the reverse direction (i.e., from the NIC to the network).

One technique that may be applied to incoming network traffic involves examining or parsing one or more headers of

an incoming packet (e.g., headers for the layer two, three and four protocols) in order to identify the packet's source and destination entities and possibly retrieve certain other information. Using identifiers of the communicating entities as a key, data from multiple packets may be aggregated or re-assembled. Typically, a datagram sent to one destination entity from one source entity is transmitted via multiple packets. Aggregating data from multiple related packets (e.g., packets carrying data from the same datagram) thus allows a datagram to be re-assembled and collectively transferred to a host computer. The datagram may then be provided to the destination entity in a highly efficient manner. For example, rather than providing data from one packet at a time (and one byte at a time) in separate "copy" operations, a "page-flip" operation may be performed. In a page-flip, an entire memory page of data may be provided to the destination entity, possibly in exchange for an empty or unused page.

In another technique, packets received from a network are placed in a queue to await transfer to a host computer. While awaiting transfer, multiple related packets may be identified to the host computer. After being transferred, they may be processed as a group by a host processor rather than being processed serially (e.g., one at a time).

Yet another technique involves submitting a number of related packets to a single processor of a multi-processor host computer system. By distributing packets conveyed between different pairs of source and destination entities among different processors, the processing of packets through their respective protocol stacks can be distributed while still maintaining packets in their correct order.

The techniques discussed above for increasing the efficiency with which packets are processed may involve a combination of hardware and software modules located on a network interface and/or a host computer system. In one particular embodiment, a parsing module on a host computer's NIC parses header portions of packets. Illustratively, the parsing module comprises a microsequencer operating according to a set of replaceable instructions stored as micro-code. Using information extracted from the packets, multiple packets from one source entity to one destination entity may be identified. A hardware re-assembly module on the NIC may then gather the data from the multiple packets.

Another hardware module on the NIC is configured to recognize related packets awaiting transfer to the host computer so that they may be processed through an appropriate protocol stack collectively, rather than serially. The re-assembled data and the packet's headers may then be provided to the host computer so that appropriate software (e.g., a device driver for the NIC) may process the headers and deliver the data to the destination entity.

Where the host computer includes multiple processors, a load distributor (which may also be implemented in hardware on the NIC) may select a processor to process the headers of the multiple packets through a protocol stack.

In another embodiment of the invention, a system is provided for randomly discarding a packet from a NIC when the NIC is saturated or nearly saturated with packets awaiting transfer to a host computer.

One Embodiment of a High Performance Network Interface Circuit

FIG. 1A depicts NIC 100 configured in accordance with an illustrative embodiment of the invention. A brief description of the operation and interaction of the various modules of NIC 100 in this embodiment follows. Descriptions incorporating much greater detail are provided in subsequent sections.

A communication packet may be received at NIC 100 from network 102 by a medium access control (MAC) module (not shown in FIG. 1A). The MAC module performs low-level processing of the packet such as reading the packet from the network, performing some error checking, detecting packet fragments, detecting over-sized packets, removing the layer one preamble, etc.

Input Port Processing (IPP) module 104 then receives the packet. The IPP module stores the entire packet in packet queue 116, as received from the MAC module or network, and a portion of the packet is copied into header parser 106. In one embodiment of the invention IPP module 104 may act as a coordinator of sorts to prepare the packet for transfer to a host computer system. In such a role, IPP module 104 may receive information concerning a packet from various modules of NIC 100 and dispatch such information to other modules.

Header parser 106 parses a header portion of the packet to retrieve various pieces of information that will be used to identify related packets (e.g., multiple packets from one same source entity for one destination entity) and that will affect subsequent processing of the packets. In the illustrated embodiment, header parser 106 communicates with flow database manager (FDBM) 108, which manages flow database (FDB) 110. In particular, header parser 106 submits a query to FDBM 108 to determine whether a valid communication flow (described below) exists between the source entity that sent a packet and the destination entity. The destination entity may comprise an application program, a communication module, or some other element of a host computer system that is to receive the packet.

In the illustrated embodiment of the invention, a communication flow comprises one or more datagram packets from one source entity to one destination entity. A flow may be identified by a flow key assembled from source and destination identifiers retrieved from the packet by header parser 106. In one embodiment of the invention a flow key comprises address and/or port information for the source and destination entities from the packet's layer three (e.g., IP) and/or layer four (e.g., TCP) protocol headers.

For purposes of the illustrated embodiment of the invention, a communication flow is similar to a TCP end-to-end connection but is generally shorter in duration. In particular, in this embodiment the duration of a flow may be limited to the time needed to receive all of the packets associated with a single datagram passed from the source entity to the destination entity.

Thus, for purposes of flow management, header parser 106 passes the packet's flow key to flow database manager 108. The header parser may also provide the flow database manager with other information concerning the packet that was retrieved from the packet (e.g., length of the packet).

Flow database manager 108 searches FDB 110 in response to a query received from header parser 106. Illustratively, flow database 110 stores information concerning each valid communication flow involving a destination entity served by NIC 100. Thus, FDBM 108 updates FDB 110 as necessary, depending upon the information received from header parser 106. In addition, in this embodiment of the invention FDBM 108 associates an operation or action code with the received packet. An operation code may be used to identify whether a packet is part of a new or existing flow, whether the packet includes data or just control information, the amount of data within the packet, whether the packet data can be re-assembled with related data (e.g., other data in a datagram sent from the source entity to the destination entity), etc. FDBM 108 may use information

retrieved from the packet and provided by header parser 106 to select an appropriate operation code. The packet's operation code is then passed back to the header parser, along with an index of the packet's flow within FDB 110.

In one embodiment of the invention the combination of header parser 106, FDBM 108 and FDB 110, or a subset of these modules, may be known as a traffic classifier due to their role in classifying or identifying network traffic received at NIC 100.

In the illustrated embodiment, header parser 106 also passes the packet's flow key to load distributor 112. In a host computer system having multiple processors, load distributor 112 may determine which processor an incoming packet is to be routed to for processing through the appropriate protocol stack. For example, load distributor 112 may ensure that related packets are routed to a single processor. By sending all packets in one communication flow or end-to-end connection to a single processor, the correct ordering of packets can be enforced. Load distributor 112 may be omitted in one alternative embodiment of the invention. In another alternative embodiment, header parser 106 may also communicate directly with other modules of NIC 100 besides the load distributor and flow database manager.

Thus, after header parser 106 parses a packet FDBM 108 alters or updates FDB 110 and load distributor 112 identifies a processor in the host computer system to process the packet. After these actions, the header parser passes various information back to IPP module 104. Illustratively, this information may include the packet's flow key, an index of the packet's flow within flow database 110, an identifier of a processor in the host computer system, and various other data concerning the packet (e.g., its length, a length of a packet header).

Now the packet may be stored in packet queue 116, which holds packets for manipulation by DMA (Direct Memory Access) engine 120 and transfer to a host computer. In addition to storing the packet in a packet queue, a corresponding entry for the packet is made in control queue 118 and information concerning the packet's flow may also be passed to dynamic packet batching module 122. Control queue 118 contains related control information for each packet in packet queue 116.

Packet batching module 122 draws upon information concerning packets in packet queue 116 to enable the batch (i.e., collective) processing of headers from multiple related packets. In one embodiment of the invention packet batching module 122 alerts the host computer to the availability of headers from related packets so that they may be processed together.

Although the processing of a packet's protocol headers is performed by a processor on a host computer system in one embodiment of the invention, in another embodiment the protocol headers may be processed by a processor located on NIC 100. In the former embodiment, software on the host computer (e.g., a device driver for NIC 100) can reap the advantages of additional memory and a replaceable or upgradeable processor (e.g., the memory may be supplemented and the processor may be replaced by a faster model).

During the storage of a packet in packet queue 116, checksum generator 114 may perform a checksum operation. The checksum may be added to the packet queue as a trailer to the packet. Illustratively, checksum generator 114 generates a checksum from a portion of the packet received from network 102. In one embodiment of the invention, a checksum is generated from the TCP portion of a packet (e.g., the TCP header and data). If a packet is not formatted

according to TCP, a checksum may be generated on another portion of the packet and the result may be adjusted in later processing as necessary. For example, if the checksum calculated by checksum generator 114 was not calculated on the correct portion of the packet, the checksum may be adjusted to capture the correct portion. This adjustment may be made by software operating on a host computer system (e.g., a device driver). Checksum generator 114 may be omitted or merged into another module of NIC 100 in an alternative embodiment of the invention.

From the information obtained by header parser 106 and the flow information managed by flow database manager 108, the host computer system served by NIC 100 in the illustrated embodiment is able to process network traffic very efficiently. For example, data portions of related packets may be re-assembled by DMA engine 120 to form aggregations that can be more efficiently manipulated. And, by assembling the data into buffers the size of a memory page, the data can be more efficiently transferred to a destination entity through "page-flipping," in which an entire memory page filled by DMA engine 120 is provided at once. One page-flip can thus take the place of multiple copy operations. Meanwhile, the header portions of the re-assembled packets may similarly be processed as a group through their appropriate protocol stack.

As already described, in another embodiment of the invention the processing of network traffic through appropriate protocol stacks may be efficiently distributed in a multi-processor host computer system. In this embodiment, load distributor 112 assigns or distributes related packets (e.g., packets in the same communication flow) to the same processor. In particular, packets having the same source and destination addresses in their layer three protocol (e.g., IP) headers and/or the same source and destination ports in their layer four protocol (e.g., TCP) headers may be sent to a single processor.

In the NIC illustrated in FIG. 1A, the processing enhancements discussed above (e.g., re-assembling data, batch processing packet headers, distributing protocol stack processing) are possible for packets received from network 102 that are formatted according to one or more pre-selected protocol stacks. In this embodiment of the invention network 102 is the Internet and NIC 100 is therefore configured to process packets using one of several protocol stacks compatible with the Internet. Packets not configured according to the pre-selected protocols are also processed, but may not receive the benefits of the full suite of processing efficiencies provided to packets meeting the pre-selected protocols.

For example, packets not matching one of the pre-selected protocol stacks may be distributed for processing in a multi-processor system on the basis of the packets' layer two (e.g., medium access control) source and destination addresses rather than their layer three or layer four addresses. Using layer two identifiers provides less granularity to the load distribution procedure, thus possibly distributing the processing of packets less evenly than if layer three/four identifiers were used.

FIG. 1B depicts one method of using NIC 100 of FIG. 1A to receive one packet from network 102 and transfer it to a host computer. State 130 is a start state, possibly characterized by the initialization or resetting of NIC 100.

In state 132, a packet is received by NIC 100 from network 102. As already described, the packet may be formatted according to a variety of communication protocols. The packet may be received and initially manipulated by a MAC module before being passed to an IPP module.

In state 134, a portion of the packet is copied and passed to header parser 106. Header parser 106 then parses the packet to extract values from one or more of its headers and/or its data. A flow key is generated from some of the retrieved information to identify the communication flow that includes the packet. The degree or extent to which the packet is parsed may depend upon its protocols, in that the header parser may be configured to parse headers of different protocols to different depths. In particular, header parser 106 may be optimized (e.g., its operating instructions configured) for a specific set of protocols or protocol stacks. If the packet conforms to one or more of the specified protocols it may be parsed more fully than a packet that does not adhere to any of the protocols.

In state 136, information extracted from the packet's headers is forwarded to flow database manager 108 and/or load distributor 112. The FDBM uses the information to set up a flow in flow database 110 if one does not already exist for this communication flow. If an entry already exists for the packet's flow, it may be updated to reflect the receipt of a new flow packet. Further, FDBM 108 generates an operation code to summarize one or more characteristics or conditions of the packet. The operation code may be used by other modules of NIC 100 to handle the packet in an appropriate manner, as described in subsequent sections. The operation code is returned to the header parser, along with an index (e.g., a flow number) of the packet's flow in the flow database.

In state 138, load distributor 112 assigns a processor number to the packet, if the host computer includes multiple processors, and returns the processor number to the header processor. Illustratively, the processor number identifies which processor is to conduct the packet through its protocol stack on the host computer. State 138 may be omitted in an alternative embodiment of the invention, particularly if the host computer consists of only a single processor.

In state 140, the packet is stored in packet queue 116. As the contents of the packet are placed into the packet queue, checksum generator 114 may compute a checksum. The checksum generator may be informed by IPP module 104 as to which portion of the packet to compute the checksum on. The computed checksum is added to the packet queue as a trailer to the packet. In one embodiment of the invention, the packet is stored in the packet queue at substantially the same time that a copy of a header portion of the packet is provided to header parser 106.

Also in state 140, control information for the packet is stored in control queue 118 and information concerning the packet's flow (e.g., flow number, flow key) may be provided to dynamic packet batching module 122.

In state 142, NIC 100 determines whether the packet is ready to be transferred to host computer memory. Until it is ready to be transferred, the illustrated procedure waits.

When the packet is ready to be transferred (e.g., the packet is at the head of the packet queue or the host computer receives the packet ahead of this packet in the packet queue), in state 144 dynamic packet batching module 122 determines whether a related packet will soon be transferred. If so, then when the present packet is transferred to host memory the host computer is alerted that a related packet will soon follow. The host computer may then process the packets (e.g., through their protocol stack) as a group.

In state 146, the packet is transferred (e.g., via a direct memory access operation) to host computer memory. And, in state 148, the host computer is notified that the packet was transferred. The illustrated procedure then ends at state 150.

One skilled in the art of computer systems and networking will recognize that the procedure described above is just one method of employing the modules of NIC 100 to receive a single packet from a network and transfer it to a host computer system. Other suitable methods are also contemplated within the scope of the invention.

#### An Illustrative Packet

FIG. 2 is a diagram of an illustrative packet received by NIC 100 from network 102. Packet 200 comprises data portion 202 and header portion 204, and may also contain trailer portion 206. Depending upon the network environment traversed by packet 200, its maximum size (e.g., its maximum transfer unit or MTU) may be limited.

In the illustrated embodiment, data portion 202 comprises data being provided to a destination or receiving entity within a computer system (e.g., user, application program, operating system) or a communication subsystem of the computer. Header portion 204 comprises one or more headers prefixed to the data portion by the source or originating entity or a computer system comprising the source entity. Each header normally corresponds to a different communication protocol.

In a typical network environment, such as the Internet, individual headers within header portion 204 are attached (e.g., prepended) as the packet is processed through different layers of a protocol stack (e.g., a set of protocols for communicating between entities) on the transmitting computer system. For example, FIG. 2 depicts protocol headers 210, 212, 214 and 216, corresponding to layers one through four, respectively, of a suitable protocol stack. Each protocol header contains information to be used by the receiving computer system as the packet is received and processed through the protocol stack. Ultimately, each protocol header is removed and data portion 202 is retrieved.

As described in other sections, in one embodiment of the invention a system and method are provided for parsing packet 200 to retrieve various bits of information. In this embodiment, packet 200 is parsed in order to identify the beginning of data portion 202 and to retrieve one or more values for fields within header portion 204. Illustratively, however, layer one protocol header or preamble 210 corresponds to a hardware-level specification related to the coding of individual bits. Layer one protocols are generally only needed for the physical process of sending or receiving the packet across a conductor. Thus, in this embodiment of the invention layer one preamble 210 is stripped from packet 200 shortly after being received by NIC 100 and is therefore not parsed.

The extent to which header portion 204 is parsed may depend upon how many, if any, of the protocols represented in the header portion match a set of pre-selected protocols. For example, the parsing procedure may be abbreviated or aborted once it is determined that one of the packet's headers corresponds to an unsupported protocol.

In particular, in one embodiment of the invention NIC 100 is configured primarily for Internet traffic. Thus, in this embodiment packet 200 is extensively parsed only when the layer two protocol is Ethernet (either traditional Ethernet or 802.3 Ethernet, with or without tagging for Virtual Local Area Networks), the layer three protocol is IP (Internet Protocol) and the layer four protocol is TCP (Transport Control Protocol). Packets adhering to other protocols may be parsed to some (e.g., lesser) extent. NIC 100 may, however, be configured to support and parse virtually any communication protocol's header. Illustratively, the protocol headers that are parsed, and the extent to which they are parsed, are determined by the configuration of a set of instructions for operating header parser 106.

As described above, the protocols corresponding to headers 212, 214 and 216 depend upon the network environment in which a packet is sent. The protocols also depend upon the communicating entities. For example, a packet received by a network interface may be a control packet exchanged between the medium access controllers for the source and destination computer systems. In this case, the packet would be likely to include minimal or no data, and may not include layer three protocol header 214 or layer four protocol header 216. Control packets are typically used for various purposes related to the management of individual connections.

Another communication flow or connection could involve two application programs. In this case, a packet may include headers 212, 214 and 216, as shown in FIG. 2, and may also include additional headers related to higher layers of a protocol stack (e.g., session, presentation and application layers in the ISO-OSI model). In addition, some applications may include headers or header-like information within data portion 202. For example, for a Network File System (NFS) application, data portion 202 may include NFS headers related to individual NFS datagrams. A datagram may be defined as a collection of data sent from one entity to another, and may comprise data transmitted in multiple packets. In other words, the amount of data constituting a datagram may be greater than the amount of data that can be included in one packet.

One skilled in the art will appreciate that the methods for parsing a packet that are described in the following section are readily adaptable for packets formatted in accordance with virtually any communication protocol.

#### One Embodiment of a Header Parser

FIG. 3 depicts header parser 106 of FIG. 1A in accordance with a present embodiment of the invention. Illustratively, header parser 106 comprises header memory 302 and parser 304, and parser 304 comprises instruction memory 306. Although depicted as distinct modules in FIG. 3, in an alternative embodiment of the invention header memory 302 and instruction memory 306 are contiguous.

In the illustrated embodiment, parser 304 parses a header stored in header memory 302 according to instructions stored in instruction memory 306. The instructions are designed for the parsing of particular protocols or a particular protocol stack, as discussed above. In one embodiment of the invention, instruction memory 306 is modifiable (e.g., the memory is implemented as RAM, EPROM, EEPROM or the like), so that new or modified parsing instructions may be downloaded or otherwise installed. Instructions for parsing a packet are further discussed in the following section.

In FIG. 3, a header portion of a packet stored in IPP module 104 (shown in FIG. 1A) is copied into header memory 302. Illustratively, a specific number of bytes (e.g., 114) at the beginning of the packet are copied. In an alternative embodiment of the invention, the portion of a packet that is copied may be of a different size. The particular amount of a packet copied into header memory 302 should be enough to capture one or more protocol headers, or at least enough information (e.g., whether included in a header or data portion of the packet) to retrieve the information described below. The header portion stored in header memory 302 may not include the layer one header, which may be removed prior to or in conjunction with the packet being processed by IPP module 104.

After a header portion of the packet is stored in header memory 302, parser 304 parses the header portion according to the instructions stored in instruction memory 306. In the presently described embodiment, instructions for operating parser 304 apply the formats of selected protocols to step

through the contents of header memory 302 and retrieve specific information. In particular, specifications of communication protocols are well known and widely available. Thus, a protocol header may be traversed byte by byte or some other fashion by referring to the protocol specifications. In a present embodiment of the invention the parsing algorithm is dynamic, with information retrieved from one field of a header often altering the manner in which another part is parsed.

For example, it is known that the Type field of a packet adhering to the traditional, form of Ethernet (e.g., version two) begins at the thirteenth byte of the (layer two) header. By comparison, the Type field of a packet following the IEEE 802.3 version of Ethernet begins at the twenty-first byte of the header. The Type field is in yet other locations if the packet forms part of a Virtual Local Area Network (VLAN) communication (which illustratively involves tagging or encapsulating an Ethernet header). Thus, in a present embodiment of the invention, the values in certain fields are retrieved and tested in order to ensure that the information needed from a header is drawn from the correct portion of the header. Details concerning the form of a VLAN packet may be found in specifications for the IEEE 802.3p and IEEE 802.3q forms of the Ethernet protocol.

The operation of header parser 106 also depends upon other differences between protocols, such as whether the packet uses version four or version six of the Internet Protocol, etc. Specifications for versions four and six of IP may be located in IETF (Internet Engineering Task Force) RFCs (Request for Comment) 791 and 2460, respectively.

The more protocols that are "known" by parser 304, the more protocols a packet may be tested for, and the more complicated the parsing of a packet's header portion may become. One skilled in the art will appreciate that the protocols that may be parsed by parser 304 are limited only by the instructions according to which it operates. Thus, by augmenting or replacing the parsing instructions stored in instruction memory 306, virtually all known protocols may be handled by header parser 106 and virtually any information may be retrieved from a packet's headers.

If, of course, a packet header does not conform to an expected or suspected protocol, the parsing operation may be terminated. In this case, the packet may not be suitable for one more of the efficiency enhancements offered by NIC 100 (e.g., data re-assembly, packet batching, load distribution).

Illustratively, the information retrieved from a packet's headers is used by other portions of NIC 100 when processing that packet. For example, as a result of the packet parsing performed by parser 304 a flow key is generated to identify the communication flow or communication connection that comprises the packet. Illustratively, the flow key is assembled by concatenating one or more addresses corresponding to one or more of the communicating entities. In a present embodiment, a flow key is formed from a combination of the source and destination addresses drawn from the IP header and the source and destination ports taken from the TCP header. Other indicia of the communicating entities may be used, such as the Ethernet source and destination addresses (drawn from the layer two header), NFS file handles or source and destination identifiers for other application datagrams drawn from the data portion of the packet.

One skilled in the art will appreciate that the communicating entities may be identified with greater resolution by using indicia drawn from the higher layers of the protocol stack associated with a packet. Thus, a combination of IP and TCP indicia may identify the entities with greater particularity than layer two information.

Besides a flow key, parser 304 also generates a control or status indicator to summarize additional information concerning the packet. In one embodiment of the invention a control indicator includes a sequence number (e.g., TCP sequence number drawn from a TCP header) to ensure the correct ordering of packets when re-assembling their data. The control indicator may also reveal whether certain flags in the packet's headers are set or cleared, whether the packet contains any data, and, if the packet contains data, whether the data exceeds a certain size. Other data are also suitable for inclusion in the control indicator, limited only by the information that is available in the portion of the packet parsed by parser 304.

In one embodiment of the invention, header parser 106 provides the flow key and all or a portion of the control indicator to flow database manager 108. As discussed in a following section, FDBM 108 manages a database or other data structure containing information relevant to communication flows passing through NIC 100.

In other embodiments of the invention, parser 304 produces additional information derived from the header of a packet for use by other modules of NIC 100. For example, header parser 106 may report the offset, from the beginning of the packet or from some other point, of the data or payload portion of a packet received from a network. As described above, the data portion of a packet typically follows the header portion and may be followed by a trailer portion. Other data that header parser 106 may report include the location in the packet at which a checksum operation should begin, the location in the packet at which the layer three and/or layer four headers begin, diagnostic data, payload information, etc. The term "payload" is often used to refer to the data portion of a packet. In particular, in one embodiment of the invention header parser 106 provides a payload offset and payload size to control queue 118.

In appropriate circumstances, header parser 106 may also report (e.g., to IPP module 104 and/or control queue 118) that the packet is not formatted in accordance with the protocols that parser 304 is configured to manipulate. This report may take the form of a signal (e.g., the No\_Assist signal described below), alert, flag or other indicator. The signal may be raised or issued whenever the packet is found to reflect a protocol other than the pre-selected protocols that are compatible with the processing enhancements described above (e.g., data re-assembly, batch processing of packet headers, load distribution). For example, in one embodiment of the invention parser 304 may be configured to parse and efficiently process packets using TCP at layer four, IP at layer three and Ethernet at layer two. In this embodiment, an IPX (Internetwork Packet Exchange) packet would not be considered compatible and IPX packets therefore would not be gathered for data re-assembly and batch processing.

At the conclusion of parsing in one embodiment of the invention, the various pieces of information described above are disseminated to appropriate modules of NIC 100. After (and as described in a following section), flow database manager 108 determines whether an active flow is associated with the flow key derived from the packet and sets an operation code to be used in subsequent processing. In addition, IPP module 104 transmits the packet to packet queue 116. IPP module 104 may also receive some of the information extracted by header parser 106, and pass it to other module of NIC 100.

In the embodiment of the invention depicted in FIG. 3, an entire header portion of a received packet to be parsed is copied and then parsed in one evolution, after which the header parser turns its attention to another packet. However,

in an alternative embodiment multiple copy and/or parsing operations may be performed on a single packet. In particular, an initial header portion of the packet may be copied into and parsed by header parser 106 in a first evolution, after which another header portion may be copied into header parser 106 and parsed in a second evolution. A header portion in one evolution may partially or completely overlap the header portion of another evolution. In this manner, extensive headers may be parsed even if header memory 302 is of limited size. Similarly, it may require more than one operation to load a full set of instructions for parsing a packet into instruction memory 306. Illustratively, a first portion of the instructions may be loaded and executed, after which other instructions are loaded.

With reference now to FIGS. 4A-4B, a flow chart is presented to illustrate one method by which a header parser may parse a header portion of a packet received at a network interface circuit from a network. In this implementation, the header parser is configured, or optimized, for parsing packets conforming to a set of pre-selected protocols (or protocol stacks). For packets meeting these criteria, various information is retrieved from the header portion to assist in the re-assembly of the data portions of related packets (e.g., packets comprising data from a single datagram). Other enhanced features of the network interface circuit may also be enabled.

The information generated by the header parser includes, in particular, a flow key with which to identify the communication flow or communication connection that comprises the received packet. In one embodiment of the invention, data from packets having the same flow key may be identified and re-assembled to form a datagram. In addition, headers of packets having the same flow key may be processed collectively through their protocol stack (e.g., rather than serially).

In another embodiment of the invention, information retrieved by the header parser is also used to distribute the processing of network traffic received from a network. For example, multiple packets having the same flow key may be submitted to a single processor of a multi-processor host computer system.

In the method illustrated in FIGS. 4A-4B, the set of pre-selected protocols corresponds to communication protocols frequently transmitted via the Internet. In particular, the set of protocols that may be extensively parsed in this method include the following. At layer two: Ethernet (traditional version), 802.3 Ethernet, Ethernet VLAN (Virtual Local Area Network) and 802.3 Ethernet VLAN. At layer three: IPv4 (with no options) and IPv6 (with no options). Finally, at layer four, only TCP protocol headers (with or without options) are parsed in the illustrated method. Header parsers in alternative embodiments of the invention parse packets formatted through other protocol stacks. In particular, a NIC may be configured in accordance with the most common protocol stacks in use on a given network, which may or may not include the protocols compatible with the header parser method illustrated in FIGS. 4A-4B.

As described below, a received packet that does not correspond to the protocols parsed by a given method may be flagged and the parsing algorithm terminated for that packet. Because the protocols under which a packet has been formatted can only be determined, in the present method, by examining certain header field values, the determination that a packet does not conform to the selected set of protocols may be made at virtually any time during the procedure. Thus, the illustrated parsing method has as one goal the

identification of packets not meeting the formatting criteria for re-assembly of data.

Various protocol header fields appearing in headers for the selected protocols are discussed below. Communication protocols that may be compatible with an embodiment of the present invention (e.g., protocols that may be parsed by a header parser) are well known to persons skilled in the art and are described with great particularity in a number of references. They therefore need not be visited in minute detail herein. In addition, the illustrated method of parsing a header portion of a packet for the selected protocols is merely one method of gathering the information described below. Other parsing procedures capable of doing so are equally suitable.

In a present embodiment of the invention, the illustrated procedure is implemented as a combination of hardware and software. For example, updateable micro-code instructions for performing the procedure may be executed by a microsequencer. Alternatively, such instructions may be fixed (e.g., stored in read-only memory) or may be executed by a processor or microprocessor.

In FIGS. 4A-4B, state 400 is a start state during which a packet is received by NIC 100 (shown in FIG. 1A) and initial processing is performed. NIC 100 is coupled to the Internet for purposes of this procedure. Initial processing may include basic error checking and the removal of the layer one preamble. After initial processing, the packet is held by IPP module 104 (also shown in FIG. 1A). In one embodiment of the invention, state 400 comprises a logical loop in which the header parser remains in an idle or wait state until a packet is received.

In state 402, a header portion of the packet is copied into memory (e.g., header memory 302 of FIG. 3). In a present embodiment of the invention a predetermined number of bytes at the beginning (e.g., 114 bytes) of the packet are copied. Packet portions of different sizes are copied in alternative embodiments of the invention, the sizes of which are guided by the goal of copying enough of the packet to capture and/or identify the necessary header information. Illustratively, the full packet is retained by IPP module 104 while the following parsing operations are performed, although the packet may, alternatively, be stored in packet queue 116 prior to the completion of parsing.

Also in state 402, a pointer to be used in parsing the packet may be initialized. Because the layer one preamble was removed, the header portion copied to memory should begin with the layer two protocol header. Illustratively, therefore, the pointer is initially set to point to the twelfth byte of the layer two protocol header and the two-byte value at the pointer position is read. As one skilled in the art will recognize, these two bytes may be part of a number of different fields, depending upon which protocol constitutes layer two of the packet's protocol stack. For example, these two bytes may comprise the Type field of a traditional Ethernet header, the Length field of an 802.3 Ethernet header or the TPID (Tag Protocol Identifier) field of a VLAN-tagged header.

In state 404, a first examination is made of the layer two header to determine if it comprises a VLAN-tagged layer two protocol header. Illustratively, this determination depends upon whether the two bytes at the pointer position store the hexadecimal value 8100. If so, the pointer is probably located at the TPID field of a VLAN-tagged header. If not a VLAN header, the procedure proceeds to state 408.

If, however, the layer two header is a VLAN-tagged header, in state 406 the CFI (Canonical Format Indicator) bit

is examined. If the CFI bit is set (e.g., equal to one), the illustrated procedure jumps to state 430, after which it exits. In this embodiment of the invention the CFI bit, when set, indicates that the format of the packet is not compatible with (i.e., does not comply with) the pre-selected protocols (e.g., the layer two protocol is not Ethernet or 802.3 Ethernet). If the CFI bit is clear (e.g., equal to zero), the pointer is incremented (e.g., by four bytes) to position it at the next field that must be examined.

In state 408, the layer two header is further tested. Although it is now known whether this is or is not a VLAN-tagged header, depending upon whether state 408 was reached through state 406 or directly from state 404, respectively, the header may reflect either the traditional Ethernet format or the 802.3 Ethernet format. At the beginning of state 408, the pointer is either at the twelfth or sixteenth byte of the header, either of which may correspond to a Length field or a Type field. In particular, if the two-byte value at the position identified by the pointer is less than 0600 (hexadecimal), then the packet corresponds to 802.3 Ethernet and the pointer is understood to identify a Length field. Otherwise, the packet is a traditional (e.g., version two) Ethernet packet and the pointer identifies a Type field.

If the layer two protocol is 802.3 Ethernet, the procedure continues at state 410. If the layer two protocol is traditional Ethernet, the Type field is tested for the hexadecimal values of 0800 and 08DD. If the tested field has one of these values, then it has also been determined that the packet's layer three protocol is the Internet Protocol. In this case the illustrated procedure continues at state 412. Lastly, if the field is a Type field having a value other than 0800 or 86DD (hexadecimal), then the packet's layer three protocol does not match the pre-selected protocols according to which the header parser was configured. Therefore, the procedure continues at state 430 and then ends.

In one embodiment of the invention the packet is examined in state 408 to determine if it is a jumbo Ethernet frame. This determination would likely be made prior to deciding whether the layer two header conforms to Ethernet or 802.3 Ethernet. Illustratively, the jumbo frame determination may be made based on the size of the packet, which may be reported by IPP module 104 or a MAC module. If the packet is a jumbo frame, the procedure may continue at state 410; otherwise, it may resume at state 412.

In state 410, the procedure verifies that the layer two protocol is 802.3 Ethernet with LLC SNAP encapsulation. In particular, the pointer is advanced (e.g., by two bytes) and the six-byte value following the Length field in the layer two header is retrieved and examined. If the header is an 802.3 Ethernet header, the field is the LLC\_SNAP field and should have a value of AAAA03000000 (hexadecimal). The original specification for an LLC SNAP header may be found in the specification for IEEE 802.2. If the value in the packet's LLC\_SNAP field matches the expected value the pointer is incremented another six bytes, the two-byte 802.3 Ethernet Type field is read and the procedure continues at state 412. If the values do not match, then the packet does not conform to the specified protocols and the procedure enters state 430 and then ends.

In state 412, the pointer is advanced (e.g., another two bytes) to locate the beginning of the layer three protocol header. This pointer position may be saved for later use in quickly identifying the beginning of this header. The packet is now known to conform to an accepted layer two protocol (e.g., traditional Ethernet, Ethernet with VLAN tagging, or 802.3 Ethernet with LLC SNAP) and is now checked to ensure that the packet's layer three protocol is IP. As



discussed above, in the illustrated embodiment only packets conforming to the IP protocol are extensively processed by the header parser.

Illustratively, if the value of the Type field in the layer two header (retrieved in state 402 or state 410) is 0800 (hexadecimal), the layer three protocol is expected to be IP, version four. If the value is 86DD (hexadecimal), the layer three protocol is expected to be IP, version six. Thus, the Type field is tested in state 412 and the procedure continues at state 414 or state 418, depending upon whether the hexadecimal value is 0800 or 86DD, respectively.

In state 414, the layer three header's conformity with version four of IP is verified. In one embodiment of the invention the Version field of the layer three header is tested to ensure that it contains the hexadecimal value 4, corresponding to version four of IP. If in state 414 the layer three header is confirmed to be IP version four, the procedure continues at state 416; otherwise, the procedure proceeds to state 430 and then ends at state 432.

In state 416, various pieces of information from the IP header are saved. This information may include the IHL (IP Header Length), Total Length, Protocol and/or Fragment Offset fields. The IP source address and the IP destination addresses may also be stored. The source and destination address values are each four bytes long in version four of IP. These addresses are used, as described above, to generate a flow key that identifies the communication flow in which this packet was sent. The Total Length field stores the size of the IP segment of this packet, which illustratively comprises the IP header, the TCP header and the packet's data portion. The TCP segment size of the packet (e.g., the size of the TCP header plus the size of the data portion of the packet) may be calculated by subtracting twenty bytes (the size of the IP version four header) from the Total Length value. After state 416, the illustrated procedure advances to state 422.

In state 418, the layer three header's conformity with version six of IP is verified by testing the Version field for the hexadecimal value 6. If the Version field does not contain this value, the illustrated procedure proceeds to state 430.

In state 420, the values of the Payload Length (e.g., the size of the TCP segment) and Next Header field are saved, plus the IP source and destination addresses. Source and destination addresses are each sixteen bytes long in version six of IP.

In state 422 of the illustrated procedure, it is determined whether the IP header (either version four or version six) indicates that the layer four header is TCP. Illustratively, the Protocol field of a version four IP header is tested while the Next Header field of a version six header is tested. In either case, the value should be 6 (hexadecimal). The pointer is then incremented as necessary (e.g., twenty bytes for IP version four, forty bytes for IP version six) to reach the beginning of the TCP header. If it is determined in state 422 that the layer four header is not TCP, the procedure advances to state 430 and ends at end state 432.

In one embodiment of the invention, other fields of a version four IP header may be tested in state 422 to ensure that the packet meets the criteria for enhanced processing by NIC 100. For example, an IHL field value other than 5 (hexadecimal) indicates that IP options are set for this packet, in which case the parsing operation is aborted. A fragmentation field value other than zero indicates that the IP segment of the packet is a fragment, in which case parsing is also aborted. In either case, the procedure jumps to state 430 and then ends at end state 432.

In state 424, the packet's TCP header is parsed and various data are collected from it. In particular, the TCP

source port and destination port values are saved. The TCP sequence number, which is used to ensure the correct re-assembly of data from multiple packets, is also saved. Further, the values of several components of the Flags field—illustratively, the URG (urgent), PSH (push), RST (reset), SYN (synch) and FIN (finish) bits—are saved. As will be seen in a later section, in one embodiment of the invention these flags signal various actions to be performed or statuses to be considered in the handling of the packet.

Other signals or statuses may be generated in state 424 to reflect information retrieved from the TCP header. For example, the point from which a checksum operation is to begin may be saved (illustratively, the beginning of the TCP header); the ending point of a checksum operation may also be saved (illustratively, the end of the data portion of the packet). An offset to the data portion of the packet may be identified by multiplying the value of the Header Length field of the TCP header by four. The size of the data portion may then be calculated by subtracting the offset to the data portion from the size of the entire TCP segment.

In state 426, a flow key is assembled by concatenating the IP source and destination addresses and the TCP source and destination ports. As already described, the flow key may be used to identify a communication flow or communication connection, and may be used by other modules of NIC 100 to process network traffic more efficiently. Although the sizes of the source and destination addresses differ between IP versions four and six (e.g., four bytes each versus sixteen bytes each, respectively), in the presently described embodiment of the invention all flow keys are of uniform size. In particular, in this embodiment they are thirty-six bytes long, including the two-byte TCP source port and two-byte TCP destination port. Flow keys generated from IP, version four, packet headers are padded as necessary (e.g., with twenty-four clear bytes) to fill the flow key's allocated space.

In state 428, a control or status indicator is assembled to provide various information to one or more modules of NIC 100. In one embodiment of the invention a control indicator includes the packet's TCP sequence number, a flag or identifier (e.g., one or more bits) indicating whether the packet contains data (e.g., whether the TCP payload size is greater than zero), a flag indicating whether the data portion of the packet exceeds a pre-determined size, and a flag indicating whether certain entries in the TCP Flags field are equivalent to pre-determined values. The latter flag may, for example, be used to inform another module of NIC 100 that components of the Flags field do or do not have a particular configuration. After state 428, the illustrated procedure ends with state 432.

State 430 may be entered at several different points of the illustrated procedure. This state is entered, for example, when it is determined that a header portion that is being parsed by a header parser does not conform to the pre-selected protocol stacks identified above. As a result, much of the information described above is not retrieved. A practical consequence of the inability to retrieve this information is that it then cannot be provided to other modules of NIC 100 and the enhanced processing described above and in following sections may not be performed for this packet. In particular, and as discussed previously, in a present embodiment of the invention one or more enhanced operations may be performed on parsed packets to increase the efficiency with which they are processed. Illustrative operations that may be applied include the re-assembly of data from related packets (e.g., packets containing data from a single datagram), batch processing of packet headers through a protocol stack, load distribution or load sharing of

protocol stack processing, efficient transfer of packet data to a destination entity, etc.

In the illustrated procedure, in state 430 a flag or signal (illustratively termed No\_Assist) is set or cleared to indicate that the packet presently held by IPP module 104 (e.g., which was just processed by the header parser) does not conform to any of the pre-selected protocol stacks. This flag or signal may be relied upon by another module of NIC 100 when deciding whether to perform one of the enhanced operations.

Another flag or signal may be set or cleared in state 430 to initialize a checksum parameter indicating that a checksum operation, if performed, should start at the beginning of the packet (e.g., with no offset into the packet). Illustratively, incompatible packets cannot be parsed to determine a more appropriate point from which to begin the checksum operation. After state 430, the procedure ends with end state 432.

After parsing a packet, the header parser may distribute information generated from the packet to one or more modules of NIC 100. For example, in one embodiment of the invention the flow key is provided to flow database manager 108, load distributor 112 and one or both of control queue 118 and packet queue 116. Illustratively, the control indicator is provided to flow database manager 108. This and other control information, such as TCP payload size, TCP payload offset and the No\_Assist signal may be returned to IPP module 104 and provided to control queue 118. Yet additional control and/or diagnostic information, such as offsets to the layer three and/or layer four headers, may be provided to IPP module 104, packet queue 116 and/or control queue 118. Checksum information (e.g., a starting point and either an ending point or other means of identifying a portion of the packet from which to compute a checksum) may be provided to checksum generator 114.

As discussed in a following section, although a received packet is parsed on NIC 100 (e.g., by header parser 106), the packets are still processed (e.g., through their respective protocol stacks) on the host computer system in the illustrated embodiment of the invention. However, after parsing a packet in an alternative embodiment of the invention, NIC 100 also performs one or more subsequent processing steps. For example, NIC 100 may include one or more protocol processors for processing one or more of the packet's protocol headers.

**Dynamic Header Parsing Instructions in One Embodiment of the Invention**

In one embodiment of the present invention, header parser 106 parses a packet received from a network according to a dynamic sequence of instructions. The instructions may be stored in the header parser's instruction memory (e.g., ROM, SRAM, DRAM, flash) that is re-programmable or can otherwise be updated with new or additional instructions. In one embodiment of the invention software executing on a host computer (e.g., a device driver) may download a set of parsing instructions for storage in the header parser memory.

The number and format of instructions stored in a header parser's instruction memory may be tailored to one or more specific protocols or protocol stacks. An instruction set configured for one collection of protocols, or a program constructed from that instruction set, may therefore be deleted or replaced by a different instruction set or program. Packets received at the network interface that are formatted in accordance with the selected protocols (e.g., "compatible" packets), as determined by analyzing or parsing packets, various enhancements in the handling of network traffic become possible as described in the follow-

ing sections. In particular, packets from one datagram that are configured according to a selected protocol may be re-assembled for efficient transfer in a host computer. In addition, header portions of such packets may be processed collectively rather than serially. And, the processing of packets from different datagrams by a multi-processor host computer may be shared or distributed among the processors. Therefore, one objective of a dynamic header parsing operation is to identify a protocol according to which a received packet has been formatted or determine whether a packet header conforms to a particular protocol.

FIG. 23, discussed in detail shortly, presents an illustrative series of instructions for parsing the layer two, three and four headers of a packet to determine if they are Ethernet, IP and TCP, respectively. The illustrated instructions comprise one possible program or microcode for performing a parsing operation. As one skilled in the art will recognize, after a particular set of parsing instructions is loaded into a parser memory, a number of different programs may be assembled. FIG. 23 thus presents merely one of a number of programs that may be generated from the stored instructions. The instructions presented in FIG. 23 may be performed or executed by a microsequencer, a processor, a microprocessor or other similar module located within a network interface circuit.

In particular, other instruction sets and other programs may be derived for different communication protocols, and may be expanded to other layers of a protocol stack. For example, a set of instructions could be generated for parsing NFS (Network File System) packets. Illustratively, these instructions would be configured to parse layer five and six headers to determine if they are Remote Procedure Call (RPC) and External Data Representation (XDR), respectively. Other instructions could be configured to parse a portion of the packet's data (which may be considered layer seven). An NFS header may be considered a part of a packet's layer six protocol header or part of the packet's data.

One type of instruction executed by a microsequencer may be designed to locate a particular field of a packet (e.g., at a specific offset within the packet) and compare the value stored at that offset to a value associated with that field in a particular communication protocol. For example, one instruction may require the microsequencer to examine a value in a packet header at an offset that would correspond to a Type field of an Ethernet header. By comparing the value actually stored in the packet with the value expected for the protocol, the microsequencer can determine if the packet appears to conform to the Ethernet protocol. Illustratively, the next instruction applied in the parsing program depends upon whether the previous comparison was successful. Thus, the particular instructions applied by the microsequencer, and the sequence in which applied, depend upon which protocols are represented by the packet's headers.

The microsequencer may test one or more field values within each header included in a packet. The more fields that are tested and that are found to comport with the format of a known protocol, the greater the certainty that the packet conforms to that protocol. As one skilled in the art will appreciate, one communication protocol may be quite different than another protocol, thus requiring examination of different parts of packet headers for different protocols. Illustratively, the parsing of one packet may end in the event of an error or because it was determined that the packet being parsed does or does not conform to the protocol(s) the instructions are designed for.

Each instruction in FIG. 23 may be identified by a number and/or a name. A particular instruction may perform a variety of tasks other than comparing a header field to an expected value. An instruction may, for example, call another instruction to examine another portion of a packet header, initialize, load or configure a register or other data structure, prepare for the arrival and parsing of another packet, etc. In particular, a register or other storage structure may be configured in anticipation of an operation that is performed in the network interface after the packet is parsed. For example, a program instruction in FIG. 23 may identify an output operation that may or may not be performed, depending upon the success or failure of the comparison of a value extracted from a packet with an expected value. An output operation may store a value in a register, configure a register (e.g., load an argument or operator) for a post-parsing operation, clear a register to await a new packet, etc.

A pointer may be employed to identify an offset into a packet being parsed. In one embodiment, such a pointer is initially located at the beginning of the layer two protocol header. In another embodiment, however, the pointer is situated at a specific location within a particular header (e.g., immediately following the layer two destination and/or source addresses) when parsing commences. Illustratively, the pointer is incremented through the packet as the parsing procedure executes. In one alternative embodiment, however, offsets to areas of interest in the packet may be computed from one or more known or computed locations. In the parsing program depicted in FIG. 23, a header is navigated (e.g., the pointer is advanced) in increments of two bytes (e.g., sixteen-bit words). In addition, where a particular field of a header is compared to a known or expected value, up to two bytes are extracted at a time from the field. Further, when a value or header field is copied for storage in a register or other data structure, the amount of data that may be copied in one operation may be expressed in multiples of two-byte units or in other units altogether (e.g., individual bytes). This unit of measurement (e.g., two bytes) may be increased or decreased in an alternative embodiment of the invention. Altering the unit of measurement may alter the precision with which a header can be accessed or a header value can be extracted.

In the embodiment of the invention illustrated in FIG. 23, a set of instructions loaded into the header parser's instruction memory comprises a number of possible operations to be performed while testing a packet for compatibility with selected protocols. Program 2300 is generated from the instruction set. Program 2300 is thus merely one possible program, microcode or sequence of instructions that can be generated from the available instruction set.

In this embodiment, the loaded instruction set enables the execution of sixteen operations that may be performed on a packet that is being parsed. Specific implementations of these operations in program 2300 are discussed in additional detail below. These instructions will be understood to be illustrative in nature and do not limit the composition of the instruction sets in other embodiments of the invention. In fact, any subset of these operations may be employed in a particular parsing program or microcode. Further, multiple operations may employ the same operation and have different effects.

A CLR\_REG operation allows the selective initialization of registers or other data structures used in program 2300. In addition, data structures used in functions performed on a packet is parsed. Initialization may comprise storing a value of zero. A number of illustrative registers that may be used by a CLR\_REG operation are identified in the following operations.

A LD\_FID operation copies a variable amount of data from a particular offset within the packet into a register configured to store a packet's flow key or other flow identifier. This register may be termed a FLOWID register. The effect of an LD\_FID operation is cumulative. In other words, each time it is invoked for one packet the generated data is appended to the flow key data stored previously.

A LD\_SEQ operation copies a variable amount of data from a particular offset within the packet into a register configured to store a packet's sequence number (e.g., a TCP sequence number). This register may be assigned the label SEQNO. This operation is also cumulative—the second and subsequent invocations of this operation for the packet cause the identified data to be appended to data stored previously.

A LD\_CTL operation loads a value from a specified offset in the packet into a CONTROL register. The CONTROL register may comprise a control indicator discussed in a previous section for identifying whether a packet is suitable for data re-assembly, packet batching, load distribution or other enhanced functions of NIC 100. In particular, a control indicator may indicate whether a No\_Assist flag should be raised for the packet, whether the packet includes any data, whether the amount of packet data is larger than a predetermined threshold, etc. Thus, the value loaded into a CONTROL register in a LD\_CTL operation may affect the post-parsing handling of the packet.

A LD\_SAP operation loads a value into the CONTROL register from a variable offset within the packet. The loaded value may comprise the packet's ethertype. In one option that may be associated with a LD\_SAP operation, the offset of the packet's layer three header may also be stored in the CONTROL register or elsewhere. As one skilled in the art will recognize, a packet's layer three header may immediately follow its layer two ethertype field if the packet conforms to the Ethernet and IP protocols.

A LD\_R1 operation may be used to load a value into a temporary register (e.g., named R1) from a variable offset within the packet. A temporary register may be used for a variety of tasks, such as accumulating values to determine the length of a header or other portion of the packet. A LD\_R1 operation may also cause a value from another variable offset to be stored in a second temporary register (e.g., named R2). The values stored in the R1 and/or R2 registers during the parsing of a packet may or may not be cumulative.

A LD\_L3 operation may load a value from the packet into a register configured to store the location of the packet's layer three header. This register may be named L3OFFSET. In one optional method of invoking this operation, it may be used to load a fixed value into the L3OFFSET register. As another option, the LD\_L3 operation may add a value stored in a temporary register (e.g., R1) to the value being stored in the L3OFFSET register.

A LD\_SUM operation stores the starting point within the packet from which a checksum should be calculated. The register in which this value is stored may be named a CSUMSTART register. In one alternative invocation of this operation, a fixed or predetermined value is stored in the register. As another option, the LD\_SUM operation may add a value stored in a temporary register (e.g., R1) to the value being stored in the CSUMSTART register.

A LD\_HDR operation loads a value into a register configured to store the location within the packet at which the header portion may be split. The value that is stored may, for example, be used during the transfer of the packet to the host computer to store a data portion of the packet in a separate location than the header portion. The loaded value

may thus identify the beginning of the packet data or the beginning of a particular header. In one invocation of a LD\_HDR operation, the stored value may be computed from a present position of a parsing pointer described above. In another invocation, a fixed or predetermined value may be stored. As yet another alternative, a value stored in a temporary register (e.g., R1) and/or a constant may be added to the loaded value.

A LD\_LEN operation stores the length of the packet's payload into a register (e.g., a PAYLOADLEN register).

An IM\_FID operation appends or adds a fixed or predetermined value to the existing contents of the FLOWID register described above.

An IM\_SEQ operation appends or adds a fixed or predetermined value to the contents of the SEQNO register described above.

An IM\_SAP operation loads or stores a fixed or predetermined value in the CSUMSTART register described above.

An IM\_R1 operation may add or load a predetermined value in one or more temporary registers (e.g., R1, R2).

An IM\_CTL operation loads or stores a fixed or predetermined value in the CONTROL register described above.

A ST\_FLAG operation loads a value from a specified offset in the packet into a FLAGS register. The loaded value may comprise one or more fields or flags from a packet header.

One skilled in the art will recognize that the labels assigned to the operations and registers described above and elsewhere in this section are merely illustrative in nature and in no way limit the operations and parsing instructions that may be employed in other embodiments of the invention.

Instructions in program 2300 comprise instruction number field 2302, which contains a number of an instruction within the program, and instruction name field 2304, which contains a name of an instruction. In an alternative embodiment of the invention instruction number and instruction name fields may be merged or one of them may be omitted.

Instruction content field 2306 includes multiple portions for executing an instruction. An "extraction mask" portion of an instruction is a two-byte mask in hexadecimal notation. An extraction mask identifies a portion of a packet header to be copied or extracted, starting from the current packet offset (e.g., the current position of the parsing pointer). Illustratively, each bit in the packet's header that corresponds to a one in the hexadecimal value is copied for comparison to a comparison or test value. For example, a value of 0xFF00 in the extraction mask portion of an instruction signifies that the entire first byte at the current packet offset is to be copied and that the contents of the second byte are irrelevant. Similarly, an extraction mask of 0x3FFF signifies that all but the two most significant bits of the first byte are to be copied. A two-byte value is constructed from the extracted contents, using whatever was copied from the packet. Illustratively, the remainder of the value is padded with zeros. One skilled in the art will appreciate that the format of an extraction mask (or an output mask, described below) may be adjusted as necessary to reflect little endian or big endian representation.

One or more instructions in a parsing program may not require any data extracted from the packet at the pointer location to be able to perform its output operation. These instructions may have an extraction mask value of 0x0000 to indicate that although a two-byte value is still retrieved from the pointer position, every bit of the value is masked off. Such an extraction mask thus yields a definite value of zero. This type of instruction may be used when, for example, an

output operation needs to be performed before another substantive portion of header data is extracted with an extraction mask other than 0x0000.

A "compare value" portion of an instruction is a two-byte hexadecimal value with which the extracted packet contents are to be compared. The compare value may be a value known to be stored in a particular field of a specific protocol header. The compare value may comprise a value that the extracted portion of the header should match or have a specified relationship to in order for the packet to be considered compatible with the pre-selected protocols.

An "operator" portion of an instruction identifies an operator signifying how the extracted and compare values are to be compared. Illustratively, EQ signifies that they are tested for equality, NE signifies that they are tested for inequality, LT signifies that the extracted value must be less than the compare value for the comparison to succeed, GE signifies that the extracted value must be greater than or equal to the compare value, etc. An instruction that awaits arrival of a new packet to be parsed may employ an operation of NP. Other operators for other functions may be added and the existing operators may be assigned other monikers.

A "success offset" portion of an instruction indicates the number of two-byte units that the pointer is to advance if the comparison between the extracted and test values succeeds. A "success instruction" portion of an instruction identifies the next instruction in program 2300 to execute if the comparison is successful.

Similarly, "failure offset" and "failure instruction" portions indicate the number of two-byte units to advance the pointer and the next instruction to execute, respectively, if the comparison fails. Although offsets are expressed in units of two bytes (e.g., sixteen-bit words) in this embodiment of the invention, in an alternative embodiment of the invention they may be smaller or larger units. Further, as mentioned above an instruction may be identified by number or name.

Not all of the instructions in a program are necessarily used for each packet that is parsed. For example, a program may include instructions to test for more than one type or version of a protocol at a particular layer. In particular, program 2300 tests for either version four or six of the IP protocol at layer three. The instructions that are actually executed for a given packet will thus depend upon the format of the packet. Once a packet has been parsed as much as possible with a given program or it has been determined that the packet does or does not conform to a selected protocol, the parsing may cease or an instruction for halting the parsing procedure may be executed. Illustratively, a next instruction portion of an instruction (e.g., "success instruction" or "failure instruction") with the value "DONE" indicates the completion of parsing of a packet. A DONE, or similar, instruction may be a dummy instruction. In other words, "DONE" may simply signify that parsing to be terminated for the present packet. Or, like instruction eighteen of program 2300, a DONE instruction may take some action to await a new packet (e.g., by initializing a register).

The remaining portions of instruction content field 2306 are used to specify and complete an output or other data storage operation. In particular, in this embodiment an "output operation" portion of an instruction corresponds to the operations included in the loaded instruction set. Thus, for program 2300, the output operation portion of an instruction identifies one of the sixteen operations described above. The output operations employed in program 2300 are further described below in conjunction with individual instructions.

An "operation argument" portion of an instruction comprises one or more arguments or fields to be stored, loaded

therwise used in conjunction with the instruction's output operation. Illustratively, the operation argument portakes the form of a multi-bit hexadecimal value. For program 2300, operation arguments are eleven bits in size. Argument or portion of an argument may have various meanings, depending upon the output operation. For example, an operation argument may comprise one or more critical values to be stored in a register or to be used to locate or delimit a portion of a header. Or, an argument bit may comprise a flag to signal an action or status. In particular, one argument bit may specify that a particular register is to be reset; a set of argument bits may comprise an offset into a packet header to a value to be stored in a register, etc. Illustratively, the offset specified by an operation argument is applied to the location of the parsing pointer before the pointer is advanced as specified by the applicable success offset or failure offset. The operation arguments used in program 2300 are explained in further detail below.

The "operation enabler" portion of an instruction content specifies whether or when an instruction's output operation is to be performed. In particular, in the illustrated embodiment of the invention an instruction's output operation may or may not be performed, depending on the result of a comparison between a value extracted from a header and the compare value. For example, an output enabler may be set to a first value (e.g., zero) if the output operation is to be performed. It may take different values if it is to be performed only when the comparison does or does not satisfy the operator (e.g., one or two, respectively). An operation enabler may take yet another value (e.g., three) if it always to be performed.

The "shift" portion of an instruction comprises a value indicating how an output value is to be shifted. A shift may be necessary because different protocols sometime require values to be formatted differently. In addition, a value indicating a length or location of a header or header field may require shifting in order to reflect the appropriate magnitude represented by the value. For example, because program 2300 is designed to use two-byte units, a value may be shifted if it is to reflect other units (e.g., bytes). A shift value in a present embodiment indicates the number of positions (e.g., bits) to right-shift an output value. In another embodiment of the invention a shift value may represent a different shift type or direction.

Finally, an "output mask" specifies how a value being extracted in a register or other data structure is to be formatted. As stated above, an output operation may require an extracted, computed or assembled value to be stored. Similar to the extraction mask, the output mask is a two-byte hexadecimal value. For every position in the output mask that contains a one, in this embodiment of the invention the corresponding bit in the two-byte value identified by the output operation and/or operation argument is to be stored. For example, a value of 0xFFFF indicates that the specified two-byte value is to be stored as is. Illustratively, for every position in the output mask that contains a zero, a zero is stored. Thus, a value of 0xF000 indicates that the most significant four bits of the first byte are to be stored, but the rest of the stored value is irrelevant, and may be padded with zeros.

An output operation of "NONE" may be used to indicate that there is no output operation to be performed or stored, in which case other instruction portions pertaining to output operation may be ignored or may comprise specified values (e.g., all zeros). In the program depicted in FIG. 23, however, a CLR\_REG output operation, which allows the selective

re-initialization of registers, may be used with an operation argument of zero to effectively perform no output. In particular, an operation argument of zero for the CLR\_REG operation indicates that no registers are to be reset. In an alternative embodiment of the invention the operation enabler portion of an instruction could be set to a value (e.g., zero) indicating that the output operation is never to be performed.

The format and sequence of instructions in FIG. 23 will be understood to represent just one method of parsing a packet to determine whether it conforms to a particular communication protocol. In particular, the instructions are designed to examine one or more portions of one or more packet headers for comparison to known or expected values and to configure or load a register or other storage location as necessary. As one skilled in the art will appreciate, instructions for parsing a packet may take any of a number of forms and be performed in a variety of sequences without exceeding the scope of the invention.

With reference now to FIG. 23, instructions in program 2300 may be described in detail. Prior to execution of the program depicted in FIG. 23, a parsing pointer is situated at the beginning of a packet's layer two header. The position of the parsing pointer may be stored in a register for easy reference and update during the parsing procedure. In particular, the position of the parsing pointer as an offset (e.g., from the beginning of the layer two header) may be used in computing the position of a particular position within a header.

Program 2300 begins with a WAIT instruction (e.g., instruction zero) that waits for a new packet (e.g., indicated by operator NP) and, when one is received, sets a parsing pointer to the twelfth byte of the layer two header. This offset to the twelfth byte is indicated by the success offset portion of the instruction. Until a packet is received, the WAIT instruction loops on itself. In addition, a CLR\_REG operation is conducted, but the operation enabler setting indicates that it is only conducted when the comparison succeeds (e.g., when a new packet is received).

The specified CLR\_REG operation operates according to the WAIT instruction's operation argument (i.e., 0x3FF). In this embodiment, each bit of the argument corresponds to a register or other data structure. The registers initialized in this operation may include the following: ADDR (e.g., to store the parsing pointer's address or location), FLOWID (e.g., to store the packet's flow key), SEQNO (e.g., to store a TCP sequence number), SAP (e.g., the packet's ethertype) and PAYLOADLEN (e.g., payload length). The following registers configured to store certain offsets may also be reset: FLOWOFF (e.g., offset within FLOWID register), SEQOFF (e.g., offset within SEQNO register), L3OFFSET (e.g., offset of the packet's layer three header), HDRSPLIT (e.g., location to split packet) and CSUMSTART (e.g., starting location for computing a checksum). Also, one or more status or control indicators (e.g. CONTROL or FLAGS register) for reporting the status of one or more flags of a packet header may be reset. In addition, one or more temporary registers (e.g., R1, R2) or other data structures may also be initialized. These registers are merely illustrative of the data structures that may be employed in one embodiment of the invention. Other data structures may be employed in other embodiments for the same or different output operations.

Temporary registers such as R1 and/or R2 may be used in program 2300 to track various headers and header fields. One skilled in the art will recognize the number of possible combinations of communication protocols and the effect of

those various combinations on the structure and format of a packet's headers. More information may need to be examined or gathered from a packet conforming to one protocol or set of protocols than from a packet conforming to another protocol or set of protocols. For example, if extension headers are used with an Internet Protocol header, values from those extension headers and/or their lengths may need to be stored, which values are not needed if extension headers are not used. When calculating a particular offset, such as an offset to the beginning of a packet's data portion for example, multiple registers may need to be maintained and their values combined or added. In this example, one register or temporary register may track the size or format of an extension header, while another register tracks the base IP header.

Instruction VLAN (e.g., instruction one) examines the two-byte field at the parsing pointer position (possibly a Type, Length or TPID field) for a value indicating a VLAN-tagged header (e.g., 8100 in hexadecimal). If the header is VLAN-tagged, the pointer is incremented a couple of bytes (e.g., one two-byte unit) and execution continues with instruction CFI; otherwise, execution continues with instruction 802.3. In either event, the instruction's operation enabler indicates that an IM\_CTL operation is always to be performed.

As described above, an IM\_CTL operation causes a control register or other data structure to be populated with one or more flags to report the status or condition of a packet. As described in the previous section, a control indicator may indicate whether a packet is suitable for enhanced processing (e.g., whether a No\_Assist signal should be generated for the packet), whether a packet includes any data and, if so, whether the size of the data portion exceeds a specified threshold. The operation argument 0x00A for instruction VLAN comprises the value to be stored in the control register, with individual bits of the argument corresponding to particular flags. Illustratively, flags associated with the conditions just described may be set to one, or true, in this IM\_CTL operation.

Instruction CFI (e.g., instruction two) examines the CFI bit or flag in a layer two header. If the CFI bit is set, then the packet is not suitable for the processing enhancements described in other sections and the parsing procedure ends by calling instruction DONE (e.g., instruction eighteen). If the CFI bit is not set, then the pointer is incremented another couple of bytes and execution continues with instruction 802.3. As explained above, a null output operation (e.g., "NONE") indicates that no output operation is performed. In addition, the output enabler value (e.g., zero) further ensures that no output operation is performed.

In instruction 802.3 (e.g., instruction three), a Type or Length field (depending on the location of the pointer and format of the packet) is examined to determine if the packet's layer two format is traditional Ethernet or 802.3 Ethernet. If the value in the header field appears to indicate 802.3 Ethernet (e.g., contains a hexadecimal value less than 0x0000), the pointer is incremented two bytes (to what should be an LLC SNAP field) and execution continues with instruction LLC\_1. Otherwise, the layer two protocol may be considered traditional Ethernet and execution continues with instruction IPV4\_1. Instruction 802.3 in this embodiment of the invention does not include an output operation. In instructions LLC\_1 and LLC\_2 (e.g., instructions four and five), a suspected layer two LLC SNAP field is examined to ensure that the packet conforms to the 802.3 Ethernet protocol. In instruction LLC\_1, a first part of the field is tested and, if successful, the pointer is incremented

two bytes and a second part is tested in instruction LLC\_2. If instruction LLC\_2 succeeds, the parsing pointer is advanced four bytes to reach what should be a Type field and execution continues with instruction IPV4\_1. If either test fails, however, the parsing procedure exits. In the illustrated embodiment of the invention, no output operation is performed while testing the LLC SNAP field.

In instruction IPV4\_1 (e.g., instruction six), the parsing pointer should be at an Ethernet Type field. This field is examined to determine if the layer three protocol appears to correspond to version four of the Internet Protocol. If this test is successful (e.g., the Type field contains a hexadecimal value of 0800), the pointer is advanced two bytes to the beginning of the layer three header and execution of program 2300 continues with instruction IPV4\_2. If the test is unsuccessful, then execution continues with instruction IPV6\_1. Regardless of the test results, the operation enabler value (e.g., three) indicates that the specified LD\_SAP output operation is always performed.

As described previously, in a LD\_SAP operation a packet's ethertype (or Service Access Point) is stored in a register. Part of the operation argument of 0x100, in particular the right-most six bits (e.g., zero) constitute an offset to a two-byte value comprising the ethertype. The offset in this example is zero because, in the present context, the parsing pointer is already at the Type field that contains the ethertype. In the presently described embodiment, the remainder of the operation argument constitutes a flag specifying that the starting position of the layer three header (e.g., an offset from the beginning of the packet) is also to be saved (e.g., in the L3OFFSET register). In particular, the beginning of the layer three header is known to be located immediately after the two-byte Type field.

Instruction IPV4\_2 (e.g., instruction seven) tests a suspected layer three version field to ensure that the layer three protocol is version four of IP. In particular, a specification for version four of IP specifies that the first four bits of the layer three header contain a value of 0x4. If the test fails, the parsing procedure ends with instruction DONE. If the test succeeds, the pointer advances six bytes and instruction IPV4\_3 is called.

The specified LD\_SUM operation, which is only performed if the comparison in instruction IPV4\_2 succeeds, indicates that an offset to the beginning of a point from which a checksum may be calculated should be stored. In particular, in the presently described embodiment of the invention a checksum should be calculated from the beginning of the TCP header (assuming that the layer four header is TCP). The value of the operation argument (e.g., 0x00A) indicates that the checksum is located twenty bytes (e.g., ten two-byte increments) from the current pointer. Thus, a value of twenty bytes is added to the parsing pointer position and the result is stored in a register or other data structure (e.g., the CSUMSTART register).

Instruction IPV4\_3 (e.g., instruction eight) is designed to determine whether the packet's IP header indicates IP fragmentation. If the value extracted from the header in accordance with the extraction mask does not equal the comparison value, then the packet indicates fragmentation. If fragmentation is detected, the packet is considered unsuitable for the processing enhancements described in other sections and the procedure exits (e.g., through instruction DONE). Otherwise, the pointer is incremented two bytes and instruction IPV4\_4 is called after performing a LD\_LEN operation.

In accordance with the LD\_LEN operation, the length of the IP segment is saved. The illustrated operation argument

(e.g., 0x03E) comprises an offset to the Total Length field where this value is located. In particular, the least-significant six bits constitute the offset. Because the pointer has already been advanced past this field, the operation argument comprises a negative value. One skilled in the art will recognize that this binary value (e.g., 111110) may be used to represent the decimal value of negative two. Thus, the present offset of the pointer, minus four bytes (e.g., two two-byte units), is saved in a register or other data structure (e.g., the PAYLOADLEN register). Any other suitable method of representing a negative offset may be used. Or, the IP segment length may be saved while the pointer is at a location preceding the Total Length field (e.g., during a previous instruction).

In instruction IPV4\_4 (e.g., instruction nine), a one-byte Protocol field is examined to determine whether the layer four protocol appears to be TCP. If so, the pointer is advanced fourteen bytes and execution continues with instruction TCP\_1; otherwise the procedure ends.

The specified LD\_FID operation, which is only performed when the comparison in instruction IPV4\_4 succeeds, involves retrieving the packet's flow key and storing it in a register or other location (e.g., the FLOWID register). One skilled in the art will appreciate that in order for the comparison in instruction IPV4\_4 to be successful, the packet's layer three and four headers must conform to IP (version four) and TCP, respectively. If so, then the entire flow key (e.g., IP source and destination addresses plus TCP source and destination port numbers) is stored contiguously in the packet's header portion. In particular, the flow key comprises the last portion of the IP header and the initial portion of the TCP header and may be extracted in one operation. The operation argument (e.g., 0x182) thus comprises two values needed to locate and delimit the flow key. Illustratively, the right-most six bits of the argument (e.g., 0x02) identify an offset from the pointer position, in two-byte units, to the beginning of the flow key. The other five bits of the argument (e.g., 0x06) identify the size of the flow key, in two-byte units, to be stored.

In instruction IPV6\_1 (e.g., instruction ten), which follows the failure of the comparison performed by instruction IPV4\_1, the parsing pointer should be at a layer two Type field. If this test is successful (e.g., the Type field holds a decimal value of 86DD), instruction IPV6\_2 is executed after a LD\_SUM operation is performed and the pointer is incremented two bytes to the beginning of the layer three protocol. If the test is unsuccessful, the procedure

indicated LD\_SUM operation in instruction IPV6\_1 is similar to the operation conducted in instruction IPV4\_2 and utilizes a different argument. Again, the checksum is calculated from the beginning of the TCP header assuming the layer four header is TCP. The specified operation argument (e.g., 0x015) thus comprises an offset to the beginning of the TCP header—twenty—one two-byte units ahead. The indicated offset is added to the present pointer position and saved in a register or other data structure (e.g., the CSUMSTART register).

Instruction IPV6\_2 (e.g., instruction eleven) tests a suspected layer three version field to further ensure that the layer three protocol is version six of IP. If the comparison succeeds, the parsing procedure ends with the invocation of instruction DONE. If it fails, instruction IPV6\_3 is invoked. Operation IM\_R1, which is performed only when the comparison succeeds in this embodiment, saves the value of the IP header from a Payload Length field. As one skilled in the art will appreciate, the Total Length field (e.g.,

IP segment size) of an IP, version four, header includes the size of the version four header. However, the Payload Length field (e.g., IP segment size) of an IP, version six, header does not include the size of the version six header. Thus, the size of the version six header, which is identified by the right-most eight bits of the output argument (e.g., 0x14, indicating twenty two-byte units) is saved. Illustratively, the remainder of the argument identifies the data structure in which to store the header length (e.g., temporary register R1). Because of the variation in size of layer three headers between protocols, in one embodiment of the invention the header size is indicated in different units to allow greater precision. In particular, in one embodiment of the invention the size of the header is specified in bytes in instruction IPV6\_2, in which case the output argument could be 0x128.

Instruction IPV6\_3 (e.g., instruction twelve) in this embodiment does not examine a header value. In this embodiment, the combination of an extraction mask of 0x0000 with a comparison value of 0x0000 indicates that an output operation is desired before the next examination of a portion of a header. After the LD\_FID operation is performed, the parsing pointer is advanced six bytes to a Next Header field of the version six IP header. Because the extraction mask and comparison values are both 0x0000, the comparison should never fail and the failure branch of instruction should never be invoked.

As described previously, a LD\_FID operation stores a flow key in an appropriate register or other data structure (e.g., the FLOWID register). Illustratively, the operation argument of 0x484 comprises two values for identifying and delimiting the flow key. In particular, the right-most six bits (e.g., 0x04) indicates that the flow key portion is located at an offset of eight bytes (e.g., four two-byte increments) from the current pointer position. The remainder of the operation argument (e.g., 0x12) indicates that thirty-six bytes (e.g., the decimal equivalent of 0x12 two-byte units) are to be copied from the computed offset. In the illustrated embodiment of the invention the entire flow key is copied intact, including the layer three source and destination addresses and layer four source and destination ports.

In instruction IPV6\_4 (e.g., instruction thirteen), a suspected Next Header field is examined to determine whether the layer four protocol of the packet's protocol stack appears to be TCP. If so, the procedure advances thirty-six bytes (e.g., eighteen two-byte units) and instruction TCP\_L is called; otherwise the procedure exits (e.g., through instruction DONE). Operation LD\_LEN is performed if the value in the Next Header field is 0x06. As described above, this operation stores the IP segment size. Once again the argument (e.g., 0x03F) comprises a negative offset, in this case negative one. This offset indicates that the desired Payload Length field is located two bytes before the pointer's present position. Thus, the negative offset is added to the present pointer offset and the result saved in an appropriate register or other data structure (e.g., the PAYLOADLEN register).

In instructions TCP\_1, TCP\_2, TCP\_3 and TCP\_4 (e.g., instructions fourteen through seventeen), no header values—other than certain flags specified in the instruction's output operations—are examined, but various data from the packet's TCP header are saved. In the illustrated embodiment, the data that is saved includes a TCP sequence number, a TCP header length and one or more flags. For each instruction, the specified operation is performed and the next instruction is called. As described above, a comparison between the comparison value of 0x0000 and a null extraction value, as used in each of these instructions, will never

fail. After instruction TCP\_4, the parsing procedure returns to instruction WAIT to await a new packet.

For operation LD\_SEQ in instruction TCP\_1, the operation argument (e.g., 0x081) comprises two values to identify and extract a TCP sequence number. The right-most six bits (e.g., 0x01) indicate that the sequence number is located two bytes from the pointer's current position. The rest of the argument (e.g., 0x2) indicates the number of two-byte units that must be copied from that position in order to capture the sequence number. Illustratively, the sequence number is stored in the SEQNO register.

For operation ST\_FLAG in instruction TCP\_2, the operation argument (e.g., 0x145) is used to configure a register (e.g., the FLAGS register) with flags to be used in a post-parsing task. The right-most six bits (e.g., 0x05) constitute an offset, in two-byte units, to a two-byte portion of the TCP header that contains flags that may affect whether the packet is suitable for post-parsing enhancements described in other sections. For example, URG, PSH, RST, SYN and FIN flags may be located at the offset position and be used to configure the register. The output mask (e.g., 0x002F) indicates that only particular portions (e.g., bits) of the TCP header's Flags field are stored.

Operation LD\_R1 of instruction TCP\_3 is similar to the operation conducted in instruction IPV6\_2. Here, an operation argument of 0x205 includes a value (e.g., the least-significant six bits) identifying an offset of five two-byte units from the current pointer position. That location should include a Header Length field to be stored in a data structure identified by the remainder of the argument (e.g., temporary register R1). The output mask (e.g., 0xF000) indicates that only the first four bits are saved (e.g., the Header Length field is only four bits in size).

As one skilled in the art may recognize, the value extracted from the Header Length field may need to be adjusted in order to reflect the use of two-byte units (e.g., sixteen bit words) in the illustrated embodiment. Therefore, in accordance with the shift portion of instruction TCP\_3, the value extracted from the field and configured by the output mask (e.g., 0xF000) is shifted to the right eleven positions when stored in order to simplify calculations.

Operation LD\_HDR of instruction TCP\_4 causes the loading of an offset to the first byte of packet data following the TCP header. As described in a later section, packets that are compatible with a pre-selected protocol stack may be separated at some point into header and data portions. Having an offset to the data portion now makes it easier to visit the packet later. Illustratively, the right-most seven bits of the 0xOFF operation argument comprise a first element of the offset to the data. One skilled in the art will recognize the pattern (e.g., 1111111) as equating to negative one. Thus, the offset value equal to the current parsing pointer (e.g., the value in the ADDR register) minus two bytes—which marks the beginning of the TCP header—is saved. The remainder of the argument signifies that the value of a temporary data structure (e.g., temporary register R1) is to be added to this offset. In this particular context, the value added in the previous instruction (e.g., the length of the TCP header) is added. These two values combine to form an offset to the beginning of the packet data, which is stored in an appropriate register or other data structure (e.g., the RSPLIT register).

Finally, and as mentioned above, instruction DONE (e.g., instruction eighteen) indicates the end of parsing of a packet. It is determined that the packet does not conform to one or more of the protocols associated with the illustrated instructions. This may be considered a "clean-up" instruc-

tion. In particular, output operation LD\_CTL, with an operation argument of 0x001 indicates that a No\_Assist flag is to be set (e.g., to one) in the control register described above in conjunction with instruction VLAN. The No\_Assist flag, as described elsewhere, may be used to inform other modules of the network interface that the present packet, is unsuitable for one or more processing enhancements described elsewhere.

It will be recognized by one skilled in the art that the illustrated program or microcode merely provides one method of parsing a packet. Other programs, comprising the same instructions in a different sequence or different instructions altogether, with similar or dissimilar formats, may be employed to examine and store portions of headers and to configure registers and other data structures.

The efficiency gains to be realized from the application of the enhanced processing described in following sections more than offset the time required to parse a packet with the illustrated program. Further, even though a header parser parses a packet on a NIC in a current embodiment of the invention, the packet may still need to be processed through its protocol stack (e.g., to remove the protocol headers) by a processor on a host computer. Doing so avoids burdening the communication device (e.g., network interface) with such a task.

One Embodiment of a Flow Database

FIG. 5 depicts flow database (FDB) 110 according to one embodiment of the invention. Illustratively FDB 110 is implemented as a CAM (Content Addressable Memory) using a re-writeable memory component (e.g., RAM, SRAM, DRAM). In this embodiment, FDB 110 comprises associative portion 502 and associated portion 504, and may be indexed by flow number 506.

The scope of the invention does not limit the form or structure of flow database 110. In alternative embodiments of the invention virtually any form of data structure may be employed (e.g., database, table, queue, list, array), either monolithic or segmented, and may be implemented in hardware or software. The illustrated form of FDB 110 is merely one manner of maintaining useful information concerning communication flows through NIC 100. As one skilled in the art will recognize, the structure of a CAM allows highly efficient and fast associative searching.

In the illustrated embodiment of the invention, the information stored in FDB 110 and the operation of flow database manager (FDBM) 108 (described below) permit functions such as data re-assembly, batch processing of packet headers, and other enhancements. These functions are discussed in detail in other sections but may be briefly described as follows.

One form of data re-assembly involves the re-assembly or combination of data from multiple related packets (e.g., packets from a single communication flow or a single datagram). One method for the batch processing of packet headers entails processing protocol headers from multiple related packets through a protocol stack collectively rather than one packet at a time. Another illustrative function of NIC 100 involves the distribution or sharing of such protocol stack processing (and/or other functions) among processors in a multi-processor host computer system. Yet another possible function of NIC 100 is to enable the transfer of re-assembled data to a destination entity (e.g., an application program) in an efficient aggregation (e.g., a memory page), thereby avoiding piecemeal and highly inefficient transfers of one packet's data at a time. Thus, in this embodiment of the invention, one purpose of FDB 110 and FDBM 108 is to generate information for the use of NIC 100 and/or a host



computer system in enabling, disabling or performing one or more of these functions.

Associative portion 502 of FDB 110 in FIG. 5 stores the flow key of each valid flow destined for an entity served by NIC 100. Thus, in one embodiment of the invention associative portion 502 includes IP source address 510, IP destination address 512, TCP source port 514 and TCP destination port 516. As described in a previous section these fields may be extracted from a packet and provided to FDBM 108 by header parser 106.

Although each destination entity served by NIC 100 may participate in multiple communication flows or end-to-end TCP connections, only one flow at a time will exist between a particular source entity and a particular destination entity. Therefore, each flow key in associative portion 502 that corresponds to a valid flow should be unique from all other valid flows. In alternative embodiments of the invention, associative portion 502 is composed of different fields, reflecting alternative flow key forms, which may be determined by the protocols parsed by the header parser and the information used to identify communication flows.

Associated portion 504 in the illustrated embodiment comprises flow validity indicator 520, flow sequence number 522 and flow activity indicator 524. These fields provide information concerning the flow identified by the flow key stored in the corresponding entry in associative portion 502. The fields of associated portion 504 may be retrieved and/or updated by FDBM 108 as described in the following section.

Flow validity indicator 520 in this embodiment indicates whether the associated flow is valid or invalid. Illustratively, the flow validity indicator is set to indicate a valid flow when the first packet of data in a flow is received, and may be reset to reassert a flow's validity every time a portion of a flow's datagram (e.g., a packet) is correctly received.

Flow validity indicator 520 may be marked invalid after the last packet of data in a flow is received. The flow validity indicator may also be set to indicate an invalid flow whenever a flow is to be torn down (e.g., terminated or aborted) for some reason other than the receipt of a final data packet. For example, a packet may be received out of order from other packets of a datagram, a control packet indicating that a data transfer or flow is being aborted may be received, an attempt may be made to re-establish or re-synchronize a flow (in which case the original flow is terminated), etc. In one embodiment of the invention flow validity indicator 520 is a single bit, flag or value.

Flow sequence number 522 in the illustrated embodiment comprises a sequence number of the next portion of data that is expected in the associated flow. Because the datagram being sent in a flow is typically received via multiple packets, the flow sequence number provides a mechanism to ensure that the packets are received in the correct order. For example, in one embodiment of the invention NIC 100 assembles data from multiple packets of a datagram. To perform this re-assembly in the most efficient manner, the packets need to be received in order. Thus, flow sequence number 522 stores an identifier to identify the next packet or portion of data that should be received.

In one embodiment of the invention, flow sequence number 522 corresponds to the TCP sequence number field and in TCP protocol headers. As one skilled in the art will recognize, a packet's TCP sequence number identifies the position of the packet's data relative to other data being sent in a datagram. For packets and flows involving protocols other than TCP, an alternative method of verifying or ensuring the receipt of data in the correct order may be employed.

Flow activity indicator 524 in the illustrated embodiment reflects the recency of activity of a flow or, in other words, the age of a flow. In this embodiment of the invention flow activity indicator 524 is associated with a counter, such as a flow activity counter (not depicted in FIG. 5). The flow activity counter is updated (e.g., incremented) each time a packet is received as part of a flow that is already stored in flow database 110. The updated counter value is then stored in the flow activity indicator field of the packet's flow. The flow activity counter may also be incremented each time a first packet of a new flow that is being added to the database is received. In an alternative embodiment, a flow activity counter is only updated for packets containing data (e.g., it is not updated for control packets). In yet another alternative embodiment, multiple counters are used for updating flow activity indicators of different flows.

Because it can not always be determined when a communication flow has ended (e.g., the final packet may have been lost), the flow activity indicator may be used to identify flows that are obsolete or that should be torn down for some other reason. For example, if flow database 110 appears to be fully populated. (e.g., flow validity indicator 520 is set for each flow number) when the first packet of a new flow is received, the flow having the lowest flow activity indicator may be replaced by the new flow.

In the illustrated embodiment of the invention, the size of fields in FDB 110 may differ from one entry to another. For example, IP source and destination addresses are four bytes large in version four of the protocol, but are sixteen bytes large in version six. In one alternative embodiment of the invention, entries for a particular field may be uniform in size, with smaller entries being padded as necessary.

In another alternative embodiment of the invention, fields within FDB 110 may be merged. In particular, a flow's flow key may be stored as a single entity or field instead of being stored as a number of separate fields as shown in FIG. 5. Similarly, flow validity indicator 520, flow sequence number 522 and flow activity indicator 524 are depicted as separate entries in FIG. 5. However, in an alternative embodiment of the invention one or more of these entries may be combined. In particular, in one alternative embodiment flow validity indicator 520 and flow activity indicator 524 comprise a single entry having a first value (e.g., zero) when the entry's associated flow is invalid. As long as the flow is valid, however, the combined entry is incremented as packets are received, and is reset to the first value upon termination of the flow.

In one embodiment of the invention FDB 110 contains a maximum of sixty-four entries, indexed by flow number 506, thus allowing the database to track sixty-four valid flows at a time. In alternative embodiments of the invention, more or fewer entries may be permitted, depending upon the size of memory allocated for flow database 110. In addition to flow number 506, a flow may be identifiable by its flow key (stored in associative portion 502).

In the illustrated embodiment of the invention, flow database 110 is empty (e.g., all fields are filled with zeros) when NIC 100 is initialized. When the first packet of a flow is received header parser 106 parses a header portion of the packet. As described in a previous section, the header parser assembles a flow key to identify the flow and extracts other information concerning the packet and/or the flow. The flow key, and other information, is passed to flow database manager 108. FDBM 108 then searches FDB 110 for an active flow associated with the flow key. Because the database is empty, there is no match.

In this example, the flow key is therefore stored (e.g., as flow number zero) by copying the IP source address, IP

destination address, TCP source port and TCP destination port into the corresponding fields. Flow validity indicator 520 is then set to indicate a valid flow, flow sequence number 522 is derived from the TCP sequence number (illustratively provided by the header parser), and flow activity indicator 524 is set to an initial value (e.g., one), which may be derived from a counter. One method of generating an appropriate flow sequence number, which may be used to verify that the next portion of data received for the flow is received in order, is to add the TCP sequence number and the size of the packet's data. Depending upon the configuration of the packet (e.g., whether the SYN bit in a Flags field of the packet's TCP header is set), however, the sum may need to be adjusted (e.g., by adding one) to correctly identify the next expected portion of data.

As described above, one method of generating an appropriate initial value for a flow activity indicator is to copy a counter value that is incremented for each packet received as part of a flow. For example, for the first packet received after NIC 100 is initialized, a flow activity counter may be incremented to the value of one. This value may then be stored in flow activity indicator 524 for the associated flow. The next packet received as part of the same (or a new) flow causes the counter to be incremented to two, which value is stored in the flow activity indicator for the associated flow. In this example, no two flows should have the same flow activity indicator except at initialization, when they may all equal zero or some other predetermined value.

Upon receipt and parsing of a later packet received at NIC 100, the flow database is searched for a valid flow matching that packet's flow key. Illustratively, only the flow keys of active flows (e.g., those flows for which flow validity indicator 520 is set) are searched. Alternatively, all flow keys (e.g., all entries in associative portion 502) may be searched but a match is only reported if its flow validity indicator indicates a valid flow. With a CAM such as FDB 110 in FIG. 1, flow keys and flow validity indicators may be searched in parallel.

If a later packet contains the next portion of data for a previous flow (e.g., flow number zero), that flow is updated appropriately. In one embodiment of the invention this includes updating flow sequence number 522 and incrementing flow activity indicator 524 to reflect its recent activity. Flow validity indicator 520 may also be set to indicate the validity of the flow, although it should already indicate that the flow is valid.

As new flows are identified, they are added to FDB 110 in a similar manner to the first flow. When a flow is terminated or torn down, the associated entry in FDB 110 is invalidated. In one embodiment of the invention, flow validity indicator 520 is merely cleared (e.g., set to zero) for a terminated flow. In another embodiment, one or more fields of a terminated flow are cleared or set to an arbitrary predetermined value. Because of the bursty nature of network packet traffic, all or most of the data from a datagram is generally received in a short amount of time. Thus, each valid flow in FDB 110 normally only needs to be maintained for a short period of time, and its entry can then be used to store a different flow.

Due to the limited amount of memory available for flow database 110 in one embodiment of the invention, the size of a field may be limited. In this embodiment, sixteen bytes are allocated for IP source address 510 and sixteen bytes are allocated for IP destination address 512. For IP addresses greater than sixteen bytes in length, the extra space may be filled with zeros. Further, TCP source port 514 and TCP destination port 516 are each allocated two bytes. Also in

this embodiment, flow validity indicator 520 comprises one bit, flow sequence number 522 is allocated four bytes and flow activity indicator 524 is also allocated four bytes.

As one skilled in the art will recognize from the embodiments described above, a flow is similar, but not identical, to an end-to-end TCP connection. A TCP connection may exist for a relatively extended period of time, sufficient to transfer multiple datagrams from a source entity to a destination entity. A flow, however, may exist only for one datagram. Thus, during one end-to-end TCP connection, multiple flows may be set up and torn down (e.g., once for each datagram). As described above, a flow may be set up (e.g., added to FDB 110 and marked valid) when NIC 100 detects the first portion of data in a datagram and may be torn down (e.g., marked invalid in FDB 110) when the last portion of data is received. Illustratively, each flow set up during a single end-to-end TCP connection will have the same flow key because the layer three and layer four address and port identifiers used to form the flow key will remain the same.

In the illustrated embodiment, the size of flow database 110 (e.g., the number of flow entries) determines the maximum number of flows that may be interleaved (e.g., simultaneously active) at one time while enabling the functions of data re-assembly and batch processing of protocol headers. In other words, in the embodiment depicted in FIG. 5, NIC 100 can set up sixty-four flows and receive packets from up to sixty-four different datagrams (i.e., sixty-four flows may be active) without tearing down a flow. If a maximum number of flows through NIC 100 were known, flow database 110 could be limited to the corresponding number of entries.

The flow database may be kept small because a flow only lasts for one datagram in the presently described embodiment and, because of the bursty nature of packet traffic, a datagram's packets are generally received in a short period of time. The short duration of a flow compensates for a limited number of entries in the flow database. In one embodiment of the invention, if FDB 110 is filled with active flows and a new flow is commenced (i.e., a first portion of data in a new datagram), the oldest (e.g., the least recently active) flow is replaced by the new one.

In an alternative embodiment of the invention, flows may be kept active for any number of datagrams (or other measure of network traffic) or for a specified length or range of time. For example, when one datagram ends its flow in FDB 110 may be kept "open" (i.e., not torn down) if the database is not full (e.g., the flow's entry is not needed for a different flow). This scheme may further enhance the efficient operation of NIC 100 if another datagram having the same flow key is received. In particular, the overhead involved in setting up another flow is avoided and more data re-assembly and packet batching (as described below) may be performed. Advantageously, a flow may be kept open in flow database 110 until the end-to-end TCP connection that encompasses the flow ends.

#### One Embodiment of a Flow Database Manager

FIGS. 6A-6E depict one method of operating a flow database manager (FDBM), such as flow database manager 108 of FIG. 1A, for managing flow database (FDB) 110. Illustratively, FDBM 108 stores and updates flow information stored in flow database 110 and generates an operation code for a packet received by NIC 100. FDBM 108 also tears down a flow (e.g., replaces, removes or otherwise invalidates an entry in FDB 110) when the flow is terminated or aborted.

In one embodiment of the invention a packet's operation code reflects the packet's compatibility with pre determined

criteria for performing one or more functions of NIC 100 (e.g., data re-assembly, batch processing of packet headers, load distribution). In other words, depending upon a packet's operation code, other modules of NIC 100 may or may not perform one of these functions, as described in following sections.

In another embodiment of the invention, an operation code indicates a packet status. For example, an operation code may indicate that a packet: contains no data, is a control packet, contains more than a specified amount of data, is the first packet of a new flow, is the last packet of an existing flow, is out of order, contains a certain flag (e.g., in a protocol header) that does not have an expected value (thus possibly indicating an exceptional circumstance), etc.

The operation of flow database manager 108 depends upon packet information provided by header parser 106 and data drawn from flow database 110. After FDBM 108 processes the packet information and/or data, control information (e.g., the packet's operation code) is stored in control queue 118 and FDB 110 may be altered (e.g., a new flow may be entered or an existing one updated or torn down).

With reference now to FIGS. 6A-6E, state 600 is a start state in which FDBM 108 awaits information drawn from a packet received by NIC 100 from network 102. In state 602, header parser 106 or another module of NIC 100 notifies FDBM 108 of a new packet by providing the packet's flow key and some control information. Receipt of this data may be interpreted as a request to search FDB 110 to determine whether a flow having this flow key already exists.

In one embodiment of the invention the control information passed to FDBM 108 includes a sequence number (e.g., TCP sequence number) drawn from a packet header. The control information may also indicate the status of certain flags in the packet's headers, whether the packet includes data and, if so, whether the amount of data exceeds a certain size. In this embodiment, FDBM 108 also receives a No\_Assist signal for a packet if the header parser determines that the packet is not formatted according to one of the pre-selected protocol stacks (i.e., the packet is not "compatible"), as discussed in a previous section. Illustratively, the No\_Assist signal indicates that one or more functions of NIC 100 (e.g., data re-assembly, batch processing, load-balancing) may not be provided for the packet.

In state 604, FDBM 108 determines whether a No\_Assist signal was asserted for the packet. If so, the procedure proceeds to state 668 (FIG. 6E). Otherwise, FDBM 108 searches FDB 110 for the packet's flow key in state 606. In

one embodiment of the invention only valid flow entries in the flow database are searched. As discussed above, a flow's validity may be reflected by a validity indicator such as flow validity indicator 520 (shown in FIG. 5). If, in state 608, it is determined that the packet's flow key was not found in the flow database, or that a match was found but the associated flow entry was not valid, the procedure advances to state 646 (FIG. 6D). If a valid match is found in the flow database, in state 610 the flow number (e.g., the flow database index for the matching entry) of the matching flow is noted and flow information stored in FDB 110 is read. Illustratively, this information includes flow validity indicator 520, flow sequence number 522 and flow activity indicator 524 (shown in FIG. 5).

In state 612, FDBM 108 determines from information received from header parser 106 whether the packet contains payload data. If not, the illustrated procedure proceeds to state 638 (FIG. 6C); otherwise the procedure continues to

In state 614, the flow database manager determines whether the packet constitutes an attempt to reset a communication connection or flow. Illustratively, this may be determined by examining the state of a SYN bit in one of the packet's protocol headers (e.g., a TCP header). In one embodiment of the invention the value of one or more control or flag bits (such as the SYN bit) are provided to the FDBM by the header parser. As one skilled in the art will recognize, one TCP entity may attempt to reset a communication flow or connection with another entity (e.g., because of a problem on one of the entity's host computers) and send a first portion of data along with the re-connection request. This is the situation the flow database manager attempts to discern in state 614. If the packet is part of an attempt to re-connect or reset a flow or connection, the procedure continues at state 630 (FIG. 6C).

In state 616, flow database manager 108 compares a sequence number (e.g., a TCP sequence number) extracted from a packet header with a sequence number (e.g., flow sequence number 522 of FIG. 5) of the next expected portion of data for this flow. As discussed in a previous section, these sequence numbers should correlate if the packet contains the flow's next portion of data. If the sequence numbers do not match, the procedure continues at state 628.

In state 618, FDBM 108 determines whether certain flags extracted from one or more of the packet's protocol headers match expected values. For example, in one embodiment of the invention the URG, PSH, RST and FIN flags from the packet's TCP header are expected to be clear (i.e., equal to zero). If any of these flags are set (e.g., equal to one) an exceptional condition may exist, thus making it possible that one or more of the functions (e.g., data re-assembly, batch processing, load distribution) offered by NIC 100 should not be performed for this packet. As long as the flags are clear, the procedure continues at state 620; otherwise the procedure continues at state 626.

In state 620, the flow database manager determines whether more data is expected during this flow. As discussed above, a flow may be limited in duration to a single datagram. Therefore, in state 620 the FDBM determines if this packet appears to be the final portion of data for this flow's datagram. Illustratively, this determination is made on the basis of the amount of data included with the present packet. As one skilled in the art will appreciate, a datagram comprising more data than can be carried in one packet is sent via multiple packets. The typical manner of disseminating a datagram among multiple packets is to put as much data as possible into each packet. Thus, each packet except the last is usually equal or nearly equal in size to the maximum transfer unit (MTU) allowed for the network over which the packets are sent. The last packet will hold the remainder, usually causing it to be smaller than the MTU.

Therefore, one manner of identifying the final portion of data in a flow's datagram is to examine the size of each packet and compare it to a figure (e.g., MTU) that a packet is expected to exceed except when carrying the last data portion. It was described above that control information is received by FDBM 108 from header parser 106. An indication of the size of the data carried by a packet may be included in this information. In particular, header parser 106 in one embodiment of the invention is configured to compare the size of each packet's data portion to a pre-selected value. In one embodiment of the invention this value is programmable. This value is set, in the illustrated embodiment of the invention, to the maximum amount of data a packet can carry without exceeding MTU. In one alternative embodiment, the value is set to an amount somewhat less than the maximum amount of data that can be carried.

Thus, in state 620, flow database manager 108 determines whether the received packet appears to carry the final portion of data for the flow's datagram. If not, the procedure continues to state 626.

In state 622, it has been ascertained that the packet is compatible with pre-selected protocols and is suitable for one or more functions offered by NIC 100. In particular, the packet has been formatted appropriately for one or more of the functions discussed above. FDBM 108 has determined that the received packet is part of an existing flow, is compatible with the pre-selected protocols and contains the next portion of data for the flow (but not the final portion). Further, the packet is not part of an attempt to re-set a flow/connection, and important flags have their expected values. Thus, flow database 110 can be updated as follows.

The activity indicator (e.g., flow activity indicator 524 of FIG. 5) for this flow is modified to reflect the recent flow activity. In one embodiment of the invention flow activity indicator 524 is implemented as a counter, or is associated with a counter, that is incremented each time data is received for a flow. In another embodiment of the invention, an activity indicator or counter is updated every time a packet having a flow key matching a valid flow (e.g., whether or not the packet includes data) is received.

In the illustrated embodiment, after a flow activity indicator or counter is incremented it is examined to determine if it "rolled over" to zero (i.e., whether it was incremented past its maximum value). If so, the counter and/or the flow activity indicators for each entry in flow database 110 are set to zero and the current flow's activity indicator is once again incremented. Thus, in one embodiment of the invention the rolling over of a flow activity counter or indicator causes the re-initialization of the flow activity mechanism for flow database 110. Thereafter, the counter is incremented and the flow activity indicators are again updated as described previously. One skilled in the art will recognize that there are many other suitable methods that may be applied in an embodiment of the present invention to indicate that one flow was active more recently than another was.

Also in state 622, flow sequence number 522 is updated. Illustratively, the new flow sequence number is determined by adding the size of the newly received data to the existing flow sequence number. Depending upon the configuration of the packet (e.g., values in its headers), this sum may need to be adjusted. For example, this sum may indicate simply the total amount of data received thus far for the flow's datagram. Therefore, a value may need to be added (e.g., one byte) in order to indicate a sequence number of the next byte of data for the datagram. As one skilled in the art will recognize, other suitable methods of ensuring that data is received in order may be used in place of the scheme described here.

Finally, in state 622 in one embodiment of the invention, flow validity indicator 520 is set or reset to indicate the flow's validity.

Then, in state 624, an operation code is associated with the packet. In the illustrated embodiment of the invention, operation codes comprise codes generated by flow database manager 108 and stored in control queue 118. In this embodiment, an operation code is three bits in size, thus allowing for eight operation codes. Operation codes may take a variety of other forms and ranges in alternative embodiments. For the illustrated embodiment of the invention, TABLE 1 describes each operation code in terms of the criteria that lead to each code's selection and the ramifications of that selection. For purposes of TABLE 1, setting up a flow comprises inserting a flow into flow data-

base 110. Tearing down a flow comprises removing or invalidating a flow in flow database 110. The re-assembly of data is discussed in a following section describing DMA engine 120.

In the illustrated embodiment of the invention, operation code 4 is selected in state 624 for packets in the present context of the procedure (e.g., compatible packets carrying the next, but not last, data portion of a flow). Thus, the existing flow is not torn down and there is no need to set up a new flow. As described above, a compatible packet in this embodiment is a packet conforming to one or more of the pre-selected protocols. By changing or augmenting the pre-selected protocols, virtually any packet may be compatible in an alternative embodiment of the invention.

Returning now to FIGS. 6A-6E, after state 624 the illustrated procedure ends at state 670.

In state 626 (reached from state 618 or state 620), operation code 3 is selected for the packet. Illustratively, operation code 3 indicates that the packet is compatible and matches a valid flow (e.g., the packet's flow key matches the flow key of a valid flow in FDB 110). Operation code 3 may also signify that the packet contains data, does not constitute an attempt to re-synchronize or reset a communication flow/connection and the packet's sequence number matches the expected sequence number (from flow database 110). But, either an important flag (e.g., one of the TCP flags URG, PSH, RST or FIN) is set (determined in state 618) or the packet's data is less than the threshold value described above (in state 620), thus indicating that no more data is likely to follow this packet in this flow. Therefore, the existing flow is torn down but no new flow is created. Illustratively, the flow may be torn down by clearing the flow's validity indicator (e.g., setting it to zero). After state 626, the illustrated procedure ends at state 670.

In state 628 (reached from state 616), operation code 2 is selected for the packet. In the present context, operation code 2 may indicate that the packet is compatible, matches a valid flow (e.g., the packet's flow key matches the flow key of a valid flow in FDB 110), contains data and does not constitute an attempt to re-synchronize or reset a communication flow/connection. However, the sequence number extracted from the packet (in state 616) does not match the expected sequence number from flow database 110. This may occur, for example, when a packet is received out of order. Thus, the existing flow is torn down but no new flow is established. Illustratively, the flow may be torn down by clearing the flow's validity indicator (e.g., setting it to zero). After state 628, the illustrated procedure ends at state 670.

State 630 is entered from state 614 when it is determined that the received packet constitutes an attempt to reset a communication flow or connection (e.g., the TCP SYN bit is set). In state 630, flow database manager 108 determines whether more data is expected to follow. As explained in conjunction with state 620, this determination may be made on the basis of control information received by the flow database manager from the header parser. If more data is expected (e.g., the amount of data in the packet equals or exceeds a threshold value), the procedure continues at state 634.

In state 632, operation code 2 is selected for the packet. Operation code 2 was also selected in state 628 in a different context. In the present context, operation code 2 may indicate that the packet is compatible, matches a valid flow and contains data. Operation code 2 may also signify in this context that the packet constitutes an attempt to re-synchronize or reset a communication flow or connection, but that no more data is expected once the flow/connection

is reset. Therefore, the existing flow is torn down and no new flow is established. Illustratively, the flow may be torn down by clearing the flow's validity indicator (e.g., setting it to zero). After state 632, the illustrated procedure ends at state 670.

In state 634, flow database manager 108 responds to an attempt to reset or re-synchronize a communication flow/connection whereby additional data is expected. Thus, the existing flow is torn down and replaced as follows. The existing flow may be identified by the flow number retrieved in state 610 or by the packet's flow key. The flow's sequence number (e.g., flow sequence number 522 in FIG. 5) is set to the next expected value. Illustratively, this value depends upon the sequence number (e.g., TCP sequence number) retrieved from the packet (e.g., by header parser 106) and the amount of data included in the packet. In one embodiment of the invention these two values are added to determine a new flow sequence number. As discussed previously, this sum may need to be adjusted (e.g., by adding one). Also in state 634, the flow activity indicator is updated (e.g., incremented). As explained in conjunction with state 622, if the flow activity indicator rolls over, the activity indicators for all flows in the database are set to zero and the present flow is again incremented. Finally, the flow validity indicator is set to indicate that the flow is valid.

In state 636, operation code 7 is selected for the packet. In the present context, operation code 7 indicates that the packet is compatible, matches a valid flow and contains data. Operation code 7 may further signify, in this context, that the packet constitutes an attempt to re-synchronize or reset a communication flow/connection and that additional data is expected once the flow/connection is reset. In effect, therefore, the existing flow is torn down and a new one (with the same flow key) is stored in its place. After state 636, the illustrated procedure ends at end state 670.

State 638 is entered after state 612 when it is determined that the received packet contains no data. This often indicates that the packet is a control packet. In state 638, flow database manager 108 determines whether one or more flags extracted from the packet by the header parser match expected or desired values. For example, in one embodiment of the invention the TCP flags URG, PSH, RST and FIN must be clear in order for DMA engine 120 to re-assemble data from multiple related packets (e.g., packets having an identical flow key). As discussed above, the TCP SYN bit may also be examined. In the present context (e.g., a packet with no data), the SYN bit is also expected to be clear (e.g., to store a value of zero). If the flags (and SYN bit) have their expected values the procedure continues at state 642. If, however, any of these flags are set, an exceptional condition may exist, thus making it possible that one or more functions offered by NIC 100 (e.g., data re-assembly, batch processing, load distribution) are unsuitable for this packet, in which case the procedure proceeds to state 640.

In state 640, operation code 1 is selected for the packet. Illustratively, operation code 1 indicates that the packet is compatible and matches a valid flow, but does not contain any data and one or more important flags or bits in the packet's header(s) are set. Thus, the existing flow is torn down and no new flow is established. Illustratively, the flow may be torn down by clearing the flow's validity indicator (e.g., setting it to zero). After state 640, the illustrated procedure ends at end state 670.

In state 642, the flow's activity indicator is updated (e.g., incremented) even though the packet contains no data. As described above in conjunction with state 622, if the activity indicator rolls over, in a present embodiment of the inven-

tion all flow activity indicators in the database are set to zero and the current flow is again incremented. The flow's validity indicator may also be reset, as well as the flow's sequence number.

In state 644, operation code 0 is selected for the packet. Illustratively, operation code 0 indicates that the packet is compatible, matches a valid flow, and that the packet does not contain any data. The packet may, for example, be a control packet. Operation code 0 further indicates that none of the flags checked by header parser 106 and described above (e.g., URG, PSH, RST and FIN) are set. Thus, the existing flow is not torn down and no new flow is established. After state 644, the illustrated procedure ends at end state 670.

State 646 is entered from state 608 if the packet's flow key does not match any of the flow keys of valid flows in the flow database. In state 646, FDBM 108 determines whether flow database 110 is full and may save some indication of whether the database is full. In one embodiment of the invention the flow database is considered full when the validity indicator (e.g., flow validity indicator 520 of FIG. 5) is set for every flow number (e.g., for every flow in the database). If the database is full, the procedure continues at state 650, otherwise it continues at state 648.

In state 648, the lowest flow number of an invalid flow (e.g., a flow for which the associated flow validity indicator is equal to zero) is determined. Illustratively, this flow number is where a new flow will be stored if the received packet warrants the creation of a new flow. After state 648, the procedure continues at state 652.

In state 650, the flow number of the least recently active flow is determined. As discussed above, in the illustrated embodiment of the invention a flow's activity indicator (e.g., flow activity indicator 524 of FIG. 5) is updated (e.g., incremented) each time data is received for a flow. Therefore, in this embodiment the least recently active flow can be identified as the flow having the least recently updated (e.g., lowest) flow activity indicator. Illustratively, if multiple flows have flow activity indicators set to a common value (e.g., zero), one flow number may be chosen from them at random or by some other criteria. After state 650, the procedure continues at state 652.

In state 652, flow database manager 108 determines whether the packet contains data. Illustratively, the control information provided to FDBM 108 by the header parser indicates whether the packet has data. If the packet does not include data (e.g., the packet is a control packet), the illustrated procedure continues at state 668.

In state 654, flow database manager 108 determines whether the data received with the present packet appears to contain the final portion of data for the associated datagram/flow. As described in conjunction with state 620, this determination may be made on the basis of the amount of data included with the packet. If the amount of data is less than a threshold value (a programmable value in the illustrated embodiment), then no more data is expected and this is likely to be the only data for this flow. In this case the procedure continues at state 668. If, however, the data meets or exceeds the threshold value, in which case more data may be expected, the procedure proceeds to state 656.

In state 656, the values of certain flags are examined. These flags may include, for example, the URG, PSH, RST, FIN bits of a TCP header. If any of the examined flags do not have their expected or desired values (e.g., if any of the flags are set), an exceptional condition may exist making one or more of the functions of NIC 100 (e.g., data re-assembly, batch processing, load distribution) unsuitable for this

packet. In this case the procedure continues at state 668; otherwise the procedure proceeds to state 658.

In state 658, the flow database manager retrieves the information stored in state 646 concerning whether flow database 110 is full. If the database is full, the procedure continues at state 664; otherwise the procedure continues at state 660.

In state 660, a new flow is added to flow database 110 for the present packet. Illustratively, the new flow is stored at the flow number identified or retrieved in state 648. The addition of a new flow may involve setting a sequence number (e.g., flow sequence number 522 from FIG. 5). Flow sequence number 522 may be generated by adding a sequence number (e.g., TCP sequence number) retrieved from the packet and the amount of data included in the packet. As discussed above, this sum may need to be adjusted (e.g., by adding one).

Storing a new flow may also include initializing an activity indicator (e.g., flow activity indicator 524 of FIG. 5). In one embodiment of the invention this initialization involves storing a value retrieved from a counter that is incremented each time data is received for a flow. Illustratively, if the counter or a flow activity indicator is incremented past its maximum storable value, the counter and all flow activity indicators are cleared or reset. Also in state 660, a validity indicator (e.g., flow validity indicator 520 of FIG. 5) is set to indicate that the flow is valid. Finally, the packet's flow key is also stored in the flow database, in the entry corresponding to the assigned flow number.

In state 662, operation code 6 is selected for the packet. Illustratively, operation code 6 indicates that the packet is compatible, did not match any valid flows and contains the first portion of data for a new flow. Further, the packet's flags have their expected or necessary values, additional data is expected in the flow and the flow database is not full. Thus, operation code 6 indicates that there is no existing flow to tear down and that a new flow has been stored in the flow database. After state 662, the illustrated procedure ends at state 670.

In state 664, an existing entry in the flow database is replaced so that a new flow, initiated by the present packet, can be stored. Therefore, the flow number of the least recently active flow, identified in state 650, is retrieved. This flow may be replaced as follows. The sequence number of the existing flow (e.g., flow sequence number 522 of FIG. 5) is replaced with a value derived by combining a sequence number extracted from the packet (e.g., TCP sequence number) with the size of the data portion of the packet. This sum may need to be adjusted (e.g., by adding one). Then the existing flow's activity indicator (e.g., flow activity indicator 524) is replaced. For example, the value of a flow activity counter may be copied into the flow activity indicator, as discussed above. The flow's validity indicator (e.g., flow validity indicator 520 of FIG. 5) is then set to indicate that the flow is valid. Finally, the flow key of the new flow is stored.

In state 666, operation code 7 is selected for the packet. Operation code 7 was also selected in state 636. In the present context, operation code 7 may indicate that the packet is compatible, did not match the flow key of any valid flows and contains the first portion of data for a new flow. Further, the packet's flags have compatible values and additional data is expected in the flow. Lastly, however, in the present context operation code 7 indicates that the flow database is full, so an existing entry was torn down and the new one was added in its place. After state 666, the illustrated procedure ends at state 670.

In state 668, operation code 5 is selected for the packet. State 668 is entered from various states and operation code 5 thus represents a variety of possible conditions or situations. For example, operation code 5 may be selected when a No\_Assist signal is detected (in state 604) for a packet. As discussed above, the No\_Assist signal may indicate that the corresponding packet is not compatible with a set of pre-selected protocols. In this embodiment of the invention, incompatible packets are ineligible for one or more of the various functions of NIC 100 (e.g., data re-assembly, batch processing, load distribution).

State 668 may also be entered, and operation code 5 selected, from state 652, in which case the code may indicate that the received packet does not match any valid flow keys and, further, contains no data (e.g., it may be a control packet).

State 668 may also be entered from state 654. In this context operation code 5 may indicate that the packet does not match any valid flow keys. It may further indicate that the packet contains data, but that the size of the data portion is less than the threshold discussed in conjunction with state 654. In this context, it appears that the packet's data is complete (e.g., comprises all of the data for a datagram), meaning that there is no other data to re-assemble with this packet's data and therefore there is no reason to make a new entry in the database for this one-packet flow.

Finally, state 668 may also be entered from state 656. In this context, operation code 5 may indicate that the packet does not match any valid flow keys, contains data, and more data is expected, but at least one flag in one or more of the packet's protocol headers does not have its expected value. For example, in one embodiment of the invention the TCP flags URG, PSH, RST and FIN are expected to be clear. If any of these flags are set an exceptional condition may exist, thus making it possible that one of the functions offered by NIC 100 is unsuitable for this packet.

As TABLE 1 reflects, there is no flow to tear down and no new flow is established when operation code 5 is selected. Following state 668, the illustrated procedure ends at state 670.

One skilled in the art will appreciate that the procedure illustrated in FIGS. 6A-6E and discussed above is but one suitable procedure for maintaining and updating a flow database and for determining a packet's suitability for certain processing functions. In particular, different operation codes may be utilized or may be implemented in a different manner, a goal being to produce information for later processing of the packet through NIC 100.

Although operation codes are assigned for all packets by a flow database manager in the illustrated procedure, in an alternative procedure an operation code assigned by the FDBM may be replaced or changed by another module of NIC 100. This may be done to ensure a particular method of treating certain types of packets. For example, in one embodiment of the invention IPP module 104 assigns a predetermined operation code (e.g., operation code 2 of TABLE 1) to jumbo packets (e.g., packets greater in size than MTU) so that DMA engine 120 will not re-assemble them. In particular, the IPP module may independently determine that the packet is a jumbo packet (e.g., from information provided by a MAC module) and therefore assign the predetermined code. Illustratively, header parser 106 and FDBM 108 perform their normal functions for a jumbo packet and IPP module 104 receives a first operation code assigned by the FDBM. However, the IPP module replaces that code before storing the jumbo packet and information concerning the packet. In one alternative

embodiment header parser 106 and/or flow database manager 108 may be configured to recognize a particular type of packet (e.g., jumbo) and assign a predetermined operation code.

The operation codes applied in the embodiment of the invention illustrated in FIGS. 6A-6E are presented and explained in the following TABLE 1. TABLE 1 includes illustrative criteria used to select each operation code and illustrative results or effects of each code.

TABLE 1

Op. Code	Criteria for Selection	Result of Operation Code
0	Compatible control packet with clear flags; a flow was previously established for this flow key.	Do not set up a new flow; Do not tear down existing flow; Do not re-assemble data (packet contains no data).
1	Compatible control packet with at least one flag or SYN bit set; a flow was previously established.	Do not set up a new flow; Tear down existing flow; Do no re-assemble data packet contains no data).
2	Compatible packet whose sequence number does not match sequence number in flow database, or SYN bit is set (indicating attempt to re-establish a connection) but there is no more data to come; a flow was previously established. Or Jumbo packet.	Do not set up a new flow; Tear down existing flow; Do not re-assemble packet data.
3	A compatible packet carrying a final portion of flow data, or a flag is set (but packet is in sequence, unlike operation code 2); a flow was previously established.	Do not set up a new flow; Tear down existing flow; Re-assemble data with previous packets.
4	Receipt of next compatible packet in sequence; a flow was previously established.	Do not set up a new flow; Do not tear down existing flow; Re-assemble data with other packets.
5	Packet cannot be re-assembled because: incompatible, a flag is set, packet contains no data or there is no more data to come. No flow was previously established.	Do not set up a flow; There is no flow to tear down; Do not re-assemble.
6	First compatible packet of a new flow; no flow was previously established.	Set up a new flow; There is no flow to tear down; Re-assemble data with packets to follow.
7	First compatible packet of a new flow, but flow database is full; no flow was previously established. Or Compatible packet, SYN bit is set and additional data will follow; a flow was previously established.	Replace existing flow; Re-assemble data with packets to follow.

The Embodiment of a Load Distributor

In one embodiment of the invention, load distributor 112 enables the processing of packets through their protocol stacks to be distributed among a number of processors. Illustratively, load distributor 112 generates an identifier (e.g., a processor number) of a processor to which a packet may be submitted. The multiple processors may be located within a host computer system that is served by NIC 100. In an alternative embodiment, one or more processors for manipulating packets through a protocol stack are located on NIC 100.

Without an effective method of sharing or distributing the processing burden, one processor could become overloaded and were required to process all or most network traffic received at NIC 100, particularly in a high-speed network environment. The resulting delay in processing network traffic could deteriorate operations on the host computer

system as well as other computer systems communicating with the host system via the network.

As one skilled in the art will appreciate, simply distributing packets among processors in a set of processors (e.g., such as in a round-robin scheme) may not be an efficient plan. Such a plan could easily result in packets being processed out of order. For example, if two packets from one communication flow or connection that are received at a network interface in the correct order were submitted to two different processors, the second packet may be processed before the first. This could occur, for example, if the processor that received the first packet could not immediately process the packet because it was busy with another task. When packets are processed out of order a recovery scheme must generally be initiated, thus introducing even more inefficiency and more delay.

Therefore, in a present embodiment of the invention packets are distributed among multiple processors based upon their flow identities. As described above, a header parser may generate a flow key from layer three (e.g., IP) and layer four (e.g., TCP) source and destination identifiers retrieved from a packet's headers. The flow key may be used to identify the communication flow to which the packet belongs. Thus, in this embodiment of the invention all packets having an identical flow key are submitted to a single processor. As long as the packets are received in order by NIC 100, they should be provided to the host computer and processed in order by their assigned processor.

Illustratively, multiple packets sent from one source entity to one destination entity will have the same flow key even if the packets are part of separate datagrams, as long as their layer three and layer four identifiers remain the same. As discussed above, separate flows are set up and torn down for each datagram within one TCP end-to-end connection. Therefore, just as all packets within one flow are sent to one processor, all packets within a TCP end-to-end connection will also be sent to the same processor. This helps ensure the correct ordering of packets for the entire connection, even between datagrams.

Depending upon the network environment in which NIC 100 operates (e.g., the protocols supported by network 102), the flow key may be too large to use as an identifier of a processor. In one embodiment of the invention described above, for example, a flow key measures 288 bits. Meanwhile, the number of processors participating in the load-balancing scheme may be much smaller. For example, in the embodiment of the invention described below in conjunction with FIG. 7, a maximum of sixty-four processors is supported. Thus, in this embodiment only a six-bit number is needed to identify the selected processor. The larger flow key may therefore be mapped or hashed into a smaller range of values.

FIG. 7 depicts one method of generating an identifier (e.g., a processor number) to specify a processor to process a packet received by NIC 100, based on the packet's flow key. In this embodiment of the invention, network 102 is the Internet and a received packet is formatted according to a compatible protocol stack (e.g., Ethernet at layer two, IP at layer three and TCP at layer four).

State 700 is a start state. In state 702 a packet is received by NIC 100 and a header portion of the packet is parsed by header parser 106 (a method of parsing a packet is described in a previous section). In state 704, load distributor 112 receives the packet's flow key that was generated by header parser 106.

Because a packet's flow key is 288 bits wide in this embodiment, in state 706 a hashing function is performed to

generate a value that is smaller in magnitude. The hash operation may, for example, comprise a thirty-two bit CRC (cyclic redundancy check) function such as ATM (Asynchronous Transfer Mode) Adaptation Layer 5 (AAL5). AAL5 generates thirty-two bit numbers that are fairly evenly distributed among the  $2^{32}$  possible values. Another suitable method of hashing is the standard Ethernet CRC-32 function. Other hash functions that are capable of generating relatively small numbers from relatively large flow keys, where the numbers generated are well distributed among a range of values, are also suitable.

With the resulting hash value, in state 708 a modulus operation is performed over the number of processors available for distributing or sharing the processing. Illustratively, software executing on the host computer (e.g., a device driver for NIC 100) programs or stores the number of processors such that it may be read or retrieved by load distributor 112 (e.g., in a register). The number of processors available for load balancing may be all or a subset of the number of processors installed on the host computer system. In the illustrated embodiment, the number of processors available in a host computer system is programmable, with a maximum value of sixty-four. The result of the modulus operation in this embodiment, therefore, is the number of the processor (e.g., from zero to sixty-three) to which the packet is to be submitted for processing. In this embodiment of the invention, load distributor 112 is implemented in hardware, thus allowing rapid execution of the hashing and modulus functions. In an alternative embodiment of the invention, virtually any number of processors may be accommodated.

In state 710, the number of the processor that will process the packet through its protocol stack is stored in the host computer's memory. Illustratively, state 710 is performed in parallel with the storage of the packet in a host memory buffer. As described in a following section, in one embodiment of the invention a descriptor ring in the host computer's memory is constructed to hold the processor number and possibly other information concerning the packet (e.g., a pointer to the packet, its size, its TCP checksum).

A descriptor ring in this embodiment is a data structure comprising a number of entries, or "descriptors," for storing information to be used by a network interface circuit's host computer system. In the illustrated embodiment, a descriptor temporarily stores packet information after the packet has been received by NIC 100, but before the packet is processed by the host computer system. The information stored in a descriptor may be used, for example, by the device driver for NIC 100 or for processing the packet through its protocol stack.

In state 712, an interrupt or other alert is issued to the host computer to inform it that a new packet has been delivered from NIC 100. In an embodiment of the invention in which NIC 100 is coupled to the host computer by a PCI (Peripheral Component Interconnect) bus, the INTA signal may be asserted across the bus. A PCI controller in the host receives the signal and the host operating system is alerted (e.g., via an interrupt).

In state 714, software operating on the host computer (e.g., a device driver for NIC 100) is invoked (e.g., by the host computer's operating system interrupt handler) to act upon a newly received packet. The software gathers information from one or more descriptors in the descriptor ring and places information needed to complete the processing of each new packet into a queue for the specified processor (i.e., according to the processor number stored in the packet's descriptor). Illustratively, each descriptor corresponds to a separate packet. The information stored in the processor

queue for each packet may include a pointer to a buffer containing the packet, the packet's TCP checksum, offsets of one or more protocol headers, etc. In addition, each processor participating in the load distribution scheme may have an associated queue for processing network packets. In an alternative embodiment of the invention, multiple queues may be used (e.g., for multiple priority levels or for different protocol stacks).

Illustratively, one processor on the host computer system is configured to receive all alerts and/or interrupts associated with the receipt of network packets from NIC 100 and to alert the appropriate software routine or device driver. This initial processing may, alternatively, be distributed among multiple processors. In addition, in one embodiment of the invention a portion of the retrieval and manipulation of descriptor contents is performed as part of the handling of the interrupt that is generated when a new packet is stored in the descriptor ring. The processor selected to process the packet will perform the remainder of the retrieval/manipulation procedure.

In state 716, the processor designated to process a new packet is alerted or woken. In an embodiment of the invention operating on a Solaris™ workstation, individual processes executed by the processor are configured as "threads." A thread is a process running in a normal mode (e.g., not at an interrupt level) so as to have minimal impact on other processes executing on the workstation. A normal mode process may, however, execute at a high priority. Alternatively, a thread may run at a relatively low interrupt level.

A thread responsible for processing an incoming packet may block itself when it has no packets to process, and awaken when it has work to do. A "condition variable" may be used to indicate whether the thread has a packet to process. Illustratively, the condition variable is set to a first value when the thread is to process a packet (e.g., when a packet is received for processing by the processor) and is set to a second value when there are no more packets to process. In the illustrated embodiment of the invention, one condition variable may be associated with each processor's queue.

In an alternative embodiment, the indicated processor is alerted in state 716 by a "cross-processor call." A cross-processor call is one way of communicating among processors whereby one processor is interrupted remotely by another processor. Other methods by which one processor alerts, or dispatches a process to, another processor may be used in place of threads and cross-processor calls.

In state 718, a thread or other process on the selected processor begins processing the packet that was stored in the processor's queue. Methods of processing a packet through its protocol stack are well known to those skilled in the art and need not be described in detail. The illustrated procedure then ends with end state 720.

In one alternative embodiment of the invention, a high-speed network interface is configured to receive and process ATM (Asynchronous Transfer Mode) traffic. In this embodiment, a load distributor is implemented as a set of instructions (e.g., as software) rather than as a hardware module. As one skilled in the art is aware, ATM traffic is connection-oriented and may be identified by a virtual connection identifier (VCI), which corresponds to a virtual circuit established between the packet's source and destination entities. Each packet that is part of a virtual circuit includes the VCI in its header.

Advantageously, a VCI is relatively small in size (e.g., sixteen bits). In this alternative embodiment, therefore, a packet's VCI may be used in place of a flow key for the



purpose of distributing or sharing the burden of processing packets through their protocol stacks. Illustratively, traffic from different VCIs is sent to different processors, but, to ensure correct ordering of packets, all packets having the same VCI are sent to the same processor. When an ATM packet is received at a network interface, the VCI is retrieved from its header and provided to the load distributor. The modulus of the VCI over the number of processors that are available for load distribution is then computed. Similar to the illustrated embodiment, the packet and its associated processor number are then provided to the host computer.

As described above, load distribution in a present embodiment of the invention is performed on the basis of a packet's layer three and/or layer four source and destination entity identifiers. In an alternative embodiment of the invention, however, load distribution may be performed on the basis of layer two addresses. In this alternative embodiment, packets having the same Ethernet source and destination addresses, for example, are sent to a single processor.

As one of skill in the art will recognize, however, this may result in a processor receiving many more packets than it would if layer three and/or layer four identifiers were used. For example, if a large amount of traffic is received through a router situated near (in a logical sense) to the host computer, the source Ethernet address for all of the traffic may be the router's address even though the traffic is from a multitude of different end users and/or computers. In contrast, if the host computer is on the same Ethernet segment as all of the end users/computers, the layer two source addresses will show greater variety and allow more effective load sharing.

Other methods of distributing the processing of packets received from a network may differ from the embodiment illustrated in FIG. 7 without exceeding the scope of the invention. In particular, one skilled in the art will appreciate that many alternative procedures for assigning a flow's packets to a processor and delivering those packets to the processor may be employed.

#### One Embodiment of a Packet Queue

As described above, packet queue 116 stores packets received from IPP module 104 prior to their re-assembly by DMA engine 120 and their transfer to the host computer system. FIG. 8 depicts packet queue 116 according to one embodiment of the invention.

In the illustrated embodiment, packet queue 116 is implemented as a FIFO (First-In First-Out) queue containing up to 256 entries. Each packet queue entry in this embodiment stores one packet plus various information concerning the packet. For example, entry 800 includes packet portion 802 plus a packet status portion. Because packets of various sizes are stored in packet queue 116, packet portion 802 may include filler 802a to supplement the packet so that the packet portion ends at an appropriate boundary (e.g., byte, word, double word).

Filler 802a may comprise random data or data having a specified pattern. Filler 802a may be distinguished from the stored packet by the pattern of the filler data or by a tag field.

Illustratively, packet status information includes TCP checksum value 804 and packet length 806 (e.g., length of the packet stored in packet portion 802). Storing the packet length may allow the packet to be easily identified and retrieved from packet portion 802. Packet status information may also include diagnostic/status information 808. Diagnostic/status information 808 may include a flag indicating that the packet is bad (e.g., incomplete, received with an error), an indicator that a checksum was or was not computed for the packet, an indicator that the checksum has

a certain value, an offset to the portion of the packet on which the checksum was computed, etc. Other flags or indicators may also be included for diagnostics, filtering, or other purposes. In one embodiment of the invention, the packet's flow key (described above and used to identify the flow comprising the packet) and/or flow number (e.g., the corresponding index of the packet's flow in flow database 110) are included in diagnostic/status information 808. In another embodiment, a tag field to identify or delimit filler 802a is included in diagnostic/status information 808.

In one alternative embodiment of the invention, any or all of the packet status information described above is stored in control queue 118 rather than packet queue 116.

In the illustrated embodiment of the invention packet queue 116 is implemented in hardware (e.g., as random access memory). In this embodiment, checksum value 804 is sixteen bits in size and may be stored by checksum generator 114. Packet length 806 is fourteen bits large and may be stored by header parser 106. Finally, portions of diagnostic/status information 808 may be stored by one or more of IPP module 104, header parser 106, flow database manager 108, load distributor 112 and checksum generator 114.

Packet queue 116 in FIG. 8 is indexed with two pointers. Read pointer 810 identifies the next entry to be read from the queue, while write pointer 812 identifies the entry in which the next received packet and related information is to be stored. As explained in a subsequent section, the packet stored in packet portion 802 of an entry is extracted from packet queue 116 when its data is to be re-assembled by DMA engine 120 and/or transferred to the host computer system.

#### One Embodiment of a Control Queue

In one embodiment of the invention, control queue 118 stores control and status information concerning a packet received by NIC 100. In this embodiment, control queue 118 retains information used to enable the batch processing of protocol headers and/or the re-assembly of data from multiple related packets. Control queue 118 may also store information to be used by the host computer or a series of instructions operating on a host computer (e.g., a device driver for NIC 100). The information stored in control queue 118 may supplement or duplicate information stored in packet queue 116.

FIG. 9 depicts control queue 118 in one embodiment of the invention. The illustrated control queue contains one entry for each packet stored in packet queue 116 (e.g., up to 256 entries). In one embodiment of the invention each entry in control queue 118 corresponds to the entry (e.g., packet) in packet queue 116 having the same number. FIG. 9 depicts entry 900 having various fields, such as CPU number 902, No\_Assist signal 904, operation code 906, payload offset 908, payload size 910 and other status information 912. An entry may also include other status or control information (not shown in FIG. 9). Entries in control queue 118 in alternative embodiments of the invention may comprise different information.

CPU (or processor) number 902, discussed in a previous section, indicates which one of multiple processors on the host computer system should process the packet's protocol headers. Illustratively, CPU number 902 is six bits in size. No\_Assist signal 904, also described in a preceding section, indicates whether the packet is compatible with (e.g., is formatted according to) any of a set of pre-selected protocols that may be parsed by header parser 106. No\_Assist signal 904 may comprise a single flag (e.g. one bit). In one embodiment of the invention the state or value of No\_Assist signal 904 may be used by flow database manager 108 to

determine whether a packet's data is re-assembleable and/or whether its headers may be processed with those of related packets. In particular, the FDBM may use the No\_Assist signal in determining which operation code to assign to the packet.

Operation code 906 provides information to DMA engine 120 to assist in the re-assembly of the packet's data. As described in a previous section, an operation code may indicate whether a packet includes data or whether a packet's data is suitable for re-assembly. Illustratively, operation code 906 is three bits in size. Payload offset 908 and payload size 910 correspond to the offset and size of the packet's TCP payload (e.g., TCP data), respectively. These fields may be seven and fourteen bits large, respectively.

In the illustrated embodiment, other status information 912 includes diagnostic and/or status information concerning the packet. Status information 912 may include a starting position for a checksum calculation (which may be seven bits in size), an offset of the layer three (e.g., IP) protocol header (which may also be seven bits in size), etc. Status information 912 may also include an indicator as to whether the size of the packet exceeds a first threshold (e.g., whether the packet is greater than 1522 bytes) or falls under a second threshold (e.g., whether the packet is 256 bytes or less). This information may be useful in re-assembling packet data. Illustratively, these indicators comprise single-bit flags.

In one alternative embodiment of the invention, status information 912 includes a packet's flow key and/or flow number (e.g., the index of the packet's flow in flow database 110). The flow key or flow number may, for example, be used for debugging or other diagnostic purposes. In one embodiment of the invention, the packet's flow number may be stored in status information 912 so that multiple packets in a single flow may be identified. Such related packet may then be collectively transferred to and/or processed by a host computer.

FIG. 9 depicts a read pointer and a write pointer for indexing control queue 118. Read pointer 914 indicates an entry to be read by DMA engine 120. Write pointer 916 indicates the entry in which to store information concerning the next packet stored in packet queue 116.

In an alternative embodiment of the invention, a second read pointer (not shown in FIG. 9) may be used for indexing control queue 118. As described in a later section, when a packet is to be transferred to the host computer, information drawn from entries in the control queue is searched to determine whether a related packet (e.g., a packet in the same flow as the packet to be transferred) is also going to be transferred. If so, the host computer is alerted so that protocol headers from the related packets may be processed collectively. In this alternative embodiment of the invention, related packets are identified by matching their flow numbers (or flow keys) in status information 912. The second read pointer may be used to look ahead in the control queue for packets with matching flow numbers.

In one embodiment of the invention CPU number 902 may be stored in the control queue by load distributor 112 and No\_Assist signal 904 may be stored by header parser 106. Operation code 906 may be stored by flow database manager 108, and payload offset 908 and payload size 910 may be stored by header parser 106. Portions of other status information may be written by the preceding modules and/or others, such as IPP module 104 and checksum generator 114. In one particular embodiment of the invention, however, many of these items of information are stored by IPP module 104 or some other module acting in somewhat of a coordinator role.

One Embodiment of a DMA Engine

FIG. 10 is a block diagram of DMA (Direct Memory Access) engine 120 in one embodiment of the invention. One purpose of DMA engine 120 in this embodiment is to transfer packets from packet queue 116 into buffers in host computer memory. Because related packets (e.g., packets that are part of one flow) can be identified by their flow numbers or flow keys, data from the related packets may be transferred together (e.g., in the same buffer). By using one buffer for data from one flow, the data can be provided to an application program or other destination in a highly efficient manner. For example, after the host computer receives the data, a page-flip operation may be performed to transfer the data to an application's memory space rather than performing numerous copy operations.

With reference back to FIGS. 1A-B, a packet that is to be transferred into host memory by DMA engine 120 is stored in packet queue 116 after being received from network 102. Header parser 106 parses a header portion of the packet and generates a flow key, and flow database manager 108 assigns an operation code to the packet. In addition, the communication flow that includes the packet is registered in flow database 110. The packet's flow may be identified by its flow key or flow number (e.g., the index of the flow in flow database 110). Finally, information concerning the packet (e.g., operation code, a packet size indicator, flow number) is stored in control queue 118 and, possibly, other portions or modules of NIC 100, and the packet is transferred to the host computer by DMA engine 120. During the transfer process, the DMA engine may draw upon information stored in the control queue to copy the packet into an appropriate buffer, as described below. Dynamic packet batching module 122 may also use information stored in the control queue, as discussed in detail in a following section.

With reference now to FIG. 10, one embodiment of a DMA engine is presented. In this embodiment, DMA manager 1002 manages the transfer of a packet, from packet queue 116, into one or more buffers in host computer memory. Free ring manager 1012 identifies or receives empty buffers from host memory and completion ring manager 1014 releases the buffers to the host computer, as described below. The free ring manager and completion ring managers may be controlled with logic contained in DMA manager 1002. In the illustrated embodiment, flow re-assembly table 1004, header table 1006, MTU table 1008 and jumbo table 1010 store information concerning buffers used to store different types of packets (as described below). Information stored in one of these tables may include a reference to, or some other means of identifying, a buffer. In FIG. 10, DMA engine 120 is partially or fully implemented in hardware.

Empty buffers into which packets may be stored are identified via a free descriptor ring that is maintained in host memory. As one skilled in the art is aware, a descriptor ring is a data structure that is logically arranged as a circular queue. A descriptor ring contains descriptors for storing information (e.g., data, flag, pointer, address). In one embodiment of the invention, each descriptor stores its index within the free descriptor ring and an identifier (e.g., memory address, pointer) of a free buffer that may be used to store packets. In this embodiment a buffer is identified in a descriptor by its address in memory, although other means of identifying a memory buffer are also suitable. In one embodiment of the invention a descriptor index is thirteen bits large, allowing for a maximum of 8,192 descriptors in the ring, and a buffer address is sixty-four bits in size.

In the embodiment of FIG. 10, software that executes on a host computer, such as a device driver for NIC 100,

maintains a free buffer array or other data structure (e.g., list, table) for storing references to (e.g., addresses of) the buffers identified in free descriptors. As descriptors are retrieved from the ring their buffer identifiers are placed in the array. Thus, when a buffer is needed for the storage of a packet, it may be identified by its index (e.g., cell, element) in the free buffer array. Then, when the buffer is no longer needed, it may be released to the host computer by placing its array index or reference in a completion descriptor. A packet stored in the buffer can then be retrieved by accessing the buffer identified in the specified element of the array. Thus, in this embodiment of the invention the size of a descriptor index (e.g., thirteen bits) may not limit the number of buffers that may be assigned by free ring manager 1012. In particular, virtually any number of buffers or descriptors could be managed by the software. For example, in one alternative embodiment of the invention buffer identifiers may be stored in one or more linked lists after being retrieved from descriptors in a free descriptor ring. When the buffer is released to the host computer, a reference to the head of the buffer's linked list may be provided. The list could then be navigated to locate the particular buffer (e.g., by its address).

As one skilled in the art will appreciate, the inclusion of a limited number of descriptors in the free descriptor ring (e.g., 8,192 in this embodiment) means that they may be re-used in a round-robin fashion. In the presently described embodiment, a descriptor is just needed long enough to retrieve its buffer identifier (e.g., address) and place it in the free buffer array, after which it may be re-used relatively quickly. In other embodiments of the invention free descriptor rings having different numbers of free descriptors may be used, thus allowing some control over the rate at which free descriptors must be re-used.

In one alternative embodiment of the invention, instead of using a separate data structure to identify a buffer for storing a packet, a buffer may be identified within DMA engine 120 by the index of the free descriptor within the free descriptor ring that referenced the buffer. One drawback to this scheme when the ring contains a limited number of descriptors, however, is that a particular buffer's descriptor may need to be re-used before its buffer has been released to the host computer. Thus, either a method of avoiding or skipping the re-use of such a descriptor must be implemented or the buffer referenced by the descriptor must be released before the descriptor is needed again. Or, in another alternative, a free descriptor ring may be of such a large size that a lengthy or even virtually infinite period of time may pass from the time a free descriptor is first used until it needs to be re-used.

Thus, in the illustrated embodiment of the invention free ring manager 1012 retrieves a descriptor from the free descriptor ring, stores its buffer identifier (e.g., memory address) in a free buffer array, and provides the array index and/or buffer identifier to flow re-assembly table 1004, header table 1006, MTU table 1008 or jumbo table 1010.

Free ring manager 1012 attempts to ensure that a buffer is always available for a packet. Thus, in one embodiment of the invention free ring manager 1012 includes descriptor cache 1012 a configured to store a number of descriptors (e.g., up to eight) at a time. Whenever there are less than a threshold number of entries in the cache (e.g., five), additional descriptors may be retrieved from the free descriptor ring. Advantageously, the descriptors are of such a size (e.g., sixteen bytes) that some multiple (e.g., four) of them can be efficiently retrieved in a sixty-four byte cache line transfer from the host computer.

Returning now to the illustrated embodiment of the invention, each buffer in host memory is one memory page

in size. However, buffers and the packets stored in the buffers may be divided into multiple categories based on packet size and whether a packet's data is being re-assembled. Re-assembly refers to the accumulation of data from multiple packets of a single flow into one buffer for efficient transfer from kernel space to user or application space within host memory. In particular, re-assembleable packets may be defined as packets that conform to a pre-selected protocol (e.g., a protocol that is parseable by header parser 106). By filling a memory page with data for one destination, page-flipping may be performed to provide a page in kernel space to the application or user space. A packet's category (e.g., whether re-assembleable or non-re-assembleable) may be determined from information retrieved from the control queue or flow database manager. In particular, and as described previously, an operation code may be used to determine whether a packet contains a re-assembleable portion of data.

In the illustrated embodiment of the invention, data portions of related, re-assembleable, packets are placed into a first category of buffers—which may be termed re-assembly buffers. A second category of buffers, which may be called header buffers, stores the headers of those packets whose data portions are being re-assembled and may also store small packets (e.g., those less than or equal to 256 bytes in size). A third category of buffers, MTU buffers, stores non-re-assembleable packets that are larger than 256 bytes, but no larger than MTU size (e.g., 1522 bytes). Finally, a fourth category of buffers, jumbo buffers, stores jumbo packets (e.g., large packets that are greater than 1522 bytes in size) that are not being re-assembled. Illustratively, a jumbo packet may be stored intact (e.g., its headers and data portions kept together in one buffer) or its headers may be stored in a header buffer while its data portion is stored in an appropriate (e.g., jumbo) non-re-assembly buffer.

In one alternative embodiment of the invention, no distinction is made between MTU and jumbo packets. Thus, in this alternative embodiment, just three types of buffers are used: re-assembly and header buffers, as described above, plus non-re-assembly buffers. Illustratively, all non-small packets (e.g., larger than 256 bytes) that are not re-assembled are placed in a non-re-assembly buffer.

In another alternative embodiment, jumbo packets may be re-assembled in jumbo buffers. In particular, in this embodiment data portions of packets smaller than a predetermined size (e.g., MTU) are re-assembled in normal re-assembly buffers while data portions of jumbo packets (e.g., packets greater in size than MTU) are re-assembled in jumbo buffers. Re-assembly of jumbo packets may be particularly effective for a communication flow that comprises jumbo frames of a size such that multiple frames can fit in one buffer. Header portions of both types of packets may be stored in one type of header buffer or, alternatively, different header buffers may be used for the headers of the different types of re-assembleable packets.

In yet another alternative embodiment of the invention buffers may be of varying sizes and may be identified in different descriptor rings or other data structures. For example, a first descriptor ring or other mechanism may be used to identify buffers of a first size for storing large or jumbo packets. A second ring may store descriptors referencing buffers for MTU-sized packets, and another ring may contain descriptors for identifying page-sized buffers (e.g., for data re-assembly).

A buffer used to store portions of more than one type of packet—such as a header buffer used to store headers and small packets, or a non-re-assembly buffer used to store MTU and jumbo packets—may be termed a “hybrid” buffer.

Illustratively, each time a packet or a portion of a packet is stored in a buffer, completion ring manager 1014 populates a descriptor in a completion descriptor ring with information concerning the packet. Included in the information stored in a completion descriptor in this embodiment is a number or reference identifying the free buffer array cell or element in which an identifier (e.g., memory address) of a buffer in which a portion of the packet is stored. The information may also include an offset into the buffer (e.g., to the beginning of the packet portion), the identity of another free buffer array entry that stores a buffer identifier for a buffer containing another portion of the packet, a size of the packet, etc. A packet may be stored in multiple buffers, for example, if the packet data and header are stored separately (e.g., the packet's data is being re-assembled in a re-assembly buffer while the packet's header is placed in a header buffer). In addition, data portions of a jumbo packet or a re-assembly packet may span two or more buffers, depending on the size of the data portion.

A distinction should be kept in mind between a buffer identifier (e.g., the memory address of a buffer) and the entry in the free buffer array in which the buffer identifier is stored. In particular, it has been described above that when a memory buffer is released to a host computer it is identified to the host computer by its position within a free buffer array (or other suitable data structure) rather than by its buffer identifier. The host computer retrieves the buffer identifier from the specified array element and accesses the specified buffer to locate a packet stored in the buffer. As one skilled in the art will appreciate, identifying memory buffers in completion descriptors by the buffers' positions in a free buffer array can be more efficient than identifying them by their memory addresses. In particular, in FIG. 10 buffer identifiers are sixty-four bits in size while an index in a free buffer array or similar data structure will likely be far smaller. Using array positions thus saves space compared to using buffer identifiers. Nonetheless, buffer identifiers may be used to directly identify buffers in an alternative embodiment of the invention, rather than filtering access to them through a free buffer array. However, completion descriptors would have to be correspondingly larger in order to accommodate them.

A completion descriptor may also include one or more flags indicating the type or size of a packet, whether the packet data should be re-assembled, whether the packet is the last of a datagram, whether the host computer should delay processing the packet to await a related packet, etc. As described in a following section, in one embodiment of the invention dynamic packet batching module 122 determines, at the time a packet is transferred to the host computer, whether a related packet will be sent shortly. If so, the host computer may be advised to delay processing the transferred packet and await the related packet in order to allow more efficient processing.

A packet's completion descriptor may be marked appropriately when the buffer identified by its buffer identifier is to be released to the host computer. For example, a flag may be set in the descriptor to indicate that the packet's buffer is being released from DMA engine 120 to the host computer or software operating on the host computer (e.g., a driver associated with NIC 100). In one embodiment of the invention, completion ring manager 1014 includes completion descriptor cache 1014a. Completion descriptor cache 1014a may store one or more completion descriptors for collective transfer from DMA engine 120 to the host computer.

Thus, empty buffers are retrieved from a free ring and used buffers are released to the host computer through a

completion ring. One reason that a separate ring is employed to release used buffers to the host computer is that buffers may not be released in the order in which they were taken. In one embodiment of the invention, a buffer (especially a flow re-assembly buffer) may not be released until it is full. Alternatively, a buffer may be released at virtually any time, such as when the end of a communication flow is detected. Free descriptors and completion descriptors are further described below in conjunction with FIG. 12.

Another reason that separate rings are used for free and completion descriptors is that the number of completion descriptors that are required in an embodiment of the invention may exceed the number of free descriptors provided in a free descriptor ring. For example, a buffer provided by a free descriptor may be used to store multiple headers and/or small packets. Each time a header or small packet is stored in the header buffer, however, a separate completion descriptor is generated. In an embodiment of the invention in which a header buffer is eight kilobytes in size, a header buffer may store up to thirty-two small packets. For each packet stored in the header buffer, another completion descriptor is generated.

FIG. 11 includes diagrams of illustrative embodiments of flow re-assembly table 1004, header table 1006, MTU table 1008 and jumbo table 1010. One alternative embodiment of the invention includes a non-re-assembly table in place of MTU table 1008 and jumbo table 1010, corresponding to a single type of non-re-assembly buffer for both MTU and jumbo packets. Jumbo table 1010 may also be omitted in another alternative embodiment of the invention in which jumbo buffers are retrieved or identified only when needed. Because a jumbo buffer is used only once in this alternative embodiment, there is no need to maintain a table to track its use.

Flow re-assembly table 1004 in the illustrated embodiment stores information concerning the re-assembly of packets in one or more communication flows. For each flow that is active through DMA engine 120, separate flow re-assembly buffers may be used to store the flow's data. More than one buffer may be used for a particular flow, but each flow has one entry in flow re-assembly table 1004 with which to track the use of a buffer. As described in a previous section, one embodiment of the invention supports the interleaving of up to sixty-four flows. Thus, flow re-assembly buffer table 1004 in this embodiment maintains up to sixty-four entries. A flow's entry in the flow re-assembly table may match its flow number (e.g., the index of the flow's flow key in flow database 110) or, in an alternative embodiment, an entry may be used for any flow.

In FIG. 11, an entry in flow re-assembly table 1004 includes flow re-assembly buffer index 1102, next address 1104 and validity indicator 1106. Flow re-assembly buffer index 1102 comprises the index, or position, within a free buffer array or other data structure for storing buffer identifiers identified in free descriptors, of a buffer for storing data from the associated flow. Illustratively, this value is written into each completion descriptor associated with a packet whose data portion is stored in the buffer. This value may be used by software operating on the host computer to access the buffer and process the data. Next address 1104 identifies the location within the buffer (e.g., a memory address) at which to store the next portion of data. Illustratively, this field is updated each time data is added to the buffer. Validity indicator 1106 indicates whether the entry is valid. Illustratively, each entry is set to a valid state (e.g., stores a first value) when a first portion of data is stored in the flow's re-assembly buffer and is invalidated (e.g.,

stores a second value) when the buffer is full. When an entry is invalidated, the buffer may be released or returned to the host computer (e.g., because it is full).

Header table 1006 in the illustrated embodiment stores information concerning one or more header buffers in which packet headers and small packets are stored. In the illustrated embodiment of the invention, only one header buffer is active at a time. That is, headers and small packets are stored in one buffer until it is released, at which time a new buffer is used. In this embodiment, header table 1006 includes header buffer index 1112, next address 1114 and validity indicator 1116. Similar to flow re-assembly table 1004, header buffer index 1112 identifies the cell or element in the free buffer array that contains a buffer identifier for a header buffer. Next address 1114 identifies the location within the header buffer at which to store the next header or small packet. This identifier, which may be a counter, may be updated each time a header or small packet is stored in the header buffer. Validity indicator 1116 indicates whether the header buffer table and/or the header buffer is valid. This indicator may be set to valid when a first packet or header is stored in a header buffer and may be invalidated when it is released to the host computer.

MTU table 1008 stores information concerning one or more MTU buffers for storing MTU packets (e.g., packets larger than 256 bytes but less than 1523 bytes) that are not being re-assembled. MTU buffer index 1122 identifies the free buffer array element that contains a buffer identifier (e.g., address) of a buffer for storing MTU packets. Next address 1124 identifies the location in the current MTU buffer at which to store the next packet. Validity indicator 1126 indicates the validity of the table entry. The validity indicator may be set to a valid state when a first packet is stored in the MTU buffer and an invalid state when the buffer is to be released to the host computer.

Jumbo table 1010 stores information concerning one or more jumbo buffers for storing jumbo packets (e.g., packets larger than 1522 bytes) that are not being re-assembled. Jumbo buffer index 1132 identifies the element within the free buffer array that stores a buffer identifier corresponding to a jumbo buffer. Next address 1134 identifies the location in the jumbo buffer at which to store the next packet. Validity indicator 1136 indicates the validity of the table entry. Illustratively, the validity indicator is set to a valid state when a first packet is stored in the jumbo buffer and is set to an invalid state when the buffer is to be released to the host computer.

In the embodiment of the invention depicted in FIG. 11, a packet larger than a specified size (e.g., 256 bytes) is not re-assembled if it is incompatible with the pre-selected protocols for NIC 100 (e.g., TCP, IP, Ethernet) or if the packet is too large (e.g., greater than 1522 bytes). Although two types of buffers (e.g., MTU and jumbo) are used for non-re-assembleable packets in this embodiment, in an alternative embodiment of the invention any number may be used, including one. Packets less than the specified size are normally not re-assembled. Instead, as described above, they are stored intact in a header buffer.

In the embodiment of the invention depicted in FIG. 11, address fields may store a memory address, offset, counter or other means of identifying a position within a buffer. Advantageously, the next address field of a table entry is initially set to the address of the buffer assigned to store packets of the type associated with the table (e.g., for re-assembly table 1004, the particular flow). As the flow is populated, the address is updated to identify the location in the buffer at which to store the next packet or portion of a packet.

Illustratively, each validity indicator stores a first value (e.g., one) to indicate validity, and a second value (e.g., zero) to indicate invalidity. In the illustrated embodiment of the invention, each index field is thirteen bits, each address field is sixty-four bits and the validity indicators are each one bit in size.

Tables 1004, 1006, 1008 and 1010 may take other forms and remain within the scope of the invention as contemplated. For example, these data structures may take the form of arrays, lists, databases, etc., and may be implemented in hardware or software. In the illustrated embodiment of the invention, header table 1006, MTU table 1008 and jumbo table 1010 each contain only one entry at a time. Thus, only one header buffer, MTU buffer and jumbo buffer are active (e.g., valid) at a time in this embodiment. In an alternative embodiment of the invention, multiple header buffers, MTU buffers and/or jumbo buffers may be used (e.g., valid) at once.

In one embodiment of the invention, certain categories of buffers (e.g., header, non-re-assembly) may store a predetermined number of packets or packet portions. For example, where the memory page size of a host computer processor is eight kilobytes, a header buffer may store a maximum of thirty-two entries, each of which is 256 bytes. Illustratively, even when one packet or header is less than 256 bytes, the next entry in the buffer is stored at the next 256-byte boundary. A counter may be associated with the buffer and decremented (or incremented) each time a new entry is stored in the buffer. After thirty-two entries have been made, the buffer may be released.

In one embodiment of the invention, buffers other than header buffers may be divided into fixed-size regions. For example, in an eight-kilobyte MTU buffer, each MTU packet may be allocated two kilobytes. Any space remaining in a packet's area after the packet is stored may be left unused or may be padded.

In one alternative embodiment of the invention, entries in a header buffer and/or non-re-assembly buffer (e.g., MTU, jumbo) are aligned for more efficient transfer. In particular, two bytes of padding (e.g., random bytes) are stored at the beginning of each entry in such a buffer. Because a packet's layer two Ethernet header is fourteen bytes long, by adding two pad bytes each packet's layer three protocol header (e.g., IP) will be aligned with a sixteen-byte boundary. Sixteen-byte alignment, as one skilled in the art will appreciate, allows efficient copying of packet contents (such as the layer three header). The addition of two bytes may, however, decrease the size of the maximum packet that may be stored in a header buffer (e.g., to 254 bytes).

As explained above, counters and/or padding may also be used with non-re-assembly buffers. Some non-re-assembleable packets (e.g., jumbo packets) may, however, be split into separate header and data portions, with each portion being stored in a separate buffer—similar to the re-assembly of flow packets. In one embodiment of the invention padding is only used with header portions of split packets. Thus, when a non-re-assembled (e.g., jumbo) packet is split, padding may be applied to the header/small buffer in which the packet's header portion is stored but not to the non-re-assembly buffer in which the packet's data portion is stored. When, however, a non-re-assembly packet is stored with its header and data together in a non-re-assembly buffer, then padding may be applied to that buffer.

In another alternative embodiment of the invention, a second level of padding may be added to each entry in a buffer that stores non-re-assembled packets that are larger than 256 bytes (e.g., MTU packets and jumbo packets that

are not split). In this alternative embodiment, a cache line of storage (e.g., sixty-four bytes for a Solaris™ workstation) is skipped in the buffer before storing each packet. The extra padding area may be used by software that processes the packets and/or their completion descriptors. The software may use the extra padding area for routing or as temporary storage for information needed in a secondary or later phase of processing.

For example, before actually processing the packet, the software may store some data that promotes efficient multi-tasking in the padding area. The information is then available when the packet is finally extracted from the buffer. In particular, in one embodiment of the invention a network interface may generate one or more data values to identify multicast or alternate addresses that correspond to a layer two address of a packet received from a network. The multicast or alternate addresses may be stored in a network interface memory by software operating on a host computer (e.g., a device driver). By storing the data value(s) in the padding, enhanced routing functions can be performed when the host computer processes the packet.

Reserving sixty-four bytes at the beginning of a buffer also allows header information to be modified or prepended if necessary. For example, a regular Ethernet header of a packet may, because of routing requirements, need to be replaced with a much larger FDDI (Fiber Distributed Data Interface) header. One skilled in the art will recognize the size disparity between these headers. Advantageously, the reserved padding area may be used for the FDDI header rather than allocating another block of memory.

In a present embodiment of the invention DMA engine 120 may determine which category a packet belongs in, and which type of buffer to store the packet in, by examining the packet's operation code. As described in a previous section, an operation code may be stored in control queue 118 for each packet stored in packet queue 116. Thus, when DMA engine 120 detects a packet in packet queue 116, it may fetch the corresponding information in the control queue and act appropriately.

An operation code may indicate whether a packet is compatible with the protocols pre-selected for NIC 100. In an illustrative embodiment of the invention, only compatible packets are eligible for data re-assembly and/or other enhanced operations offered by NIC 100 (e.g., packet batching or load distribution). An operation code may also reflect the size of a packet (e.g., less than or greater than a predetermined size), whether a packet contains data or is a control packet, and whether a packet initiates, continues or ends a flow. In this embodiment of the invention, eight different operation codes are used. In alternative embodiments of the invention more or less than eight codes may be used. TABLE 1 lists operation codes that may be used in one embodiment of the invention.

FIGS. 12A-12B illustrate descriptors from a free descriptor ring and a completion descriptor ring in one embodiment of the invention. FIG. 12A also depicts a free buffer array for storing buffer identifiers retrieved from free descriptors.

Free descriptor ring 1200 is maintained in host memory and is populated with descriptors such as free descriptor 1202. Illustratively, free descriptor 1202 comprises ring index 1204, the index of descriptor 1202 in free ring 1200, and buffer identifier 1206. A buffer identifier in this embodiment is a memory address, but may, alternatively, comprise a pointer or any other suitable means of identifying a buffer in host memory.

In the illustrated embodiment, free buffer array 1210 is constructed by software operating on a host computer (e.g.,

a device driver). An entry in free buffer array 1210 in this embodiment includes array index field 1212, which may be used to identify the entry, and buffer identifier field 1214. Each entry's buffer identifier field thus stores a buffer identifier retrieved from a free descriptor in free descriptor ring 1200.

In one embodiment of the invention, free ring manager 1012 of DMA engine 120 retrieves descriptor 1202 from the ring and stores buffer identifier 1206 in free buffer array 1210. The free ring manager also passes the buffer identifier to flow re-assembly table 1004, header table 1006, MTU table 1008 or jumbo table 1010 as needed. In another embodiment the free ring manager extracts descriptors from the free descriptor ring and stores them in a descriptor cache until a buffer is needed, at which time the buffer's buffer identifier is stored in the free buffer array. In yet another embodiment, a descriptor may be used (e.g., the buffer that it references may be used to store a packet) while still in the cache.

In one embodiment of the invention descriptor 1202 is sixteen bytes in length. In this embodiment, ring index 1204 is thirteen bits in size, buffer identifier 1206 (and buffer identifier field 1214 in free buffer array 1210) is sixty-four bits, and the remaining space may store other information or may not be used. The size of array index field 1212 depends upon the dimensions of array 1210; in one embodiment the field is thirteen bits in size.

Completion descriptor ring 1220 is also maintained in host memory. Descriptors in completion ring 1220 are written or configured when a packet is transferred to the host computer by DMA engine 120. The information written to a descriptor, such as descriptor 1222, is used by software operating on the host computer (e.g., a driver associated with NIC 100) to process the packet. Illustratively, an ownership indicator (described below) in the descriptor indicates whether DMA engine 120 has finished using the descriptor. For example, this field may be set to a particular value (e.g., zero) when the DMA engine finishes using the descriptor and a different value (e.g., one) when it is available for use by the DMA engine. However, in another embodiment of the invention, DMA engine 120 issues an interrupt to the host computer when it releases a completion descriptor. Yet another means of alerting the host computer may be employed in an alternative embodiment. Descriptor 1222, in one embodiment of the invention, is thirty-two bytes in length.

In the illustrated embodiment of the invention, information stored in descriptor 1222 concerns a transferred packet and/or the buffer it was stored in, and includes the following fields. Data size 1230 reports the amount of data in the packet (e.g., in bytes). The data size field may contain a zero if there is no data portion in the packet or no data buffer (e.g., flow re-assembly buffer, non-re-assembly buffer, jumbo buffer, MTU buffer) was used. Data buffer index 1232 is the index, within free buffer array 1210, of the buffer identifier for the flow re-assembly buffer, non-re-assembly buffer, jumbo buffer or MTU buffer in which the packet's data was stored. When the descriptor corresponds to a small packet fully stored in a header buffer, this field may store a zero or remain unused. Data offset 1234 is the offset of the packet's data within the flow re-assembly buffer, non-re-assembly buffer, jumbo buffer or MTU buffer (e.g., the location of the first byte of data within the data buffer).

In FIG. 12B, flags field 1236 includes one or more flags concerning a buffer or packet. For example, if a header buffer or data is being released (e.g., because it is full), a release header or release data flag, respectively, is set. A

release flow flag may be used to indicate whether a flow has, at least temporarily, ended. In other words, if a release flow flag is set (e.g., stores a value of one), this indicates that there are no other packets waiting in the packet queue that are in the same flow as the packet associated with descriptor 1222. Otherwise, if this flag is not set (e.g., stores a value of zero), software operating on the host computer may queue this packet to await one or more additional flow packets so that they may be processed collectively. A split flag may be included in flags field 1236 to identify whether a packet's contents (e.g., data) spans multiple buffers. Illustratively, if the split flag is set, there will be an entry in next data buffer index 1240, described below.

Descriptor type 1238, in the presently described embodiment of the invention, may take any of three values. A first value (e.g., one) indicates that DMA engine 120 is releasing a flow buffer for a flow that is stale (e.g., no packet has been received in the flow for some period of time). A second value (e.g., two) may indicate that a non-re-assembleable packet was stored in a buffer. A third value (e.g., three) may be used to indicate that a flow packet (e.g., a packet that is part of a flow through NIC 100) was stored in a buffer.

Next buffer index 1240 stores an index, in free buffer array 1210, of an entry containing a buffer identifier corresponding to a buffer storing a subsequent portion of a packet of the entire packet, or its data, could not fit into the first assigned buffer. The offset in the next buffer may be assumed to be zero. Header size 1242 reports the length of the header (e.g., in bytes). The header size may be set to zero if the header buffer was not used for this packet (e.g., the packet is not being re-assembled and is not a small packet). Header buffer index 1244 is the index, in free buffer array 1210, of the buffer identifier for the header buffer used to store this packet's header. Header offset 1246 is the offset of the packet's header within the buffer (e.g., header buffer) in which the header was stored. The header offset may take the form of a number of bytes into the buffer at which the header may be found. Alternatively, the offset may be an index value, reporting the index position of the header. For example, in an embodiment of the invention mentioned above, entries in the header buffer are stored in 256-byte units. Thus, each entry begins at a 256-byte boundary regardless of the actual size of the entries. The 256-byte entries may be numbered or indexed within the buffer.

In the illustrated embodiment, flow number 1250 is the packet's flow number (e.g., the index in flow database 110 or the packet's flow key). Flow number 1250 may be used to identify packets in the same flow. Operation code 1252 is generated by flow database manager 108, as described in a previous section, and used by DMA engine 120 to process the packet and transfer it into an appropriate memory buffer. Methods of transferring a packet depending upon its operation code are described in detail in the following section. No\_Assist signal 1254, also described in a previous section, may be set or raised when the packet is not compatible with the protocols pre-selected for NIC 100. One problem of incompatibility is that header parser 106 may not be able to parse the packet, in which case the packet will not receive the subsequent benefits. Processor identifier 1256, which may be generated by load distributor 112, identifies a host computer system processor for processing the packet. As described in a previous section, load distributor 112 attempts to share or distribute the load of processing the packet among multiple processors by having all packets within one flow processed by the same processor. Processor header offset 1258 reports an offset within the buffer from the first byte of the packet's layer three protocol

(e.g., IP) header. With this value, software operating on the host computer may easily strip off one or more headers or header portions.

Checksum value 1260 is a checksum computed for this packet by checksum generator 114. Packet length 1262 is the length (e.g., in bytes) of the entire packet.

Ownership indicator 1264 is used in the presently described embodiment of the invention to indicate whether NIC 100 or software operating on the host computer "owns" completion descriptor 1222. In particular, a first value (e.g., zero) is placed in the ownership indicator field when NIC 100 (e.g., DMA engine 120) has completed configuring the descriptor. Illustratively, this first value is understood to indicate that the software may now process the descriptor. When finished processing the descriptor, the software may store a second value (e.g., one) in the ownership indicator to indicate that NIC 100 may now use the descriptor for another packet.

One skilled in the art will recognize that there are numerous methods that may be used to inform host software that a descriptor has been used by, or returned to, DMA engine 120. In one embodiment of the invention, for example, one or more registers, pointers or other data structures are maintained to indicate which completion descriptors in a completion descriptor ring have or have not been used. In particular, a head register may be used to identify a first of a series of descriptors that are owned by host software, while a tail register identifies the last descriptor in the series. DMA engine 120 may update these registers as it configures and releases descriptors. Thus, by examining these registers the host software and the DMA engine can determine how many descriptors have or have not been used.

Finally, other information, flags and indicators may be stored in other field 1266. Other information that may be stored in one embodiment of the invention includes the length and/or offset of a TCP payload, flags indicating a small packet (e.g., less than 257 bytes) or a jumbo packet (e.g., more than 1522 bytes), a flag indicating a bad packet (e.g., CRC error), a checksum starting position, etc.

In alternative embodiments of the invention only information and flags needed by the host computer (e.g., driver software) are included in descriptor 1222. Thus, in one alternative embodiment one or more fields other than the following may be omitted: data size 1230, data buffer index 1232, data offset 1234, a split flag, next data buffer index 1240, header size 1242, header buffer index 1244, header offset 1246 and ownership indicator 1264.

In addition, a completion descriptor may be organized in virtually any form; the order of the fields of descriptor 1222 in FIG. 12 is merely one possible configuration. It is advantageous, however, to locate ownership indicator 1264 towards the end of a completion descriptor since this indicator may be used to inform host software when the DMA engine has finished populating the descriptor. If the ownership indicator were placed in the beginning of the descriptor, the software may read it and attempt to use the descriptor before the DMA engine has finished writing to it.

One skilled in the art will recognize that other systems and methods than those described in this section may be implemented to identify storage areas in which to place packets being transferred from a network to a host computer without exceeding the scope of the invention.

Methods of Transferring a Packet into a Memory Buffer by a DMA Engine

FIGS. 13-20 are flow charts describing procedures for transferring a packet into a host memory buffer. In these procedures, a packet's operation code helps determine

which buffer or buffers the packet is stored in. An illustrative selection of operation codes that may be used in this procedure are listed and explained in TABLE 1.

The illustrated embodiments of the invention employ four categories of host memory buffers, the sizes of which are programmable. The buffer sizes are programmable in order to accommodate various host platforms, but are programmed to be one memory page in size in present embodiments in order to enhance the efficiency of handling and processing network traffic. For example, the embodiments discussed in this section are directed to the use of a host computer system employing a SPARC™ processor, and so each buffer is eight kilobytes in size. These embodiments are easily adjusted, however, for host computer systems employing memory pages having other dimensions.

One type of buffer is for re-assembling data from a flow, another type is for headers of packets being re-assembled and for small packets (e.g., those less than or equal to 256 bytes in size) that are not re-assembled. A third type of buffer stores packets up to MTU size (e.g., 1522 bytes) that are not re-assembled, and a fourth type stores jumbo packets that are greater than MTU size and which are not re-assembled. These buffers are called flow re-assembly, header, MTU and jumbo buffers, respectively.

The procedures described in this section make use of free descriptors and completion descriptors as depicted in FIG. 12. In particular, in these procedures free descriptors retrieved from a free descriptor ring store buffer identifiers (e.g., memory addresses, pointers) for identifying buffers in which to store a portion of a packet. A used buffer may be returned to a host computer by identifying the location within a free buffer array or other data structure used to store the buffer's buffer identifier. One skilled in the art will recognize that these procedures may be readily adapted to work with alternative methods of obtaining and returning buffers for storing packets.

FIG. 13 is a top-level view of the logic controlling DMA engine 120 in this embodiment of the invention. State 1300 is a start state.

In state 1302, a packet is stored in packet queue 116 and associated information is stored in control queue 118. One embodiment of a packet queue is depicted in FIG. 8 and one embodiment of a control queue is depicted in FIG. 9. DMA engine 120 may detect the existence of a packet in packet queue 116 by comparing the queue's read and write pointers. As long as they do not reference the same entry, then it is understood that a packet is stored in the queue. Alternatively, DMA engine 120 may examine control queue 118 to determine whether an entry exists there, which would indicate that a packet is stored in packet queue 116. As long as the control queue's read and write pointers do not reference the same entry, then an entry is stored in the control queue and a packet must be stored in the packet queue.

In state 1304, the packet's associated entry in the control queue is read. Illustratively, the control queue entry includes the packet's operation code, the status of the packet's No\_Assist signal (e.g., indicating whether or not the packet is compatible with a pre-selected protocol), one or more indicators concerning the size of the packet (and/or its data portion), etc.

In state 1306, DMA engine 120 retrieves the packet's flow number. As described previously, a packet's flow number is the index of the packet's flow in flow database 110. A packet's flow number may, as described in a following section, be provided to and used by dynamic packet batching module 122 to enable the collective processing of headers from related packets. In one embodiment of the invention, a

packet's flow number may be provided to any of a number of NIC modules (e.g., IPP module 104, packet batching module 122, DMA engine 120, control queue 118) after being generated by flow database manager 108. The flow number may also be stored in a separate data structure (e.g., a register) until needed by dynamic packet batching module 122 and/or DMA engine 120. In one embodiment of the invention DMA engine 120 retrieves a packet's flow number from dynamic packet batching module 122. In an alternative embodiment of the invention, the flow number may be retrieved from a different location or module.

Then, in states 1308-1318, DMA engine 120 determines the appropriate manner of processing the packet by examining the packet's operation code. The operation code may, for example, indicate which buffer the engine should transfer the packet into and whether a flow is to be set up or torn down in flow re-assembly buffer table 1004.

The illustrated procedure continues at state 1400 (FIG. 14) if the operation code is 0, state 1500 (FIG. 15) for operation code 1, state 1600 (FIG. 16) for operation code 2, state 1700 (FIG. 17) for operation code 3, state 1800 (FIG. 18) for operation code 4, state 1900 (FIG. 19) for operation code 5 and state 2000 (FIG. 20) for operation codes 6 and 7.

#### 25 A Method of Transferring a Packet with Operation 0

FIG. 14 depicts an illustrative procedure in which DMA engine 120 transfers a packet associated with operation code 0 to a host memory buffer. As reflected in TABLE 1, operation code 0 indicates in this embodiment that the packet is compatible with the protocols that may be parsed by NIC 100. As explained above, compatible packets are eligible for re-assembly, such that data from multiple packets of one flow may be stored in one buffer that can then be efficiently provided (e.g., via a page-flip) to a user or program's memory space. Packets having operation code 0, however, are small and contain no flow data for re-assembly. They are thus likely to be control packets. Therefore, no new flow is set up, no existing flow is torn down and the entire packet may be placed in a header buffer.

In state 1400, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set (e.g., equal to one), then there is a header buffer ready to receive this packet and the procedure continues at state 1404.

Otherwise, in state 1402 a header buffer is prepared or initialized for storing small packets (e.g., packets less than 257 bytes in size) and headers of re-assembled packets (and, possibly, headers of other packets—such as jumbo packets). In the illustrated embodiment, this initialization process involves obtaining a free ring descriptor and retrieving its buffer identifier (e.g., its reference to an available host memory buffer). The buffer identifier may then be stored in a data structure such as free buffer array 1210 (shown in FIG. 12A). As described above, in one embodiment of the invention free ring manager 1012 maintains a cache of descriptors referencing empty buffers. Thus, a descriptor may be retrieved from this cache and its buffer allocated to header buffer table 1006. If the cache is empty, new descriptors may be retrieved from a free descriptor ring in host memory to replenish the cache.

When a new buffer identifier is retrieved from the cache or from the free descriptor ring, the buffer identifier's position in the free buffer array is placed in header buffer index 1112 of header buffer table 1006. Further, an initial



storage location in the buffer identifier (e.g., its starting address) is stored in next address field 1114 and validity indicator 1116 is set to a valid state.

In state 1404, the packet is copied or transferred (e.g., via a DMA operation) into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes are inserted before the packet in order to align the beginning of the packet's layer three (e.g., IP) header with a sixteen-byte boundary. In addition, a header buffer may be logically partitioned into cells of predetermined size (e.g., 256 bytes), in which case the packet or padding may begin at a cell boundary.

In state 1406, a completion descriptor is written or configured to provide information to the host computer (e.g., a software driver) for processing the packet. In particular, the header buffer index (e.g. the index within the free buffer array of the buffer identifier that references the header buffer) and the packet's offset in the header buffer are placed in the descriptor. Illustratively, the offset may identify the location of the cell in which the header is stored, or it may identify the first byte of the packet. The size of the packet is also stored in the descriptor, illustratively within a header size field. A data size field within the descriptor is set to zero to indicate that the entire packet was placed in the header buffer (e.g., there was no data portion to store in a separate data buffer). A release header flag is set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time.

As described in a later section, in one embodiment of the invention a release flow flag may also be set, depending upon dynamic packet batching module 122. For example, if the packet batching module determines that another packet in the same flow will soon be transferred to the host computer, the release flow flag will be cleared (e.g., a zero will be stored). This indicates that the host computer should wait the next flow packet before processing this one. Then, collectively processing multiple packets from a single flow, the packets can be processed more efficiently while requiring less processor time.

In the descriptor type field, a value is stored to indicate if a flow packet was transferred to host memory. Also, a determined value (e.g., zero) is stored in the ownership indicator field to indicate that DMA engine 120 is done using the descriptor and/or is releasing a packet to the host computer. Illustratively, the host computer will detect the change in the ownership indicator (e.g., from one to zero) to use the stored information to process the packet. In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or other signal to alert the host computer a descriptor is being released. In another alternative embodiment, the host computer polls the NIC to determine if a packet has been received and/or transferred. In yet another alternative embodiment, the descriptor type field is used to inform the host computer that the DMA engine is releasing a descriptor. In this alternative embodiment, when a zero value is placed in the descriptor type field the host computer may understand that the DMA engine is releasing the descriptor.

In the present embodiment of the invention, the ownership indicator field is not changed until DMA engine 120 is done with any other processing involving this packet or until making all entries in the descriptor. For example, the ownership indicator field may be set to a value described below a header buffer or other buffer may be full at some time, after state 1406. By delaying

the setting of the ownership indicator, a release header flag can be set before the descriptor is reclaimed by the host computer, thus avoiding the use of another descriptor.

In state 1408, it is determined whether the header buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, up to thirty-two entries may be stored in a header buffer. Thus, a counter may be used to keep track of entries placed in each new header buffer and the buffer can be considered full when thirty-two entries are stored. Other methods of determining whether a buffer is full are also suitable. For example, after a packet is stored in the header buffer a new next address field may be calculated and the difference between the new next address field and the initial address of the buffer may be compared to the size of the buffer (e.g., eight kilobytes). If less than a predetermined number of bytes (e.g., 256) are unused, the buffer may be considered full.

If the buffer is full, in state 1410 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer via a descriptor. In this embodiment of the invention a release header flag in the descriptor is set. If the descriptor that was written in state 1406 was already released (e.g., its ownership indicator field changed), another descriptor may be used in this state. If another descriptor is used simply to report a full header buffer, the descriptor's header size and data size fields may be set to zero to indicate that no new packet was transferred with this descriptor.

If the header buffer is not full, then in state 1412 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet. The processing associated with a packet having operation code 0 then ends with end state 1499. In one embodiment of the invention, the ownership indicator field of a descriptor that is written in state 1406 is not changed, or an interrupt is not issued, until end state 1499. Delaying the notification of the host computer allows the descriptor to be updated or modified for as long as possible before turning it over to the host.

A Method of Transferring a Packet with Operation Code 1

FIG. 15 depicts an illustrative procedure in which DMA engine 120 transfers a packet associated with operation code 1 to a host memory buffer. As reflected in TABLE 1, in this embodiment operation code 1 indicates that the packet is compatible with the protocols that may be parsed by NIC 100. A packet having operation code 1, however, may be a control packet having a particular flag set. No new flow is set up, but a flow should already exist and is to be torn down; there is no data to re-assemble and the entire packet may be stored in a header buffer.

In state 1500, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there is a header buffer ready to receive this packet and the procedure continues at state 1504.

Otherwise, in state 1502 a new header buffer is prepared or initialized for storing small packets and headers of re-assembled packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, its buffer identifier (e.g., pointer, address, index) is stored in free buffer array 1210 and its initial storage location (e.g., address or cell location) is stored in next address field 1114 of header buffer table 1006. The index or position of the buffer identifier within the free buffer array is stored in header buffer index 1112. Finally, validity indicator 1116 is set to a valid state.

In state 1504 the packet is copied into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes are inserted before the packet in order to align the beginning of the packet's layer three (e.g., IP) header with a sixteen-byte boundary. And, the packet (with or without padding) may be placed into a pre-defined area or cell of the buffer.

In the illustrated embodiment, operation code 1 indicates that the packet's existing flow is to be torn down. Thus, in state 1506 it is determined whether a flow re-assembly buffer is valid (e.g., active) for this flow by examining the flow's validity indicator in flow re-assembly buffer table 1004. If, for example, the indicator is valid, then there is an active buffer storing data from one or more packets in this flow. Illustratively, the flow is torn down by invalidating the flow re-assembly buffer and releasing it to the host computer. If there is no valid flow re-assembly buffer for this flow, the illustrated procedure continues at state 1512. Otherwise, the procedure proceeds to state 1508.

In state 1508, a completion descriptor is configured to release the flow's re-assembly buffer and to provide information to the host computer for processing the current packet. In particular, the header buffer index and the offset of the first byte of the packet (or location of the packet's cell) within the header buffer are placed in the descriptor. The index within the free buffer array of the entry containing the re-assembly buffer's buffer identifier is stored in a data index of the descriptor. The size of the packet is stored in a data size field and a data size field is set to zero to indicate no separate buffer was used for storing this packet's data. A release header flag is set in the descriptor if the re-assembly buffer is full and a release data flag is set to indicate no more data will be placed in this flow's present re-assembly buffer (e.g., it is being released). In addition, a release flow flag is set to indicate that DMA engine 120 is tearing down the packet's flow. The header buffer may not be seen if it is full until a later state of this procedure. In an embodiment of the invention, the release header flag may be set at that time.

In state 1510, the flow's entry in flow re-assembly buffer table 1004 is invalidated. After state 1510, the procedure proceeds to state 1514.

In state 1512, a completion descriptor is configured with information somewhat different than that of state 1508. In particular, the header buffer index, the offset to this packet within the header buffer and the packet size are placed in the same descriptor fields as above. The data size field is set to zero, as above, but no data index needs to be stored in the descriptor. A release data flag is set (e.g., because there is no flow re-assembly buffer to release). A release header flag is still set in the descriptor if the header buffer is full and a release flow flag is set to indicate that DMA engine 120 is tearing down the packet's flow. Also, the descriptor type field is set to a value indicating that DMA engine 120 is releasing the flow packet into host memory.

In state 1514, it is determined whether the header buffer

buffer are no larger than 256 bytes, a counter is used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are stored.

If the buffer is full, in state 1516 the header buffer is invalidated. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer via the descriptor configured in state 1508 or state 1512. In this embodiment of the invention a release header flag in the descriptor is set to indicate that the header buffer is full.

If the header buffer is not full, then in state 1518 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet.

The processing associated with a packet having operation code 1 then ends with end state 1599. In this end state, the descriptor used for this packet is turned over to the host computer by changing its ownership indicator field (e.g., from one to zero), issuing an interrupt, or some other mechanism.

One skilled in the art will appreciate that in an alternative embodiment of the invention a change in the descriptor type field to any value other than the value (e.g., zero) it had when DMA engine 120 was using it, may constitute a surrender of "ownership" of the descriptor to the host computer or software operating on the host computer. The host computer will detect the change in the descriptor type field and subsequently use the stored information to process the packet.

A Method of Transferring a Packet with Operation Code 2

FIGS. 16A-16F illustrate a procedure in which DMA engine 120 transfers a packet associated with operation code 2 to a host memory buffer. As reflected in TABLE 1, operation code 2 may indicate that the packet is compatible with the protocols that may be parsed by NIC 100, but that it is out of sequence with another packet in the same flow. It may also indicate an attempt to re-establish a flow, but that no more data is likely to be received after this packet. For operation code 2, no new flow is set up and any existing flow with the packet's flow number is to be torn down. The packet's data is not to be re-assembled with data from other packets in the same flow.

Because an existing flow is to be torn down (e.g., the flow's re-assembly buffer is to be invalidated and released to the host computer), in state 1600 it is determined whether a flow re-assembly buffer is valid (e.g., active) for the flow having the flow number that was read in state 1306. This determination may be made by examining the validity indicator in the flow's entry in flow re-assembly buffer table 1004. Illustratively, if the indicator is valid then there is an active buffer storing data from one or more packets in the flow. If there is a valid flow re-assembly buffer for this flow, the illustrated procedure continues at state 1602. Otherwise, the procedure proceeds to state 1606.

In state 1602, a completion descriptor is written or configured to release the existing flow re-assembly buffer. In particular, the flow re-assembly buffer's index (e.g., the location within the free buffer array that contains the buffer identifier corresponding to the flow re-assembly buffer) is written to the descriptor. In this embodiment of the invention, no offset needs to be stored in the descriptor's data offset field and the data size field may be set to zero because no new data was stored in the re-assembly buffer. Similarly, the header buffer is not yet being released, therefore the header index and header offset fields of the descrip-

Illustratively, the descriptor's release header flag is cleared (e.g., a zero is stored in the flag) because the header buffer is not to be released. The release data flag is set (e.g., a one is stored in the flag), however, because no more data will be placed in the released flow re-assembly buffer. Further, a release flow flag in the descriptor is also set, to indicate that the flow associated with the released flow re-assembly buffer is being torn down.

The descriptor type field may be changed to a value indicating that DMA engine 120 is releasing a stale flow buffer (e.g., a flow re-assembly buffer that has not been used for some time). Finally, the descriptor is turned over to the host computer by changing its ownership indicator field or by issuing an interrupt or using some other mechanism. In one embodiment of the invention, however, the descriptor is not released to the host computer until end state 1699.

Then, in state 1604, the flow re-assembly buffer is invalidated by modifying validity indicator 1106 in the flow's entry in flow re-assembly buffer table 1004 appropriately.

In state 1606, it is determined whether the present packet is a small packet (e.g., less than or equal to 256 bytes in size), suitable for storage in a header buffer. If so, the illustrated procedure proceeds to state 1610. Information stored in packet queue 116 and/or control queue 118 may be used to make this determination.

In state 1608, it is determined whether the present packet is a jumbo packet (e.g., greater than 1522 bytes in size), such that it should be stored in a jumbo buffer. If so, the illustrated procedure proceeds to state 1650. If not, the procedure continues at state 1630.

In state 1610 (reached from state 1606), it has been determined that the present packet is a small packet suitable for storage in a header buffer. Therefore, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there should be a header buffer ready to receive this packet and the procedure continues at state 1614.

Otherwise, in state 1612 a new header buffer is prepared or initialized for storing small packets and headers of re-assembled packets. This initialization process may involve obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indicator of the first storage location in the buffer is placed in the next address field 1114 of header buffer table 1006. The buffer identifier's position or index within the free buffer array is stored in header buffer index 1112, and validity indicator 1116 is set to a valid state.

In state 1614 the packet is copied or transferred (e.g., via DMA operation) into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes are inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet may be positioned within a cell of predetermined size (e.g., 256 bytes) within the header buffer.

In state 1616, a completion descriptor is written or configured to provide necessary information to the host com-

puter (e.g., a software driver) for processing the packet. In particular, the header buffer index (e.g. the position within the free buffer array of the header buffer's buffer identifier) and the packet's offset within the header buffer are placed in the descriptor. Illustratively, this offset may serve to identify the first byte of the packet, the first pad byte before the packet or the beginning of the packet's cell within the buffer. The size of the packet is also stored in the descriptor in a header size field. A data size field within the descriptor may be set to zero to indicate that the entire packet was placed in the header buffer (e.g., no separate data portion was stored). A release header flag is set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag is cleared (e.g., set to a value of zero), because there is no separate data portion being conveyed to the host computer.

Also, the descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. And, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator field is not changed until end state 1699 below. In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or other signal to alert the host computer that a descriptor is being released.

In state 1618, it is determined whether the header buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are stored.

If the buffer is full, in state 1620 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to an invalid state and communicating this status to the host computer. In this embodiment of the invention, a release header flag in the descriptor is set. The illustrated procedure then ends with end state 1699.

If the header buffer is not full, then in state 1622 the next address field of header buffer table 1006 is updated to indicate the address or cell boundary at which to store the next header or small packet. The illustrated procedure then ends with end state 1699.

In state 1630 (reached from state 1608), it has been determined that the packet is not a small packet or a jumbo packet. The packet may, therefore, be stored in a non-re-assembly buffer (e.g., an MTU buffer) used to store packets that are up to MTU in size (e.g., 1522 bytes). Thus, in state 1630 DMA engine 120 determines whether a valid (e.g., active) MTU buffer exists. Illustratively, this determination is made by examining validity indicator 1126 of MTU buffer table 1008, which manages an active MTU buffer. If the validity indicator is set, then there is an MTU buffer ready to receive this packet and the procedure continues at state 1634.

Otherwise, in state 1632 a new MTU buffer is prepared or initialized for storing non-re-assembleable packets up to 1522 bytes in size. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer (e.g., a buffer identifier). If the

cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in the free buffer array. The buffer's initial address or some other indication of the first storage location in the buffer is placed in next address field 1124 of MTU buffer table 1008. Further, the position of the buffer identifier within the free buffer array is stored in MTU buffer index 1122 and validity indicator 1126 is set to a valid state.

In state 1634 the packet is copied or transferred (e.g., via a DMA operation) into the MTU buffer at the address or location specified in the next address field. As described above, in one embodiment of the invention pad bytes may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In another embodiment of the invention packets may be aligned in an MTU buffer in cells of predefined size (e.g., two kilobytes), similar to entries in a header buffer.

In state 1636, a completion descriptor is written or configured to provide necessary information to the host computer (e.g., a software driver) for processing the packet. In particular, the MTU buffer index (e.g. the free buffer array element that contains the buffer identifier for the MTU buffer) and offset (e.g., the offset of the first byte of this packet within the MTU buffer) are placed in the descriptor in data index and data offset fields, respectively. The size of the packet is also stored in the descriptor, illustratively within a data size field. A header size field within the descriptor is set to zero to indicate that the entire packet was placed in the MTU buffer (e.g., no separate header portion was stored in a header buffer). A release data flag is set in the descriptor if the MTU buffer is full. However, the MTU buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release data flag may be set (or cleared) at that time. A release header flag is cleared (e.g., set to zero), because there is no separate header portion being conveyed to the host computer.

Further, the descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Also, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In a present embodiment of the invention the ownership field is not set until end state 1699. In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or other signal to alert the host computer that a descriptor is being released, or communicates this event to the host computer through the descriptor type field.

In state 1638, it is determined whether the MTU buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the MTU buffer are eight kilobytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer may be considered full when a predetermined number of entries (e.g., four) are stored. In an alternative embodiment of the invention DMA engine 120 determines how much free space within the buffer has yet to be used. If no space remains, or if less than a predetermined amount of space is available, the buffer may be considered full.

When the MTU buffer is full, in state 1640 it is invalidated to indicate that it is not used again. Illustratively, this involves

setting the MTU buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention, a release data flag in the descriptor is set. The illustrated procedure then ends with end state 1699.

If the MTU buffer is not full, then in state 1642 the next address field of MTU buffer table 1008 is updated to indicate the address or location (e.g., cell boundary) at which to store the next packet. The illustrated procedure then ends with end state 1699.

In state 1650 (reached from state 1608), it has been determined that the packet is a jumbo packet (e.g., that it is greater than 1522 bytes in size). In this embodiment of the invention jumbo packets are stored in jumbo buffers and, if splitting of jumbo packets is enabled (e.g., as determined in state 1654 below), headers of jumbo packets are stored in a header buffer. DMA engine 120 determines whether a valid (e.g., active) jumbo buffer exists. Illustratively, this a determination is made by examining validity indicator 1136 of jumbo buffer table 1010, which manages the active jumbo buffer. If the validity indicator is set, then there is a jumbo buffer ready to receive this packet and the procedure continues at state 1654. As explained above, a jumbo buffer table may not be used in an embodiment of the invention in which a jumbo buffer is used only once (e.g., to store just one, or just part of one, jumbo packet).

Otherwise, in state 1652 a new jumbo buffer is prepared or initialized for storing a non-re-assembleable packet that is larger than 1522 bytes. This initialization process may involve obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer (e.g., a buffer identifier). If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, its buffer identifier (e.g., pointer, address, index) is stored in a free buffer array (or other data structure). The buffer's initial address or other indication of the first storage location in the buffer is placed in next address field 1134 of jumbo buffer table 1010. Also, the location of the buffer identifier within the free buffer array is stored in jumbo buffer index 1132 and validity indicator 1136 is set to a valid state.

Then, in state 1654 DMA engine 120 determines whether splitting of jumbo buffers is enabled. If enabled, the header of a jumbo packet is stored in a header buffer while the packet's data is stored in one or more jumbo buffers. If not enabled, the entire packet will be stored in one or more jumbo buffers. Illustratively, splitting of jumbo packets is enabled or disabled according to the configuration of a programmable indicator (e.g., flag, bit, register) that may be set by software operating on the host computer (e.g., a device driver). If splitting is enabled, the illustrated procedure continues at state 1670. Otherwise, the procedure continues with state 1656.

In state 1656, DMA engine 120 determines whether the packet will fit into one jumbo buffer. For example, in an embodiment of the invention using eight kilobyte pages, if the packet is larger than eight kilobytes a second jumbo buffer will be needed to store the additional contents. If the packet is too large, the illustrated procedure continues at state 1662.

In state 1658, the packet is copied or transferred (e.g., via a DMA operation) into the current jumbo buffer, at the location specified in the next address field 1134 of jumbo buffer table 1010. When the packet is transferred intact like this, padding may be added to align a header portion of the

packet with a sixteen-byte boundary. One skilled in the art will appreciate that the next address field may not need to be related to account for this new packet because the jumbo header will be released. In other words, in one embodiment of the invention a jumbo buffer may be used just once (e.g., to store one packet or a portion of one packet).

In state 1660, a completion descriptor is written or configured to release the jumbo buffer and to provide information to the host computer for processing the packet. The jumbo buffer index (e.g., the position within the free buffer array of the buffer identifier for the jumbo buffer) and the offset of the packet within the jumbo buffer are placed in the descriptor. Illustratively, these values are stored in data size and data offset fields, respectively. The size of the packet (e.g., the packet length) may be stored in a data size

header size field is cleared (e.g., a zero is stored) to indicate that the header buffer was not used (e.g., the header is not stored separately from the packet's data). Because there is no separate packet header, header index and header offset fields are not used or are set to zero (e.g., the values in their fields do not matter). A release header flag is cleared and a release data flag is set to indicate that no more data will be placed in this jumbo buffer (e.g., because it is released).

Further, the descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-reassemblable packet into host memory. And, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In an alternative embodiment, the descriptor may be released by issuing an interrupt or alert. In yet another embodiment, changing the descriptor type field (e.g., to a non-zero value) may signal the release of the descriptor. In one embodiment of the invention, the ownership indicator is not set until end state 1668. After state 1660, the illustrated procedure ends at state 1668.

In state 1662, a first portion of the packet is stored in the jumbo buffer (e.g., valid) jumbo buffer, at the location identified in the next address field 1134. Then, because the full packet will not fit into this buffer, in state 1664 a new jumbo buffer is prepared and the remainder of the packet is stored in the new buffer.

In state 1666, a completion descriptor is written or configured. The contents are similar to those described in state 1660. This descriptor must reflect that two jumbo buffers were used to store the packet.

The jumbo buffer index (e.g., the index, within the free buffer array, of the buffer identifier that identifies the jumbo buffer) and the offset of the packet within the first jumbo buffer are placed in the descriptor, as above. The size of the packet (e.g., the packet length) is stored in a data size

header size field is cleared (e.g., a zero is stored) to indicate that the header buffer was not used (e.g., the header is not stored separately from the packet's data). Because there is no separate packet header, header index and header offset fields are not used (e.g., the values stored in their fields do not matter).

A release header flag is cleared and a release data flag is set to indicate that no more data will be placed in these buffers (e.g., because they are being released). A second release data flag is set to reflect the use of a second jumbo buffer, and the index (within the free buffer array) of the second buffer for the second buffer is stored in a next

Further, the descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-reassemblable packet into host memory. Finally, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field, or some other mechanism is employed, to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention, the descriptor is not released to the host computer until end state 1699 below.

In state 1668, the jumbo buffer entry or entries in jumbo buffer table 1010 are invalidated (e.g., validity indicator 1136 is set to invalid) to ensure that they are not used again. In the procedure described above a jumbo packet was stored in, at most, two jumbo buffers. In an alternative embodiment of the invention a jumbo buffer may be stored across any number of buffers. The descriptor(s) configured to report the transfer of such a packet is/are constructed accordingly, as will be obvious to one skilled in the art.

After state 1668, the illustrated procedure ends with end state 1699.

In state 1670 (reached from state 1654), it has been determined that the present jumbo packet will be split to store the packet header in a header buffer and the packet data in one or more jumbo buffers. Therefore, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there is a header buffer ready to receive this packet and the procedure continues at state 1674.

Otherwise, in state 1672 a new header buffer is prepared or initialized for storing small packets and headers of other packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indication of the first storage location or cell in the buffer is placed in next address field 1114 of header buffer table 1006. Also, the index of the buffer identifier within the free buffer array is stored in header buffer index 1112 and validity indicator 1116 is set to a valid state.

In state 1674 the packet's header is copied or transferred (e.g., via a DMA operation) into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes are inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet's header may be positioned within a cell of predetermined size (e.g., 256 bytes) within the buffer.

In state 1676, DMA engine 120 determines whether the packet's data (e.g., the TCP payload) will fit into one jumbo buffer. If the packet is too large, the illustrated procedure continues at state 1682.

In state 1678, the packet's data is copied or transferred (e.g., via a DMA operation) into the current jumbo buffer, at the location specified in the next address field 1134 of jumbo buffer table 1010. One skilled in the art will appreciate that

the next address field may not need to be updated to account for this new packet because the jumbo buffer will be released. In other words, in one embodiment of the invention a jumbo buffer may be used just once (e.g., to store one packet or a portion of one packet).

In state 1680, a completion descriptor is written or configured to release the jumbo buffer and to provide information to the host computer for processing the packet. The header buffer index (e.g. the index of the header buffer's buffer identifier within the free buffer array) and offset of the packet's header within the buffer are placed in the descriptor in header index and header offset fields, respectively. Illustratively, this offset may serve to identify the first byte of the header, the first pad byte before the header or the location of the cell in which the header is stored. The jumbo buffer index (e.g., the position or index within the free buffer array of the buffer identifier that identifies the jumbo buffer) and the offset of the first byte of the packet's data within the jumbo buffer are placed in data index and data offset fields, respectively. Header size and data size fields are used to store the size of the packet's header (e.g., the offset of the payload within the packet) and data (e.g., payload size), respectively.

A release header flag is set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag is also set, because no more data will be placed in the jumbo buffer (e.g., it is being released to the host computer).

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Also, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not changed until end state 1699 below. In an alternative embodiment, the descriptor may be released by issuing an interrupt or other alert. In yet another alternative embodiment, changing the descriptor type value may signal the release of the descriptor.

After state 1680, the illustrated procedure proceeds to state 1688.

In state 1682, a first portion of the packet's data is stored in the present (e.g., valid) jumbo buffer, at the location specified in the buffer's next address field 1134.

Because all of the packet's data will not fit into this buffer, in state 1684 a new jumbo buffer is prepared and the remainder of the packet is stored in that buffer.

In state 1686, a completion descriptor is written or configured. The contents are similar to those described in states 1680 and 1682, but this descriptor must reflect that two jumbo buffers were used to store the packet. The header buffer index (e.g. the index of the free buffer array element containing the header buffer's buffer identifier) and offset (e.g., the location of the packet's header within the header buffer) are placed in the descriptor in header index and header offset fields, respectively. The jumbo buffer index (e.g., the index, within the free buffer array, of the buffer identifier that references the jumbo buffer) and the offset of the first byte of the packet's data within the jumbo buffer are placed in data index and data offset fields, respectively. Header size and data size fields are used to store the size of the packet's header (e.g., as measured by the offset of the packet's data from the start of the packet) and data (e.g., payload size), respectively.

A release header flag is set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag is also set, because no more data will be placed in the jumbo buffer (e.g., it is being released to the host computer). Further, a split packet flag is set to indicate that a second jumbo buffer was used, and the location (within the free buffer array or other data structure) of the second buffer's buffer identifier is stored in a next index field.

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Finally, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not changed until end state 1699 below.

In state 1688, the jumbo buffer's entry in jumbo buffer table 1010 is invalidated (e.g., validity indicator 1136 is set to invalid) to ensure that it is not used again. In the procedure described above, a jumbo packet was stored in, at most, two jumbo buffers. In an alternative embodiment of the invention a jumbo packet may be stored across any number of buffers. The descriptor that is configured to report the transfer of such a packet is constructed accordingly, as will be obvious to one skilled in the art.

In state 1690, it is determined whether the header buffer is full. In this embodiment of the invention, where each header buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer may be considered full when thirty-two entries are stored.

If the buffer is full, in state 1692 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention, a release header flag in the descriptor is set. The illustrated procedure then ends with end state 1699.

If the header buffer is not full, then in state 1694 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet. The illustrated procedure then ends with end state 1699.

In end state 1699, a descriptor may be turned over to the host computer by changing a value in the descriptor's descriptor type field (e.g., from one to zero), as described above. Illustratively, the host computer (or software operating on the host computer) detects the change and understands that DMA engine 120 is returning ownership of the descriptor to the host computer.

A Method of Transferring a Packet with Operation Code 3

FIGS. 17A-17 C illustrate one procedure in which DMA engine 120 transfers a packet associated with operation code 3 to a host memory buffer. As reflected in TABLE 1, operation code 3 may indicate that the packet is compatible with a protocol that can be parsed by NIC 100 and that it carries a final portion of data for its flow. No new flow is set up, but a flow should already exist and is to be torn down. The packet's data is to be re-assembled with data from previous flow packets. Because the packet is to be re-assembled, the packet's header should be stored in a header buffer and its data in the flow's re-assembly buffer. The flow's active re-assembly buffer may be identified by the flow's entry in flow re-assembly buffer table 1004.

In state 1700, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set (e.g., equal to one), then it is assumed that there is a header buffer ready to receive this packet and the procedure continues at state 1704.

Otherwise, in state 1702 a new header buffer is prepared and initialized for storing small packets and headers of assembled packets. This initialization process may involve obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its buffer identifier (e.g., a reference to an available memory buffer). If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

Illustratively, when a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is placed in a free buffer array. The buffer's initial address or other indication of the first storage location or cell in the buffer is placed in next address field 1114 of header buffer table 1006. Further, the index of the buffer identifier in the free buffer array is stored in header buffer index field 1112 and validity indicator 1116 is set to a valid state.

In state 1704 the packet's header is copied or transferred to the header buffer at the address or location specified in the next address field of header buffer table 1006. As explained above, in one embodiment of the invention padding may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) with a sixteen-byte boundary. In addition, the header may be positioned within a cell of predetermined size (e.g., 16 bytes) within the header buffer.

In the illustrated embodiment, operation code 3 indicates that an existing flow is to be torn down (e.g., the flow re-assembly buffer is to be invalidated and released to the host computer). Thus, in state 1706 it is determined whether the flow re-assembly buffer is valid (e.g., active) for this flow by examining the validity indicator in the flow's entry in the flow re-assembly buffer table 1004. Illustratively, if the validity indicator is valid then there should be an active buffer for this flow. If there is no active buffer for this flow, the illustrated procedure continues at state 1712. Otherwise, the procedure continues at state 1708.

In state 1708, a new flow re-assembly buffer is prepared and initialized for this packet's data. Illustratively, a free ring descriptor is obtained from a cache maintained by free ring manager 1012 and its reference to an empty buffer is retrieved. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache. If a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or other indication of the first storage location is placed in next address field 1114 of the flow's entry in flow re-assembly buffer table 1004. The flow's entry in the re-assembly buffer table may be updated by its flow number. The location within the free buffer array of the buffer identifier is stored in header buffer index field 1112, and validity indicator 1116 is set to a valid state.

In state 1710, the packet's data is copied or transferred to the flow re-assembly buffer (e.g., via a DMA operation) into the address or location specified in the next address field of the flow's entry in flow re-assembly buffer table 1004.

In state 1712, a completion descriptor is written or configured to release the flow's re-assembly buffer and to provide information to the host computer for processing the packet. In particular, the header buffer index (e.g., the index, within the free buffer array, of the header buffer's identifier) and the offset of the packet's header within the header buffer are placed in the descriptor. Illustratively, this offset serves to identify the first byte of the header, the first pad byte preceding the header or the cell in which the header is stored. The flow re-assembly buffer index (e.g., the index, within the free buffer array, of the flow re-assembly buffer's identifier) and the offset of the packet's data within that buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) portions are stored in data size and header size fields, respectively. The descriptor type field is given a value that indicates that a flow packet has been transferred to host memory. A release header flag may be set if the header buffer is full and a release data flag may be set to indicate that no more data will be placed in this flow re-assembly buffer (e.g., because it is being released). In addition, a release flow flag is set to indicate that DMA engine 120 is tearing down the packet's flow. The header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment, the release header flag may be set (or cleared) at that time.

Then, in state 1714, the flow re-assembly buffer is invalidated by modifying validity indicator 1106 in the flow's entry in flow re-assembly buffer table 1004 appropriately. After state 1714, the procedure continues at state 1730.

In state 1716, DMA engine 120 determines whether the packet's TCP payload (e.g., the packet's data portion) will fit into the valid flow re-assembly buffer. If not, the illustrated procedure continues at state 1722.

In state 1718, the packet data is copied or transferred (e.g., via a DMA operation) into the flow's re-assembly buffer, at the location specified in the next address field 1104 of the flow's entry in flow re-assembly table 1004. One skilled in the art will appreciate that the next address field may or may not be updated to account for this new packet because the re-assembly buffer is being released.

In state 1720, a completion descriptor is written or configured to release the flow's re-assembly buffer and to provide information to the host computer for processing the packet. The header buffer index (e.g., the location or index, within the free buffer array, of the header buffer's identifier) and the offset of the packet's header within the header buffer are placed in the descriptor. The flow re-assembly buffer index (e.g., the location or index within the free buffer array of the flow re-assembly buffer's identifier) and the offset of the packet's data within that buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is given a value that indicates that a flow packet has been transferred to host memory. A release header flag is set if the header buffer is full and a release data flag is set to indicate that no more data will be placed in this flow re-assembly buffer (e.g., because it is being released). As explained above, the header buffer may not be tested to see if it is full until a later state of this procedure, at which time the release header flag may be set. Finally, a release flow flag is set to indicate that DMA engine 120 is tearing down the packet's flow. After state 1720, the illustrated procedure resumes at state 1728.

In state 1722, a first portion of the packet's payload (e.g., data) is stored in the flow's present (e.g., valid) re-assembly buffer, at the location identified in the buffer's next address field 1104.

Because the full payload will not fit into this buffer, in state 1724 a new flow re-assembly buffer is prepared and the remainder of the payload is stored in that buffer. In one embodiment of the invention information concerning the first buffer is stored in a completion descriptor. This information may include the position within the free buffer array of the first buffer's buffer identifier and the offset of the first portion of data within the buffer. The flow's entry in flow re-assembly buffer table 1004 may then be updated for the second buffer (e.g., store a first address in next address field 1104 and the location of buffer's identifier in the free buffer array in re-assembly buffer index 1102).

In state 1726, a completion descriptor is written or configured. The contents are similar to those described for states 1712 and 1720 but this descriptor must reflect that two re-assembly buffers were used.

Thus, the header buffer index (e.g., the position within the free buffer array of the buffer identifier corresponding to the header buffer) and the offset of the packet's header within the header buffer are placed in the descriptor, as above. The first flow re-assembly buffer index (e.g., the position, within the free buffer array, of the buffer identifier corresponding to the first flow re-assembly buffer used to store this packet's payload) and the offset of the packet's first portion of data within that buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is given a value that indicates that a flow packet has been transferred to host memory. A release header flag is set if the header buffer is full and a release data flag is set to indicate that no more data will be placed in this flow re-assembly buffer. A release flow flag is set to indicate that DMA engine 120 is tearing down the packet's flow.

Because two re-assembly buffers were used, a split packet flag is set and the index, within the free buffer array, of the re-assembly buffer's buffer identifier is stored in a next index field. Additionally, because the packet contains the final portion of data for the flow, a release next data buffer flag is also set to indicate that the second flow re-assembly buffer is being released.

In state 1728, the flow's entry in flow re-assembly buffer table 1004 is invalidated to ensure that it is not used again.

In state 1730, it is determined whether the header buffer is full. In this embodiment of the invention, where each header buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter is used to keep track of entries placed into each new header buffer. The header buffer is considered full when thirty-two entries are stored. When the header buffer is full, in state 1732 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host memory. In this embodiment of the invention a release header flag in the descriptor is set.

When the header buffer is not full, then in state 1734 the next address field of header buffer table 1006 is updated to the address at which to store the next header or packet.

Processing associated with a packet having operation code 4 concludes with end state 1799. In this end state, the DMA engine 120 used for this packet is turned over to the host

computer by changing its ownership indicator field (e.g., from one to zero). Alternatively, some other mechanism may be used, such as issuing an interrupt or changing the descriptor's descriptor type field. Illustratively, the descriptor type field would be changed to a value indicating that DMA engine 120 transferred a flow packet into host memory.

In one alternative embodiment of the invention an optimization may be performed when processing a packet with operation code 3. This optimization takes advantage of the knowledge that the packet contains the last portion of data for its flow. In particular, instead of loading a descriptor into flow re-assembly buffer table 1004 the descriptor may be used where it is—in a descriptor cache maintained by free ring manager 1012.

For example, instead of retrieving a buffer identifier from a descriptor and storing it in an array in state 1708 above, only to store one packet's data in the identified buffer before releasing it, it may be more efficient to use the descriptor without removing it from the cache. In this embodiment, when a completion descriptor is written the values stored in its data index and data offset fields are retrieved from a descriptor in the descriptor cache. Similarly, when the first portion of a code 3 packet's data fits into the flow's active buffer but a new one is needed just for the remaining data, a descriptor in the descriptor cache may again be used without first loading it into a free buffer array and the flow re-assembly buffer table. In this situation, the completion descriptor's next index field is retrieved from the descriptor in the descriptor cache.

A Method of Transferring a Packet with Operation Code 4

FIGS. 8A-18D depict an illustrative procedure in which DMA engine 120 transfers a packet associated with operation code 4 to a host memory buffer. As reflected in TABLE 1, operation code 4 in this embodiment indicates that the packet is compatible with the protocols that may be parsed by NIC 100 and continues a flow that is already established. No new flow is set up, the existing flow is not to be torn down, and the packet's data is to be re-assembled with data from other flow packets. Because the packet is to be re-assembled, the packet's header should be stored in a header buffer and its data in the flow's re-assembly buffer.

In state 1800, DMA engine 120 determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there should be a header buffer ready to receive this packet and the procedure continues at state 1804.

Otherwise, in state 1802 a new header buffer is prepared or initialized for storing small packets and headers of re-assembled packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indication of the first storage location in the buffer is placed in next address field 1114 of header buffer table 1006. Also, the position or index of the buffer identifier within the free buffer array is stored in header buffer index 1112 and validity indicator 1116 is set to a valid state.

In state 1804 the packet's header is copied or transferred into the header buffer at the address or location specified in



the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes are inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet's header may be positioned within a cell of predetermined size (e.g., 256 bytes) within the buffer.

In the illustrated embodiment, operation code 4 indicates that an existing flow is to be continued. Thus, in state 1806 it is determined whether a flow re-assembly buffer is valid (e.g., active) for this flow by examining the validity indicator in the flow's entry in flow re-assembly buffer table 1004. Illustratively, if the indicator is valid then there is an active buffer storing data from one or more packets in this flow. If there is a valid flow re-assembly buffer for this flow, the illustrated procedure continues at state 1808. Otherwise, the procedure proceeds to state 1810.

In state 1808, it is determined whether the packet's data (e.g., its TCP payload) portion is too large for the current flow re-assembly buffer. If the data portion is too large, two flow re-assembly buffers will be used and the illustrated procedure proceeds to state 1830. Otherwise, the procedure continues at state 1820.

In state 1810, because it was found (in state 1806) that there was no valid flow re-assembly buffer for this packet, a new flow re-assembly buffer is prepared. Illustratively, a free ring descriptor is obtained from a cache maintained by free ring manager 1012 and its reference to an empty buffer is retrieved. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or other indicator of its first storage location is placed in next address field 1104 of the flow's entry in flow re-assembly buffer table 1004. The flow's entry in the table may be recognized by its flow number. The location of the buffer identifier in the free buffer array is stored in re-assembly buffer index 1102, and validity indicator 1106 is set to a valid state.

In state 1812, the packet's data is copied or transferred (e.g., via a DMA operation) into the address or location specified in the next address field of the flow's entry in flow re-assembly buffer table 1004.

In state 1814, a completion descriptor is written or configured to provide information to the host computer for processing the packet. In particular, the header buffer index (e.g., the index within the free buffer array of the buffer identifier that identifies the header buffer) and the offset of the packet's header within the header buffer are placed in the descriptor. Illustratively, this offset may serve to identify the first byte of the header, the first pad byte preceding the header or the header's cell within the header buffer. The flow re-assembly buffer index (e.g., the index within the free buffer array of the buffer identifier that identifies the flow re-assembly buffer) and the offset of the packet's data within the buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is given a value indicating that a flow packet has been transferred to host memory. A release header flag is set if the header buffer is full but a release data flag is not set, because more data will be received in this flow re-assembly buffer. The header buffer may be tested to see if it is full until a later state of this

procedure. In such an embodiment, the release header flag may be set (or cleared) at that time.

In one embodiment of the invention a release flow flag may also be set, depending upon dynamic packet batching module 122. For example, if the packet batching module determines that another packet in the same flow will soon be transferred to the host computer, the release flow flag will be cleared (e.g., a zero will be stored). This indicates that the host computer should await the next flow packet before processing this one. By collectively processing multiple packets from a single flow, the packets can be processed more efficiently and less processor time is required. If, however, no other packets in the same flow are identified, the release flow flag may be set (e.g., a one is stored) to indicate that the host computer should process the flow packets it has received so far, without waiting for more.

In state 1816, the flow's entry in flow re-assembly buffer table 1004 is updated. In particular, next address field 1104 is updated to identify the location in the re-assembly buffer at which the next flow packet's data should be stored. After state 1816, the illustrated procedure continues at state 1838.

In state 1820 (reached from state 1808), it is known that the packet's data, or TCP payload, will fit within the flow's current re-assembly buffer. Thus, the packet data is copied or transferred into the buffer at the location identified in next address field 1104 of the flow's entry in flow re-assembly buffer table 1004.

In state 1822, a completion descriptor is written or configured to provide information to the host computer for processing the packet. In particular, the header buffer index (e.g., the index within the free buffer array of the buffer identifier that identifies the header buffer) and the offset of the packet's header within the header buffer are placed in the descriptor. The flow re-assembly buffer index (e.g., the index within the free buffer array of the buffer identifier that identifies the flow re-assembly buffer) and the offset of the packet's data within that buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is given a value indicating that a flow packet has been transferred to host memory. A release header flag is set if the header buffer is full but a release data flag is set only if the flow re-assembly buffer is now full. The header and flow re-assembly buffers may not be tested to see if they are full until a later state of this procedure. In such an embodiment, the flags may be set (or cleared) at that time.

In one embodiment of the invention a release flow flag may also be set, depending upon dynamic packet batching module 122. For example, if the packet batching module determines that another packet in the same flow will soon be transferred to the host computer, the release flow flag will be cleared. This indicates that the host computer should await the next flow packet before processing this one. By collectively processing multiple packets from a single flow, the packets can be processed more efficiently and less processor time is required. If, however, no other packets in the same flow are identified, the release flow flag may be set to indicate that the host computer should process the flow packets received so far, without waiting for more.

In state 1824, the flow re-assembly buffer is examined to determine if it is full. In the presently described embodiment of the invention this test is conducted by first determining how much data (e.g., how many bytes) has been stored in the buffer. Illustratively, the flow's next address field and the

amount of data stored from this packet are summed. Then, the initial buffer address (e.g., before any data was stored in it) is subtracted from this sum. This value, representing how much data is now stored in the buffer, is then compared to the size of the buffer (e.g., eight kilobytes).

If the amount of data currently stored in the buffer equals the size of the buffer, then it is full. In the presently described embodiment of the invention it is desirable to completely fill flow re-assembly buffers. Thus, a flow re-assembly buffer is not considered full until its storage space is completely populated with flow data. This scheme enables the efficient processing of network packets.

If the flow re-assembly buffer is full, in state 1826 the buffer is invalidated to ensure it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention, a release data flag in the descriptor is set. After state 1826, the procedure continues at state 1838.

If the flow re-assembly buffer is not full, then in state 1828 next address field 1104 in the flow's entry in flow re-assembly buffer table 1004 is updated to indicate the address at which to store the next portion of flow data. After state 1828, the procedure continues at state 1838.

In state 1830 (reached from state 1808), it is known that the packet's data will not fit into the flow's current re-assembly buffer. Therefore, some of the data is stored in the current buffer and the remainder in a new buffer. In particular, in state 1830 a first portion of data (e.g., an amount sufficient to fill the buffer) is copied or transferred into the current flow re-assembly buffer.

In state 1832, a new descriptor is loaded from a descriptor cache maintained by free ring manager 1012. Its identifier of a new buffer is retrieved and the remaining data from the packet is stored in the new buffer. In one embodiment of the invention, after the first portion of data is stored information from the flow's entry in flow re-assembly table 1004 is stored in a completion descriptor. Illustratively, this information includes re-assembly buffer index 1102 and the offset of the first portion of data within the full buffer. Then the new descriptor can be loaded—its index is stored in re-assembly buffer index 1102 and an initial address is stored in next address 1104.

In state 1834, a completion descriptor is written or configured to provide information to the host computer for processing the packet. In particular, the header buffer index (e.g., the location of the header buffer's buffer identifier within the free buffer array) and the offset of the packet's header within the header buffer are placed in the descriptor. The flow re-assembly buffer index (e.g., the location of the flow re-assembly buffer's buffer identifier within the free buffer array) and the offset of the packet's data within that buffer are also stored in the descriptor.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is given a value indicating that a flow packet has been transferred to host memory. A release header flag is set if the header buffer is full and a release data flag is set because the first flow re-assembly buffer is being released. The header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment, the release header flag may be set (or cleared) at that time.

Because two re-assembly buffers were used, a split packet in the descriptor is set and the index, within the free descriptor ring, of the descriptor that references the second re-assembly buffer is stored in a next index field.

In one embodiment of the invention a release flow flag may also be set, depending upon dynamic packet batching module 122. For example, if the packet batching module determines that another packet in the same flow will soon be transferred to the host computer, the release flow flag will be cleared. This indicates that the host computer should await the next flow packet before processing this one. By collectively processing multiple packets from a single flow, the packets can be processed more efficiently and less processor time is required. If, however, no other packets in the same flow are identified, the release flow flag may be set to indicate that the host computer should process the flow packets received so far, without waiting for more.

In state 1836, next address field 1104 in the flow's entry in flow re-assembly buffer table 1004 is updated to indicate the address in the new buffer at which to store the next portion of flow data.

In state 1838, it is determined whether the header buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are stored.

If the buffer is full, in state 1840 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention, a release header flag in the descriptor is set.

If the header buffer is not full, then in state 1842 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet.

The processing associated with a packet having operation code 4 then ends with end state 1899. In this end state, the descriptor used for this packet is turned over to the host computer by changing its ownership indicator field (e.g., from one to zero). In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or uses other means to alert the host computer that a descriptor is being released.

In one alternative embodiment of the invention the optimization described above for packets associated with operation code 3 may be performed when processing a packet with operation code 4. This optimization is useful, for example, when a code 4 packet's data is too large to fit in the current flow re-assembly buffer. Instead of loading a new descriptor for the second portion of data, the descriptor may be used where it is—in a descriptor cache maintained by free ring manager 1012. This allows DMA engine 120 to finish transferring the packet and turn over the completion descriptor before adjusting flow re-assembly buffer table 1004 to reflect a new buffer.

In particular, instead of loading information from a new descriptor in state 1832 above, it may be more efficient to use the descriptor without removing it from the cache. In this embodiment a new buffer for storing a remainder of the packet's data is accessed by retrieving its buffer identifier from a descriptor in the free ring manager's descriptor cache. The data is stored in the buffer and, after the packet's completion descriptor is configured and released, the necessary information is loaded into the flow re-assembly table as described above.

Illustratively, re-assembly buffer index 1102 stores the buffer identifier's index within the free buffer array, and an initial memory address of the buffer, taking into account the newly stored data, is placed in next address 1104.

A Method of Transferring a Packet with Operation Code 5  
 FIGS. 19A-19E depict a procedure in which DMA engine 120 transfers a packet associated with operation code 5 to a host memory buffer. As reflected in TABLE 1, operation code 5 in one embodiment of the invention may indicate that a packet is incompatible with the protocols that may be parsed by NIC 100. It may also indicate that a packet contains all of the data for a new flow (e.g., no more data will be received for the packet's flow). Therefore, for operation code 5, no new flow is set up and there should not be any flow to tear down. The packet's data, if there is any, is not to be re-assembled.

In state 1900, it is determined whether the present packet is a small packet (e.g., less than or equal to 256 bytes in size) suitable for storage in a header buffer. If so, the illustrated procedure proceeds to state 1920.

Otherwise, in state 1902 it is determined whether the present packet is a jumbo packet (e.g., greater than 1522 bytes in size), such that it should be stored in a jumbo buffer. If so, the illustrated procedure proceeds to state 1940. If not, the procedure continues at state 1904.

In state 1904, it has been determined that the packet is not a small packet or a jumbo packet. The packet may, therefore, be stored in a non-re-assembly buffer used to store packets that are no greater in size than MTU (Maximum Transfer Unit) in size, which is 1522 bytes in a present embodiment. This buffer may be called an MTU buffer. Therefore, DMA engine 120 determines whether a valid (e.g., active) MTU buffer exists. Illustratively, this determination is made by examining validity indicator 1126 of MTU buffer table 1008, which manages the active MTU buffer. If the validity indicator is set, then there should be a MTU buffer ready to receive this packet and the procedure continues at state 1908.

Otherwise, in state 1906 a new MTU buffer is prepared or initialized for storing non-re-assembleable packets up to 1522 bytes in size. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its buffer identifier (e.g., a reference to an empty host memory buffer). If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indication of the first storage location in the buffer is placed in the next address field 1124 of MTU buffer table 1008. The buffer identifier's index or position within the free buffer array is stored in MTU buffer index 1122, and validity indicator 1126 is set to a valid state.

In state 1908 the packet is copied or transferred (e.g., via DMA operation) into the MTU buffer at the address or location specified in the next address field of MTU buffer table 1008. As described above, in one embodiment of the invention pad bytes may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet may be positioned within a cell of predetermined size (e.g., two kilobytes) within the MTU buffer.

In state 1910, a completion descriptor is written or configured to provide necessary information to the host computer for processing the packet. In particular, the MTU buffer index (e.g. the location within the free buffer array of the buffer identifier for the MTU buffer) and offset (e.g., the

offset to the packet or the packet's cell within the buffer) are placed in the descriptor in data index and data offset fields, respectively. The size of the packet is stored in a data size field. A header size field within the descriptor may be set to zero to indicate that the entire packet was placed in the MTU buffer (e.g., no separate header portion was stored in a header buffer). A release data flag is set in the descriptor if the MTU buffer is full. The MTU buffer may not, however, be tested to see if it is full until a later state of this procedure.

In such an embodiment of the invention, the release data flag may be set (or cleared) at that time. A release header flag may be cleared (e.g., not set), because there is no separate header portion being conveyed to the host computer.

Further, the descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Also, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention, the ownership indicator is not set until end state 1999 below. In an alternative embodiment of the invention, the descriptor may be released by issuing an interrupt or other alert. In yet another alternative embodiment, changing the descriptor's descriptor type field may signal the descriptor's release.

In state 1912, DMA engine 120 determines whether the MTU buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size, each entry in the MTU buffer may be allotted two kilobytes of space and a counter may be used to keep track of entries placed into an MTU buffer. The buffer may be considered full when a predetermined number of entries (e.g., four) are stored. In an alternative embodiment of the invention entries in an MTU buffer may or may not be allocated a certain amount of space, in which case DMA engine 120 may calculate how much storage space within the buffer has yet to be used. If no space remains, or if less than a predetermined amount of space is still available, the buffer may be considered full.

If the MTU buffer is full, in state 1914 the buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the MTU buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention a release data flag in the descriptor is set. The illustrated procedure then ends with end state 1999.

If the MTU buffer is not full, then in state 1916 the next address field of MTU buffer table 1008 is updated to indicate the address at which to store the next packet. The illustrated procedure then ends with end state 1999.

In state 1920 (reached from state 1900), it has been determined that the present packet is a small packet suitable for storage in a header buffer. Therefore, DMA engine 120 (e.g., DMA manager 1002) determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there is a header buffer ready to receive this packet and the procedure continues at state 1924.

Otherwise, in state 1922 a new header buffer is prepared or initialized for storing small packets and headers of re-assembled packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indicator of the first storage location or cell in the buffer is placed in next address field 1114 of header buffer table 1006. Further, the buffer identifier's position within the free buffer array is stored in header buffer index 1112 and validity indicator 1116 is set to a valid state.

In state 1924 the packet is copied or transferred (e.g., via a DMA operation) into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet may be positioned within a cell of predetermined size (e.g., 256 bytes) within the buffer.

In state 1926, a completion descriptor is written or configured to provide necessary information to the host computer (e.g., a software driver) for processing the packet. In particular, the header buffer index (e.g. the index of the free buffer array element that contains the header buffer's identifier) and offset are placed in the descriptor, in header index and header offset fields, respectively. Illustratively, this offset serves to identify the first byte of the packet, the first pad byte preceding the packet or the location of the packet's cell within the buffer. The size of the packet is also stored in the descriptor, illustratively within a header size field. A data size field within the descriptor may be set to zero to indicate that the entire packet was placed in the header buffer (e.g., no separate data portion was stored in another buffer). A release header flag may be set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag may be cleared (e.g., not set), because there is no separate data portion being conveyed to the host computer.

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Also, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not set until end state 1999 below.

In state 1928 it is determined whether the header buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter is used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are stored.

If the buffer is full, in state 1930 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention a release header flag in the descriptor is set. The illustrated procedure then ends with end state 1999.

If the header buffer is not full, then in state 1932 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet. The illustrated procedure then ends with end state 1999.

In state 1940 (reached from state 1902), it has been determined that the packet is a jumbo packet (e.g., that it is

greater than 1522 bytes in size). In this embodiment of the invention a jumbo packet's data portion is stored in a jumbo buffer. Its header is also stored in the jumbo buffer unless splitting of jumbo packets is enabled, in which case its header is stored in a header buffer. DMA engine 120 thus determines whether a valid (e.g., active) jumbo buffer exists. Illustratively, this determination is made by examining validity indicator 1136 of jumbo buffer table 1010, which manages an active jumbo buffer. If the validity indicator is set, then there is a jumbo buffer ready to receive this packet and the procedure continues at state 1944.

Otherwise, in state 1942 a new jumbo buffer is prepared or initialized for storing a non-re-assembleable packet that is larger than 1522 bytes. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or other indication of the first storage location within the buffer is placed in next address field 1134 of jumbo buffer table 1010. The position of the buffer identifier within the free buffer array is stored in jumbo buffer index 1132, and validity indicator 1136 is set to a valid state.

Then, in state 1944, DMA engine 120 determines whether splitting of jumbo buffers is enabled. If enabled, the header of a jumbo packet is stored in a header buffer while the packet's data is stored in one or more jumbo buffers. If not enabled, the entire packet will be stored in one or more jumbo buffers. Illustratively, splitting of jumbo packets is enabled or disabled according to the configuration of a programmable indicator (e.g., flag, bit, register) that is set by software operating on the host computer (e.g., a device driver). If splitting is enabled, the illustrated procedure continues at state 1960. Otherwise, the procedure proceeds to state 1946.

In state 1946, DMA engine 120 determines whether the packet will fit into one jumbo buffer. For example, in an embodiment of the invention using eight kilobyte pages, if the packet is larger than eight kilobytes a second jumbo buffer will be needed to store the additional contents. If the packet is too large, the illustrated procedure continues at state 1952.

Otherwise, in state 1948 the packet is copied or transferred (e.g., via a DMA operation) into the current jumbo buffer, at the location specified in the next address field 1134 of jumbo buffer table 1010. When the packet is transferred intact like this, padding may be added to align a header portion of the packet with a sixteen-byte boundary. One skilled in the art will appreciate that the next address field may not need to be updated to account for this new packet because the jumbo buffer will be released. In other words, in one embodiment of the invention a jumbo buffer is only used once (e.g., to store one packet or a portion of one packet). In an alternative embodiment of the invention a jumbo buffer may store portions of two or more packets, in which case next address field 1134 may need to be updated.

In state 1950, a completion descriptor is written or configured to release the jumbo buffer and to provide information to the host computer for processing the packet. The jumbo buffer index (e.g., the index, within the free buffer array, of the buffer identifier that corresponds to the jumbo buffer) and the offset of the first byte of the packet within the

jumbo buffer are placed in the descriptor, in data index and data size fields, respectively. The size of the packet (e.g., the packet length) is stored in a data size field.

A header size field may be cleared (e.g., a zero is stored) to indicate that the header buffer was not used (e.g., the header was not stored separately from the packet's data). Because the packet was stored intact, header index and header offset fields may or may not be used (e.g., the values stored in their fields do not matter). A release header flag is cleared and a release data flag is set to indicate that no more data will be placed in this jumbo buffer (e.g., because it is being released).

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Finally, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention, the ownership indicator is not changed until end state 1999 below. After state 1950, the illustrated procedure resumes at state 1958. In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or uses some other means, possibly not until end state 1999, to alert the host computer that a descriptor is being released.

In state 1952, a first portion of the packet is stored in the present (e.g., valid) jumbo buffer, at the location identified in the buffer's next address field 1134. Because the whole packet will not fit into this buffer, in state 1954 a new jumbo buffer is prepared and the remainder of the packet is stored in that buffer.

In state 1956, a completion descriptor is written or configured. The contents are similar to those described in state 1950 but this descriptor must reflect that two jumbo buffers were used to store the packet. Thus, the jumbo buffer index (e.g., the index, within the free buffer array, of the array element containing the header buffer's buffer identifier) and the offset of the first byte of the packet within the first jumbo buffer are placed in the descriptor, as above. The size of the packet (e.g., the packet length) is stored in a data size field.

A header size field may be cleared (e.g., a zero is stored) to indicate that the header buffer was not used (e.g., the header was not stored separately from the packet's data). Because there is no separate packet header, header index and header offset fields may or may not be used (e.g., the values stored in their fields do not matter).

A release header flag is cleared and a release data flag is set to indicate that no more data will be placed in these jumbo buffers (e.g., because they are being released). Further, a split packet flag is set to indicate that a second jumbo buffer was used, and the index (within the free buffer array) of the buffer identifier for the second buffer is stored in a next index field.

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. And, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not changed until end state 1999 below.

In state 1958, the jumbo buffer's entry in jumbo buffer table 1010 is invalidated (e.g., validity indicator 1136 is set to invalid) to ensure that it is not used again. In the procedure described above, a jumbo packet was stored in, at most, two jumbo buffers. In an alternative embodiment of the invention, a jumbo buffer may be stored across any number

of buffers. The descriptor that is configured to report the transfer of such a packet is constructed accordingly, as will be obvious to one skilled in the art.

After state 1958, the illustrated procedure ends at end state 1999.

In state 1960 (reached from state 1944), it has been determined that the present jumbo packet will be split to store the packet header in a header buffer and the packet data in one or more jumbo buffers. Therefore, DMA engine 120 (e.g., DMA manager 1002) first determines whether there is a valid (e.g., active) header buffer. Illustratively, this determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there is a header buffer ready to receive this packet and the procedure continues at state 1964.

Otherwise, in state 1962 a new header buffer is prepared or initialized for storing small packets and headers of other packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indication of the first storage location or cell in the buffer is placed in next address field 1114 of header buffer table 1006. The index or position of the buffer identifier within the free buffer array is stored in header buffer index 1112, and validity indicator 1116 is set to a valid state.

In state 1964 the packet's header is copied or transferred (e.g., via a DMA operation) into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the header may be positioned within a cell of predetermined size (e.g., 256 bytes) in the buffer.

In state 1966, DMA engine 120 determines whether the packet's data (e.g., the TCP payload) will fit into one jumbo buffer. If the packet is too large to fit into one (e.g., the current jumbo buffer), the illustrated procedure continues at state 1972.

In state 1968, the packet's data is copied or transferred (e.g., via a DMA operation) into the current jumbo buffer, at the location specified in the next address field 1134 of jumbo buffer table 1010. One skilled in the art will appreciate that the next address field may not need to be updated to account for this new packet because the jumbo buffer will be released. In other words, in one embodiment of the invention a jumbo buffer is only used once (e.g., to store one packet or a portion of one packet).

In state 1970, a completion descriptor is written or configured to release the jumbo buffer and to provide information to the host computer for processing the packet. The header buffer index (e.g. the free buffer array position of the buffer identifier corresponding to the header buffer) and offset of the packet's header are placed in the descriptor in header index and header offset fields, respectively. Illustratively, this offset serves to identify the first byte of the header, the first pad byte preceding the header or the cell in which the header is stored. The jumbo buffer index (e.g., the

index within the free buffer array of the buffer identifier that references the jumbo buffer) and the offset of the first byte of the packet's data within the jumbo buffer are placed in data index and data offset fields, respectively. Header size and data size fields are used to store the size of the packet's header (e.g., the offset of the payload within the packet) and data (e.g., payload size), respectively.

A release header flag may be set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag is also set, because no more data will be placed in the jumbo buffer (e.g., it is being released to the host computer).

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Also, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not set until end state 1999 below.

After state 1970, the illustrated procedure proceeds to state 1978.

In state 1972, a first portion of the packet's data is stored in the present (e.g., valid) jumbo buffer, at the location identified in the buffer's next address field 1134. Because all of the packet's data will not fit into this buffer, in state 1974 a new jumbo buffer is prepared and the remainder of the packet is stored in that buffer.

In state 1976, a completion descriptor is written or configured. The contents are similar to those described in states 1970 but this descriptor must reflect that two jumbo buffers were used to store the packet. The header buffer index (e.g. the free buffer array element that contains the header buffer's identifier) and offset of the header are placed in the descriptor in header index and header offset fields, respectively. The jumbo buffer index (e.g., the free buffer array element containing the jumbo buffer's buffer identifier) and the offset of the first byte of the packet's data within the jumbo buffer are placed in data index and data offset fields, respectively. Header size and data size fields are used to store the size of the packet's header (e.g., the offset of the payload within the packet) and data (e.g., payload size), respectively.

A release header flag is set in the descriptor if the header buffer is full. However, the header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment of the invention, the release header flag may be set (or cleared) at that time. A release data flag is also set, because no more data will be placed in the jumbo buffer (e.g., it is being released to the host computer). Further, a split packet flag is set to indicate that a second jumbo buffer was used, and the position or index within the free buffer array of the second buffer's buffer identifier is stored in a next index field.

The descriptor type field is changed to a value indicating that DMA engine 120 transferred a non-re-assembleable packet into host memory. Finally, a predetermined value (e.g., zero) is stored in the descriptor's ownership indicator field to indicate that DMA engine 120 is releasing a packet to the host computer and turning over ownership of the descriptor. In one embodiment of the invention the ownership indicator is not set until end state 1999 below. In an alternative embodiment of the invention DMA engine 120 issues an interrupt or uses some other signal to alert the host computer that a descriptor is being released.

In state 1978, the jumbo buffer's entry in jumbo buffer table 1010 is invalidated (e.g., validity indicator 1136 is set

to invalid) to ensure that it is not used again. In the procedure described above, a jumbo packet was stored in, at most, two jumbo buffers. In an alternative embodiment of the invention a jumbo buffer may be stored across any number of buffers. The descriptor that is configured to report the transfer of such a packet is constructed accordingly, as will be obvious to one skilled in the art.

In state 1980, it is determined whether the header buffer is full. In this embodiment of the invention, where each buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are stored.

If the buffer is full, in state 1982 the header buffer is invalidated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention a release header flag in the descriptor is set. The illustrated procedure then ends with end state 1999.

If the header buffer is not full, then in state 1984 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or small packet. The illustrated procedure then ends with end state 1999.

In end state 1999, a descriptor may be turned over to the host computer by storing a particular value (e.g., zero) in the descriptor's ownership indicator field as described above. Illustratively, the host computer (or software operating on the host computer) detects the change and understands that DMA engine 120 is returning ownership of the descriptor to the host computer.

A Method of Transferring a Packet with Operation Code 6 or Operation Code 7

FIGS. 20A-20B depict an illustrative procedure in which DMA engine 120 transfers a packet associated with operation code 6 or 7 to a host memory buffer. As reflected in TABLE 1, operation codes 6 and 7 may indicate that a packet is compatible with the protocols pre-selected for NIC 100 and is the first packet of a new flow. The difference between these operation codes in this embodiment of the invention is that operation code 7 is used when an existing flow is to be replaced (e.g., in flow database 110 and/or flow re-assembly buffer table 1004) by the new flow. With operation code 6, in contrast, no flow needs to be torn down. For both codes, however, a new flow is set up and the associated packet's data may be re-assembled with data from other packets in the newly established flow. Because the packet data is to be re-assembled, the packet's header should be stored in a header buffer and its data in a new flow re-assembly buffer.

As described in a previous section, the flow that is torn down to make room for a new flow (in the case of operation code 7) may be the least recently used flow. Because flow database 110 and flow re-assembly buffer table 1004 contain only a limited number of entries in the presently described embodiment of the invention, when they are full and a new flow arrives an old one must be torn down. Choosing the least recently active flow for replacement is likely to have the least impact on network traffic through NIC 100. In one embodiment of the invention DMA engine 120 tears down the flow in flow re-assembly buffer table 1004 that has the same flow number as the flow that has been replaced in flow database 110.

In state 2000, DMA engine 120 determines whether there is a valid (e.g., active) header buffer. Illustratively, this

determination is made by examining validity indicator 1116 of header buffer table 1006, which manages the active header buffer. If the validity indicator is set, then there is a header buffer ready to receive this packet and the procedure continues at state 2004.

Otherwise, in state 2002 a new header buffer is prepared or initialized for storing small packets and headers of re-assembled packets. Illustratively, this initialization process involves obtaining a free ring descriptor from a cache maintained by free ring manager 1012 and retrieving its reference to an empty buffer. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or some other indication of the first storage location or cell in the buffer is placed in next address field 1114 of header buffer table 1006. The position or index of the buffer identifier within the free buffer array is stored in header buffer index 1112, and validity indicator 1116 is set to a valid state.

In state 2004 the packet's header is copied or transferred into the header buffer at the address or location specified in the next address field of header buffer table 1006. As described above, in one embodiment of the invention pad bytes may be inserted before the header in order to align the beginning of the packet's layer three protocol (e.g., IP) header with a sixteen-byte boundary. In addition, the packet's header may be positioned in a cell of predetermined size (e.g., 256 bytes) within the buffer.

As discussed above, operation code 7 indicates that an old flow is to be torn down in flow re-assembly buffer table 1004 to make room for a new flow. This requires the release of any flow re-assembly buffer that may be associated with the flow being torn down.

Thus, in state 2006 it is determined whether a flow re-assembly buffer is valid (e.g., active) for a flow having the flow number that was read from control queue 118 for this packet. As explained in a previous section, for operation code 7 the flow number represents the entry in flow database 110 (and flow re-assembly buffer table 1004) that is being replaced with the new flow. DMA engine 120 thus examines the validity indicator in the flow's entry in flow re-assembly buffer table 1004. Illustratively, if the indicator is valid then there is an active buffer storing data from one or more packets in the flow that is being replaced. If there is a valid flow re-assembly buffer for this flow, the illustrated procedure continues at state 2008. Otherwise, the procedure proceeds to state 2010. It will be understood that the illustrated procedure will normally proceed to state 2008 for operation code 7 and state 2010 for operation code 6.

In state 2008, a completion descriptor is written or configured to release the replaced flow's re-assembly buffer. In particular, the flow re-assembly buffer index (e.g., the index within the free buffer array of the flow re-assembly buffer's buffer identifier) is written to the descriptor. In this embodiment of the invention, no offset needs to be stored in the descriptor's data offset field and the data size field is set to zero because no new data was stored in the buffer that is being released. Similarly, the header buffer is not yet being released, and therefore the header index and header offset fields of the descriptor need not be used and a zero may be stored in the header size field.

The descriptor's release header flag is cleared (e.g., a zero is stored in the flag) because the header buffer is not being released. The release data flag is set (e.g., a one is stored in

the flag), however, because no more data will be placed in the released flow re-assembly buffer. Further, a release flow flag in the descriptor is set to indicate that the flow associated with the released flow re-assembly buffer is being torn down.

The descriptor type field is changed to a value indicating that DMA engine 120 is releasing a stale flow buffer (e.g., a flow re-assembly buffer that has not been used for some time). Finally, the descriptor used to release the replaced flow's re-assembly buffer and terminate the associated flow is turned over to the host computer by changing its ownership indicator field (e.g., from one to zero). In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or employs some other means of alerting the host computer that a descriptor is being released.

In state 2010, a new flow re-assembly buffer is prepared for the flow that is being set up. Illustratively, a free ring descriptor is obtained from a cache maintained by free ring manager 1012 and its buffer identifier (e.g., a reference to an empty memory buffer) is retrieved. If the cache is empty, new descriptors may be retrieved from the free descriptor ring in host memory to replenish the cache.

When a new descriptor is obtained from the cache or from the free descriptor ring, the buffer identifier (e.g., pointer, address, index) contained in the descriptor is stored in a free buffer array. The buffer's initial address or other indication of the first storage location in the buffer is placed in next address field 1104 of the flow's entry in flow re-assembly buffer table 1004. The flow's entry in the table may be recognized by its flow number. The position or index of the buffer identifier within the free buffer array is stored in re-assembly buffer index 1102, and validity indicator 1106 is set to a valid state.

In state 2012, the packet's data is copied or transferred (e.g., via a DMA operation) into the address or location specified in the next address field of the flow's entry in flow re-assembly buffer table 1004.

In state 2014, a completion descriptor is written or configured to provide information to the host computer for processing the packet. In particular, the header buffer index (e.g., the location or position within the free buffer array of the buffer identifier that references the header buffer) and the offset of the packet's header within the header buffer are placed in the descriptor. Illustratively, the offset identifies the first byte of the header, the first pad byte preceding the header or the location of the header's cell in the header buffer.

The flow re-assembly buffer index (e.g., the location or position, within the free buffer array, of the buffer identifier that references the flow re-assembly buffer) and the offset of the packet's data within that buffer are also stored in the descriptor. It will be recognized, however, that the offset reported for this packet's data may be zero, because the packet data is stored at the very beginning of the new flow re-assembly buffer.

The size of the packet's data (e.g., the size of the packet's TCP payload) and header (e.g., the offset of the TCP payload within the packet) are stored in data size and header size fields, respectively. The descriptor type field is changed to a value indicating that DMA engine 120 transferred a flow packet into host memory. A release header flag is set if the header buffer is full but a release data flag is not set, because more data will be placed in this flow re-assembly buffer. The header buffer may not be tested to see if it is full until a later state of this procedure. In such an embodiment, the release header flag may be set (or cleared) at that time.

In one embodiment of the invention a release flow flag may also be set, depending upon dynamic packet batching

module 122. For example, if the packet batching module determines that another packet in the same flow will soon be transferred to the host computer, the release flow flag will be cleared (e.g., a zero will be stored). This indicates that the host computer should await the next flow packet before processing this one. By collectively processing multiple packets from a single flow, the packets can be processed more efficiently and less processor time will be required for network traffic. If, however, no other packets in the same flow are identified, the release flow flag may be set to indicate that the host computer should process the flow packets received so far, without waiting for more.

In state 2016, the flow's entry in flow re-assembly buffer table 1004 is updated. In particular, next address field 1104 is updated to identify the location in the re-assembly buffer which the next flow packet's data should be stored.

In state 2018, it is determined whether the header buffer is full. In this embodiment of the invention, where each header buffer is eight kilobytes in size and entries in the header buffer are no larger than 256 bytes, a counter may be used to keep track of entries placed into each new header buffer. The buffer is considered full when thirty-two entries are added.

If the buffer is full, in state 2020 the header buffer is validated to ensure that it is not used again. Illustratively, this involves setting the header buffer table's validity indicator to invalid and communicating this status to the host computer. In this embodiment of the invention, a release flow flag in the descriptor is set.

If the header buffer is not full, then in state 2022 the next address field of header buffer table 1006 is updated to indicate the address at which to store the next header or full packet.

The processing associated with a packet having operation codes 6 and 7 then ends with end state 2099. In this end state, the descriptor used for this packet (e.g., the descriptor that is configured in state 2014) is turned over to the host computer by changing its ownership indicator field (e.g., from one to zero). In one alternative embodiment of the invention, DMA engine 120 issues an interrupt or employs other means (e.g., such as the descriptor's descriptor type field) to alert the host computer that a descriptor is being used.

**Embodiment of a Packet Batching Module**  
 FIG. 21 is a diagram of dynamic packet batching module 122 in one embodiment of the invention. In this embodiment, packet batching module 122 alerts a host computer to the transfer, or impending transfer, of multiple packets from one communication flow. The related packets can then be processed through an appropriate protocol stack sequentially, rather than processing one at a time. As one skilled in the art will recognize, this increases the efficiency with which network traffic may be handled by the host computer.

In the illustrated embodiment, a packet is transferred from the host computer by DMA engine 120 (e.g., by clearing its payload into an appropriate buffer). When a packet is transferred, packet batching module 122 determines whether a related packet (e.g., a packet in the same flow) will soon be transferred as well. In particular, packet batching module 122 examines packets that are to be transferred after the present packet. One skilled in the art will recognize that the higher the rate of packet arrival at NIC 100, the more packets that are likely to await transfer to a host computer at a given time. The more packets that await transfer, the more packets that may be examined by the packet batching module and the greater the benefit

it may provide. In particular, as the number of packets awaiting transfer increases, packet batching module 122 may identify a greater number of related packets for collective processing. As the number of packets processed together increases, the amount of host processor time required to process each packet decreases.

Thus, if a related packet is found the packet batching module alerts the host computer so that the packets may be processed as a group. As described in a previous section, in one embodiment of the invention dynamic packet batching module 122 alerts the host computer to the availability of a related packet by clearing a release flow flag in a completion descriptor associated with a transferred packet. The flag may, for example, be cleared by DMA engine 120 in response to a signal or alert from dynamic packet batching module 122.

In contrast, in an alternative embodiment of the invention dynamic packet batching module 122 or DMA engine 120 may alert the host computer when no related packets are found or when, for some other reason, the host processor should not delay processing a transferred packet. In particular, a release flow flag may be set when the host computer is not expected to receive a packet related to a transferred packet in the near future (e.g., thus indicating that the associated flow is being released or torn down). For example, it may be determined that the transferred packet is the last packet in its flow or that a particular packet does't even belong to a flow (e.g., this may be reflected in the packet's associated operation code).

With reference now to FIG. 21, packet batching module 122 in one embodiment of the invention includes memory 2102 and controller 2104. Illustratively, each entry in memory 2102, such as entry 2106, comprises two fields: flow number 2108 and validity indicator 2110. In alternative embodiments of the invention, other information may be stored in memory 2102. Read pointer 2112 and write pointer 2114 serve as indices into memory 2102.

In the illustrated embodiment, memory 2102 is an associative memory (e.g., a CAM) configured to store up to 256 entries. Each entry corresponds to and represents a packet stored in packet queue 116. As described in a previous section, packet queue 116 may also contain up to 256 packets in one embodiment of the invention. When a packet is, or is about to be transferred, by DMA engine 120 from packet queue 116 to the host computer, memory 2102 may be searched for an entry having a flow number that matches the flow number of the transferred packet. Because memory 2102 is a CAM in this embodiment, all entries in the memory may be searched simultaneously or nearly simultaneously. In this embodiment, memory 2102 is implemented in hardware, with the entries logically arranged as a ring. In alternative embodiments, memory 2102 may be virtually any type of data structure (e.g., array, table, list, queue) implemented in hardware or software. In one particular alternative embodiment, memory 2102 is implemented as a RAM, in which case the entries may be examined in a serial manner.

The maximum of 256 entries in the illustrated embodiment matches the maximum number of packets that may be stored in a packet queue. Because the depth of memory 2102 matches the depth of the packet queue, when a packet is stored in the packet queue its flow number may be automatically stored in memory 2102. Although the same number of entries are provided for in this embodiment, in an alternative embodiment of the invention memory 2102 may be configured to hold a smaller or greater number of entries than the packet queue. And, as discussed in a previous



section, for each packet stored in the packet queue, related information may also be stored in the control queue.

In the illustrated embodiment of the invention, flow number 2108 is the index into flow database 110 of the flow comprising the corresponding packet. As described above, in one embodiment of the invention a flow includes packets carrying data from one datagram sent from a source entity to a destination entity. Illustratively, each related packet has the same flow key and the same flow number. Flow number 2108 may comprise the index of the packet's flow key in flow database 110.

Validity indicator 2110 indicates whether the information stored in the entry is valid or current. In this embodiment, validity indicator 2110 may store a first value (e.g., one) when the entry contains valid data, and a second value (e.g., zero) when the data is invalid. For example, validity indicator 2110 in entry 2106 may be set to a valid state when the corresponding entry in packet queue 116 contains a packet awaiting transfer to the host computer and belongs to a flow (e.g., which may be indicated by the packet's operation code). Similarly, validity indicator 2110 may be set to an invalid state when the entry is no longer needed (e.g., when the corresponding packet is transferred to the host computer).

Flow validity indicator 2110 may also be set to an invalid state when a corresponding packet's operation code indicates that the packet does not belong to a flow. It may also be set to an invalid state when the corresponding packet is a control packet (e.g., contains no data) or is otherwise non-re-assembleable (e.g., because it is out of sequence, incompatible with a pre-selected protocol, has an unexpected control flag set). Validity indicator 2110 may be managed by controller 2104 during operation of the packet batching module.

In the illustrated embodiment of the invention, an entry's flow number is received from a register in which it was placed for temporary storage. A packet's flow number may be temporarily stored in a register, or other data structure, in order to facilitate its timely delivery to packet batching module 122. Temporary storage of the flow number also allows the flow database manager to turn its attention to a later packet. A flow number may, for example, be provided to dynamic packet batching module 122 at nearly the same time that the associated packet is stored in packet queue 116. Illustratively, the flow number may be stored in the register of flow database manager 108 or by IPP module 104. In an alternative embodiment, the flow number is received from control queue 118 or some other module of NIC 100.

In the illustrated embodiment of the invention, memory 2102 contains an entry corresponding to each packet in packet queue 116. When a packet in the packet queue is transferred to a host computer (e.g., when it is written to a assembly buffer), controller 2104 invalidates the memory entry that corresponds to that packet. Memory 2102 is then searched for another entry having the same flow number as the transferred packet. Afterwards, when a new packet is added in packet queue 116, perhaps in place of the transferred packet, a new entry is stored in memory 2102.

In an alternative embodiment of the invention, memory 2102 may be configured to hold entries for only a subset of a maximum number of packets stored in packet queue 116 (e.g., just re-assembleable packets). Entries in memory 2102 may still be populated when a packet is stored in the packet queue. However, if memory 2102 is full when a new packet is received, then creation of an entry for the new packet must be delayed until a packet is transferred and its entry in memory 2102 is invalidated. Therefore, in this alternative embodiment

entries in memory 2102 may be created by extracting information from entries in control queue 118 rather than packet queue 116. Controller 2104 would therefore continually attempt to copy information from entries in control queue 118 into memory 2102. The function of populating memory 2102 may be performed independently or semi-independently of the function of actually comparing the flow numbers of memory entries to the flow number of a packet being transferred to the host computer.

In this alternative embodiment a second read pointer may be used to index control queue 118 to assist in the population of memory 2102. In particular, the second read pointer may be used by packet batching module 122 to find and fetch entries for memory 2102. Illustratively, if the second, or "lookahead" read pointer references the same entry as the control queue's write pointer, then it could be determined that no new entries were added to control queue 118 since the last check by controller 2104. Otherwise, as long as there is an empty (e.g., invalid) entry in memory 2102, the necessary information (e.g., flow number) may be copied into memory 2102 for the packet corresponding to the entry referenced by the lookahead read pointer. The lookahead read pointer would then be incremented.

Returning now to FIG. 21, read pointer 2112 of dynamic packet batching module 122 identifies the current entry in memory 2102 (e.g., the entry corresponding to the packet at the front of the packet queue or the next packet to be transferred). Illustratively, this pointer is incremented each time a packet is transferred to the host computer. Write pointer 2114 identifies the position at which the next entry in memory 2102 is to be stored. Illustratively, the write pointer is incremented each time an entry is added to memory 2102. One manner of collectively processing headers from related packets is to form them into one "super-" header. In this method, the packets' data portions are stored separately (e.g., in a separate memory page or buffer) from the super-header.

Illustratively, a super-header comprises one combined header for each layer of the packet's associated protocol stack (e.g., one TCP header and one IP header). To form each layer's portion of a super-header, the packet's individual headers may be merged to make a regular-sized header whose fields accurately reflect the assembled data and combined headers. For example, merged header fields relating to payload or header length would indicate the size of the aggregated data or aggregated headers, the sequence number of a merged TCP header would be set appropriately, etc. The super-header portion may then be processed through its protocol stack similar to the manner in which a single packet's header is processed.

This method of collectively processing related packet's headers (e.g., with "super-" headers) may require modification of the instructions for processing packets (e.g., a device driver). For example, because multiple headers are merged for each layer of the protocol stack, the software may require modification to recognize and handle the super-headers. In one embodiment of the invention the number of headers folded or merged into a super-header may be limited. In an alternative embodiment of the invention the headers of all the aggregated packets, regardless of number, may be combined.

In another method of collectively processing related packet's header portions, packet data and headers may again be stored separately (e.g., in separate memory pages). But, instead of combining the packet's headers for each layer of the appropriate protocol stack to form a super-header, they may be submitted for individual processing in quick suc-

cession. For example, all of the packet's layer two headers may be processed in a rapid sequence—one after the other—then all of the layer three headers, etc. In this manner, packet processing instructions need not be modified, but headers are still processed more efficiently. In particular, a set of instructions (e.g., for each protocol layer) may be loaded once for all related packets rather than being separately loaded and executed for each packet.

As discussed in a previous section, data portions of related packets may be transferred into storage areas of predetermined size (e.g., memory pages) for efficient transfer from the host computer's kernel space into application or user space. Where the transferred data is of memory page size, the data may be transferred using highly efficient "page-flipping," wherein a full page of data is provided to application or user memory space.

FIGS. 22A–22B present one method of dynamic packet batching with packet batching module 122. In the illustrated method, memory 2102 is populated with flow numbers of packets stored in packet queue 116. In particular, a packet's flow number and operation code are retrieved from control queue 118, IPP module 104, flow database manager 108 or other module(s) of NIC 100. The packet's flow number is stored in the flow number portion of an entry in memory 2102, and validity indicator 2110 is set in accordance with the operation code. For example, if the packet is not re-assemblable (e.g., codes 2 and 5 in TABLE 1), the validity indicator may be set to zero; otherwise it may be set to one.

The illustrated method may operate in parallel to the operation of DMA engine 120. In other words, dynamic packet batching module 122 may search for packets related to a packet in the process of being transferred to a host memory buffer. Alternatively, a search may be conducted shortly after or before the packet is transferred. Because memory 2102 may be associative in nature, the search operation may be conducted quickly, thus introducing little, if any, delay into the transfer process.

FIG. 22A may be considered a method of searching for a related packet, while FIG. 22B may be considered a method of populating the dynamic packet batching module's memory.

FIGS. 22A–22B each reflect one "cycle" of a dynamic packet batching operation (e.g., one search and creation of a new memory entry). Illustratively, however, the operation of packet batching module 122 runs continuously. That is, at the end of one cycle of operation another cycle immediately begins. In this manner, controller 2104 strives to ensure memory 2102 is populated with entries for packets that are stored in packet queue 116. If memory 2102 is not large enough to store an entry for each packet in packet queue 116, then controller 2104 attempts to keep the memory as full as possible and to quickly replace an existing entry with a new one.

State 2200 is a start state for a memory search cycle. In state 2200, it is determined whether a packet (e.g., the packet at the front of the packet queue) is being transferred to the host computer. This determination may, for example, be made by the operation of DMA engine 120 or the status of the packet in packet queue 116 or control queue 118. Alternatively, state 2202 is initiated by DMA engine 120 as the packet is copied into a buffer in the host computer. One purpose of state 2202 is simply to determine whether memory 2102 should be searched for a packet related to one that will be, or is being transferred. Until a packet is determined to be transferred, the illustrated process continues in state 2202.

When, however, it is time for a search to be conducted (e.g., a packet is being transferred), the method continues at state 2204. In state 2204, the entry in memory 2102 corresponding to the packet being transferred is invalidated. Illustratively, this consists of storing a predetermined value (e.g., zero) in validity indicator 2110 for the packet's entry. In a present embodiment of the invention read pointer 2112 identifies the entry corresponding to the packet to be transferred. As one skilled in the art will recognize, one reason for invalidating a transferred packet's entry is so that when memory 2102 is searched for an entry associated with a packet related to the transferred packet, the transferred packet's own entry will not be identified.

In one embodiment of the invention the transferred packet's flow number is copied into a register (e.g., a hardware register) when dynamic packet batching module 122 is to search for a related packet. This may be particularly helpful (e.g., to assist in comparing the flow number to flow numbers of other packets) if memory 2102 is implemented as a RAM instead of a CAM.

In state 2206, read pointer 2112 is incremented to point to the next entry in memory 2102. If read pointer is incremented to the same entry that is referenced by write pointer 2114, and that entry is also invalid (as indicated by validity indicator 2110), it may be determined that memory 2102 is now empty.

Then, in state 2208, memory 2102 is searched for a packet related to the packet being transferred (e.g., the memory is searched for an entry having the same flow number). As described above, entries in memory 2102 are searched associatively in one embodiment of the invention. Thus, the result of the search operation may be a single signal indicating whether or not a match was found.

In the illustrated embodiment of the invention, only valid entries (e.g., those having a value of one in their validity indicators) are searched. As explained above, an entry may be marked invalid (e.g., its validity indicator stores a value of zero) if the associated packet is considered incompatible. Entries for incompatible packets may be disregarded because their data is not ordinarily re-assembled and their headers are not normally batched. In an alternative embodiment of the invention, all entries may be searched but a match is reported only if a matching entry is valid.

In state 2210, the host computer is alerted to the availability or non-availability of a related packet. In this embodiment of the invention, the host computer is alerted by storing a predetermined value in a specific field of the transferred packet's completion descriptor (described in a previous section). As discussed in the previous section, when a packet is transferred a descriptor in a descriptor ring in host memory is populated with information concerning the packet (e.g., an identifier of its location in host memory, its size, an identifier of a processor to process the packet's headers). In particular, a release flow flag or indicator is set to a first value (e.g., zero) if a related packet is found, and a second value if no related packet is found. Illustratively, DMA engine 120 issues the alert or stores the necessary information to indicate the existence of a related packet in response to notification from dynamic packet batching module 122. Other methods of notifying the host computer of the presence of a related packet are also suitable (e.g., an indicator, flag, key), as will be appreciated by one skilled in the art.

In FIG. 22B, state 2220 is a start state for a memory population cycle.

In state 2222, it is determined whether a new packet has been received at the network interface. Illustratively, a new

entry is made in the packet batching module's memory for each packet received from the network. The receipt of a new packet may be signaled by IPP module 104. For example, the receipt of a new packet may be indicated by the storage of the packet's flow number, by IPP module 104, in a temporary location (e.g., a register). Until a new packet is received, the illustrated procedure waits. When a packet is received, the procedure continues at state 2224.

In state 2224, if memory 2102 is configured to store fewer entries than packet queue 116 (and, possibly, control queue 118), memory 2102 is examined to determine if it is full.

In one embodiment of the invention memory 2102 may be considered full if the validity indicator is set (e.g., equal to one) for each entry or for the entry referenced by write pointer 2114. If the memory is full, the illustrated procedure waits until the memory is not full. As one skilled in the art will recognize, memory 2102 and other data structures in NIC 100 may be tested for saturation (e.g., whether they are filled) by comparing their read and write pointers.

In state 2226, a new packet is represented in memory 2102 by storing its flow number in the entry identified by write pointer 2114 and storing an appropriate value in the entry's validity indicator field. If, for example, the packet is not re-assemblable (e.g., as indicated by its operation code), the entry's validity indicator may be set to an invalid state. For purposes of the operation of dynamic packet batching module 122, a TCP control packet may or may not be considered re-assemblable. Thus, depending upon the implementation of a particular embodiment the validity indicator for a packet that is a TCP control packet may be set to a valid or invalid state.

In an alternative embodiment of the invention an entry in memory 2102 is populated with information from the control queue entry identified by the second read pointer described above. This pointer may then be incremented to the next entry in control queue 118.

In state 2228, write pointer 2114 is incremented to the next entry of memory 2102, after which the illustrated method ends at end state 2230. If write pointer 2114 references the same entry as read pointer 2112, it may be determined that memory 2102 is full. One skilled in the art will recognize that many other suitable methods of managing pointers for memory 2102 may be employed.

As mentioned above, in one embodiment of the invention one or both of the memory search and memory population operations run continuously. Thus, end state 2230 may be removed from the procedure illustrated in FIG. 22B, in which case the procedure would return to state 2222 after state 2228.

Advantageously, in the illustrated embodiment of the invention the benefits provided to the host computer by dynamic packet batching module 122 increase as the host computer becomes increasingly busy. In particular, the greater the load placed on a host processor, the more delay that will be incurred until a packet received from NIC 100 may be processed. As a result, packets may queue up in packet queue 116 and, the more packets in the packet queue, the more entries that can be maintained in memory 2102.

The more entries that are stored in memory 2102, the further ahead dynamic packet batching module can look for a related packet. The further ahead it scans, the more likely it is that a related packet will be found. As more related packets are found and identified to the host computer for collective processing, the amount of processor time spent on network traffic decreases and overall processor utilization increases.

One skilled in the art will appreciate that other systems and methods may be employed to identify multiple packets

from a single communication flow or connection without exceeding the scope of the present invention.

Early Random Packet Discard in One Embodiment of the Invention

Packets may arrive at a network interface from a network at a rate faster than they can be transferred to a host computer. When such a situation exists, the network interface must often drop, or discard, one or more packets. Therefore, in one embodiment of the present invention a system and method for randomly discarding a packet are provided. Systems and methods discussed in this section may be applicable to other communication devices as well, such as gateways, routers, bridges, modems, etc.

As one skilled in the art will recognize, one reason that a packet may be dropped is that a network interface is already storing the maximum number of packets that it can store for transfer to a host computer. In particular, a queue that holds packets to be transferred to a host computer, such as packet queue 116 (shown in FIG. 1A), may be fully populated when another packet is received from a network. Either the new packet or a packet already stored in the queue may be dropped.

Partly because of the bursty nature of much network traffic, multiple packets may often be dropped when a network interface is congested. And, in some network interfaces, if successive packets are dropped one particular network connection or flow (e.g., a connection or flow that includes all of the dropped packets) may be penalized even if it is not responsible for the high rate of packet arrival. If a network connection or flow is penalized too heavily, the network entity generating the traffic in that connection or flow may tear it down in the belief that a "broken pipe" has been encountered. As one skilled in the art will recognize, a broken pipe occurs when a network entity interprets a communication problem as indicating that a connection has been severed.

For certain network traffic (e.g., TCP traffic), the dropping of a packet may initiate a method of flow control in which a network entity's window (e.g., number of packets it transmits before waiting for an acknowledgement) shrinks or is reset to a very low number. Thus, every time a packet from a TCP communicant is dropped by a network interface at a receiving entity, the communicant must re-synchronize its connection with the receiving entity. If one or a subset of communicants are responsible for a large percentage of network traffic received at the entity, then it seems fair that those communicants should be penalized in proportion to the amount of traffic that it is responsible for.

In addition, it may be wise to prevent certain packets or types of packets from being discarded. For example, discarding a small control packet may do very little to alleviate congestion in a network interface and yet have a drastic and negative effect upon a network connection or flow. Further, if a network interface is optimized for packets adhering to a particular protocol, it may be more efficient to avoid dropping such packets. Even further, particular connections, flows or applications may be prioritized, in which case higher priority traffic should not be dropped.

Thus, in one embodiment of a network interface according to the present invention, a method is provided for randomly discarding a packet when a communication device's packet queue is full or is filled to some threshold level. Intelligence may be added to such a method by selecting certain types of packets for discard (e.g., packets from a particular flow, connection or application) or excepting certain types of packets from being discarded (e.g., control packets, packets conforming to a particular protocol or set of protocols).

A provided method is random in that discarded packets are selected randomly from those packets that are considered discardable. Applying a random discard policy may be sufficient to avoid broken pipes by distributing the impact of dropped packets among multiple connections or flows. In addition, if a small number of transmitting entities are responsible for a majority of the traffic received at a network interface, dropping packets randomly may ensure that the offending entities are penalized proportionately. Different embodiments of the invention that are discussed below provide various combinations of randomness and intelligence, and one of these attributes may be omitted in one or more embodiments.

FIG. 24 depicts a system and method for randomly discarding packets in a present embodiment of the invention. In this embodiment, packet queue 2400 is a hardware FIFO (e.g., first-in first-out) queue that is 16 KB in size. In other embodiments of the invention the packet queue may be smaller or larger or may comprise another type of data structure (e.g., list, array, table, heap) implemented in hardware or software.

Similar to packet queue 116 discussed in a previous section, packet queue 2400 receives packets from a network and holds them for transfer to a host computer. Packets arriving from a network may arrive from the network at a high rate and may be processed or examined by one or more modules (e.g., header parser 106, flow database manager 108) prior to being stored in packet queue 2400. For example, where the network is capable of transmitting one gigabit of traffic per second, packets conforming to one set of protocols (e.g., Ethernet, IP and TCP) may be received at a rate of approximately 1.48 million packets per second. After being stored in packet queue 2400, packets are transferred to a host computer at a rate partially dependent upon events and conditions internal to the host computer. Thus, the network interface may not be able to control the rate of packet transmittal to the host computer.

In the illustrated embodiment, packet queue 2400 is divided into a plurality of zones or regions, any of which may overlap or share a common boundary. Packet queue 2400 may be divided into any number of regions, and the invention is not limited to the three regions depicted in FIG. 24. Illustratively, region zero (represented by the numeral 2402) encompasses the portion of packet queue 2400 from 0 KB (e.g., no packets are stored in the queue) to 8 KB (e.g., half full). Region one (represented by the numeral 2404) encompasses the portion of the packet queue from 8 KB to 12 KB. Region two (represented by the numeral 2406) encompasses the remaining portion of the packet queue, from 12 KB to 16 KB. In an alternative embodiment, regions may only be defined for a portion of packet queue 2400. For example, only the upper half (e.g., above 8 KB) may be divided into one or more regions.

The number and size of the different regions and the location of boundaries between the regions may vary according to several factors. Among the factors are the type of packets received at the network interface (e.g., the protocols according to which the packets are configured), the size of the packets, the rate of packet arrival (e.g., expected rate, average rate, peak rate), the rate of packet transfer to the host computer, the size of the packet queue, etc. For example, in another embodiment of the invention, packet queue 2400 is divided into five regions. A first region extends from 0 KB to 8 KB; a second region ranges from 8 KB to 10 KB; a third from 10 KB to 12 KB; a fourth from 12 KB to 14 KB; and a final region extends from 14 KB to 16 KB.

During operation of a network interface according to a present embodiment, traffic indicator 2408 indicates how full packet queue 2400 is. Traffic indicator 2408, in one embodiment of the invention, comprises read pointer 810 and/or write pointer 812 (shown in FIG. 8). In the presently discussed embodiment in which packet queue 2400 is fully partitioned, traffic indicator 2408 will generally be located in one of the regions into which the packet queue was divided or at a dividing boundary. Thus, during operation of a network interface appropriate action may be taken, as described below, depending upon how full the packet queue is (e.g., depending upon which region is identified by traffic indicator 2408).

In FIG. 24, counter 2410 is incremented as packets arrive at packet queue 2400. In the illustrated embodiment, counter 2410 continuously cycles through a limited range of values, such as zero through seven. In one embodiment of the invention, each time a new packet is received the counter is incremented by one. In an alternative embodiment, counter 2410 may not be incremented when certain "non-discardable" packets are received. Various illustrative criteria for identifying non-discardable packets are presented below.

For one or more regions of packet queue 2400, an associated programmable probability indicator indicates the probability that a packet will be dropped when traffic indicator 2408 indicates that the level of traffic in the packet queue has reached the associated region. Therefore, in the illustrated embodiment probability indicator 2412 indicates the probability that a packet will be dropped while the packet queue is less than half full (e.g., when traffic indicator 2408 is located in region zero). Similarly, probability indicators 2414 and 2416 specify the probability that a new packet will be dropped when traffic indicator 2408 identifies regions one and two, respectively.

In the illustrated embodiment, probability indicators 2412, 2414 and 2416 each comprise a set, or mask, of sub-indicators such as bits or flags. Illustratively, the number of sub-indicators in a probability indicator matches the range of counter values—in this case, eight. In one embodiment of the invention, each sub-indicator may have one of two values (e.g., zero or one) indicating whether a packet is dropped. Thus, the sub-elements of a probability indicator may be numbered from zero to seven (illustratively, from right to left) to correspond to the eight possible values of counter 2410. For each position in a probability indicator that stores a first value (e.g., one), when the value of counter 2410 matches the number of that bit, the next discardable packet received for packet queue 2400 will be dropped. As discussed above, certain types of packets (e.g., control packets) may not be dropped. Illustratively, counter 2410 is only incremented for discardable packets.

In FIG. 24, probability indicator 2412 (e.g., 00000000) indicates that no packets are to be dropped as long as the packet queue is less than half full (e.g., as long as traffic indicator 2408 is in region zero). Probability indicator 2414 (e.g., 00000001) indicates that every eighth packet is to be dropped when there is at least 8 KB stored in the packet queue. In other words, when traffic indicator 2408 is located in region one, there is a 12.5% probability that a discardable packet will be dropped. In particular, when counter 2410 equals zero the next discardable packet, or a packet already stored in the packet queue, is discarded. Probability indicator 2416 (e.g., 01010101) specifies that every other discardable packet is to be dropped. There is thus a 50% probability that a discardable packet will be dropped when the queue is more than three-quarters full. Illustratively, when a packet is dropped, counter 2410 is still incremented.

As another example, in the alternative embodiment described above in which the packet queue is divided into five regions, suitable probability indicators may include the following. For regions zero and one, 00000000; for region two, 00000001; for region three, 00000101; and for region four, 01111111. Thus, in this alternative embodiment, region one is treated as an extension to region zero. Further, the probability of dropping a packet has a wider range, from 0% to 87.5%.

In one alternative embodiment described above, only a portion of a packet queue is partitioned into regions. In this alternative embodiment, a default probability or null probability (e.g., 00000000) of dropping a packet may be associated with the un-partitioned portion. Illustratively, this ensures that no packets are dropped before the level of traffic stored in the queue reaches a first threshold. Even in an embodiment where the entire queue is partitioned, a default or null probability may be associated with a region that encompasses or borders a 0 KB threshold.

Just as a packet queue may be divided into any number of regions for purposes of the present invention, probability indicators may comprise bit masks of any size or magnitude, and need not be of equal size or magnitude. Further, probability indicators are programmable in a present embodiment, thus allowing them to be altered even during the operation of a network interface.

One skilled in the art will recognize that discarding packets on the basis of a probability indicator injects randomness into the discard process. A random early discard policy may be sufficient to avoid the problem of broken pipes discussed above. In particular, in one embodiment of the invention, all packets are considered discardable, such that all packets are counted by counter 2410 and all are candidates for being dropped. As already discussed, however, in another embodiment of the invention intelligence is added in the process of excluding certain types of packets from being discarded.

It will be understood that probability indicators and a counter simply constitute one system for enabling the random discard of packets in a network interface. Other mechanisms are also suitable. In one alternative embodiment, a random number generator may be employed in place of a counter and/or probability indicators to enable a random discard policy. For example, when a random number is generated, such as M, the Mth packet (or every Mth packet) after the number is generated may be dropped. Or, the random number may specify a probability of dropping a packet. The random number may thus be limited to (e.g., hashed into) a certain range of values or probabilities. As another alternative, a random number generator may be used in tandem with multiple regions or thresholds within a packet queue. In this alternative embodiment a programmable value, represented here as N, may be associated with a region or queue threshold. Then, when a traffic indicator reaches that threshold or region, the Nth packet (or every Nth packet) may be dropped until another threshold or boundary is reached.

In yet another alternative embodiment of the invention, the probability of dropping a packet is expressed as a binary fraction. As one skilled in the art will recognize, a binary fraction consists of a series of bits in which each bit represents one half of the magnitude of its more significant neighbor. For example, a binary fraction may use four digits in one embodiment of the invention. From left to right, the bits may represent 0.5, 0.25, 0.125 and 0.0625, respectively. Thus, a binary fraction of 1010 would be interpreted as indicating a 62.5% probability of dropping a packet (e.g.,

50% plus 12.5%). The more positions (e.g., bits) used in a binary fraction, the greater precision that may be attained.

In one implementation of this alternative embodiment a separate packet counter is associated with each digit. The counter for the leftmost bit increments at twice the rate of the next counter, which increments twice as fast as the next counter, etc. In other words, when the counter for the most significant (e.g., left) bit increments from 0 to 1 the other counters do not change. When the most significant counter increments again, from 1 back to 0, then the next counter increments from 0 to 1. Likewise, the counter for the third bit does not increment from 0 to 1 until the second counter returns to 0. In summary, the counter for the most significant bit changes (i.e., increments) each time a packet is received. The counter for the next most significant bit maintains each value (i.e., 0 or 1) for two packets before incrementing. Similarly, the counter for the third most significant bit maintains each counter value for four packets before incrementing and the counter for the least significant bit maintains its values for eight packets before incrementing.

Each time a packet is received or a counter is incremented the counters are compared to the probability indicator (e.g., the specified binary fraction). In one embodiment the determination of whether a packet is dropped depends upon which of the fraction's bits are equal to one. Illustratively, for each fraction bit equal to one a random packet is dropped if the corresponding counter is equal to one and the counters for any bits of higher significance are equal to zero. Thus for the example fraction 1010, whenever the most significant bit's counter is equal to one a random packet is dropped. In addition, a random packet is also dropped whenever the counter for the third bit is equal to one and the counters for the first two bits are equal to zero.

A person skilled in the art may also derive other suitable mechanisms for specifying and enforcing a probability of dropping a packet received at a network interface without exceeding the scope of the present invention.

As already mentioned, intelligence may be imparted to a random discard policy in order to avoid discarding certain types of packets. In a previous section, methods of parsing a packet received from a network were described. In particular, in a present embodiment of the invention a packet received from a network is parsed before it is placed into a packet queue such as packet queue 2400. During the parsing procedure various information concerning the packet may be gleaned. This information may be used to inject intelligence into a random discard policy. In particular, one or more fields of a packet header may be copied, an originating or destination entity of the packet may be identified, a protocol may be identified, etc.

Thus, in various embodiments of the invention, certain packets or types of packets may be immune from being discarded. In the embodiment illustrated in FIG. 24, for example, control packets are immune. As one skilled in the art will appreciate, control packets often contain information essential to the establishment, re-establishment or maintenance of a communication connection. Dropping a control packet may thus have a more serious and damaging effect than dropping a packet that is not a control packet. In addition, because control packets generally do not contain data, dropping a control packet may save very little space in the packet queue.

Many other criteria for immunizing packets are possible. For example, when a packet is parsed according to a procedure described in a previous section, a No\_Assist flag or signal may be associated with the packet to indicate whether the packet is compatible with a set of pre-selected

communication protocols. Illustratively, if the flag is set to a first value (e.g., one) or the signal is raised, the packet is considered incompatible and is therefore ineligible for certain processing enhancements (e.g., re-assembly of packet data, batch processing of packet headers, load-balancing). Because a packet for which a No\_Assist flag is set to the first value may be a packet conforming to an unexpected protocol or unique format, it may be better not to drop such packets. For example, a network manager may want to ensure receipt of all such packets in order to determine whether a parsing procedure should be augmented with the ability to parse additional protocols.

Another reason for immunizing a No\_Assist packet (e.g., packets that are incompatible with a set of selected protocols) from being discarded concerns the reaction to dropping the packet. Because the packet's protocols were not identified, it may not be known how the packet's protocols respond to the loss of a packet. In particular, if the sender of the packet does not lower its transmission rate in response to the dropped packet (e.g., as a form of congestion control), then there is no benefit to dropping it.

A packet's flow number may be used to immunize certain packets in another alternative embodiment of the invention. As discussed in a previous section, a network interface may include a flow database and flow database manager to maintain a record of multiple communication flows received by the network interface. It may be efficacious to prevent packets from one or more certain flows from being discarded. Immunized flows may include a flow involving a high-priority network entity, a flow involving a particular application, etc. For example, it may be considered relatively less damaging to discard packets from an animated or streaming graphics application in which a packet, or a few packets, may be lost without seriously affecting the destination entity and the packets may not even need to be retransmitted. In contrast, the consequences may be more severe if a few packets are dropped from a file transfer connection. The packets will likely need to be retransmitted, and the transmitting entity's window may be shrunk as a result—thus decreasing the rate of file transfer.

In yet another alternative embodiment of the invention, a probability indicator may comprise a bit mask in which each bit corresponds to a separate, specific flow through the network interface. In particular, the bits may correspond to the flows maintained in the flow database described in a previous section.

Although embodiments of the invention discussed thus far in this section involve discarding packets as they arrive at a packet queue, in an alternative embodiment packets may be discarded from within the packet queue. In particular, as the packet queue is filled (e.g., as a traffic indicator reaches pre-defined regions or thresholds), packets already stored in the queue may be discarded at random according to one or more probability indicators. In the embodiment illustrated in FIG. 24, for example, when traffic indicator 2408 reaches a certain threshold, such as the boundary between regions one and two or the end of the queue, packets may be deleted in one or more regions according to related probability indicators. Such probability indicators would likely have different values than those indicated in FIG. 24.

In a present embodiment of the invention, probability indicators and/or the specifications (e.g., boundaries) into which a packet queue is partitioned are programmable and may be adjusted by software operating on a host computer (e.g., a device driver). Criteria for immunizing packets may also be programmable. Methods of discarding packets in a network interface or other communication device may thus

be altered in accordance with the embodiments described in this section, even during continued operation of such a device. Various other embodiments and criteria for randomly discarding packets and/or applying criteria for the intelligent discard of packets will be apparent to those skilled in the art.

FIGS. 25A–25B comprise a flow chart demonstrating one method of implementing a policy for randomly discarding packets in a network interface according to the embodiment of the invention substantially similar to the embodiment illustrated in FIG. 24. In this embodiment, a packet is received while packet queue 2400 is not yet full. As one skilled in the will appreciate, this embodiment provides a method of determining whether to discard the packet. Once packet queue 2400 is full, when another packet is received the network interface generally must drop a packet—either the one just received or one already stored in the queue—in which case the only decision is which packet to drop.

In FIG. 25A, state 2500 is a start state. State 2500 may reflect the initialization of the network interface (and packet queue 2400) or may reflect a point in the operation of the network interface at which one or more parameters or aspects concerning the packet queue and the random discard policy are to be modified.

In state 2502, one or more regions are identified in packet queue 2400, perhaps by specifying boundaries such as the 8 KB and 12 KB boundaries depicted in FIG. 24. Although the regions depicted in FIG. 24 fully encompass packet queue 2400 when viewed in unison, regions in an alternative embodiment of the invention may encompass less than the entire queue.

In state 2504, one or more probability indicators are assigned and configured. In the illustrated embodiment, one probability indicator is associated with each region. Alternatively, multiple regions may be associated with one probability indicator. Even further, one or more regions may not be explicitly associated with a probability indicator, in which case a default or null probability indicator may be assumed. As described above, a probability indicator may take the form of a multi-bit mask, whereby the number of bits in the mask reflect the range of possible values maintained by a packet counter. In another embodiment of the invention, a probability indicator may take the form of a random number or a threshold value against which a randomly generated number is compared when a decision must be whether to discard a packet.

In state 2506, if certain types of packets are to be prevented from being discarded, criteria are expressed to identify the exempt packets. Some packets that may be exempted are control packets, packets conforming to unknown or certain known protocols, packets belonging to a particular network connection or flow, etc. In one embodiment of the invention, no packets are exempt from being discarded.

In state 2508, a packet or traffic counter is initialized. As described above, the counter may be incremented, possibly through a limited range of values, when a discardable packet is received for storage in packet queue 2400. The limited range of counter values may correspond to the number of bits in a mask form of a probability indicator. Alternatively, the counter may be configured to increment through a greater range, in which case a counter value may be filtered through a modulus or hash function prior to being compared to a probability indicator as described below.

In state 2510, a packet is received from a network and may be processed through one or more modules (e.g., a header parser, an IPP module) prior to its arrival at packet

queue 2400. Thus, in state 2510 the packet is ready to be stored in the packet queue. One or more packets may already be stored in the packet queue and a traffic indicator (e.g., a pointer or index) identifies the level of traffic stored in the queue (e.g., by a storage location and/or region in the queue).

In state 2512, it may be determined whether the received packet is discardable. For example, if the random discard policy that is in effect allows for the exemption of some packets from being discarded, in state 2512 it is determined whether the received packet meets any of the exemption criteria. If so, the illustrated procedure continues at state 2522. Otherwise, the procedure continues at state 2514.

In state 2514, an active region of packet queue 2400 is identified. In particular, the region of the packet queue to which the queue is presently populated with traffic is determined. The level of traffic stored in the queue depends upon the number and size of packets that have been stored in the queue to await transfer to a host computer. The slower the transfer process, the higher the level of traffic may reach in the queue. Although the level of traffic stored in the queue rises and falls as packets are stored and transferred, the level may be identified at a given time by examining the traffic indicator. The traffic indicator may comprise a pointer identifying the position of the last or next packet to be stored in the queue. Such a pointer may be compared to another pointer that identifies the next packet to be transferred to the host computer in order to reveal how much traffic is stored in the queue.

In state 2516, the counter value (e.g., a value between zero and seven in the embodiment of FIG. 24) is compared to the probability indicator associated with the active region. As previously described, the counter is incremented as discardable packets are received at the queue. This comparison is conducted so as to determine whether the received packet should be discarded. As explained above, in the embodiment of FIG. 24 the setting of the probability indicator bit corresponding to the counter value is examined. For example, if the counter has a value of N, then bit number N of the probability indicator mask is examined. If the bit is set to a first state (e.g., one) the packet is to be discarded; otherwise it is not to be discarded.

In state 2518, the counter is incremented to reflect the receipt of a discardable packet, whether or not the packet is to be discarded. In the presently discussed embodiment of the invention, if the counter contains its maximum value (e.g., seven) prior to being incremented, incrementing it results in resetting it to its minimum value (e.g., zero).

In state 2520, if the packet is to be discarded the illustrated procedure continues at state 2524. Otherwise, the procedure continues at state 2522. In state 2522, the packet is stored in packet queue 2400 and the illustrated procedure ends with state 2526. In state 2524, the packet is discarded and the illustrated procedure ends with end state 2526.

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The foregoing descriptions of embodiments of the invention have been presented for purposes of illustration and description only. They are not intended to be exhaustive or to limit the invention to the forms disclosed. Many modifications and variations will be apparent to practitioners skilled in the art. Accordingly, the above disclosure is not intended to limit the invention; the scope of the invention is defined by the appended claims.

What is claimed is:  
 A method of transferring a packet to a computer system, wherein the packet is received at a communication device connected to a network, comprising:

1. parsing a header portion of a first packet received at a communication device to determine if said first packet conforms to a pre-selected protocol;

generating a flow key to identify a first communication flow that includes said first packet;

transferring said first packet to a host computer system for processing in accordance with said pre-selected protocol; and

associating an operation code with said first packet, wherein said operation code indicates a status of said first packet.

2. The method of claim 1, wherein said parsing comprises: copying a header portion of said first packet into a header memory; and

examining said header portion according to a series of parsing instructions;

wherein said parsing instructions are configured to reflect a set of pre-selected communication protocols.

3. The method of claim 2, wherein said parsing instructions are updateable.

4. The method of claim 2, further comprising copying a value from a field in a header of said header portion.

5. The method of claim 1, wherein said parsing comprises: extracting an identifier of a source of said first packet from said header portion; and

extracting an identifier of a destination of said first packet from said header portion.

6. The method of claim 5, wherein said generating comprises combining said source identifier and said destination identifier.

7. The method of claim 1, wherein said generating comprises retrieving an identifier of a communication connection from said header portion.

8. The method of claim 1, further comprising storing said first packet in a packet memory prior to said transferring.

9. The method of claim 1, further comprising storing said flow key in a flow database, wherein said flow database is configured to facilitate management of said first communication flow.

10. The method of claim 9, further comprising associating a flow number with said first packet, wherein said flow number comprises an index of said flow key within said flow database.

11. The method of claim 10, further comprising storing said flow number in a flow memory.

12. The method of claim 9, further comprising updating an entry in said flow database associated with said flow key when a second packet in said first communication flow is received.

13. A computer readable storage medium storing instructions that, when executed by a computer, cause the computer to perform a method of transferring a packet received at a network interface from a network to a host computer system, the method comprising:

receiving a packet from a network at a network interface for a host computer system;

parsing a header portion of said packet to extract an identifier of a source entity and an identifier of a destination entity;

generating a flow key from said source identifier and said destination identifier to identify a communication flow comprising said packet;

determining whether a header in said header portion conforms to a pre-selected protocol;

storing said flow key in a database;

associating an operation code with said packet, wherein said operation code identifies a status of said packet; storing said packet in a packet memory; if said header conforms to said pre-selected protocol: storing a data portion of said packet in a re-assembly buffer; and storing said header portion in a header buffer; and if said header conforms to a protocol other than said pre-selected protocol, storing said packet in a non-re-assembly buffer.

14. The method of claim 1, wherein said associating comprises: retrieving one or more header fields of said header portion; and analyzing said header fields to determine said status of said first packet.

15. The method of claim 14, wherein said analyzing comprises: determining whether said first packet includes a data portion; and if said first packet includes a data portion, determining whether said data portion exceeds a pre-determined size.

16. The method of claim 14, wherein said analyzing comprises determining whether said first packet was received out of order in said first communication flow.

17. The method of claim 1, further comprising storing said operation code in a control memory.

18. The method of claim 1, wherein said first packet is determined to conform to said pre-selected protocol, said transferring comprising: storing a data portion of said first packet in a re-assembly storage area, wherein said re-assembly storage area is configured to only store data portions of packets in said first communication flow; and storing one or more headers from said header portion in a header storage area.

19. The method of claim 1, wherein said transferring comprises: if said first packet is smaller than a predetermined threshold, storing said first packet in a first storage area; and if said first packet is larger than said predetermined threshold, storing said first packet in a second storage area.

20. The method of claim 1, further comprising determining whether a second packet received from said network is part of said first communication flow.

21. The method of claim 20, wherein said determining comprises: maintaining a packet memory configured to store one or more packets received from said network; maintaining a flow memory configured to store, for each of said one or more packets, an identifier of a communication flow comprising said packet; and searching said flow memory for a first identifier of said first communication flow.

22. The method of claim 21, wherein said first identifier comprises said flow key.

23. The method of claim 21, wherein said first identifier comprises a flow number of said first packet, wherein said flow number is an index of said flow key within a flow database.

24. The method of claim 1, wherein said host computer system comprises a plurality of processors, further comprising:

identifying a quantity of processors in said host computer system available for processing packets; and associating a first processor identifier with said first packet to identify a first processor in said host computer system for processing said first packet.

25. The method of claim 24, further comprising: receiving a second packet in said first communication flow; and associating said first processor identifier with said second packet.

26. The method of claim 24, further comprising: receiving a second packet from a second communication flow; and associating a second processor identifier with said second packet to identify a second processor in said host computer system for processing said second packet.

27. The method of claim 1, further comprising alerting said host computer system to the arrival of said first packet.

28. The method of claim 1, further comprising: maintaining a packet memory configured to store packets received from said network; and randomly discarding a packet if said packet memory contains a pre-determined level of traffic.

29. The method of claim 28, wherein said packet is said first packet.

30. The method of claim 28, wherein said packet memory comprises a plurality of regions, said randomly discarding comprising: identifying one of said plurality of regions, wherein a level of traffic stored in said packet memory has reached said region; applying a probability indicator associated with said region to determine a probability that said first packet should be discarded; and if said probability exceeds a predetermined threshold, discarding said first packet.

31. The method of claim 1, wherein said communication device is a network interface.

32. A method of transferring a packet received at a network interface to a host computer system, comprising: receiving a packet from a network; storing said packet in a packet memory; parsing a header portion of said packet; extracting a value stored in said header portion; identifying a communication flow comprising said packet; determining whether a header in said header portion conforms to a pre-selected protocol; determining whether a second packet in said packet memory is part of said communication flow; if the host computer system contains a plurality of processors, identifying a processor to process said packet; and storing said packet in a host memory area.

33. A method of transferring a packet received at a network interface from a network to a host computer system, comprising: receiving a packet from a network at a network interface for a host computer system; parsing a header portion of said packet to extract an identifier of a source entity and an identifier of a destination entity; generating a flow key from said source identifier and said destination identifier to identify a communication flow comprising said packet;



determining whether a header in said header portion conforms to a pre-selected protocol;  
 storing said flow key in a database;  
 associating an operation code with said packet, wherein said operation code identifies a status of said packet;  
 storing said packet in a packet memory;  
 if said header conforms to said pre-selected protocol:  
 storing a data portion of said packet in a re-assembly buffer; and  
 storing said header portion in a header buffer; and  
 if said header conforms to a protocol other than said pre-selected protocol, storing said packet in a non-re-assembly buffer.

34. The method of claim 33, wherein said parsing comprises executing a series of updateable instructions configured to parse a packet header conforming to one of a set of pre-selected protocols.

35. The method of claim 33, further comprising storing said operation code in a control memory.

36. The method of claim 33, further comprising storing a flow number of said packet in a flow memory, wherein said flow number comprises an index of said flow key in said database.

37. The method of claim 36, further comprising indicating whether said packet memory includes another packet with said flow number or said flow key.

38. The method of claim 33, wherein the host computer system comprises multiple processors, further comprising identifying a first processor in the host computer system to process said packet in accordance with said pre-selected protocol.

39. The method of claim 38, further comprising:  
 receiving a second packet at said network interface, wherein said second packet is part of a second communication flow; and  
 identifying a second processor in the host computer system to process said second packet.

40. The method of claim 33, further comprising informing said host computer system of said receipt of said packet.

41. The method of claim 33, wherein said packet memory comprises a plurality of regions, further comprising:  
 determining a level of network traffic stored in said packet memory; and  
 applying a probability indicator associated with one of said regions to determine whether to discard a packet received from said network.

42. An apparatus for transferring a packet to a host computer system, comprising:

a traffic classifier configured to classify a first packet received from a network by a communication flow that includes said first packet;

a packet memory configured to store said first packet;

a packet batching module configured to determine whether another packet in said packet memory belongs to said communication flow; and

a flow re-assembler configured to re-assemble a data portion of said first packet with a data portion of a second packet in said communication flow;

wherein said first packet data portion and said second packet data portion are stored in a host computer memory area to enable efficient transfer of said memory area contents.

43. The apparatus of claim 42, wherein said traffic classifier comprises:

a parser configured to parse a header portion of said first packet;

a flow database configured to store a flow key identifying said communication flow; and

a flow database manager configured to manage said flow database;

wherein said flow key is generated from an identifier of a source of said first packet and an identifier of a destination of said first packet.

44. A computer system for receiving a packet from a network, comprising:

a memory configured to store packets received from a network; and

a communication device configured to receive a first packet from said network, the communication device comprising:

a parser configured to extract information from a header portion of a first packet;

a flow manager configured to examine said information;

a flow database configured to store an identifier of a first communication flow comprising multiple packets, including said first packet; and

a re-assembler for storing data portions of said multiple packets in a first portion of said memory; and

a processor for processing said first packet.

45. The apparatus of claim 42, further comprising:

a load distributor for identifying a first processor within the host computer system for processing said first packet and said second packet;

wherein said load distributor identifies a second processor in the host computer system for processing a packet from a different communication flow.

46. The apparatus of claim 42, further comprising:

a probability indicator for determining a probability of discarding a packet at said packet memory when a level of traffic stored in said packet memory is within a pre-determined region associated with said probability indicator.

47. A device for receiving a packet from a network and transferring the packet to a host computer system, comprising:

a parser configured to parse a header portion of a packet received from a network, wherein said parsing comprises:

determining whether a header within said header portion conforms to one of a set of communication protocols; and

if said header conforms to one of said communication protocols,

extracting information from said header portion to identify a communication flow to which said packet belongs;

a flow memory configured to store a flow identifier for identifying said communication flow;

a flow manager configured to assign an operation code to said packet, wherein said operation code:  
 indicates a status of said packet; and  
 indicates a manner of transferring said packet to the host computer system;

a packet memory configured to store said packet; and

a transfer module configured to transfer said packet from said packet memory to a host computer system in accordance with said operation code.

48. The device of claim 47, wherein the device is a network interface.

49. The device of claim 47, said flow memory comprising flow database configured to store a flow key, wherein said flow key is assembled from an identifier of a source of said packet and an identifier of a destination of said packet.

50. The device of claim 47, wherein said flow manager is further configured to update said flow memory as additional packets in said communication flow are received from the network.

51. The device of claim 47, said flow memory comprising flow memory configured to store a flow number, wherein said flow number comprises an index of said communication flow in a flow database.

52. The device of claim 47, further comprising a control module configured to store said operation code.

53. A computer readable storage medium storing instructions that, when executed by a computer, cause the computer to perform a method of transferring a packet from a communication device to a host computer, the method comprising:

parsing a header portion of a first packet received at a communication device to determine if said first packet conforms to a pre-selected protocol;

generating a flow key to identify a first communication flow that includes said first packet;

transferring said first packet to a host computer system for processing in accordance with said pre-selected protocol; and

associating an operation code with said first packet, wherein said operation code indicates a status of said first packet.

54. The device of claim 47, wherein said host computer system is a multi-processor host computer system, further comprising a load distributor configured to select one of said multiple processors for processing said packet in accordance with one of said communication protocols.

55. The device of claim 47, wherein said transfer module is configured to transfer a data portion of said packet into one of a set of host memory areas in accordance with said operation code.

56. The device of claim 47, further comprising a packet batching module configured to determine whether said packet memory contains another packet in said communication flow.

57. The device of claim 47, wherein said packet memory comprises multiple regions, and wherein each of said multiple regions is associated with a probability indicator configured to indicate a probability of discarding a packet received at the device.

58. An apparatus for transferring a packet from a network to a host computer system, comprising:

a parser module configured to:

parse a header portion of a first packet received from a network to extract an identifier of a source of said first packet and an identifier of a destination of said first packet;

generate a flow key from said source identifier and said destination identifier to identify a communication flow comprising said first packet; and

determine whether a header in said header portion conforms to a pre-selected

protocol;

a flow database configured to store said flow key;

a flow database manager configured to associate an operation code with said first packet, wherein said operation code identifies a status of said first packet;

a packet memory configured to store said first packet; and

a transfer module configured to:

if said header conforms to said pre-selected protocol:

store a data portion of said first packet in a re-assembly buffer; and

store said header portion in a header buffer; and

if said header conforms to a protocol other than said pre-selected protocol,

store said packet in a non-re-assembly buffer.

59. The apparatus of claim 58, wherein said transfer module comprises a re-assembly engine configured to re-assemble, in said re-assembly buffer, a data portion of said first packet with a data portion of a second packet in said first communication flow.

60. The apparatus of claim 58, further comprising a flow memory configured to store a flow number associated with said first packet, wherein said flow number comprises an index of said flow key in said flow database.

61. The apparatus of claim 58, further comprising:

a load distributor configured to identify a first processor in said host computer system for processing said first packet, said first processor being identified on the basis of said flow key;

wherein said host computer system is a multi-processor computer system; and

wherein a second processor in said host computer system is identified for processing a packet from a communication flow other than said first communication flow.

62. The apparatus of claim 58, further comprising:

a packet batching module configured to determine whether said packet memory includes another packet in said first communication flow.

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Zaumen et al.

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[45] Date of Patent: Sep. 12, 2000

[54] MANAGEMENT OF ENTRIES IN A NETWORK ELEMENT FORWARDING MEMORY

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[58] Field of Search 370/229, 330, 370/381, 386, 428, 469, 475, 237, 254, 389, 396, 397, 401, 402, 468; 365/49; 395/180, 182.03

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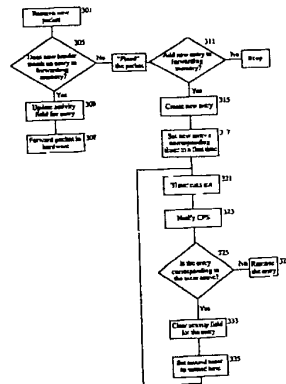
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Primary Examiner—Douglas W. Olms  
 Assistant Examiner—Shick Hom  
 Attorney, Agent, or Firm—Blakely Sokoloff Taylor & Zafman

[57] ABSTRACT

The invention generally provides for a network element and methods in the network element for allowing a matching entry in a forwarding memory to be found in a single search of the memory, for determining when an entry should be placed in the memory, and for determining when an entry should be removed from the memory, in order to make more efficient use of the fixed space available in the memory. The invention is particularly useful in making more efficient use of a Content Addressable Memory (CAM) for storing flow entries, and configuring the CAM to index an associated memory that stores forwarding and quality of service information for each CAM entry.

36 Claims, 3 Drawing Sheets



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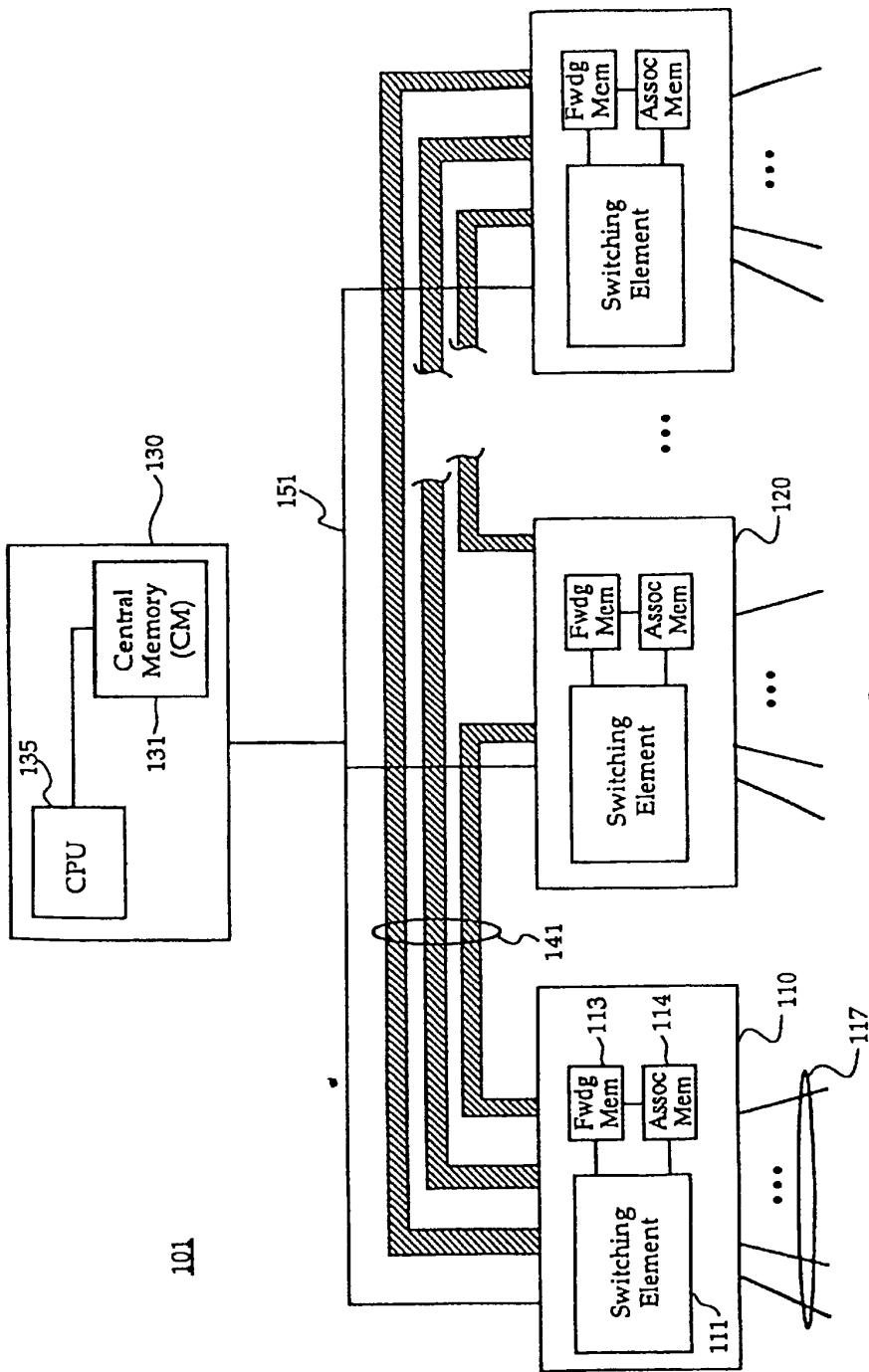


FIG. 1

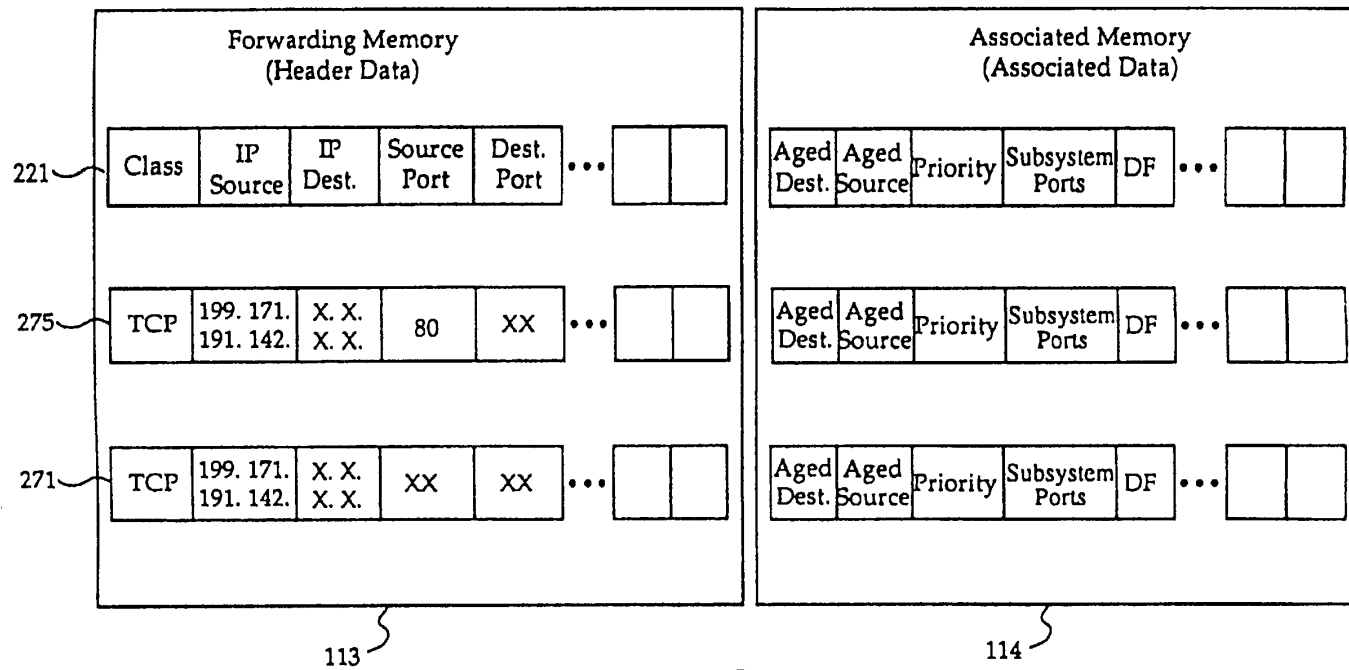


FIG. 2

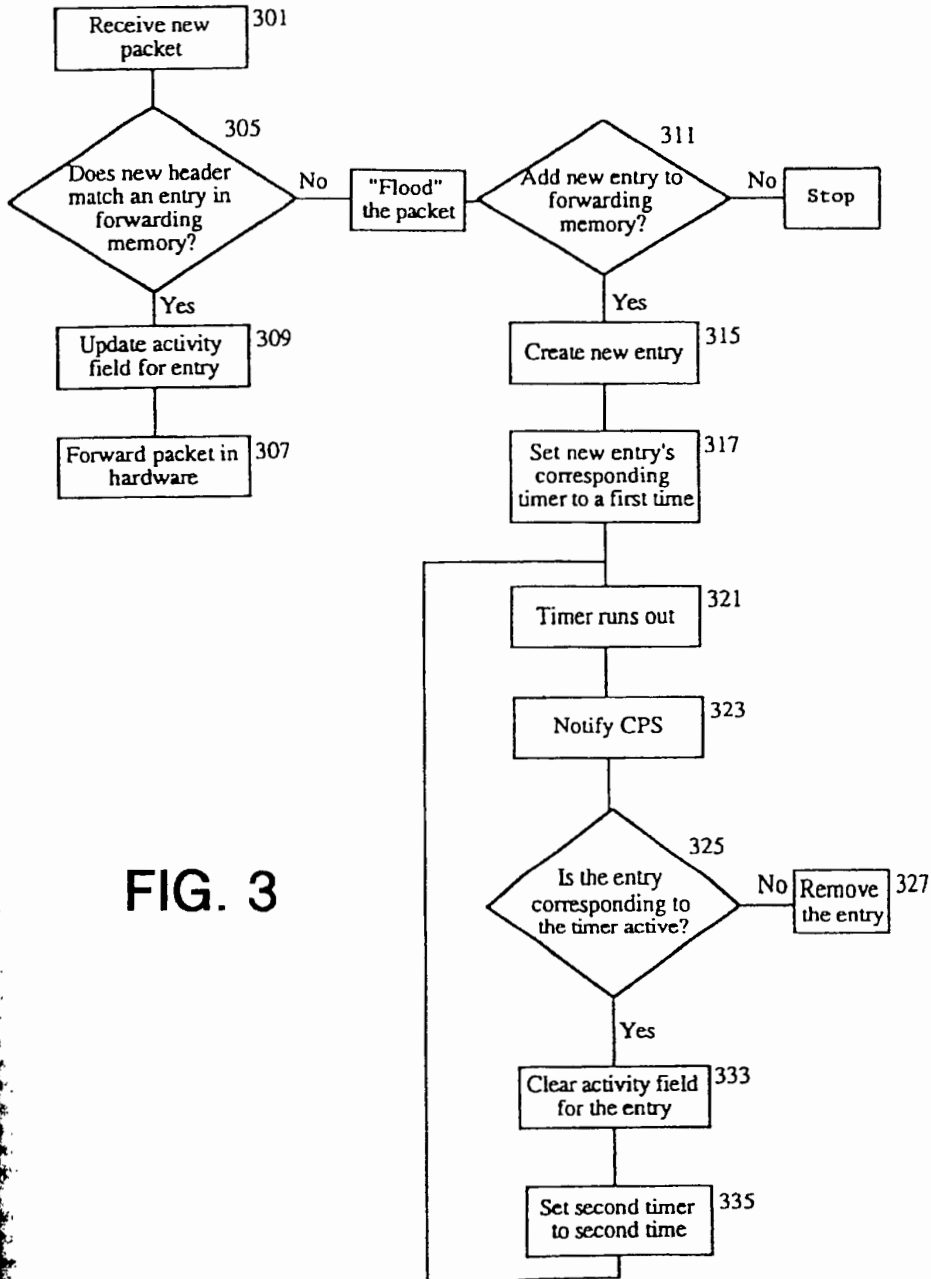


FIG. 3

## MANAGEMENT OF ENTRIES IN A NETWORK ELEMENT FORWARDING MEMORY

### BACKGROUND

#### 1. Field of the Invention

The invention is generally related to network elements for communication between computers, and more specifically related to the creation and elimination of entries in a forwarding memory.

#### 2. Description of Related Art

Communication between computers has become an important aspect of everyday life in both private and business environments. Computers converse with each other based upon a physical medium for transmitting the messages back and forth, and upon a set of rules implemented by electronic hardware attached to and programs running on the computers. These rules, often called protocols, define the orderly transmission and receipt of messages in a network of connected computers.

A local area network (LAN) is the most basic and simplest network that allows communication between a source computer and destination computer. The LAN can be envisioned as a cloud to which computers (also called endstations or nodes) that wish to communicate with one another are attached. At least one network element will connect with all the endstations in the LAN. An example of a simple network element is the repeater which is a physical layer that forwards bits. The repeater may have a number of ports, each endstation being attached to one port. The repeater receives bits that may form a packet of data that contains a message from a source endstation, and blindly forwards the packet bit-by-bit. The bits are then received by other endstations in the LAN, including the destination. A single LAN, however, may be insufficient to meet the requirements of an organization that has many endstations, because of the limited number of physical connections available to and the limited message handling capability of a single repeater. Thus, because of these physical limitations, a repeater-based approach can support only a limited number of endstations over a limited geographical area.

The capability of computer networks, however, has been increased by connecting different subnetworks to form larger networks that contain thousands of endstations communicating with each other. These LANs can in turn be connected together to create even larger enterprise networks, including wide area network (WAN) links.

To facilitate communication between subnets in a larger network, more complex electronic hardware and software have been proposed and are currently used in conventional networks. Also, new sets of rules for reliable and orderly communication among those endstations have been defined in network standards based on the principle that the endstations are interconnected by suitable network elements define a network hierarchy, where endstations within the same subnet have a common classification. A network is thus defined by a topology which defines the features and the relative position of nodes and endstations within the

interconnection of endstations through packet forwarding networks has traditionally followed a peer-to-peer architectural abstraction. In such a model, a given source computer communicates with the same peer endstation (usually the destination) across the network by attaching a header to the data unit received

from a higher layer, a layer provides services to enable the operation of the layer above it. A received packet will typically have several headers that were added to the original payload by the different layers operating at the source.

There are several layer partitioning schemes in the prior art, such as the Arpanet and the Open Systems Interconnect (OSI) models. The seven layer OSI model used here to describe the invention is a convenient model for mapping the functionality and detailed implementations of other models. Aspects of the Arpanet, however, (now redefined by the Internet Engineering Task Force, or IETF) will also be used in specific implementations of the invention to be discussed below.

The relevant layers for background purposes here are Layer 1 (physical), Layer 2 (data link), and Layer 3 (network), and to a limited extent Layer 4 (transport). A brief summary of the functions associated with these layers follows.

The physical layer transmits unstructured bits of information across a communication link. The repeater is an example of a network element that operates in this layer. The physical layer concerns itself with such issues as the size and shape of connectors, conversion of bits to electrical signals, and bit-level synchronization.

Layer 2 provides for transmission of frames of data and error detection. More importantly, the data link layer as referred to in this invention is typically designed to "bridge," or carry a packet of information across a single hop, i.e., a hop being the journey taken by a packet in going from one node to another. By spending only minimal time processing a received packet before sending the packet to its next destination, the data link layer can forward a packet much faster than the layers above it, which are discussed next. The data link layer provides addressing that may be used to identify a source and a destination between any computers interconnected at or below the data link layer. Examples of Layer 2 bridging protocols include those defined in IEEE 802 such as CSMA/CD, token bus, and token ring (including Fiber Distributed Data Interface, or FDDI).

Similar to Layer 2, Layer 3 also includes the ability to provide addresses of computers that communicate with each other. The network layer, however, also works with topological information about the network hierarchy. The network layer may also be configured to "route" a packet from the source to a destination using the shortest path. Finally, the network layer can control congestion by simply dropping selected packets, which the source might recognize as a request to reduce the packet rate.

Finally, Layer 4, the transport layer, provides an application program such as an electronic mail program with a "port address" which the application can use to interface with Layer 3. A key difference between the transport layer and the lower layers is that a program on the source computer carries a conversation with a similar program on the destination computer, whereas in the lower layers, the protocols are between each computer and its immediate neighbors in the network, where the ultimate source and destination endstations may be separated by a number of intermediate nodes. Examples of Layer 4 and Layer 3 protocols include the Internet suite of protocols such as TCP (Transmission Control Protocol) and IP (Internet Protocol).

Endstations are the source and ultimate destination of a packet, whereas a node refers to an intermediate point between the endstations. A node will typically include a network element which has the capability to receive and forward messages on a packet-by-packet basis.



Generally speaking, the larger and more complex networks typically rely on nodes that have higher layer (Layers 3 and 4) functionalities. A very large network consisting of several smaller subnetworks must typically use a Layer 3 network element known as a router which has knowledge of the topology of the subnetworks.

A router can form and store a topological map of the network around it based upon exchanging information with its neighbors. If a LAN is designed with Layer 3 addressing capability, then routers can be used to forward packets between LANs by taking advantage of the hierarchical routing information available from the endstations. Once a table of endstation addresses and routes has been compiled by the router, packets received by the router can be forwarded after comparing the packet's Layer 3 destination address to an existing and matching entry in the memory.

As packets are being transmitted and received between endstations, they must traverse intermediate nodes in which a network element receives a packet and forwards it towards its final destination. When a packet arrives at such an element, the packet's headers (or portions of the headers) are collected and an attempt is then made to match using hardwired logic the destination of the packet to a known Layer 2 destination address in an address table stored in a forwarding memory. Alternatively, a matching cycle may be performed in software based on the Layer 3 information contained in the received packet's header.

As a high performance device, the forwarding memory must be able to produce the matching entry from among thousands of entries in a relatively short time. This speed is important because the decision to forward the received packet to its destination must be made as soon as possible after receiving the packet to make room for other arriving packets.

Existing techniques for implementing the forwarding memory include the use of a content addressable memory (CAM) to store a Layer 2 address table. The CAM is typically implemented as a hardwired logic integrated circuit and is nicely suited for the job of storing an address table in a network element. The high performance offered by a CAM, however, comes at a high cost because of its unique and complex hardware requirements. Therefore, a CAM for use as a forwarding memory in networking applications is typically selected to provide space for only a limited number of entries.

One way to make efficient use of the forwarding memory is to reduce the number of entries by discarding stale entries after a given time has elapsed, the rationale being that since there has not been much activity in the past, there will not be much in the future. The price paid for using this approach is that if a subsequent matching packet does arrive fairly quickly after the entry is discarded, then a new identical entry must be created. This will interfere with both header processing and forwarding memory operations. It would be desirable, therefore, to devise a technique for even more efficient use of the forwarding memory in a networking application. What is needed is a network element that makes efficient use of the forwarding memory in order to forward packets faster and save costly storage space in the forwarding memory.

#### SUMMARY

The invention generally provides for a network element and methods in the network element for allowing a matching entry in a forwarding memory to be found in a single search of the memory, for determining when an entry should be

placed in the memory, and for determining when an entry should be removed from the memory, in order to make more efficient use of the fixed space available in the memory. The invention is particularly useful in making more efficient use of a Content Addressable Memory (CAM) for storing flow entries, and configuring the CAM to index an associated memory that stores forwarding and quality of service information for each CAM entry.

A flow is defined by the network element as a series of related packets that may be represented by a single entry containing Layer 3 and higher layer information in the forwarding memory. The network element is configured to identify such packets as members of a flow. The network element selects certain fields in the entry to include wildcards. Wildcarding the entry may result in multiple flows matching the entry, which can then handle a greater number of received packets, thereby reducing the number of entries in the forwarding memory in return for coarser granularity in routing and quality of service control.

To ensure a deterministic matching result following a single search of the forwarding memory having wildcarded entries, the network element is configured to produce only the most specific match where multiple matches exist in the forwarding memory. In one embodiment, the network element is configured to order the entries in the forwarding memory most specific, so that the first matching entry will always be the most specific entry among multiple matching entries. Alternatively, the most specific match can be determined by dedicated hardware coupled to the forwarding memory.

Regardless of whether wildcards are used, entries are aged using dual time-out periods in another embodiment of the invention. When an entry is placed in the forwarding memory, a first timer is set to a first time. If no matching packets arrive before the first time elapses, the entry is marked for removal. If a matching packet does arrive before the first time elapses, then a second timer is set to a second time that is different than the first time. Subsequently, the entry is removed if either no matching packet arrives by the time the second time elapses, or a matching packet arrives late (after the second time has elapsed). Additional timers such as a third, fourth, . . . could be used which would be equivalent to changing the second timer dynamically. In the preferred embodiment of the invention, the second time is longer than the first time.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above aspects and features of the invention will be better understood by referring to the drawings, detailed description, and claims below, where:

FIG. 1 is a block diagram of a network element for implementing the invention.

FIG. 2 illustrates a forwarding memory and associated memory configured according to another embodiment of the invention.

FIG. 3 shows a flow diagram of steps to practice an embodiment of the invention.

#### DETAILED DESCRIPTION

Although as generally summarized above, the invention may be applied to manage any type of forwarding entry in a network element, the invention is particularly useful for managing end-to-end flows. A flow is a sequence of packets arriving at and identified by the network element as a single Layer 3 entry in the forwarding memory. The packets are

related in that they originate from the same end-node and normally have the same destination end-node based on their Layer 3 (network layer) and Layer 4 (transport layer) headers as defined by the Open System Interconnect (OSI) Reference Model. The packets in a flow normally receive the same quality of service (QOS) by the network element.

Membership in a flow can be based in part upon the transport layer (Layer 4) protocol used such as Transmission Control Protocol (TCP) or User Datagram Protocol (UDP), the network layer (Layer 3) addresses such as Internet Protocol (IP) addresses, and the application source and destination UDP or TCP ports (part of the transport layer protocol). Similar definitions for other protocols can be developed by those skilled in the art.

FIG. 1 illustrates an exemplary setting for practicing the invention in a network element 101. The network element is configured to relay packets and contains a number of subsystems 110 that are interconnected by internal links 141. A central processing system (CPS) having a programmed central processing unit (CPU) 135 and a central memory 130 couples with the different subsystems 110 through a conventional computer communication bus, such as a Peripheral Components Interconnect (PCI) bus. Each subsystem 110 has a hardware search engine that includes a hardwired logic switching element 111 coupled to a forwarding memory 113 and associated memory 114. The address table used for forwarding packets through the network element is stored in the forwarding memory 113, while the forwarding and quality of service (QOS) information associated with each entry is stored in the associated memory 114. In a preferred embodiment, the forwarding memory is implemented by a random access memory (RAM) while the associated memory includes a random access memory (RAM). Alternatively, the associated data normally stored in the separate RAM can be stored in the RAM together with the address table. In yet another embodiment, the forwarding memory may be implemented by a programmed processor or hardwired logic circuit that implements a hash table.

The network element 101 forwards packets received by an external connection 117 to one or more other external connections based on the packets' headers and programmed criteria in the CPS and the individual subsystems 110. For example, a newly arrived packet at the subsystem 110 will be processed by a hardware class filter in the switching element 111 which identifies the packet as a member of one or more predefined packet types. The packet's headers are evaluated against the entries in the forwarding memory 113 that are of the identified class. A matching entry will identify one or more subsystem ports identified in the associated memory 114 as well as a certain QOS. The packet will be forwarded, based on the associated data, out of the subsystem 110 or to another subsystem 120, as stored in the associated memory. In the event of a "miss" (no matching entry), the CPS 130 may be configured to take forwarding aspects based on its software routines. Throughout this disclosure, references are made to the network element performing certain actions or causing certain other actions to be performed. These refer, in general, to actions or decisions by the programmed CPU 135. However, one skilled in the art will recognize that other means for implementing those actions or decisions can be used, including hardwired logic circuits, in order to obtain certain advantages such as speed of execution.

The CPS 130 is configured to evaluate, based on predefined criteria, whether or not a flow entry 221 is added to the forwarding memory 113 in response

to a subsystem receiving a new packet having unmatching Layer 3 headers. As shown in FIG. 2, the header data for a flow entry according to one embodiment of the invention include but are not limited to the following fields: class, IP source address, IP destination address, application source port, and application destination port. The flow entry 221 can alternatively be configured to store header data for message traffic that is handled in accordance with network layer, transport layer, and higher layer protocols other than TCP/IP. Thus, similar definitions for other protocols can be developed by those skilled in the art.

Regardless of the particular protocols used for each entry in the forwarding memory, the associated memory identifies internal and/or external ports of the inbound subsystem, queuing, priority, header replacement information for routing, age, and distributed flow indication.

In the first embodiment of the invention, when the CPS 130 has determined that a flow entry should be created, wildcards are used so that some of the fields in the entry will contain "don't care" bits that will match all combinations. Exemplary entries 271 and 275 which contain certain wildcarded fields are shown in FIG. 2. For example, by removing dependency upon the application source and destination ports, all packets transferred between the same source and destination IP addresses using TCP will match the entry 271 and will be forwarded based on the same associated data.

As another example, a flow can be defined as having wildcards in both the source and destination port fields as well as the IP destination, with the IP source identified as the address of a particular site on the Internet. Thereafter, all traffic from that site will match the flow entry and will normally receive the same priority and quality of service.

Using wild cards in the header data of an entry for defining flow membership will reduce the total number of entries in the address table as the flow is broadly defined, thus resulting in more frequent matches. This comes at the expense of coarser granularity for the network element 101's ability to control QOS. For finer granularity (more specific control over packet forwarding) more specific entries can be added to the forwarding memory in order to more specifically define priority and QOS for certain packets. However, doing so may result in multiple matching entries where wildcarding is used. For example, referring to the exemplary forwarding and associated memories in FIG. 2, entry 271 will match all traffic from the specified IP source. If entry 275 is added by the network element to specifically control QOS for packets originating from application port 80, then a subsequent packet originating with port 80 on the endstation assigned to the source IP address specified will yield two matching entries 271 and 275. As the network element is preferably configured to forward packets based on deterministic criteria, multiple matching entries presents a problem that needs to be dealt with in a predictive manner.

An important aspect of the invention, therefore, lies in solving the multiple matching entry problem by ordering the entries from a least specific to a most specific fashion in the forwarding memory 113. The ordering is normally set by requiring that the number of wildcard bits be lower in earlier entries, by placing entries that support resource-reservation protocols such as RSVP before those having default values, and by ordering entries to support administrative criteria. However, ordering may be different in order to satisfy certain administrative criteria.

The three TCP class entries shown in the forwarding memory 113 of FIG. 2 are given as an example of the ordering scheme. Entry 271 is less specific than entry 275

use the former includes wildcards in the application port field whereas the latter does not. In general, by using entries such that an entry has more wildcarded in a given field than the one above it, and by defining the match to be the one to use for forwarding the packet, a sequential search of the forwarding memory 113 from top to bottom will be sufficient to produce a single and usually most specific entry among multiple matching entries. This may also be referred to as the longest matching entry, or the one having the fewest wildcards.

Alternatively, the multiple match situation can be handled by providing additional hardware that is configured specially to detect and select the most specific match as the single entry, given a number of matching entries.

Thus, as a first embodiment of the invention, the above discussion of the forwarding memory 113 describes a technique for managing the entries in a forwarding memory so as to provide for faster forwarding of packets using only a sequential search so that the most specific is matched first, or by using the most specific from a number of matching entries. Also, an example was given for detecting and matching Layer 3 flows based on different granularity levels through the use of wildcarding.

A second embodiment of the invention is now discussed which focuses on how to remove Layer 3 flows to use the forwarding memory more efficiently. The embodiment is illustrated in FIG. 3 as an exemplary series of steps to be performed in a network element having a forwarding memory 113 as in FIG. 1. The steps are described while referring to the architecture of FIGS. 1 and 2, and the flow diagram of FIG. 3.

When a new packet is received by the network element in block 301, its header is passed to header matching logic (not shown) in switching element 111. The header matching logic then initiates a matching cycle on the forwarding memory 113 to determine if the new headers matching existing forwarding entry, as in decision block 305.

In decision block 305, the test is whether the new headers match an entry in the forwarding memory 113. If yes, then the packet is forwarded to its destination outside the network element 101 as between subsystems 110 (or within the network element 101) using forwarding and quality of service information in the associated memory. The forwarding memory 113 will generate a pointer to an associated entry in the associated memory that contains associated data or the matching entry. The associated data will include external or internal subsystem port, any routing information if the matching entry is of a hardware route type as indicated in the entry's class field, and priority information relating to the packet in an external port. Also, whenever a match occurs with an existing entry in the forwarding memory 113, the activity field or aged destination bits are updated to reflect the match, as in block 309.

Returning to decision block 305, if the received packet does not match any known headers, i.e., not matching any entries in the forwarding memory 113, then the packet is "flooded" on all internal and external ports of the inbound subsystem. In that case, block 311 calls for a decision as to whether or not to add the entry to the forwarding memory. The decision block 311 is preferably performed by CPS 130 in response to identifying relevant portions of the headers of the new packet from the inbound subsystem. For packets that fall within the class, such that a Layer 3 flow entry may need to be added, the header portions sent to the CPS include the IP address and destination addresses, and the application source and destination ports (Layers 3 and 4). If the class filter in

the subsystem 110 indicates that a hardware route is supported by the network element 101 for the received packet, then the Layer 2 source and destination addresses are also sent to the CPS. The CPS 130 then determines, based on previously programmed information in the CPS about the header fields, whether or not an entry should be added to the forwarding memory.

If the CPS 130 determines that an entry should be added to the forwarding memory as in block 311, then the CPS 130 causes the entry to be created in the forwarding memory 113 as in block 315. The CPS 130 can place don't care bits in any field of the entry for the desired level of granularity. The associated data of the new entry will also be provided by the CPS 130 and will include at least an output port (external and/or internal) in the subsystem 110, queuing and priority information to be used by the output ports of the outbound subsystem, and any header replacement information required for routing. The activity or aged destination field of the new entry will also indicate that the entry is new, i.e., no match as of yet.

Once the CPS 130 has determined that a new entry should be created as in block 311, the CPS 130 sets a timer or counter to a first time in block 317. The timer corresponds to the new entry and is normally a software timer within the CPS 130. The CPS 130 will include provisions such as pointers for the timer that identify its corresponding new entry as the one in forwarding memory 113 of subsystem 110.

When the timer runs out in block 321, the CPS 130 is notified in block 323, normally by an interrupt to CPU 135 or, alternatively, by polling. Based on its pointer provisions, the CPS 130 identifies the corresponding entry and determines whether the entry corresponding to the timer is still active by reading the value of its activity or aged destination field in the associated memory 114, as in decision block 325. If the activity field indicates that a received packet has not matched the entry since the timer was set to a first time, then the CPS 130 instructs the removal of the entry in block 327. If, however, the activity field indicated that the subsystem received a packet having headers that match the entry during the first time interval, then a second timer corresponding to the same entry is set to a second time in block 335. Also, the activity field is cleared to indicate no matching packets as of yet.

The above procedure beginning with block 321 repeats thereafter for each subsequent time-out of the second timer. Although the first and second timers are defined as separate timers, an alternative embodiment casts the first and second timer as the same software timer having two different time intervals.

An important aspect of the invention lies in the second time being preferably longer than the first time, where preferred numbers include approximately one second for the first time and three seconds for the second time. Furthermore, the first and second times can be chosen based on network layer addresses, Layer 4 protocols, and Layer 4 port numbers.

Exceptions to the above removal of entries based on time-out periods include the situation of RSVP signaling, where a flow entry is managed explicitly by RSVP. In that case, RSVP signaling between the source and destination will determine when the flow entry should be removed from the forwarding memory 123.

Other exceptions are packets destined to UDP port 111 (Layer 4 information). It has been observed that such packets appear to contribute greatly to packet flow entries

which result in only a single matching packet before the first time expires. The network element 101 will thus be preferably configured to not make a Layer 3 flow entry for such packets.

The use of dual time periods described above thus presents a simple yet effective technique for keeping the number of entries in a forwarding memory 113 to a minimum. The technique's simplicity in verifying the age status of an entry in response to a time-out of two different time periods expedites the entire forwarding process. However, additional timers and time periods can be used to further fine tune the invention's entry removal mechanism, which may be viewed as dynamically changing the second time upon each time-out of the second timer.

The rationale behind the shorter first and longer second intervals can perhaps be explained by analyzing the probability of packets arriving at the network element 101 which match a given entry. An assumption is made that the intervals between the arrival of such packets are independent of each other. For a given stream of arriving packets, the probability of an interpacket gap exceeding a first time  $t_1$  is  $P_1$ , and the probability of an interpacket gap exceeding a second time  $t_2$  is  $P_2$ . Since the assumption is that  $t_1 < t_2$ , then  $P_2 < P_1$  must be true in most circumstances.

If the sole basis for removing entries from the forwarding memory is to use  $t_1$  as a time-out period, such that if an interpacket gap exceeds  $t_1$  then the flow entry is removed, then the probability of not prematurely removing a flow for the first  $n$  packets is  $(1-P_1)^n = (1-P_1)(1-P_1)^{n-1}$ .

If, however, two timeout intervals are used,  $t_1$  for the first interval, and  $t_2$  for subsequent intervals between arriving packets, then the probability of not prematurely removing the entry for the first  $n$  packets is  $(1-P_1)(1-P_2)^{n-1}$ . Since  $P_2 < P_1 < 1$ , so is  $(1-P_1)^{n-1} < (1-P_2)^{n-1}$ , and thus the use of two interval times increases the probability of not prematurely removing a multi-packet flow, yet still effectively remove entries which only receive a single matching packet.

To summarize, the invention presents a technique in a network element for managing the entries in the forwarding memory. After identifying a first received packet as a member of a flow, an entry is created in the forwarding memory which identifies the flow. Thereafter, the entry is removed if a subsequent packet having a matching header is not received before a first time has elapsed. If, however, the subsequent packet having a matching header is received before the first time has elapsed, then the flow entry is kept and a timer is reset to a second longer time, such that the flow entry will be kept for subsequent packets arriving within the longer second time. Such a technique takes advantage of the pattern that if two packets arrive within the shorter first time, then the likelihood of more matching packets arriving within a subsequent longer time has substantially increased.

In another embodiment, yet more efficient use of a forwarding memory is made by implementing a longest-match approach, where the forwarding contains wildcarded entries. The wildcarding scheme allows for default routes to be defined based on any level of granularity desired for source and destination addresses, subnets, as well as transport layer ports.

The embodiments of the invention described above for exemplary purposes are, of course, subject to other variations in structure and implementation within the capabilities of one reasonably skilled in the art. For example, although many operations have been described as occurring sequentially, some of these can be implemented concur-

rently or even in a different order so long as the dependencies between them permit such deviation. Also, the invention can be implemented in a network element having a centralized forwarding memory rather than one having the distributed architecture of FIG. 1. Thus, the details above should be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a network element having a forwarding memory for storing a plurality of entries used for forwarding received packets, a method of managing the storage of the entries comprising the steps of:

making a first entry in the forwarding memory based upon a header of a first received packet; and one of marking the first entry for removal if a second packet having a header matching the first entry is not received before a first time has elapsed, and waiting a second time not equal to the first time before marking the first entry for removal if the second packet having the header matching the first entry is received before the first time has elapsed.

2. The method as in claim 1 wherein the second time is longer than the first time.

3. The method as in claim 2 where the first time is approximately one second and the second time is approximately three seconds.

4. The method as in claim 1 further comprising the step of marking the first entry for removal if a third packet having a third header matching the first entry is not received before the second time has elapsed.

5. The method as in claim 1 further comprising the step of waiting a third time before marking the first entry for removal if a third packet having a third header matching the first entry is received before the second time has elapsed.

6. The method as in claim 1 prior to the step of making the first entry, further comprising the step of

searching the forwarding memory for a match between the header of the first received packet and an entry in the forwarding memory,

and wherein the step of making the first entry is performed in response to not finding the match.

7. The method as in claim 5 wherein the third time is different than the second time.

8. The method as in claim 6 further comprising the step of selecting a most specific one of a number of matching entries.

9. The method as in claim 1 further comprising the step of ordering the plurality of entries in the forwarding memory from most specific to least specific, the most specific having the fewest wildcard characters of any of the plurality of entries.

10. The method as in claim 1 wherein the header further comprises a Layer 4 address.

11. The method as in claim 10 wherein the header further comprises a Layer 4 address.

12. The method as in claim 1 wherein at least one of the first time and the second time is selected based on predefined network layer addresses.

13. In a network element having an address table for storing a plurality of entries used for forwarding received packets, and a timer associated with each entry, a method of managing the entries in the address table comprising the steps of:

receiving a first packet;  
making a first entry in the address table based upon a header of the first packet;  
setting a first timer to a first time; and

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setting a second timer to a second time not equal to the first time if a second packet matching the first entry is received before the first time has elapsed.

14. The method as in claim 13 wherein the second time is longer than the first time.

15. The method as in claim 14 wherein the first time is approximately one second and the second time is approximately three seconds.

16. The method as in claim 13 further comprising the step of

deleting the first entry if the second packet matching the first entry is not received before the first time has elapsed.

17. The method as in claim 13 wherein the first timer is the second timer.

18. The method as in claim 13

wherein the first entry comprises an activity field for indicating that the first entry has matched a received second packet.

19. The method as in claim 13 prior to setting the second timer further comprising the steps of:

searching the address table to find a matching entry in response to receiving the second packet, the first entry being a most specific one of a plurality of matching entries.

20. The method as in claim 13 further comprising the steps of:

ordering the plurality of entries in the forwarding memory from most specific to least specific, the most specific having the fewest wildcard characters of any of the plurality of entries; and

searching the address table to find a matching entry.

21. The method as in claim 20 wherein the step of searching the address table to find the matching entry includes searching based on Layer 3 and Layer 4 headers of a received packet.

22. A network element for managing a plurality of entries in a forwarding memory, comprising:

means for initiating a search of the forwarding memory for an entry matching a portion of a first header of a received first packet;

means for making a first entry in the forwarding memory in response to finding no entry matching the portion of the first header of the received first packet, the first entry having an activity field indicating whether the first entry has matched a received second packet;

means for setting a first timer to a first time;

means for checking the activity field in response to the first timer running out; and

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means for setting a second timer to a second time not equal to the first time in response to the activity field indicating that the first entry has matched the received second packet.

23. The network element as in claim 22 wherein the second time is longer than the first time.

24. The network element as in claim 23 wherein the first time is approximately one second and the second time is approximately three seconds.

25. The network element as in claim 22 further comprising

means for invalidating the first entry in response to the activity field indicating that the first entry has not matched the received second packet.

26. The network element as in claim 22 further comprising means for setting a third timer to a third time in response to the activity field indicating that the first entry has matched a received third packet before expiration of the second time.

27. The network element as in claim 22 wherein the first header is a Layer 3 header.

28. The network element as in claim 26 wherein the third time is approximately equal to the second time.

29. The network element as in claim 22 wherein the first entry comprises Layer 4 information.

30. The network element as in claim 22 wherein the second timer is the first timer.

31. The network element as in claim 22 further comprising

memory configured for storing the forwarding memory and the plurality of entries; and

means for ordering the plurality of entries in the memory from most specific to least specific.

32. The network element as in claim 31 wherein the memory is a content addressable memory.

33. The network element as in claim 22 wherein at least one of the means for making the first entry, means for setting the first timer, means for checking the activity field, and means for setting the second timer is a programmed processor.

34. The network element as in claim 22 wherein the first timer is a software timer.

35. The network element as in claim 22 wherein the means for initiating the search is a header matching logic circuit.

36. The network element as in claim 22 further comprising means for updating the activity field in response to the first entry matching the received second packet prior to the first timer running out.

\* \* \* \* \*

7/8/03

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7-15-03

Our Ref./Docket No: APPT-001-1

Patent

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Applicant(s): Dietz, *et al.*  
 Application No.: 09/608237  
 Filed: June 30, 2000  
 Title: METHOD AND APPARATUS FOR  
 MONITORING TRAFFIC IN A NETWORK

Group Art Unit: 2157  
 Examiner: Moustafa M. Meky

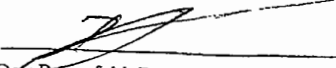
**RESPONSE TO OFFICE ACTION UNDER 37 CFR 1.111**

Mail Stop No Fee Amendment  
 Commissioner for Patents  
 P.O. Box 1450  
 Alexandria, VA 22313-1450

Dear Commissioner:  
 This is a response to the Office Action of June 25, 2003.

Certificate of Facsimile Transmission under 37 CFR 1.8

I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark Office at telephone number ~~703-308-9052~~ addressed the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on ~~7/02~~ 7/8/03 ~~746-7239~~

Date: 7/8/03 Signed:   
 Name: Dov Rosenfeld, Reg. No. 38687

A

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p. 8

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**INTRODUCTORY REMARKS:**

In response to the Office Action of June 25, 2003, kindly amend this application as follows and kindly consider the following remarks.

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AMENDMENT(S) TO THE ABSTRACT:

7/5/03

Kindly amend the abstract as follows:

ABSTRACT

A monitor for and a method of examining packets passing through a connection point on a computer network. Each packets conforms to one or more protocols. The method includes receiving a packet from a packet acquisition device and performing one or more parsing/extraction operations on the packet to create a parser record comprising a function of selected portions of the packet. The parsing/extraction operations depend on one or more of the protocols to which the packet conforms. The method further includes looking up a flow-entry database containing flow-entries for previously encountered conversational flows. The lookup uses the selected packet portions and determining if the packet is of an existing flow. If the packet is of an existing flow, the method classifies the packet as belonging to the found existing flow, and if the packet is of a new flow, the method stores a new flow-entry for the new flow in the flow-entry database, including identifying information for future packets to be identified with the new flow-entry. For the packet of an existing flow, the method updates the flow-entry of the existing flow. Such updating may include storing one or more statistical measures. Any stage of a flow, state is maintained, and the method performs any state processing for an identified state to further the process of identifying the flow. The method thus examines each and every packet passing through the connection point in real time until the application program associated with the conversational flow is determined. ~~The method~~



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### AMENDMENT(S) TO THE CLAIMS:

7/8/03

The following listing of claims will replace all prior versions, and listings, of claims on the application. Claims being amended are set forth in a larger font than all other claims. All claims are set forth below with one of the following annotations.

- (Original): Claim filed with the application following the specification.
- (Currently amended): Claim being amended in the current amendment paper.
- (Previously amended): Claim not being currently amended, but which was amended in a previous amendment paper.
- (Cancelled): Claim cancelled or deleted from the application.
- (Withdrawn): Claim still in the application, but in a non-elected status.
- (Previously added): Claim added in an earlier amendment paper.
- (New): Claim being added in the current amendment paper.
- (Reinstated - formerly claim # \_): Claim deleted in an earlier amendment paper, but re-presented with a new claim number in current amendment.
- (Previously reinstated): Claim deleted in an earlier amendment and reinstated in an earlier amendment paper.
- (Re-presented - formerly dependent claim # \_): Dependent claim re-presented in independent form in current amendment paper.
- (Previously re-presented): Dependent claim re-presented in independent form in an earlier amendment, but not currently amended.

### CLAIMS

What is claimed is:

1. (Original) A packet monitor for examining packets passing through a connection point on a computer network in real-time, the packets provided to the packet monitor via a packet acquisition device connected to the connection point, the packet monitor comprising:
  - (a) a packet-buffer memory configured to accept a packet from the packet acquisition device;
  - (b) a parsing/extraction operations memory configured to store a database of parsing/extraction operations that includes information describing how to determine at least one of the protocols used in a packet from data in the packet;

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- (c) a parser subsystem coupled to the packet buffer and to the pattern/extraction operations memory, the parser subsystem configured to examine the packet accepted by the buffer, extract selected portions of the accepted packet, and form a function of the selected portions sufficient to identify that the accepted packet is part of a conversational flow-sequence;
- (d) a memory storing a flow-entry database including a plurality of flow-entries for conversational flows encountered by the monitor;
- (e) a lookup engine connected to the parser subsystem and to the flow-entry database, and configured to determine using at least some of the selected portions of the accepted packet if there is an entry in the flow-entry database for the conversational flow sequence of the accepted packet;
- (f) a state patterns/operations memory configured to store a set of predefined state transition patterns and state operations such that traversing a particular transition pattern as a result of a particular conversational flow-sequence of packets indicates that the particular conversational flow-sequence is associated with the operation of a particular application program, visiting each state in a traversal including carrying out none or more predefined state operations;
- (g) a protocol/state identification mechanism coupled to the state patterns/operations memory and to the lookup engine, the protocol/state identification engine configured to determine the protocol and state of the conversational flow of the packet; and
- (h) a state processor coupled to the flow-entry database, the protocol/state identification engine, and to the state patterns/operations memory, the state processor, configured to carry out any state operations specified in the state patterns/operations memory for the protocol and state of the flow of the packet,

the carrying out of the state operations furthering the process of identifying which application program is associated with the conversational flow-sequence of the packet, the state processor progressing through a series of states and state operations until there are no more state operations to perform for the accepted packet, in which case the state processor updates the flow-entry, or until a final state is reached that indicates that no more analysis of the flow is required, in which case the result of the analysis is announced.

2. (Original) A packet monitor according to claim 1, wherein the flow-entry includes the state of the flow, such that the protocol/state identification mechanism determines the state of the packet from the flow-entry in the case that the lookup engine finds a flow-entry for the flow of the accepted packet.
3. (Original) A packet monitor according to claim 1, wherein the parser subsystem includes a mechanism for building a hash from the selected portions, and wherein the hash is used by the lookup engine to search the flow-entry database, the hash designed to spread the flow-entries across the flow-entry database.

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4. (Original) A packet monitor according to claim 1, further comprising:
  - a compiler processor coupled to the parsing/extraction operations memory, the compiler processor configured to run a compilation process that includes:
    - receiving commands in a high-level protocol description language that describe the protocols that may be used in packets encountered by the monitor, and
    - translating the protocol description language commands into a plurality of parsing/extraction operations that are initialized into the parsing/extraction operations memory.
5. (Original) A packet monitor according to claim 4, wherein the protocol description language commands also describe a correspondence between a set of one or more application programs and the state transition patterns/operations that occur as a result of particular conversational flow-sequences associated with an application program, wherein the compiler processor is also coupled to the state patterns/operations memory, and wherein the compilation process further includes translating the protocol description language commands into a plurality of state patterns and state operations that are initialized into the state patterns/operations memory.
6. (Original) A packet monitor according to claim 1, further comprising:
  - a cache memory coupled to and between the lookup engine and the flow-entry database providing for fast access of a set of likely-to-be-accessed flow-entries from the flow-entry database.
7. (Original) A packet monitor according to claim 6, wherein the cache functions as a fully associative, least-recently-used cache memory.
8. (Original) A packet monitor according to claim 7, wherein the cache functions as a fully associative, least-recently-used cache memory and includes content addressable memories configured as a stack.
9. (Original) A packet monitor according to claim 1, wherein one or more statistical measures about a flow are stored in each flow-entry, the packet monitor further comprising:
  - a calculator for updating the statistical measures in a flow-entry of the accepted packet.
10. (Original) A packet monitor according to claim 9, wherein, when the application program of a flow is determined, one or more network usage metrics related to said application and determined from the statistical measures are presented to a user for network performance monitoring.
- 11.-59. (Cancelled)

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REMARKS

7/8/03

*Status of the Application:*

Claims 1-59 are the claims of record of the application. Claims 1-10 have been allowed. Claims 11-59 have been rejected.

*Amendment to the Abstract:*

Applicants have amended the abstract to remove a spurious phrase at the end, this being a typographical error.

*Amendment to the Claims:*

Applicants have cancelled the rejected claims.

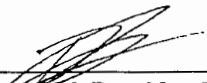
*Conclusion*

The only remaining claims are those allowed by the Examiner. A notice of Allowance for the remaining claims is respectfully requested.

If the Examiner has any questions or comments that would advance the prosecution and allowance of this application, an email message to the undersigned at [dov@inventek.com](mailto:dov@inventek.com), or a telephone call to the undersigned at +1-510-547-3378 is requested.

Respectfully Submitted,

7/8/03  
Date

  
Dov Rosenfeld, Reg. No. 38687

Address for correspondence:

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# INVENTEK

## Fax

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**Patent Application Ser. No.:** 09/608237

**Ref./Docket No.:** APPT-001-1

**Applicant(s):** Dietz, et al.

**Examiner.:** Moustafa M. Meky

**Filing Date:** June 30, 2000

**Art Unit:** 2157

### FAX COVER PAGE

**TO:** Commissioner for Patents  
 P.O. Box 1450  
 Alexandria, VA 22313-1450

United States Patent and Trademark Office  
 (Examiner Moustafa M. Meky, Art Unit 2157)

**Fax No.:** ~~703-308-9052~~ 746-7239

**DATE:** July 08, 2003

**FROM:** Dov Rosenfeld, Reg. No. 38687

**RE:** Response to Office Action

Number of pages including cover: 13

OFFICIAL COMMUNICATION

PLEASE URGENTLY DELIVER A COPY OF  
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 2157

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Date: 7/8/03

Signed:   
 Name: Dov Rosenfeld, Reg. No. 38687

<h2 style="text-align: center;">TRANSMITTAL FORM</h2> <p style="text-align: center;"><i>(to be used for all correspondence after initial filing)</i></p>	Application Number	09/608237 <span style="font-size: 2em; font-family: cursive;">7/8/03</span>
	Filing Date	30 Jun 2000
	First Named Inventor	Dietz, Russell S.
	Group Art Unit	2157
	Examiner Name	Moustafa M. Meky
Attorney Docket Number		APPT-001-1

**CLOSURES (check all that apply)**

<input type="checkbox"/> Fee Transmittal Form <input type="checkbox"/> Fee Attached <input type="checkbox"/> Amendment / Response <input type="checkbox"/> After Final <input type="checkbox"/> Affidavits/declaration(s) Extension of Time Request Express Abandonment Request Information Disclosure Statement Certified Copy of Priority Document(s) Response to Missing Parts/ Incomplete Application <input type="checkbox"/> Response to Missing Parts under 37 CFR 1.52 or 1.53	<input type="checkbox"/> Assignment Papers (for an Application) <input type="checkbox"/> Drawing(s) <input type="checkbox"/> Licensing-related Papers <input type="checkbox"/> Petition Routing Slip (PTO/SB/69) and Accompanying Petition <input type="checkbox"/> To Convert a Provisional Application <input type="checkbox"/> Power of Attorney, Revocation Change of Correspondence Address <input type="checkbox"/> Terminal Disclaimer <input type="checkbox"/> Small Entity Statement <input type="checkbox"/> Request of Refund	<input type="checkbox"/> After Allowance Communication to Group <input type="checkbox"/> Appeal Communication to Board of Appeals and Interferences <input type="checkbox"/> Appeal Communication to Group (Appeal Notice, Brief, Reply Brief) <input type="checkbox"/> Proprietary Information <input type="checkbox"/> Status Letter <input type="checkbox"/> Additional Enclosure(s) (please identify below): <div style="border: 1px solid black; padding: 2px; width: fit-content;">Return Postcard</div>
Remarks		

**NATURE OF APPLICANT, ATTORNEY, OR AGENT/ CORRESPONDENCE ADDRESS**

Individual name	Dov Rosenfeld, Reg. No. 38687
Signature	
Date	July 8, 2003

**ADDRESS FOR CORRESPONDENCE**

Individual name	Dov Rosenfeld 5507 College Avenue, Suite 2 Oakland, CA 94618, Tel: +1-510-547-3378
-----------------	--

**CERTIFICATE OF FACSIMILE TRANSMISSION**

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Sender printed name	Dov Rosenfeld, Reg. No. 38687	Date
Signature		July 8, 2003

7/18/03  
Patent

Our Ref./Docket No: APPT-001-1

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

<p>Applicant(s): Dietz, <i>et al.</i>          Application No.: 09/608237          Filed: June 30, 2000          Title: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK</p>	<p>Group Art Unit: 2157          Examiner: Moustafa M. Meky</p>
--	---

**TRANSMITTAL: RESPONSE TO OFFICE ACTION**

Mail Stop Non Fee Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

Transmitted herewith is a response to an office action for the above referenced application. Included with the response are:

formal drawings (with separate letter);

This application has:

a small entity status. If a claim for such status has not earlier been made, consider this as a claim for small entity status.

No additional fee is required.

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Date: 7/18/03

Signed: 

Name: Dov Rosenfeld, Reg. No. 38687



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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/608,237	06/30/2000	Russell S. Dietz	APPT-001-1	9993
	7590 07/17/2003		EXAMINER	
Dov Rosenfeld Suite 2 5507 College Avenue Oakland, CA 94618			MEKY, MOUSTAFA M	
			ART UNIT	PAPER NUMBER
			2157	8
DATE MAILED: 07/17/2003				

**Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)**  
(application filed on or after May 29, 2000)

The patent term adjustment to date is 589 days. If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the term adjustment will be 589 days.

If a continued prosecution application (CPA) was filed in the above-identified application, the filing date that determines patent term adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) system. (<http://pair.uspto.gov>)

Any questions regarding the patent term extension or adjustment determination should be directed to the Office of Patent Legal Administration at (703)305-1383.



**PART B - FEE(S) TRANSMITTAL**

**Complete and send this form, together with applicable fee(s), to: Mail Mail Stop ISSUE FEE  
 Commissioner for Patents  
 Alexandria, Virginia 22313-1450  
Fax (703)746-4000**

**INSTRUCTIONS:** This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 4 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Legibly mark-up with any corrections or use Block 1)  
 7590 07/17/2003

Dov Rosenfeld  
 Suite 2  
 5507 College Avenue  
 Oakland, CA 94618

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

**Certificate of Mailing or Transmission**  
 I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Box Issue Fee address above, or being facsimile transmitted to the USPTO, on the date indicated below.

_____ (Depositor's name)
_____ (Signature)
_____ (Date)

APPLICATION NO	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/608,237	06/30/2000	Russell S. Dietz	APPT-001-1	9993

TITLE OF INVENTION: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

APPLN TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	\$1300	\$0	\$1300	10/17/2003

EXAMINER	ART UNIT	CLASS-SUBCLASS
MEKY, MOUSTAFA M	2157	709-224000

- |   |   |
|---|---|
| <p>1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).</p> <p><input type="checkbox"/> Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.</p> <p><input type="checkbox"/> "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. <b>Use of a Customer Number is required.</b></p> | <p>2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.</p> <p>1 _____</p> <p>2 _____</p> <p>3 _____</p> |
|---|---|

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the USPTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE \_\_\_\_\_ (B) RESIDENCE: (CITY and STATE OR COUNTRY) \_\_\_\_\_

Please check the appropriate assignee category or categories (will not be printed on the patent)  individual  corporation or other private group entity  government

- |   |   |
|---|---|
| <p>4a. The following fee(s) are enclosed:</p> <p><input type="checkbox"/> Issue Fee</p> <p><input type="checkbox"/> Publication Fee</p> <p><input type="checkbox"/> Advance Order - # of Copies _____</p> | <p>4b. Payment of Fee(s):</p> <p><input type="checkbox"/> A check in the amount of the fee(s) is enclosed.</p> <p><input type="checkbox"/> Payment by credit card. Form PTO-2038 is attached.</p> <p><input type="checkbox"/> The Commissioner is hereby authorized by charge the required fee(s), or credit any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).</p> |
|---|---|

Commissioner for Patents is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above.

(Authorized Signature) \_\_\_\_\_ (Date) \_\_\_\_\_

**NOTE:** The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Alexandria, Virginia 22313-1450. **DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, Alexandria, Virginia 22313-1450.**

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMIT THIS FORM WITH FEE(S)



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

7590 07/17/2003
Dov Rosenfeld
Suite 2
5507 College Avenue
Oakland, CA 94618

EXAMINER

MEKY, MOUSTAFA M

Table with 2 columns: ART UNIT, CLASS-SUBCLASS. Values: 2157, 709-224000

DATE MAILED: 07/17/2003

Table with 5 columns: APPLICATION NO., FILING DATE, FIRST NAMED INVENTOR, ATTORNEY DOCKET NO., CONFIRMATION NO. Values: 09/608,237, 06/30/2000, Russell S. Dietz, APPT-001-1, 9993

TITLE OF INVENTION: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

Table with 6 columns: APPLN. TYPE, SMALL ENTITY, ISSUE FEE, PUBLICATION FEE, TOTAL FEE(S) DUE, DATE DUE. Values: nonprovisional, NO, \$1300, \$0, \$1300, 10/17/2003

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE REFLECTS A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE APPLIED IN THIS APPLICATION. THE PTOL-85B (OR AN EQUIVALENT) MUST BE RETURNED WITHIN THIS PERIOD EVEN IF NO FEE IS DUE OR THE APPLICATION WILL BE REGARDED AS ABANDONED.

HOW TO REPLY TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

- A. If the status is the same, pay the TOTAL FEE(S) DUE shown above.
B. If the status is changed, pay the PUBLICATION FEE (if required) and twice the amount of the ISSUE FEE shown above and notify the United States Patent and Trademark Office of the change in status, or

If the SMALL ENTITY is shown as NO:

- A. Pay TOTAL FEE(S) DUE shown above, or
B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check the box below and enclose the PUBLICATION FEE and 1/2 the ISSUE FEE shown above.
[ ] Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

II. PART B - FEE(S) TRANSMITTAL should be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). Even if the fee(s) have already been paid, Part B - Fee(s) Transmittal should be completed and returned. If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Box ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

ppg

<b>Notice of Allowability</b>	<b>Application No.</b>	<b>Applicant(s)</b>	
	09/608,237	DIETZ ET AL.	
	<b>Examiner</b>	<b>Art Unit</b>	
	Moustafa M Meky	2157	

-- **The MAILING DATE of this communication appears on the cover sheet with the correspondence address--**  
 All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1.  This communication is responsive to the amendment filed 7/8/2003.
2.  The allowed claim(s) is/are 1-10.
3.  The drawings filed on 30 June 2000 are accepted by the Examiner.
4.  Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
  - a)  All    b)  Some\*    c)  None    of the:
    1.  Certified copies of the priority documents have been received.
    2.  Certified copies of the priority documents have been received in Application No. \_\_\_\_\_.
    3.  Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

\* Certified copies not received: \_\_\_\_\_.
5.  Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).
  - (a)  The translation of the foreign language provisional application has been received.
6.  Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application. **THIS THREE-MONTH PERIOD IS NOT EXTENDABLE**


7.  A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.
8.  CORRECTED DRAWINGS must be submitted.
  - (a)  including changes required by the Notice of Draftsperson's Patent Drawing Review ( PTO-948) attached
    - 1)  hereto or 2)  to Paper No. \_\_\_\_\_.
  - (b)  including changes required by the proposed drawing correction filed \_\_\_\_\_, which has been approved by the Examiner.
  - (c)  including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No. \_\_\_\_\_.

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet.

9.  DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

**Attachment(s)**

- |  |  |
|--|--|
| 1 <input type="checkbox"/> Notice of References Cited (PTO-892)  | 2 <input type="checkbox"/> Notice of Informal Patent Application (PTO-152) |
| 3 <input type="checkbox"/> Notice of Draftsperson's Patent Drawing Review (PTO-948)                    | 4 <input type="checkbox"/> Interview Summary (PTO-413), Paper No. _____.   |
| 5 <input type="checkbox"/> Information Disclosure Statements (PTO-1449), Paper No. _____.              | 6 <input type="checkbox"/> Examiner's Amendment/Comment                    |
| 7 <input type="checkbox"/> Examiner's Comment Regarding Requirement for Deposit of Biological Material | 8 <input type="checkbox"/> Examiner's Statement of Reasons for Allowance   |
|  | 9 <input type="checkbox"/> Other   |

  
 MOUSTAFA M. MEKY  
 PRIMARY EXAMINER

Jul 08 03 03:45p

Dov Rosenfeld

+1-510-291-2985

P.6

S/N 09/608237

Page 6

APPT-001-1

Applicant(s) believe(s) that no Extension of Time is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition for an extension of time.

Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:

one months (\$110)

two months (\$410)

two months (\$930)

four months (\$1450)

If an additional extension of time is required, please consider this as a petition therefor.

A credit card payment form for the required fee(s) is attached.

The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 50-0292 (A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED):

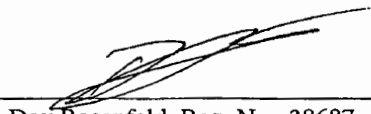
Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.

Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

7/8/03

Date

  
Dov Rosenfeld, Reg. No. 38687

Address for correspondence:  
Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618  
Tel. +1-510-547-3378; Fax: +1-510-291-2985

Jul 08 03 03:45p

Dov Rosenfeld

+1-510-291-2985

p.5

Our Ref./Docket No: APPT-001-1

Patent 7/8/03

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

<p>Applicant(s): Dietz, <i>et al.</i>  Application No.: 09/608237  Filed: June 30, 2000  Title: METHOD AND APPARATUS FOR  MONITORING TRAFFIC IN A NETWORK</p>	<p>Group Art Unit: 2157  Examiner: Moustafa M. Meky</p>
---	---

**TRANSMITTAL: RESPONSE TO OFFICE ACTION**

Mail Stop No Fee Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

Transmitted herewith is a response to an office action for the above referenced application.  
Included with the response are:

       formal drawings (with separate letter);

This application has:

       a small entity status. If a claim for such status has not earlier been made, consider  
this as a claim for small entity status.

  X   No additional fee is required.

**Certificate of Facsimile Transmission under 37 CFR 1.8**

I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark  
Office at telephone number 703-308-9052 addressed the Commissioner for Patents, P.O. Box 1450,  
Alexandria, VA 22313-1450 on. 7/8/03

Date: 7/8/03

Signed: 

Name: Dov Rosenfeld, Reg. No. 38687

S/N 09/608237

Page 4

APPT-001-1

Applicant(s) believe(s) that no Extension of Time is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition for an extension of time.

Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:

- one months (\$110)                       two months (\$410)
- two months (\$930)                       four months (\$1450)

If an additional extension of time is required, please consider this as a petition therefor.

A credit card payment form for the required fee(s) is attached.

The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 50-0292 (A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED):

- Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.
- Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

7/8/03  
Date

  
Dov Rosenfeld, Reg. No. 38687

Address for correspondence:  
Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618  
Tel. +1-510-547-3378; Fax: +1-510-291-2985



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

Table with columns: APPLICATION NO., FILING DATE, FIRST NAMED INVENTOR, ATTORNEY DOCKET NO., CONFIRMATION NO., EXAMINER, ART UNIT, PAPER NUMBER. Includes applicant information for Dov Rosenfeld and examiner MEKY, MOUSTAFA M.

Notice of Fee Increase on January 1, 2003

If a reply to a "Notice of Allowance and Fee(s) Due" is filed in the Office on or after January 1, 2003, then the amount due will be higher than that set forth in the "Notice of Allowance and Fee(s) Due" since there will be an increase in fees effective on January 1, 2003.

The current fee schedule is accessible from: http://www.uspto.gov/main/howtofees.htm.

If the issue fee paid is the amount shown on the "Notice of Allowance and Fee(s) Due," but not the correct amount in view of the fee increase, a "Notice to Pay Balance of Issue Fee" will be mailed to applicant.

Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at (703) 305-8283.



Received from < 41 810 291 2085 > on 07/24/03 11:51:18 PM Eastern Daylight Time

cw

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail Stop ISSUE FEE  
Commissioner for Patents  
Alexandria, Virginia 22313-1450  
Fax (703)746-4000

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 4 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Please Legibly mark-up with any corrections in the boxes)  
7590 07/17/2003

Dov Rosenfeld  
Suite 2  
5507 College Avenue  
Oakland, CA 94618

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission  
I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Box Issue Fee address above, or being facsimile transmitted to the USPTO, on the date indicated below.

Dov Rosenfeld (Depositor's name)  
(Signature)  
24 Sep 03 (Date)

09/26/2003 TTRAN2 00000068 09508237  
01 FC:1501 1300.00 OP  
02 FC:8001 30.00 OP

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/608,237	06/30/2000	Russell S. Dietz	APFT-001-1	9993

TITLE OF INVENTION: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	\$1300	\$0	\$1300	10/17/2003

EXAMINER	ART UNIT	CLASS-SUBCLASS
MEKY, MOUSTAFA M	2157	709-224000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).  
 Change of correspondence address (or Change of Correspondence Address form PTO/SB/1122) attached.  
 "Fee Address" indication (or "Fee Address" indication form PTO/SB/47, Rev 03-02 or more recent) attached. Use of a Customer Number is required.

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1. Dov Rosenfeld  
2. INVENTEK  
3.

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the USPTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

Hi/tn, Inc.

(B) RESIDENCE: (CITY AND STATE OR COUNTRY)

Los Gatos, CA

Please check the appropriate assignee category or categories (will not be printed on the patent)  individual  corporation or other private group entity  government

4a. The following fee(s) are enclosed:

Issue Fee

Publication Fee

Advance Order - # of Copies 10

4b. Payment of Fee(s):

A check is the amount of the fee(s) is enclosed.

Payment by credit card. Form PTO-2038 is attached.

The Commissioner is hereby authorized by charge the required fee(s), or credit any overpayment, to Deposit Account Number 40-6242 (enclose an extra copy of this form).

Commissioner for Patents is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above.

(Authorized Signature)

(Date)

24 Sep 03

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant, a registered attorney or agent, or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, Alexandria, Virginia 22313-1450.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMIT THIS FORM WITH FEE(S)

PTOL-85 (REV. 05-03) Approved for use through 04/30/2004. OMB 0651-0033

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE



p-4

5862-162-2985

Dov Rosenfeld

Sep 24 03 06:50P



Sep 24 03 06:32p

Dov Rosenfeld

+1-510-2985

P. 1

*aw*



# INVENTEK

Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618, USA  
Phone: (510)547-3378; Fax: (510)653-7992  
dov@inventek.com

Fax

**OUR REF:** APPT-001-1

**TO:** Mail Stop Issue Fee  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

**FAX No.:** (703) 746-4000

**DATE:** September 24, 2003

**FROM:** Dov Rosenfeld, Reg. No., 38,687

**RE:** Issue Fee for Application No.: 09/608237

*Number of pages including cover: 5*

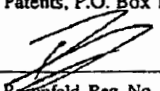
**OFFICIAL COMMUNICATION**  
**ISSUE FEE PAYMENT**

Included herewith are:

- A transmittal letter and copy
- Fee(s) Transmittal (form PTOL-85)
- Credit Card charge form for issue fee

**Certificate of Facsimile Transmission under 37 CFR 1.8**

I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark Office at telephone number (703) 746-4000 addressed to Mail Stop Issue Fee, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on.

Date: September 24, 2003 Signed:   
Name: Dov Rosenfeld, Reg. No. 38687

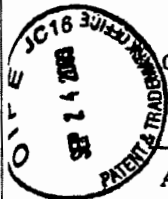
Received from <+1 510 291 2985> at 9/24/03 9:32:27 PM [Eastern Daylight Time]

Sep 24 03 06:32p

Dov Rosenfeld

+1-510-2985

P. 2



Our Ref./Docket No: APPT-001-1

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, <i>et al.</i>	Group Art Unit: 2755
Application No.: 09/608237	Examiner:
Filed: June 30, 2000	Notice of Allowance Mailed: July, 17, 2003
Title: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK	Confirmation No: 9993

SUBMISSION OF ISSUE FEE

Mail Stop ISSUE FEE  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

Transmitted herewith is a completed "Issue Fee Transmittal" Form. Included with the form are:

- A credit card payment form for the issue fee and any advance order of copies;
- drawing corrections (with separate letter);
- formal drawings (with separate letter);

The Commissioner is hereby authorized to charge payment of the any missing fee or credit any overpayment to Deposit Account No. 50-0292  
(A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED):

Respectfully Submitted,

24 Sep 03  
Date

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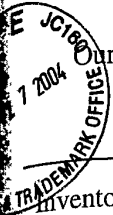
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Our Ref./Docket No: A/PPT-001-1

Patent

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**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Inventor(s): Dietz, *et al.*  
Assignee: Hi/fn, Inc.  
Patent No: 6651099  
Issue Date: November, 18, 2003  
Application No.: 09/608237  
Filed: June 30, 2000  
Title: METHOD AND APPARATUS FOR  
MONITORING TRAFFIC IN A NETWORK

Certificate  
MAR 05 2004  
of Correction

**REQUEST FOR CERTIFICATE OF CORRECTIONS**

Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

The above patent contains significant error as indicated on the attached Certificate of Correction form (submitted in duplicate).

X Such error arose through the fault of the Patent and Trademark Office. It is requested that the certificate be issued at no cost to the applicant.

However, if it is determined that the error arose through the fault of applicant(s), please note that such error is of clerical error or minor nature and occurred in good faith and therefore issuance of the certificate of Correction is respectfully requested. The Commissioner is authorized to charge Deposit Account No. 50-0292 any required fee. A duplicate of this request is attached.

Such errors specifically:

- In col. 3, line 14, delete the word "lo"
- In col. 15, line 45, kindly replace "ump" with "--jump--"
- In col. 28, line 65, change "MEB" to "--MIB--".

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Date: 2/25/04 Signed: *[Signature]*  
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8 MAR 2004

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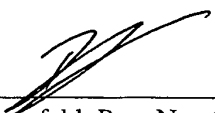
Page 2

The undersigned requests being contacted at (510) 547-3378 if there are any questions or clarifications, or if there are any problems with issuance of the Certificate of Correction.

Respectfully Submitted,

Feb. 25, 2004

Date

  
\_\_\_\_\_  
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## UNITED STATES PATENT AND TRADEMARK OFFICE CERTIFICATE OF CORRECTION

PATENT NO : 6651099 *Bl*

DATED : November 18, 2003

INVENTOR(S) : Dietz, et al.

It is certified that an error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In col. 3, line 14, delete the word "lo" *C*

In col. 15, line 45, kindly replace "ump" with --jump-- *C*

In col. 28, line 65, change "MEB" to --MIB-- *C*

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## UNITED STATES PATENT AND TRADEMARK OFFICE CERTIFICATE OF CORRECTION

PATENT NO : 6651099

DATED : November 18, 2003

INVENTOR(S) : Dietz, et al.

It is certified that an error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In col. 3, line 14, delete the word "lo"

In col. 15, line 45, kindly replace "ump" with --jump--

In col. 28, line 65, change "MEB" to --MIB--.

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US006243667B1

United States Patent  
Kerr et al.

(10) Patent No.: US 6,243,667 B1  
(45) Date of Patent: \*Jun. 5, 2001

54) NETWORK FLOW SWITCHING AND FLOW DATA EXPORT

(75) Inventors: Darren R. Kerr, Union City; Barry L. Bruins, Los Altos, both of CA (US)  
(73) Assignee: Cisco Systems, Inc., San Jose, CA (US)

(\* Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

- (21) Appl. No.: 08/655,429
- (22) Filed: May 28, 1996
- (51) Int. Cl.<sup>7</sup> ..... G06F 9/34
- (2) U.S. Cl. .... 703/27; 703/20; 370/379; 370/392; 370/389
- (8) Field of Search ..... 395/500, 200.01, 395/200.13, 683, 185.04; 370/352, 389, 392, 351, 410

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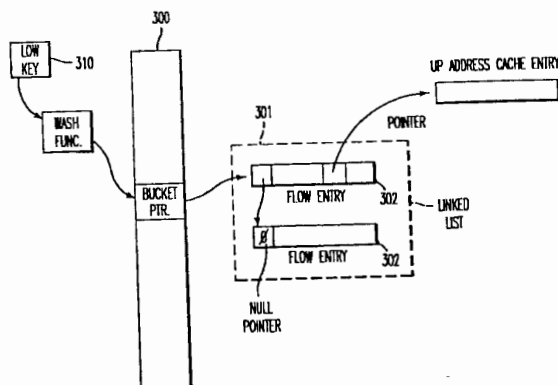
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Primary Examiner—Kevin J. Teska  
Assistant Examiner—Thai Phan  
(74) Attorney, Agent, or Firm—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

(57) ABSTRACT

The invention provides a method and system for switching in networks responsive to message flow patterns. A message "flow" is defined to comprise a set of packets to be transmitted between a particular source and a particular destination. When routers in a network identify a new message flow, they determine the proper processing for packets in that message flow and cache that information for that message flow. Thereafter, when routers in a network identify a packet which is part of that message flow, they process that packet according to the proper processing for packets in that message flow. The proper processing may include a determination of a destination port for routing those packets and a determination of whether access control permits routing those packets to their indicated destination.

19 Claims, 5 Drawing Sheets



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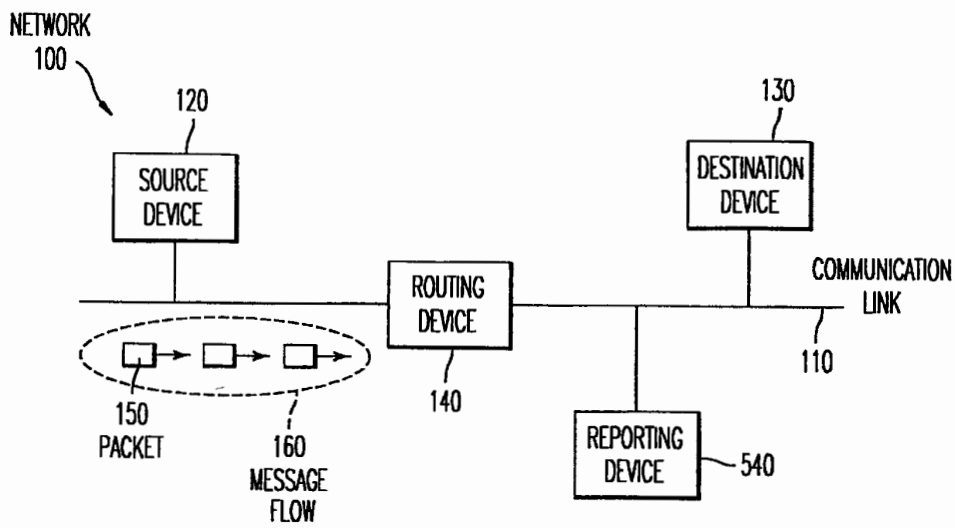


FIG. 1

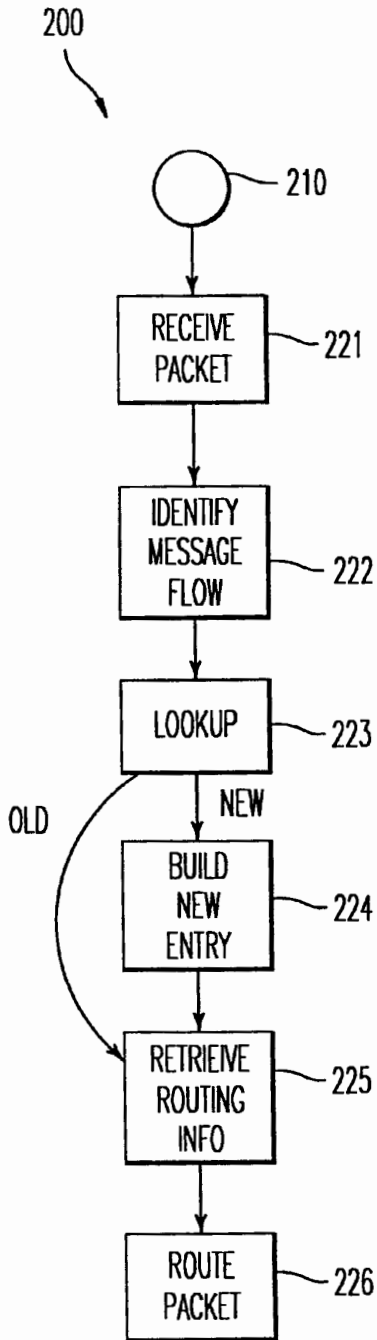


FIG. 2A

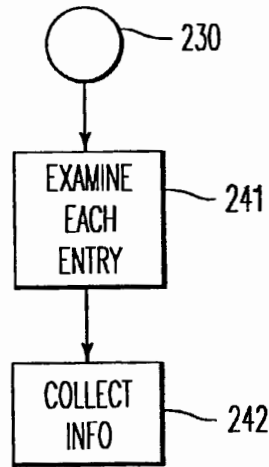


FIG. 2B

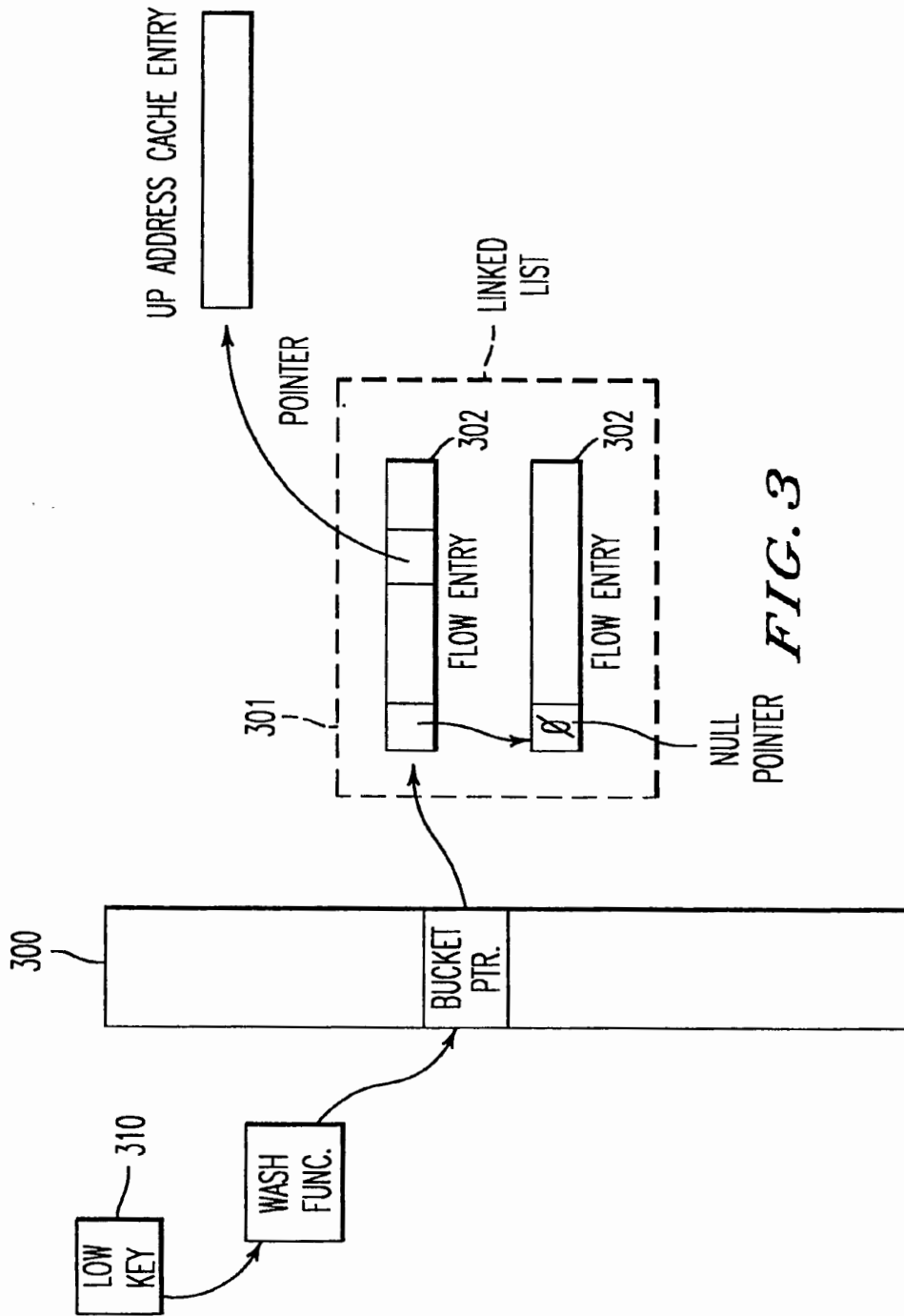


FIG. 3

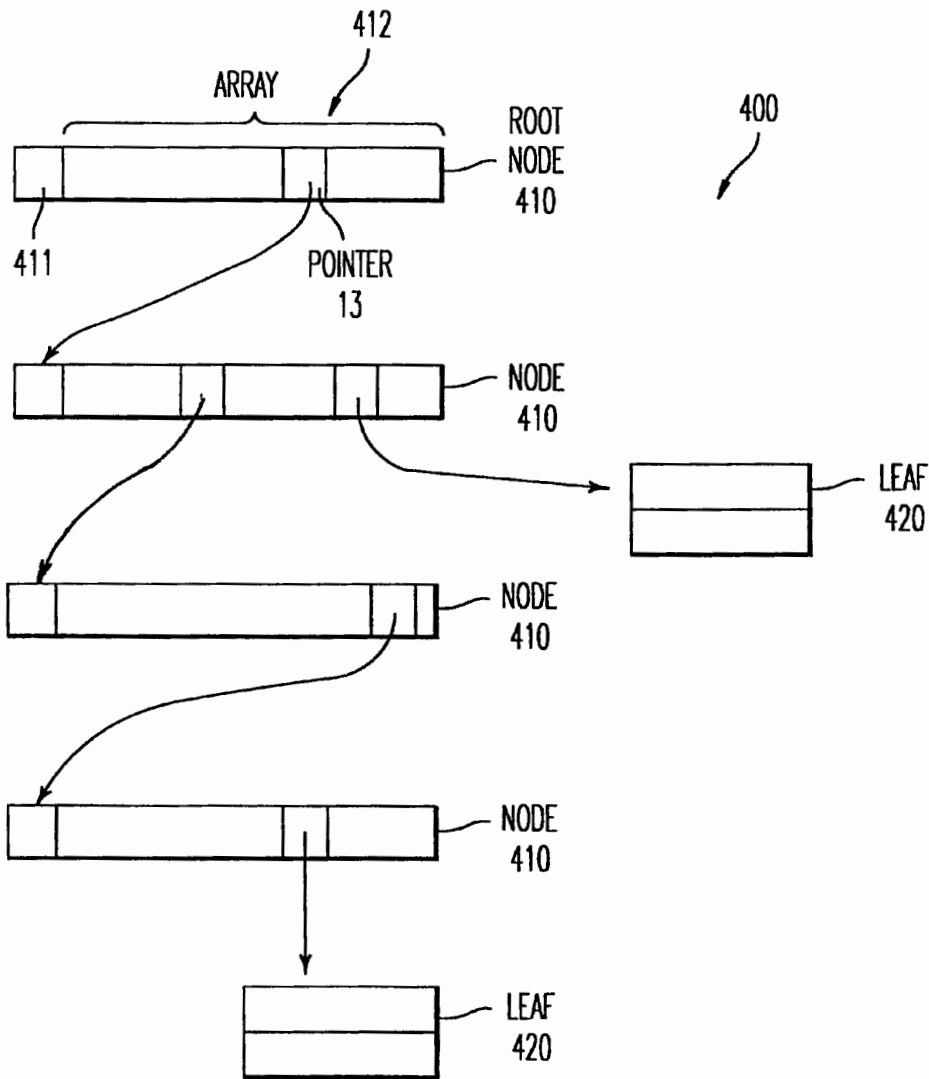
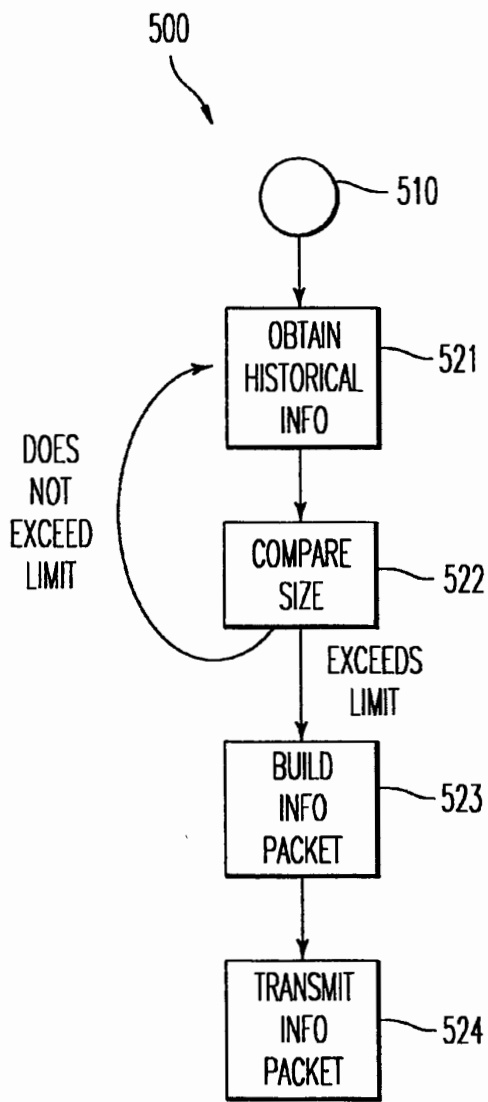
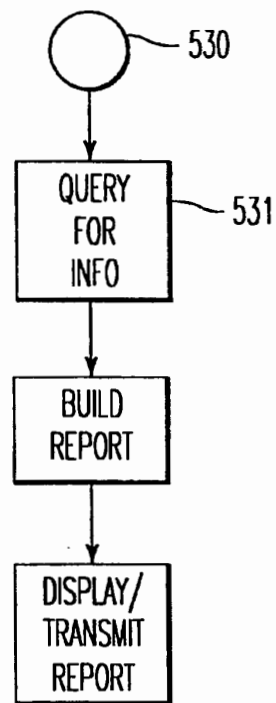


FIG. 4



*FIG. 5A*



*FIG. 5B*

## NETWORK FLOW SWITCHING AND FLOW DATA EXPORT

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

This invention relates to network switching and data export responsive to message flow patterns.

#### 2. Description of Related Art

In computer networks, it commonly occurs that message traffic between a particular source and a particular destination will continue for a time with unchanged routing or switching parameters. For example, when using the file-transfer protocol "FTP" there is substantial message traffic between the file's source location and the file's destination location, comprising the transfer of many packets which have similar headers, differing in the actual data which is transmitted. During the time when message traffic continues, routing and switching devices receiving packets comprising that message traffic must examine those packets and determine the processing thereof.

One problem which has arisen in the art is that processing demands on routing and switching devices continue to grow with increased network demand. It continues to be advantageous to provide techniques for processing packets more quickly. This problem has been exacerbated by addition of more complex forms of processing, such as the use of access control lists.

It would therefore be advantageous to provide techniques in which the amount of processing required for any individual packet could be reduced. With inventive techniques described herein, information about message flow patterns is used to identify packets for which processing has already been determined, and therefore to process those packets without having to re-determine the same processing. The amount of processing required for any individual packet is therefore reduced.

Information about message flow patterns would also be valuable for providing information about use of the network, and could be used for a variety of purposes by network administrators, routing devices, service providers, and users.

Accordingly, it would be advantageous to provide a technique for network switching and data export responsive to message flow patterns.

### SUMMARY OF THE INVENTION

The invention provides a method and system for switching in networks responsive to message flow patterns. A message "flow" is defined to comprise a set of packets to be transmitted between a particular source and a particular destination. When routers in a network identify a new message flow, they determine the proper processing for packets in that message flow and cache that information for that message flow. Thereafter, when routers in a network identify a packet which is part of that message flow, they process that packet according to the proper processing for packets in that message flow. The proper processing may include a determination of a destination port for routing those packets and a determination of whether access control permits routing those packets to their indicated destination.

In another aspect of the invention, information about message flow patterns is collected, responsive to identified message flows and their packets. The collected information is reported to devices on the network. The collected information is used for a variety of purposes, including: to diagnose actual or potential network problems, to determine

patterns of usage by date and time or by location, to determine which services and which users use a relatively larger or smaller amount of network resources, to determine which services are accessed by particular users, to determine which users access particular services, or to determine usage which falls within selected parameters (such as: access during particular dates or times, access to prohibited services, excessive access to particular services, excessive use of network resources, or lack of proper access).

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a network in which routing responsive to message flow patterns is performed.

FIG. 2 shows a method for routing in networks responsive to message flow patterns.

FIG. 3 shows data structures for use with a method for routing in networks responsive to message flow patterns.

FIG. 4 shows an IP address cache for use with a method for routing in networks responsive to message flow patterns.

FIG. 5 shows a method for collecting and reporting information about message flow patterns.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

In the following description, a preferred embodiment of the invention is described with regard to preferred process steps and data structures. However, those skilled in the art would recognize, after perusal of this application, that embodiments of the invention may be implemented using a set of general purpose computers operating under program control, and that modification of a set of general purpose computers to implement the process steps and data structures described herein would not require undue invention.

#### Message Flows

FIG. 1 shows a network in which routing responsive to message flow patterns is performed.

A network 100 includes at least one communication link 110, at least one source device 120, at least one destination device 130, and at least one routing device 140. The routing device 140 is disposed for receiving a set of packets 150 from the source device 120 and routing them to the destination device 130.

The communication link 110 may comprise any form of physical media layer, such as ethernet, FDDI, or HDLC serial link.

The routing device 140 comprises a routing processor for performing the process steps described herein, and may include specific hardware constructed or programmed performing the process steps described herein, a general purpose processor operating under program control, or some combination thereof.

A message flow 160 consists of a unidirectional stream of packets 150 to be transmitted between particular pairs of transport service access points (thus, network-layer addresses and port numbers). In a broad sense, a message flow 160 thus refers to a communication "circuit" between communication end-points. In a preferred embodiment, a message flow 160 is defined by a network-layer address for a particular source device 120, a particular port number at the source device 120, a network-layer address for a particular destination device 130, a particular port number at the destination device 130, and a particular transmission protocol type. For example, the transmission protocol type may

identify a known transmission protocol, such as UDP, TCP, ICMP, or IGMP (internet group management protocol).

In a preferred embodiment for use with a network of networks (an "internet"), the particular source device 120 is identified by its IP (internet protocol) address. The particular port number at the source device 120 is identified by either a port number which is specific to a particular process, or by a standard port number for the particular transmission protocol type. For example, a standard port number for the TCP protocol type is 6 and a standard port number for the UDP protocol type is 17. Other protocols which may have standard port numbers include the FTP protocol, the TELNET protocol, an internet telephone protocol, or an internet video protocol such as the "CUSEeMe" protocol; these protocols are known in the art of networking. Similarly, the particular destination device 130 is identified by its IP (internet protocol) address; the particular port number at the destination device 130 is identified by either a port number which is specific to a particular process, or a standard port number for the particular transmission protocol type.

It will be clear to those skilled in the art, after perusing this application, that the concept of a message flow is quite broad, and encompasses a wide variety of possible alternatives within the scope and spirit of the invention. For example, in alternative embodiments, a message flow may be bi-directional instead of unidirectional, a message flow may be identified at a different protocol layer level than that of transport service access points, or a message flow may be identified responsive to other factors. These other factors may include one or more of the following: information in packet headers, packet length, time of packet transmission, or routing conditions on the network (such as relative network congestion or administrative policies with regard to routing and transmission).

#### Network Flow Switching

FIG. 2 shows a method for routing in networks responsive to message flow patterns.

In broad overview, the method for routing in networks responsive to message flow patterns comprises two parts. In a first part, the routing device 140 builds and uses a flow cache described in further detail with regard to FIG. 3), in which routing information to be used for packets 150 in each particular message flow 160 is recorded and from which such routing information is retrieved for use. In a second part, the routing device 140 maintains the flow cache, such as by removing entries for message flows 160 which are no longer considered valid.

A method 200 for routing in networks responsive to message flow patterns is performed by the routing device 140.

At a flow point 210, the routing device 140 is disposed for building and using the flow cache.

At a step 221, the routing device 140 receives a packet 150.

At a step 222, the routing device 140 identifies a message flow 160 for the packet 150. In a preferred embodiment, the routing device 140 examines a header for the packet 150 and identifies the IP address for the source device 120, the IP address for the destination device 130, and the protocol type for the packet 150. The routing device 140 determines the port number for the source device 120 and the port number for the destination device 130 responsive to the protocol type. Responsive to this set of information, the routing device 140 determines a flow key 310 (described with reference to FIG. 3) for the message flow 160.

At a step 223, the routing device 140 performs a lookup in a flow cache for the identified message flow 160. If the lookup is unsuccessful, the identified message flow 160 is a "new" message flow 160, and the routing device 140 continues with the step 224. If the lookup is successful, the identified message flow 160 is an "old" message flow 160, and the routing device 140 continues with the step 225.

In a preferred embodiment, the routing device 140 determines a hash table key responsive to the flow key 310. This aspect of the step 223 is described in further detail with regard to FIG. 3.

At a step 224, the routing device 140 builds a new entry in the flow cache. The routing device 140 determines proper treatment of packets 150 in the message flow 160 and enters information regarding such proper treatment in a data structure pointed to by the new entry in the flow cache. In a preferred embodiment, the routing device 140 determines the proper treatment by performing a lookup in an IP address cache as shown in FIG. 4.

In a preferred embodiment, the proper treatment of packets 150 in the message flow 160 includes treatment with regard to switching (thus, the routing device 140 determines an output port for switching packets 150 in the message flow 160), with regard to access control (thus, the routing device 140 determines whether packets 150 in the message flow 160 meet the requirements of access control, as defined by access control lists in force at the routing device 140), with regard to accounting (thus, the routing device 140 creates an accounting record for the message flow 160), with regard to encryption (thus, the routing device 140 determines encryption treatment for packets 150 in the message flow 160), and any special treatment for packets 150 in the message flow 160.

In a preferred embodiment, the routing device 140 performs any special processing for new message flows 160 at this time. For example, in one preferred embodiment, the routing device 140 requires that the source device 120 or the destination device 130 must authenticate the message flow 160. In that case, the routing device 140 transmits one or more packets 150 to the source device 120 or the destination device 130 to request information (such as a user identifier and a password) to authenticate the new message flow 160, and receives one or more packets 150 comprising the authentication information. This technique could be useful for implementing security "firewalls" and other authentication systems.

Thereafter, the routing device 140 proceeds with the step 225, using the information from the new entry in the flow cache, just as if the identified message flow 160 were an "old" message flow 160 and the lookup in a flow cache had been successful.

At a step 225, the routing device 140 retrieves routing information from the entry in the flow cache for the identified message flow 160.

In a preferred embodiment, the entry in the flow cache includes a pointer to a rewrite function for at least part of a header for the packet 150. If this pointer is non-null, the routing device 140 invokes the rewrite function to alter the header for the packet 150.

At a step 226, the routing device 140 routes the packet 150 responsive to the routing information retrieved at the step 225.

Thus, in a preferred embodiment, the routing device 140 does not separately determine, for each packet 150 in the message flow 160, the information stored in the entry in the flow cache. Rather, when routing a packet 150 in the



message flow 160, the routing device 140 reads the information from the entry in the flow cache and treats the packet 150 according to the information in the entry in the flow cache.

Thus, in a preferred embodiment, the routing device 140 routes the packet 150 to an output port, determines whether access is allowed for the packet 150, determines encryption treatment for the packet 150, and performs any special treatment for the packet 150, all responsive to information in the entry in the flow cache.

In a preferred embodiment, the routing device 140 also enters accounting information in the entry in the flow cache for the packet 150. When routing each packet 150 in the message flow 160, the routing device 140 records the cumulative number of packets 150 and the cumulative number of bytes for the message flow 160.

Because the routing device 140 processes each packet 150 in the message flow 160 responsive to the entry for the message flow 160 in the flow cache, the routing device 140 is able to implement administrative policies which are designated for each message flow 160 rather than for each packet 150. For example, the routing device 140 is able to reserve specific amounts of bandwidth for particular message flows 160 and to queue packets 150 for transmission responsive to the bandwidth reserved for their particular message flows 160.

Because the routing device 140 is able to associate each packet 150 with a particular message flow 160 and to associate each message flow 160 with particular network-layer source and destination addresses, the routing device 140 is able to associate network usage with particular workstations (and therefore with particular users) or with particular services available on the network. This can be used for accounting purposes, for enforcing administrative policies, or for providing usage information to interested parties.

For a first example, the routing device 140 is able to monitor and provide usage information regarding access using the HTTP protocol to world wide web pages at particular sites.

For a second example, the routing device 140 is able to monitor usage information regarding relative use of network resources, and to give priority to those message flows 160 which use relatively fewer network resources. This can occur when a first message flow 160 is using a relatively low-bandwidth transmission channel (such as a 28.8 kilobits per second modem transmission channel) and when a second message flow 160 is using a relatively high-bandwidth transmission channel (such as a T-1 transmission line).

At a flow point 230, the routing device 140 is disposed for maintaining the flow cache.

At a step 241, the routing device 140 examines each entry in the flow cache and compares a current time with a last time a packet 150 was routed using that particular entry. If the difference exceeds a first selected timeout, the message flow 160 represented by that entry is considered to have expired due to nonuse and thus to no longer be valid.

In a preferred embodiment, the routing device 140 also examines the entry in the flow cache and compares a current time with a first time a packet 150 was routed using that particular entry. If the difference exceeds a second selected timeout, the message flow 160 represented by that entry is considered to have expired due to age and thus to no longer be valid. The second selected timeout is preferably about one minute.

Expiring message flows 160 due to age artificially requires that a new message flow 160 must be created for the

next packet 150 in the same communication session represented by the old message flow 160 which was expired. However, it is considered preferable to do so because it allows information to be collected and reported about message flows 160 without having to wait for those message flows 160 to expire from nonuse. For example, a multiple-broadcast communication session could reasonably last well beyond the time message flows 160 are expired for age, and if not so expired would mean that information about network usage would not account for significant network usage.

In a preferred embodiment, the routing device 140 also examines the entry in the flow cache and determines if the "next hop" information has changed. If so, the message flow 160 is expired due to changed conditions. Other changed conditions which might cause a message flow 160 to be expired include changes in access control lists or other changes which might affect the proper treatment of packets 150 in the message flow 160. The routing device 140 also expires entries in the flow cache on a least-recently-used basis if the flow cache becomes too full.

If the message flow 160 is still valid, the routing device 140 continues with the next entry in the flow cache until all entries have been examined. If the message flow 160 is no longer valid, the routing device 140 continues with the step 242.

At a step 242, the routing device 140 collects historical information about the message flow 160 from the entry in the flow cache, and deletes the entry.

#### Flow Cache

FIG. 3 shows data structures for use with a method for routing in networks responsive to message flow patterns.

A flow cache 300 comprises a memory which associates flow keys 310 with information about message flows 160 identified by those flow keys 310. The flow cache 300 includes a set of buckets 301. Each bucket 301 includes a linked list of entries 302. Each entry 302 includes information about a particular message flow 160, including routing, access control, accounting, special treatment for packets 150 in that particular message flow 160, and a pointer to information about treatment of packets 150 to the destination device 130 for that message flow 160.

In a preferred embodiment, the flow cache 300 includes a relatively large number of buckets 301 (preferably about 16,384 buckets 301), so as to minimize the number of entries 302 per bucket 301 and thus so as to minimize the number of memory accesses per entry 302. Each bucket 301 comprises a four-byte pointer to a linked list of entries 302. The linked list preferably includes only about one or two entries 302 at the most.

In a preferred embodiment, each entry 302 includes a set of routing information, a set of access control information, a set of special treatment information, and a set of accounting information, for packets 150 in the message flow 160.

The routing information comprises the output port for routing packets 150 in the message flow 160.

The access control information comprises whether access is permitted for packets 150 in the message flow 160.

The accounting information comprises a time stamp for the first packet 150 in the message flow 160, a time stamp for the most recent packet 150 in the message flow 160, a cumulative count for the number of packets 150 in the message flow 160, and a cumulative count for the number of bytes 150 in the message flow 160.

#### IP Address Cache

FIG. 4 shows an IP address cache for use with a method for routing in networks responsive to message flow patterns.

An IP address cache 400 comprises a tree having a root node 410, a plurality of inferior nodes 410, and a plurality of leaf data structures 420.

Each node 410 comprises a node/leaf indicator 411 and an array 412 of pointers 413.

The node/leaf indicator 411 indicates whether the node 410 is a node 410 or a leaf data structure 420; for nodes 410 it is set to a "node" value, while for leaf data structures 420 it is set to a "leaf" value.

The array 412 has room for exactly 256 pointers 413; thus, the IP address cache 400 comprises an M-trie with a branching width of 256 at each level. M-tries are known in the art of tree structures. IP addresses comprise four bytes, each having eight bits and therefore 256 possible values. Thus, each possible IP address can be stored in the IP address cache 400 using at most four pointers 413.

The inventors have discovered that IP addresses in actual use are unexpectedly clustered, so that the size of the IP address cache 400 is substantially less, by a factor of about five to a factor of about ten, than would be expected for a set of randomly generated four-byte IP addresses.

Each pointer 413 represents a subtree of the IP address cache 400 for its particular location in the array 412. Thus, for the root node 410, the pointer 413 at location 3 represents IP addresses having the form 3.xxx.xxx.xxx, where "xxx" represents any possible value from zero to 255. Similarly, in a subtree for IP addresses having the form 3.xxx.xxx.xxx, the pointer 413 at location 141 represents IP addresses having the form 3.141.xxx.xxx. Similarly, in a subtree for IP addresses having the form 3.141.xxx.xxx, the pointer 413 at location 59 represents IP addresses having the form 3.141.59.xxx. Similarly, in a subtree for IP addresses having the form 3.141.59.xxx, the pointer 413 at location 26 represents the IP address 3.141.59.26.

Each pointer 413 is either null, to indicate that there are no IP addresses for the indicated subtree, or points to an inferior node 410 or leaf data structure 420. A least significant bit of each pointer 413 is reserved to indicate the type of the pointed-to structure; that is, whether the pointed-to structure is a node 410 or a leaf data structure 420. In a preferred embodiment where pointers 413 must identify an address which is aligned on a four-byte boundary, the two least significant bits of each pointer 413 are unused for addressing, and reserving the least significant bit for this purpose does not reduce the scope of the pointer 413.

Each leaf data structure comprises information about the IP address, stored in the IP address cache 400. In a preferred embodiment this information includes the proper processing for packets 150 addressed to that IP address, such as a determination of a destination port for routing those packets and a determination of whether access control permits routing those packets to their indicated destination.

#### Flow Data Export

FIG. 5 shows a method for collecting and reporting information about message flow patterns.

A method 500 for collecting and reporting information about message flow patterns is performed by the routing device 140.

At a flow point 510, the routing device 140 is disposed for obtaining information about a message flow 160. For example, in a preferred embodiment, as noted herein, the routing device 140 obtains historical information about a message flow 160 in the step 242. In alternative embodiments, the routing device 140 may obtain informa-

tion about message flows 160, either in addition or instead, by occasional review of entries in the flow cache, or by directly monitoring packets 150 in message flows 160.

It will be clear to those skilled in the art, after perusing this application, that the concept of reporting information about message flows is quite broad, and encompasses a wide variety of possible alternatives within the scope and spirit of the invention. For example, in alternative embodiments, information about message flows may include bi-directional traffic information instead of unidirectional traffic information, information about message flows may include information at a different protocol layer level other than that of transport service access points and other than that at which the message flow is itself defined, or information about message flows may include actual data transmitted as part of the message flow itself. These actual data may include one or more of the following: information in packet headers, information about files of file names transmitted during the message flow, or usage conditions of the message flow (such as whether the message flow involves steady or bursty transmission of data, or is relatively interactive or relatively unidirectional).

At a step 521, the routing device 140 obtains historical information about a particular message flow 160, and records that information in a flow data table.

At a step 522, the routing device 140 determines a size of the flow data table, and compares that size with a selected size value. If the flow data table exceeds the selected size value, the routing device 140 continues with the step 523 to report flow data. If the flow data table does not exceed the selected size value, the routing device 140 returns to the step 521 to obtain historical information about a next particular message flow 160.

At a step 523, the routing device 140 builds an information packet, responsive to the information about message flows 160 which is recorded in the flow data table.

At a step 524, the routing device 140 transmits the information packet to a selected destination device 130 on the network 100. In a preferred embodiment, the selected destination device 130 is determined by an operating parameter of the routing device 140. This operating parameter is set when the routing device 140 is initially configured, and may be altered by an operator of the routing device 140.

In a preferred embodiment, the selected destination device 130 receives the information packet and builds (or updates) a database in the format for the RMON protocol. The RMON protocol is known in the art of network monitoring.

At a flow point 530, a reporting device 540 on the network 100 is disposed for reporting using information about message flows 160.

At a step 531, the reporting device 540 queries the selected destination device 130 for information about message flows 160. In a preferred embodiment, the reporting device 540 uses the RMON protocol to query the selected destination device 130 and to obtain information about message flows 160.

At a step 532, the reporting device 540 builds a report about a condition of the network 100, responsive to information about message flows 160.

At a step 533, the reporting device 540 displays or transmits that report about the condition of the network 100 to interested parties.

In preferred embodiments, the report may comprise one or more of a wide variety of information, and interested parties

may use that information for one or more of a wide variety of purposes. Some possible purposes are noted herein:

Interested parties may diagnose actual or potential network problems. For example, the report may comprise information about packets 150 in particular message flows 160, including a time stamp for a first packet 150 and a time stamp for a last packet 150 in the message flow 160, a cumulative total number of bytes in the message flow 160, a cumulative total number of packets 150 in the message flow 160, or other information relevant to diagnosing actual or potential network problems.

Interested parties may determine patterns of usage of the network by date and time or by location. For example, the report may comprise information about which users or which services on the network are making relatively heavy use of resources. In a preferred embodiment, usage of the network 100 is displayed in a graphical form which shows use of the network 100 in a false-color map, so that network administrators and other interested parties may rapidly determine which services, which users, and which communication links are relatively loaded or relatively unloaded with demand.

Interested parties may determine which services are accessed by particular users, or which users access particular services. For example, the report may comprise information about which services are accessed by particular users at a particular device on the network 100, or which users access a particular service at a particular device on the network 100. This information may be used to market or otherwise enhance these services. In a preferred embodiment, users who access a particular world wide web page using the HTTP protocol are recorded, and information is sent to those users about changes to that web page and about further services available from the producers of that web page. Providers of the particular web page may also collect information about access to their web page in response to date and time of access, and location of accessing user.

Information about patterns of usage of the network, or about which services are accessed by particular users, or which users access particular services, may be used to implement accounting or billing for resources, or to set limits for resource usage, such as by particular users, by particular service providers, or by particular protocol types (and therefore by particular types of services).

Interested parties may determine usage which falls within (or without) selected parameters. These selected parameters may involve access during particular dates or times, such as for example access to particular services during or outside normal working hours. For example, it may be desirable to record those accesses to a company database which occur outside normal working hours.

These selected parameters may involve access to prohibited services, excessive access to particular services, or excessive use of network resources, such as for example access to particular servers using the HTTP protocol or the FTP protocol which fall within (or without) a particular administrative policy. For example, it may be desirable to record accesses to repositories of games or other recreational material, particularly those accesses which occur within normal working hours.

These selected parameters may involve or lack of proper access, such as for example access control list failures or unauthorized attempts to access secure services. For example, it may be desirable to record unauthorized attempts to access secure services, particularly those attempts which form a pattern which might indicate a concerted attempt to gain unauthorized access.

In alternative embodiments, the routing device 140 could save the actual packets 150 for the message flow 160, or some part thereof, for later examination. For example, a TELNET session (a message flow 160 comprising use of the TELNET protocol by a user and a host) could be recorded in its entirety, or some portion thereof, for later examination, e.g., to diagnose problems noted with the network or with the particular host.

In further alternative embodiments, the routing device 140 could save the actual packets 150 for selected message flows 160 which meet certain selected parameters, such as repeated unauthorized attempts to gain access.

In embodiments where actual packets 150 of the message flow 160 are saved, it would be desirable to perform a name translation (such as a reverse DNS lookup), because the IP addresses for the source device 120 and the destination device 130 are transitory. Thus, it would be preferable to determine the symbolic names for the source device 120 and the destination device 130 from the IP addresses, so that the recorded data would have greater meaning at a later time.

#### Alternative Embodiments

Although preferred embodiments are disclosed herein, many variations are possible which remain within the concept, scope, and spirit of the invention, and these variations would become clear to those skilled in the art after perusal of this application.

#### We claim:

1. A method for routing messages in a data network wherein a set of packets is isolated for specialized policy treatment by a plurality of routing devices in the data network, the method comprising the steps of:

identifying a first one message of a first plurality of messages associated with an application layer, said first plurality of messages having at least one policy treatment in common, said first plurality of messages being identified in response to an address of a selected source device and an address of a selected destination device, wherein said policy treatment comprises at least one of the access control information, security information, queuing information, accounting information, traffic profiling information, and policy information;

generating a unique hash key by each of the routing devices that receives the first plurality of messages, the unique hash key being based upon the address of the selected source device, the address of the selected destination device, a port number associated with the selected source device, a port number associated with the selected destination device, and a protocol type corresponding to the first plurality of messages;

recording said first policy treatment by building a corresponding entry in a flow cache, wherein the first plurality of messages is identified by the unique hash key;

recording information about said first plurality of messages;

transmitting said information to at least one selected device on said network based upon a predetermined operating parameter;

identifying a second one message of said first plurality of messages; and

routing said second one message responsive to said first routing treatment.

2. A method as in claim 1, wherein

said first one message comprises a packet;

said first plurality of messages comprises a stream of packets associated with a selected source device and a selected destination device.

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3. A method as in claim 2, wherein said stream of packets is associated with a first selected port number at said source device and a second selected port number at said destination device.

4. A method as in claim 1, wherein said first plurality of messages comprises a message flow.

5. A method as in claim 1, wherein said first plurality of messages comprises an ordered sequence, and said first one message has a selected position in said ordered sequence.

6. A method as in claim 1, wherein said step of recording comprises building an entry flow cache, wherein said flow cache includes a plurality of entries, one said entry for each said plurality of messages, each said entry including a unicast destination address.

7. A method as in claim 1, including a step of identifying a first packet of a second stream of packets, wherein the packets of said second stream of packets have at least one second policy treatment in common, said second routing treatment differing from said first policy treatment.

8. A method as in claim 1, wherein said policy treatment comprises a destination output port for routing said first message.

9. A method as in claim 1, wherein said information comprises

- an arrival time for an initial one message in said plurality of messages;
- an arrival time for most recent one message in said plurality of messages;
- a cumulative count of bytes in said plurality of messages; or
- a cumulative count of said one messages in said plurality of messages.

10. A method as in claim 1, comprising the steps of receiving said information at said selected device on said network; recording said information in a database at said selected device; and making said information available to a second device on said network.

11. A system for routing packets in a data network wherein a set of packets is isolated for specialized policy treatment, said system comprising:

- a source device for outputting a stream of packets;
- a destination device for receiving said stream of packets; and
- a plurality of routing devices for transporting said stream of packets from said source device to said destination device, each of said plurality of routing devices comprising,

means for receiving said stream of packets, said stream of packets comprising a plurality of message flows associated with an application layer, each said packet being associated with one selected message flow, each said message flow having at least one policy treatment in common, wherein said policy treatment comprises at least one of access control information, security information, queuing information, accounting information, traffic profiling information, and policy information;

means for associating packets with a first one of said message flows,

means for generating a unique hash key upon receipt of the stream of packets, the unique hash key being based upon an address of the source device, an address of the destination device, a port number associated with the

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source device, a port number associated with the destination device, and a protocol type corresponding to the first plurality of messages,

means for caching an entry associated with said first one of said message flows, wherein said first one of said message flows is identified by the unique hash key,

means for recording information about said first one of said message flows;

means for transmitting said information to the destination device on said network based upon a predetermined operating parameter, and

means for routing packets responsive to entries in said caching means.

12. A system as in claim 11, wherein said entry comprises access control information.

13. A system as in claim 12, wherein said entry comprises a destination output port for routing packets.

14. A system as in claim 11, wherein said information comprises

- a transmission time for an initial one message in said plurality of messages;
- a transmission time for a most recent one message in said plurality of messages;
- a cumulative count of bytes in said plurality of messages; or
- a cumulative count of said one messages in said plurality of messages.

15. The system as in claim 11,

wherein the caching means comprises a plurality of buckets, each bucket including a linked list that includes a maximum of two entries.

16. A method for routing messages in a data network wherein a set of packets is isolated for specialized policy treatment by plurality devices in the data network, said method comprising the steps of:

- identifying a first one packet of a first stream of packets defining a first message flow associated with an application layer, wherein said first stream of packets comprise an ordered sequence and said first packet has a selected position in said ordered sequence, said first stream of packets having at least one first routing policy treatment in common, wherein said policy treatment comprises at least one of access control information, security information, queuing information, accounting information, traffic profiling information, and policy information; and
- generating a unique hash key by each of the routing devices that receives the first stream of packets, the unique hash key being based upon an address of a selected source device, an address of a selected destination device, a port number associated with the selected source device, a port number associated with the selected destination device, and a selected protocol type, said first routing treatment being identified by the unique hash key;
- recording said unique hash key by building an entry in a flow cache;
- identifying subsequent packets of a said first stream of packets defining said first message flow;
- recording information about said first stream of packets;
- transmitting said information to at least one selected device on said network based upon a predetermined operating parameter; and
- routing said subsequent packets responsive to said first policy treatment.

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17. A method as in claim 16, comprising the step of identifying a first one packet of a second stream of packets defining a second message flow, said second stream of packets having at least one second policy treatment in common, said second policy treatment differing from said first policy treatment. 5

18. A method as in claim 16, wherein said policy treatment further comprises a destination output port for routing said first one packet.

19. A method as in claim 16, wherein said information 10 comprises

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a transmission time for said first packet of said first stream of packets;

a transmission time for a most recent one packet in said first stream of packets;

a cumulative count of bytes in said first stream of packets; or

a cumulative count of packets in said first stream of packets.

\* \* \* \* \*



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(54) **METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK**

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(57) **ABSTRACT**

(\*) **Notice:** Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
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A monitor for and a method of examining packets passing  
through a connection point on a computer network. Each  
packet conforms to one or more protocols. The method  
includes receiving a packet from a packet acquisition device  
and performing one or more parsing/extraction operations  
on the packet to create a parser record comprising a function  
of selected portions of the packet. The parsing/extraction  
operations depend on one or more of the protocols to which  
the packet conforms. The method further includes looking  
up a flow-entry database containing flow-entries for previ-  
ously encountered conversational flows. The lookup uses the  
selected packet portions and determining if the packet is of  
an existing flow. If the packet is of an existing flow, the  
method classifies the packet as belonging to the found  
existing flow, and if the packet is of a new flow, the method  
stores a new flow-entry for the new flow in the flow-entry  
database, including identifying information for future pack-  
ets to be identified with the new flow. For the packet  
of an existing flow, the method updates the flow-entry of the  
existing flow. Such updating may include storing one or  
more statistical measures. Any stage of a flow, state is  
maintained, and the method performs any state processing  
for an identified state to further the process of identifying  
the flow. The method thus examines each and every packet  
passing through the connection point in real time until the  
application program associated with the conversational flow  
is determined.

(21) **Appl. No.:** 09/608,237

(22) **Filed:** Jun. 30, 2000

**Related U.S. Application Data**

(60) Provisional application No. 60/141,903, filed on Jun. 30,  
1999.

(51) **Int. Cl.** ..... G06F 13/00

(52) **U.S. Cl.** ..... 709/224; 370/389

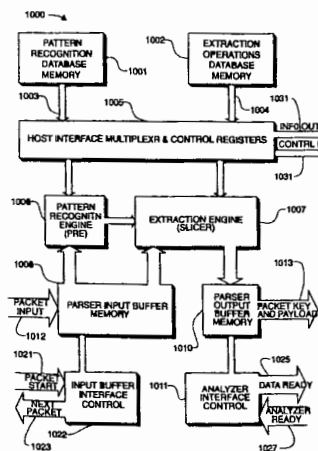
(58) **Field of Search** ..... 709/200, 201,  
709/220, 223, 224, 231, 232, 236, 238,  
239, 240, 246; 370/389, 392, 395/32

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**10 Claims, 18 Drawing Sheets**



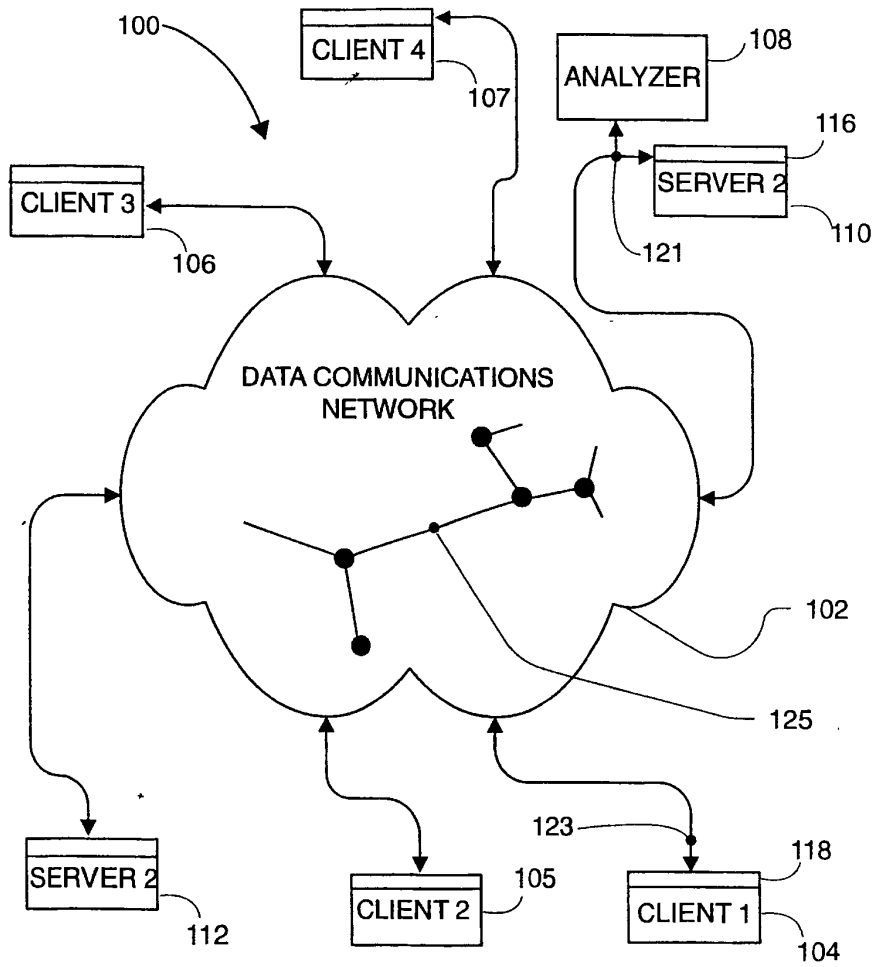


FIG. 1

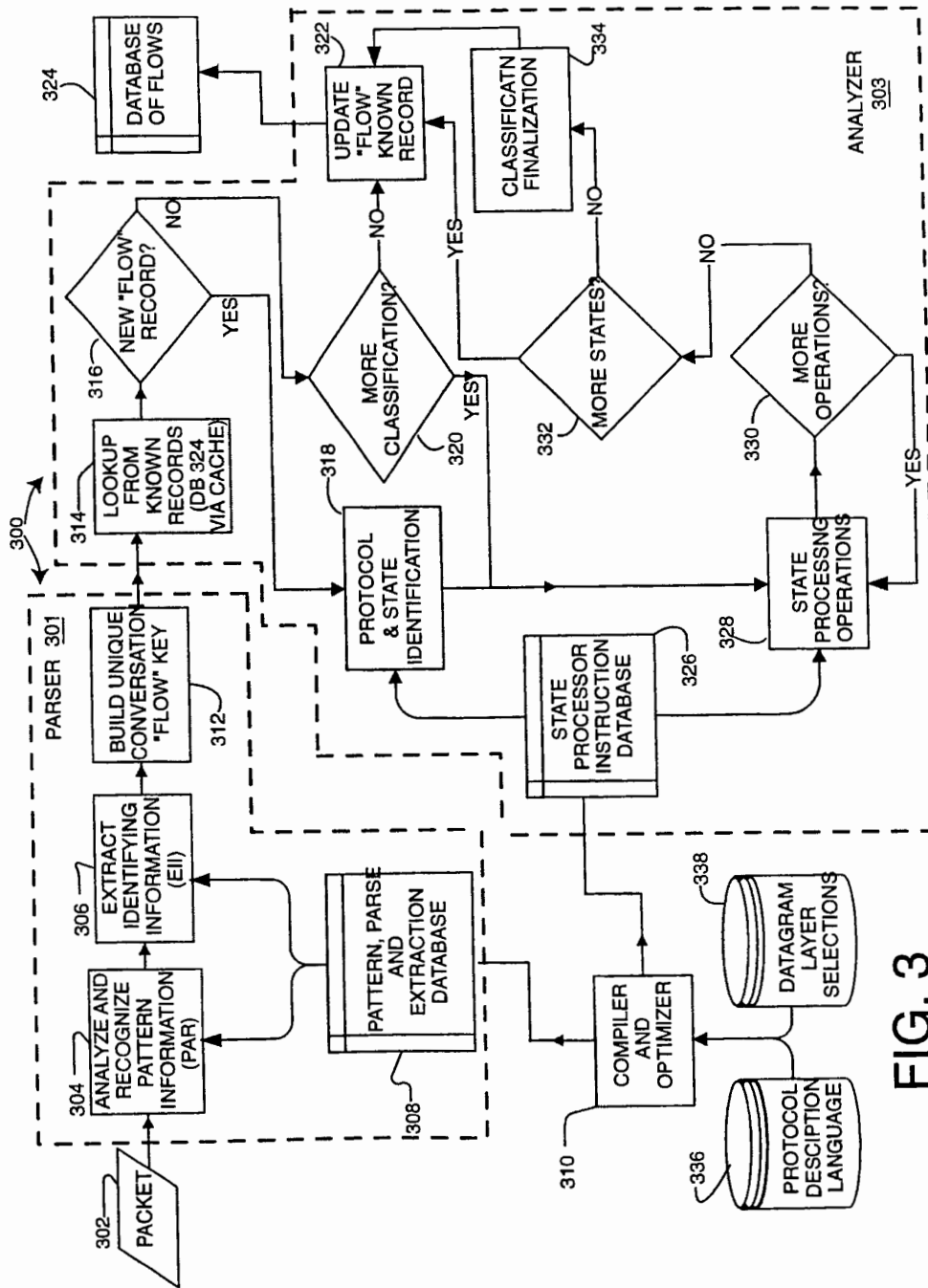


FIG. 3



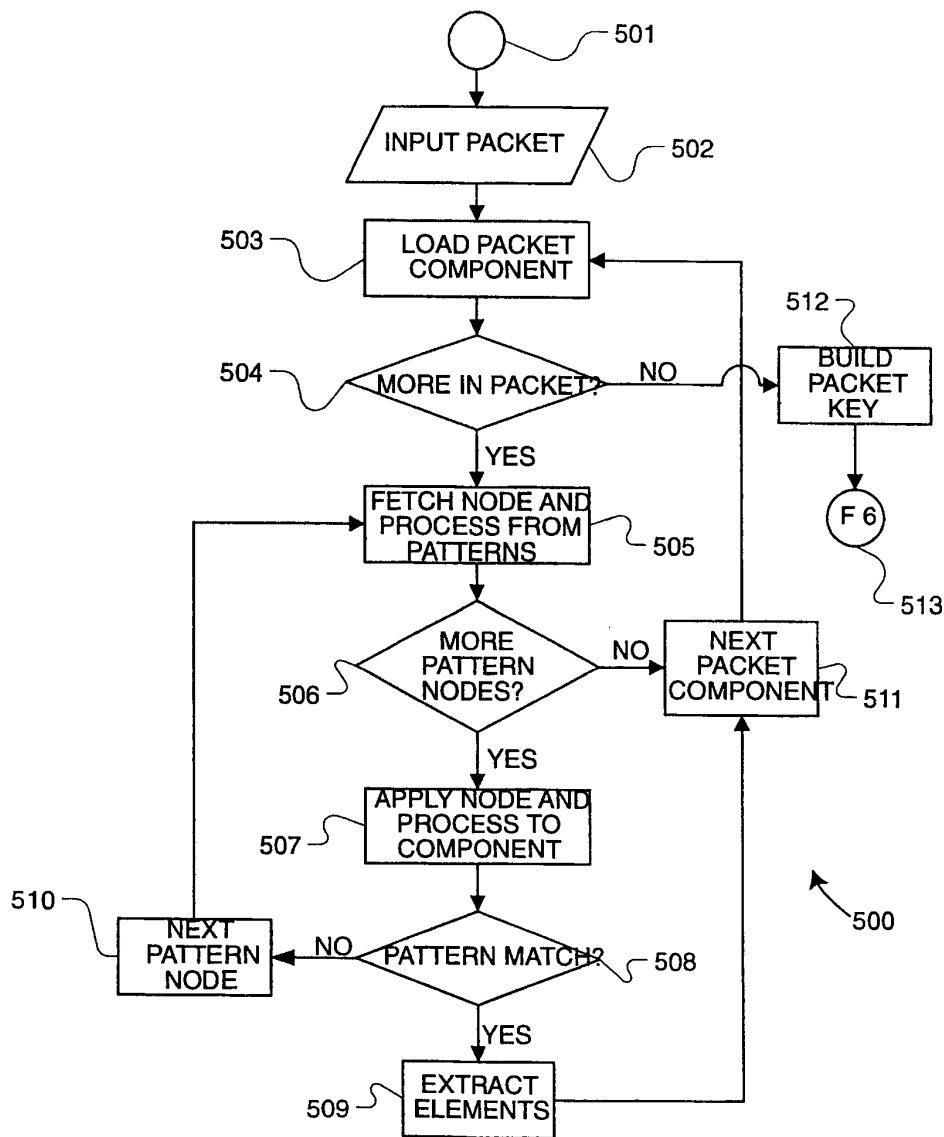


FIG. 5

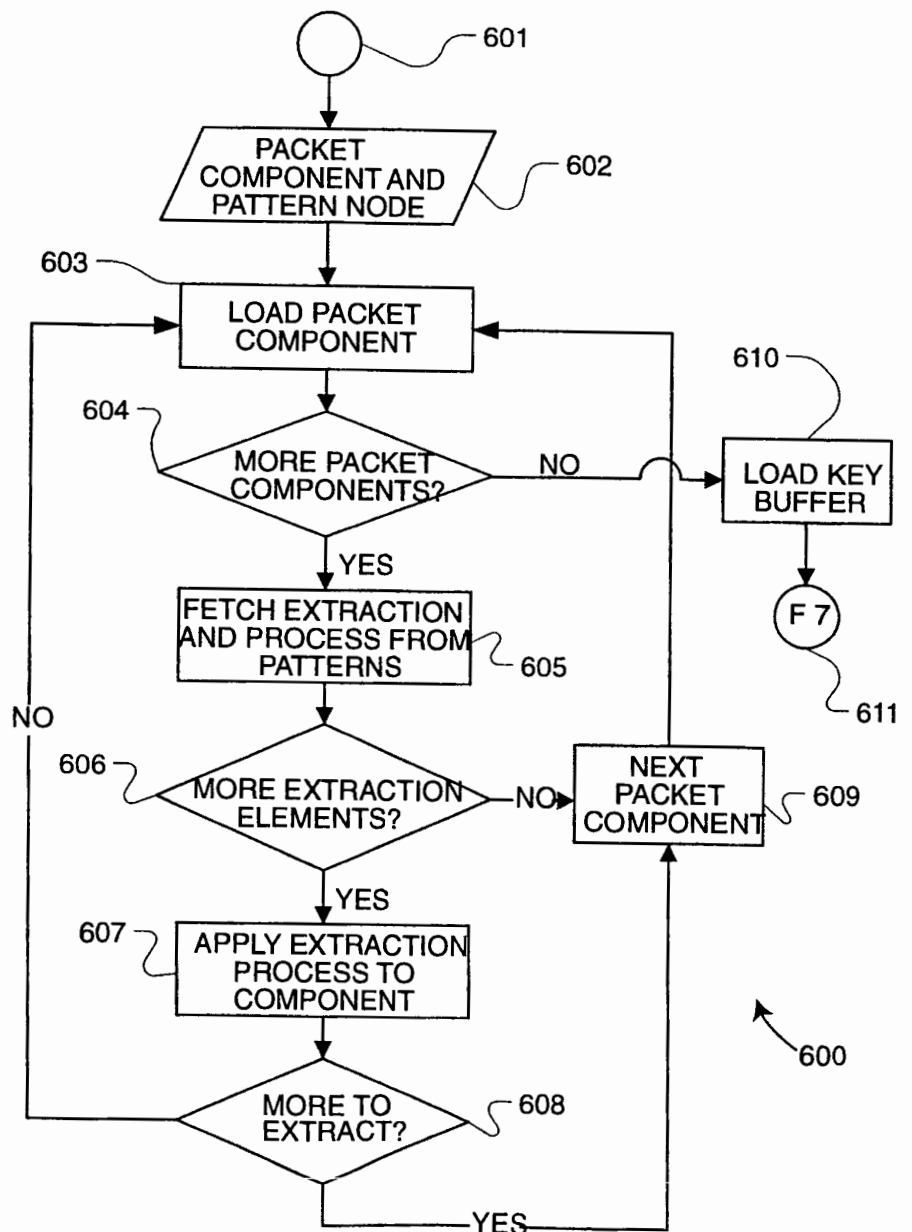


FIG. 6

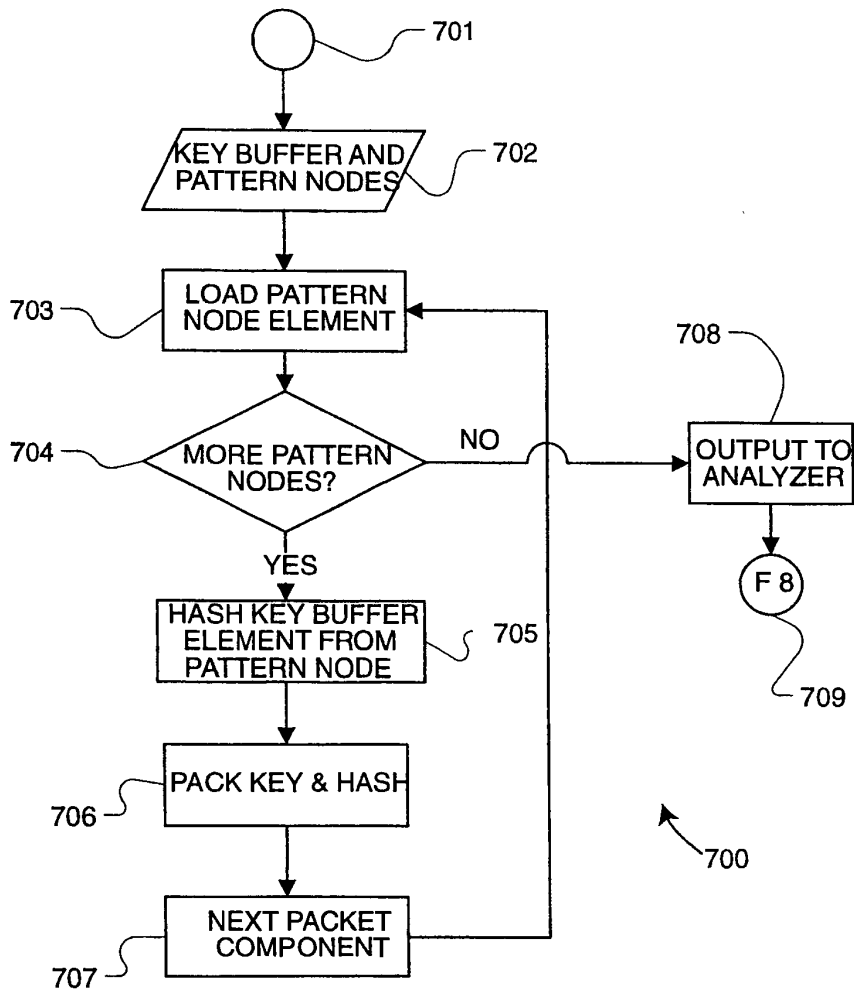


FIG. 7

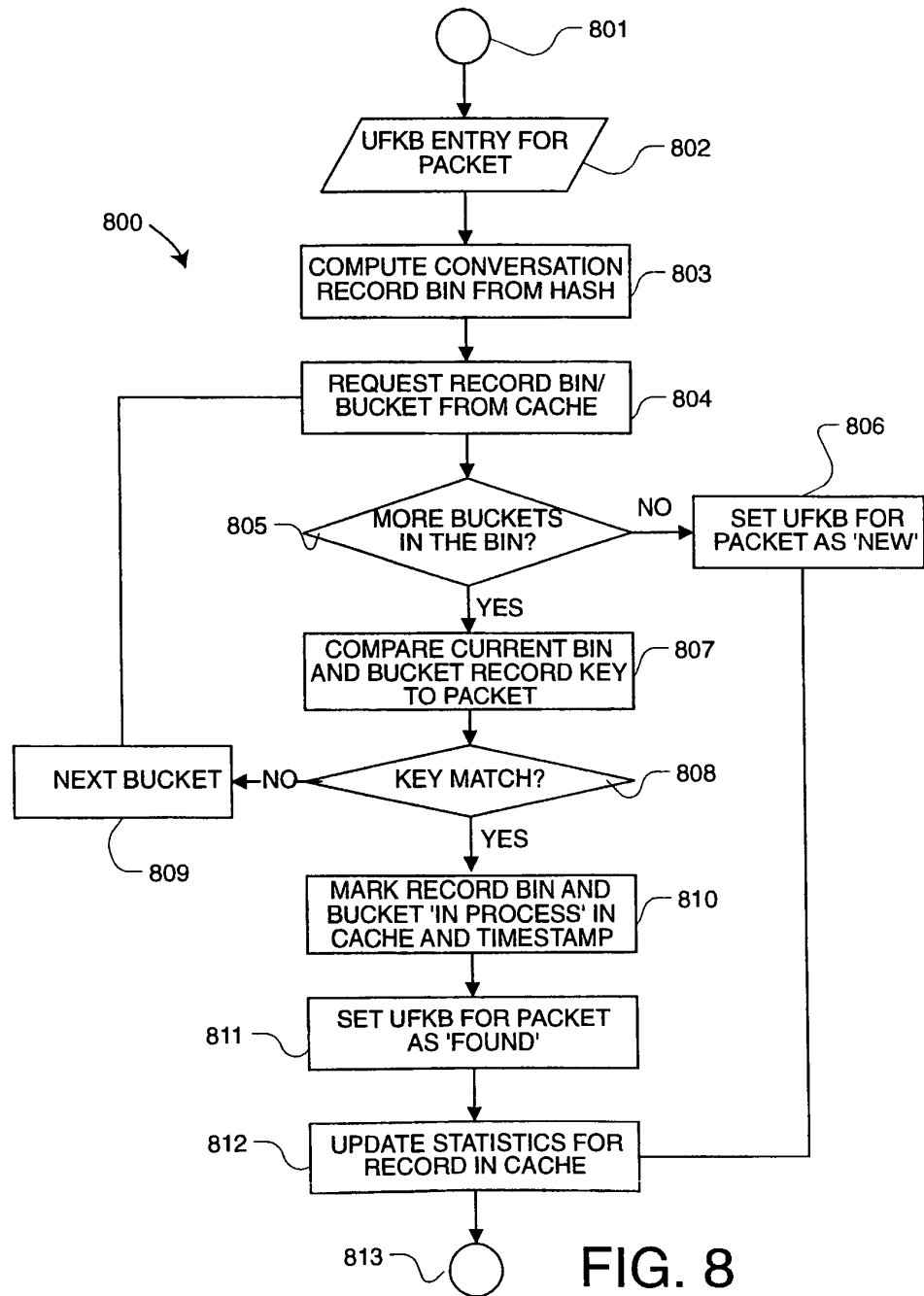


FIG. 8

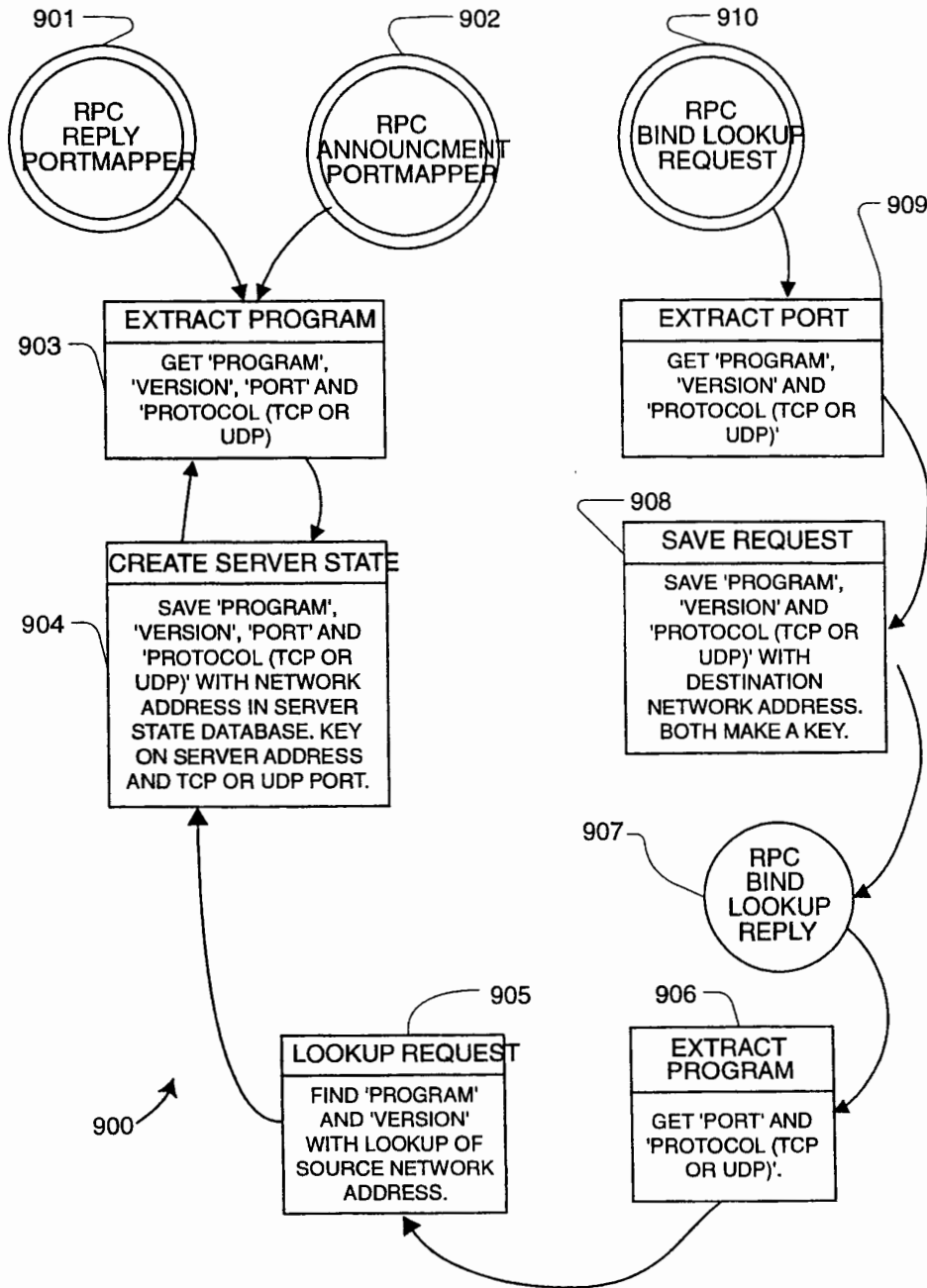


FIG. 9

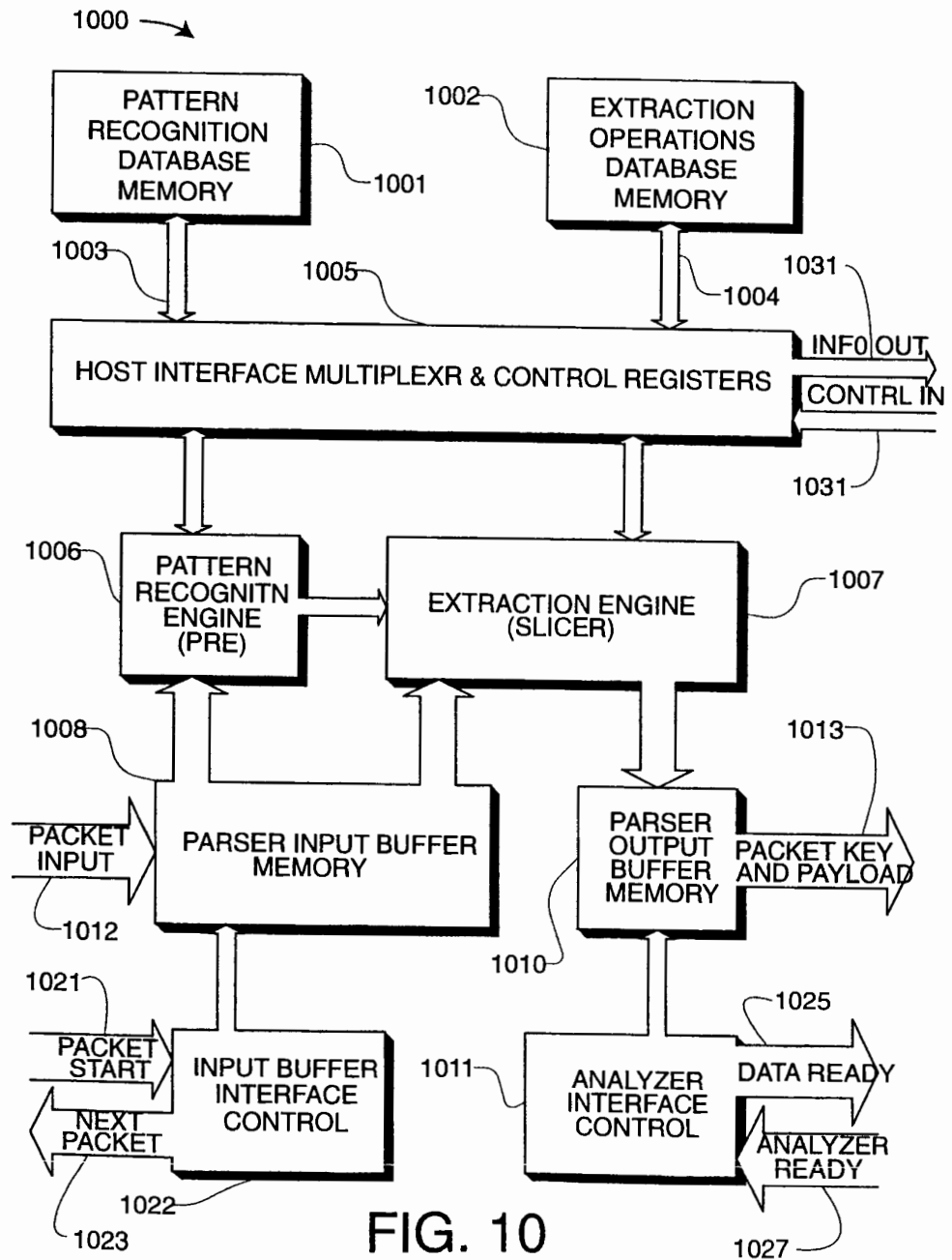


FIG. 10

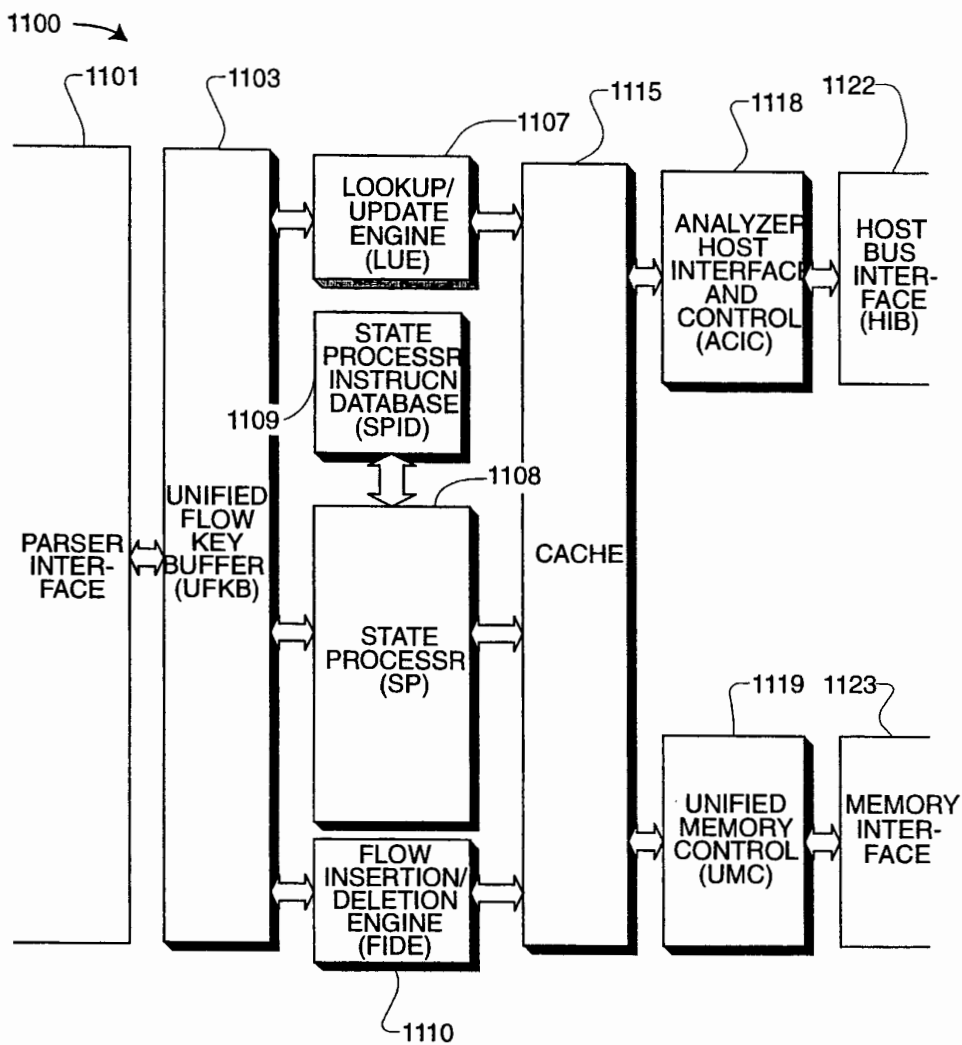


FIG. 11

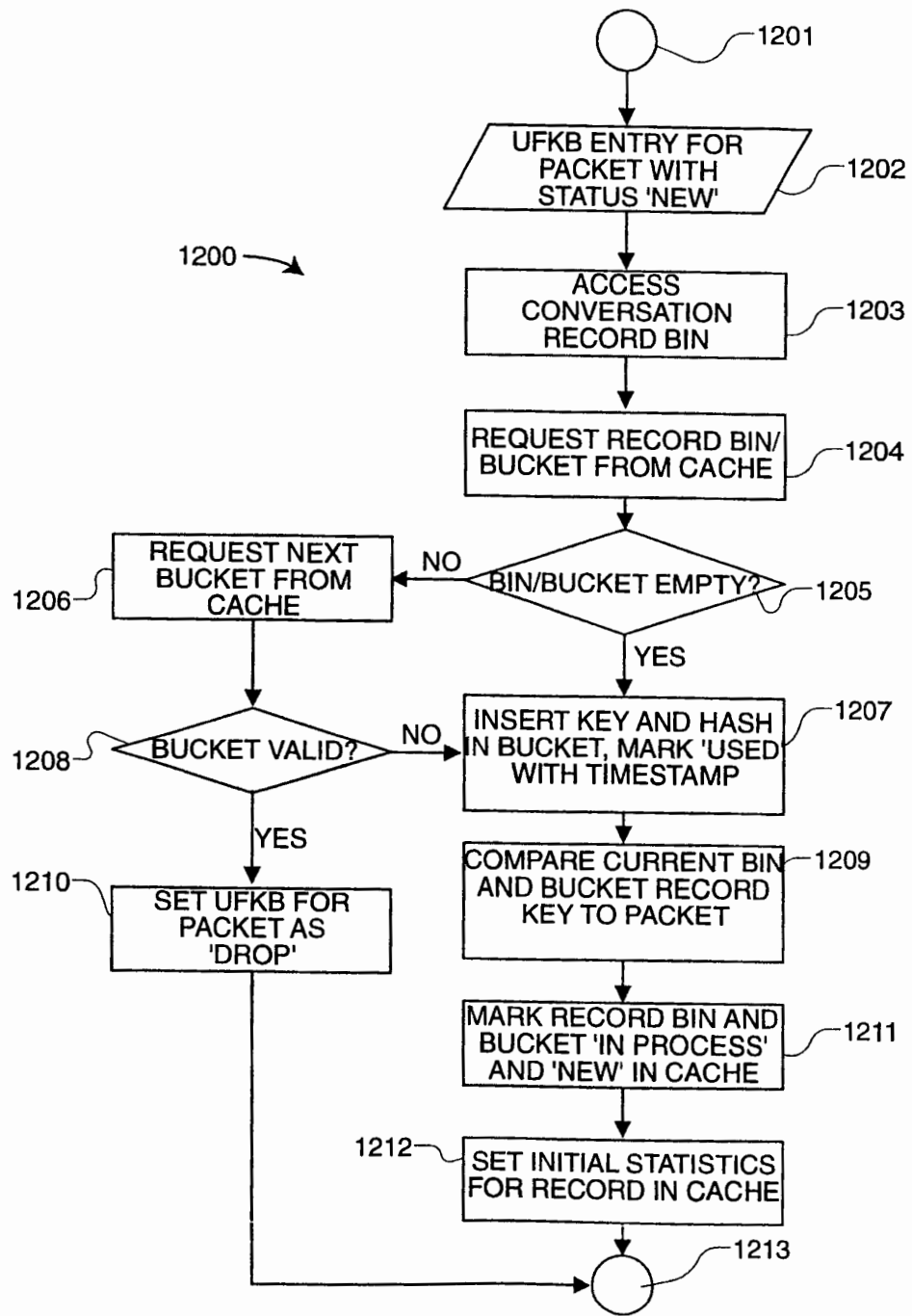


FIG. 12



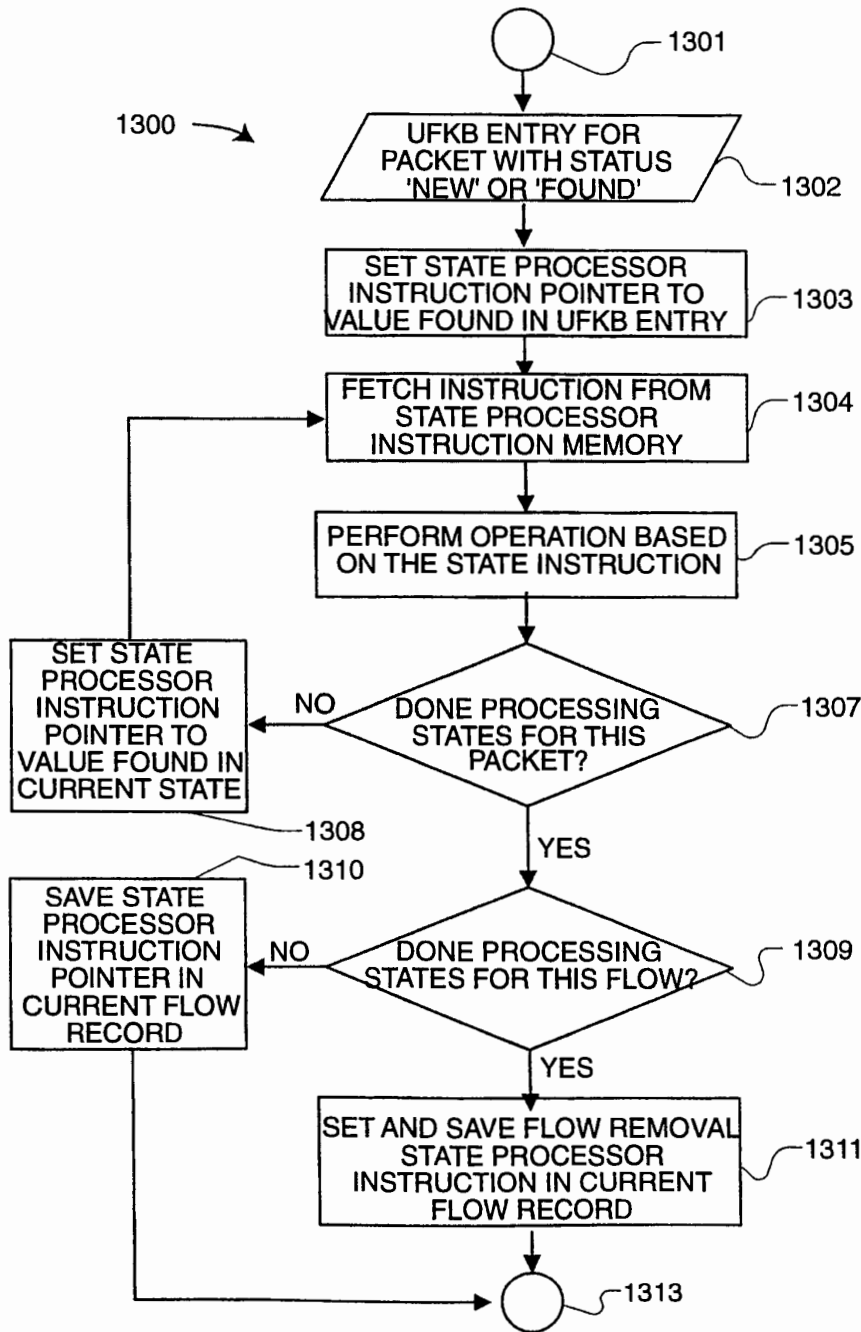


FIG. 13

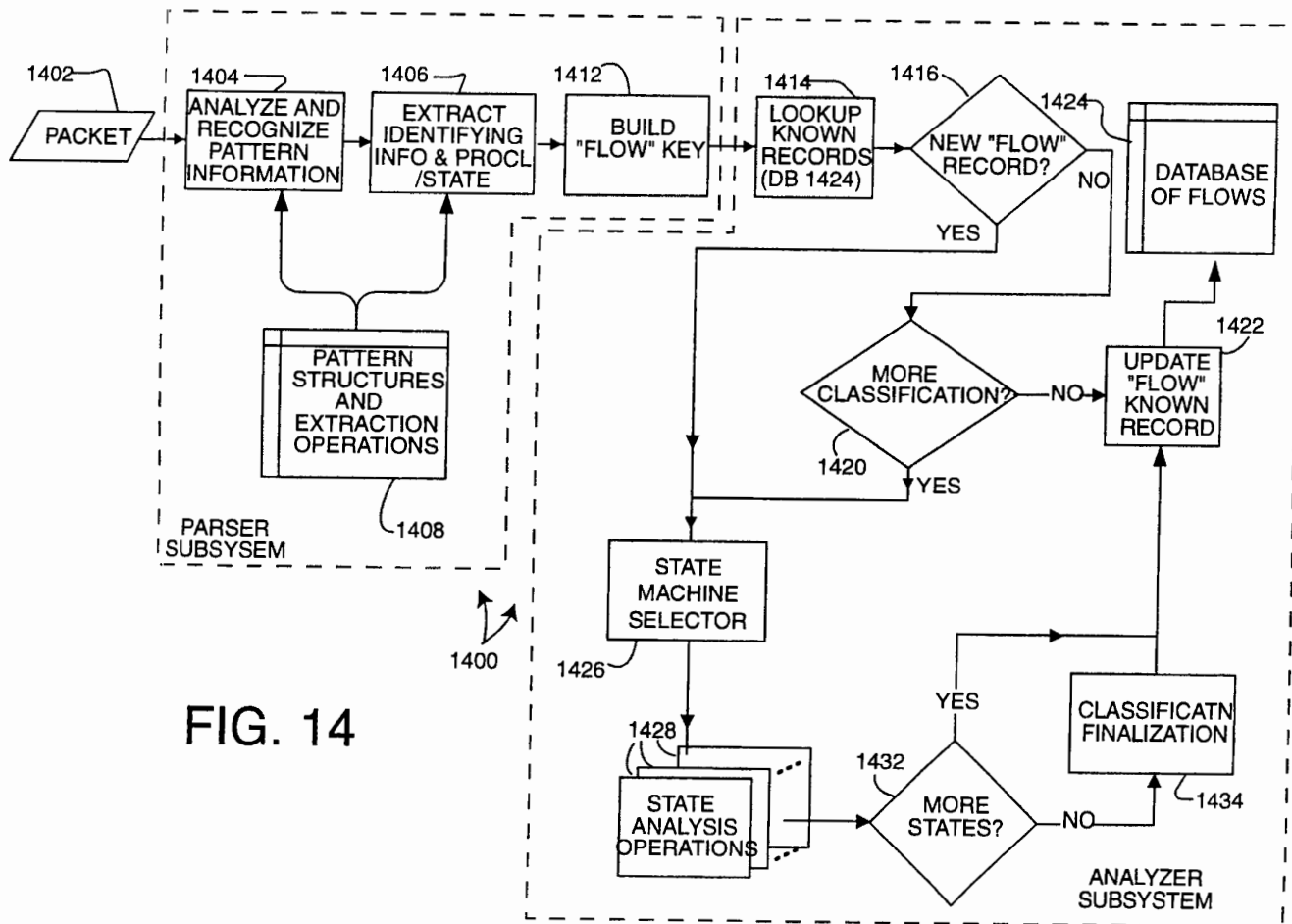


FIG. 14

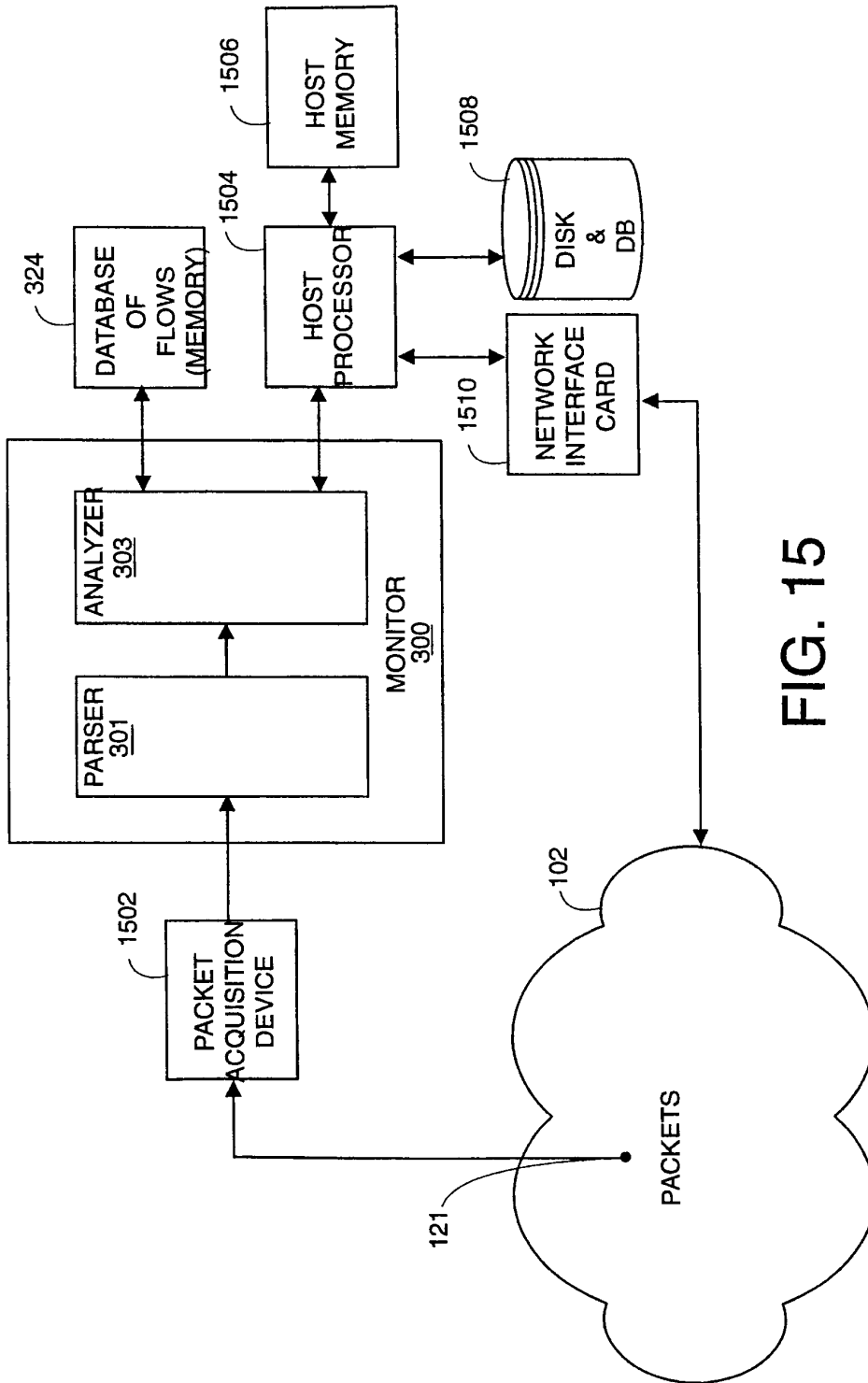


FIG. 15

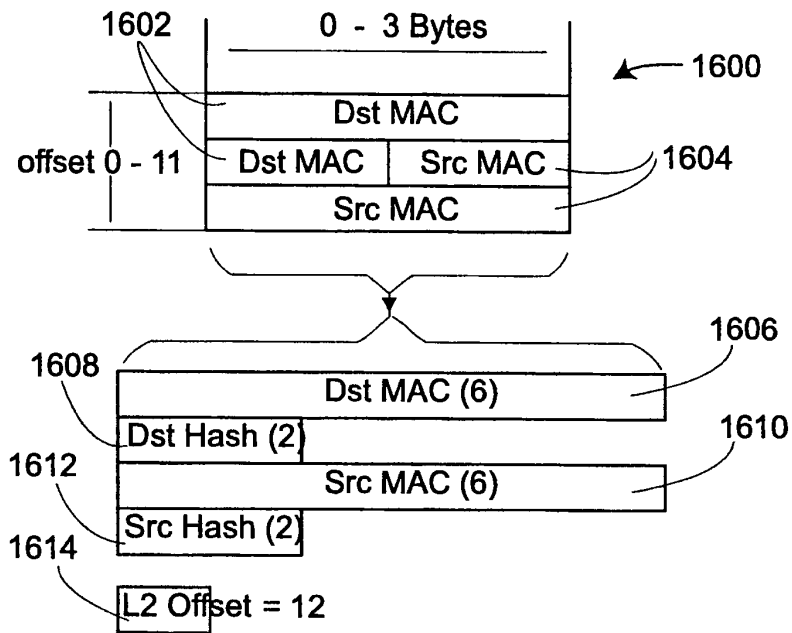


FIG. 16

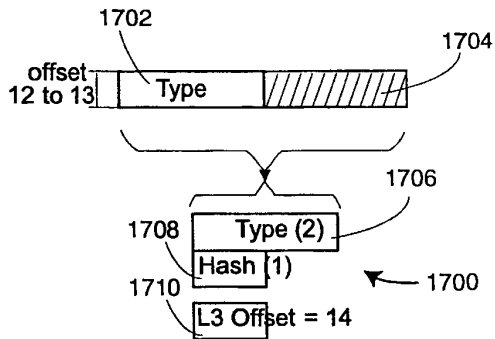


FIG. 17A

IDP = 0x0600*
IP = 0x0800*
CHAOSNET = 0x0804
ARP = 0x0806
VIP = 0x0BAD*
VLOOP = 0x0BAE
VECHO = 0x0BAF
NETBIOS-3COM = 0x3C00 -
0x3C0D#
DEC-MOP = 0x6001
DEC-RC = 0x6002
DEC-DRP = 0x6003*
DEC-LAT = 0x6004
DEC-DIAG = 0x6005
DEC-LAVC = 0x6007
RARP = 0x8035
ATALK = 0x809B*
VLOOP = 0x80C4
VECHO = 0x80C5
SNA-TH = 0x80D5*
ATALKARP = 0x80F3
IPX = 0x8137*
SNMP = 0x814C#
IPv6 = 0x86DD*
LOOPBACK = 0x9000
Apple = 0x080007
* L3 Decoding
# L5 Decoding

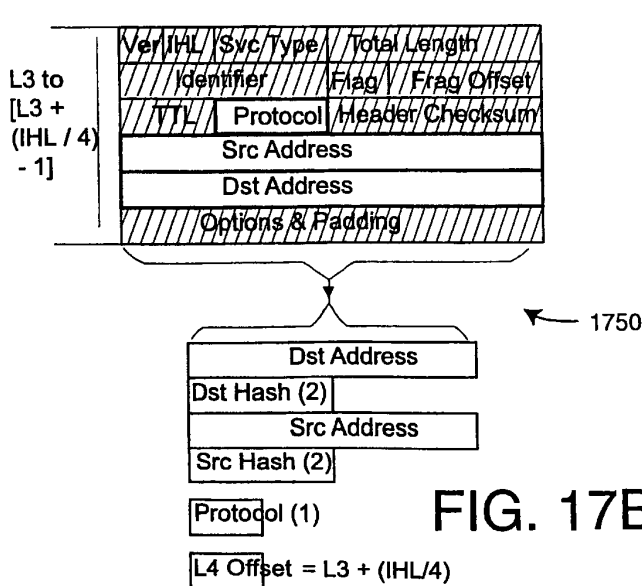


FIG. 17B

ICMP = 1
IGMP = 2
GGP = 3
TCP = 6*
EGP = 8
IGRP = 9
PUP = 12
CHAOS = 16
UDP = 17*
IDP = 22#
ISO-TP4 = 29
DDP = 37#
ISO-IP = 80
VIP = 83#
EIGRP = 88
OSPF = 89
* L4 Decoding
# L3 Re-Decoding

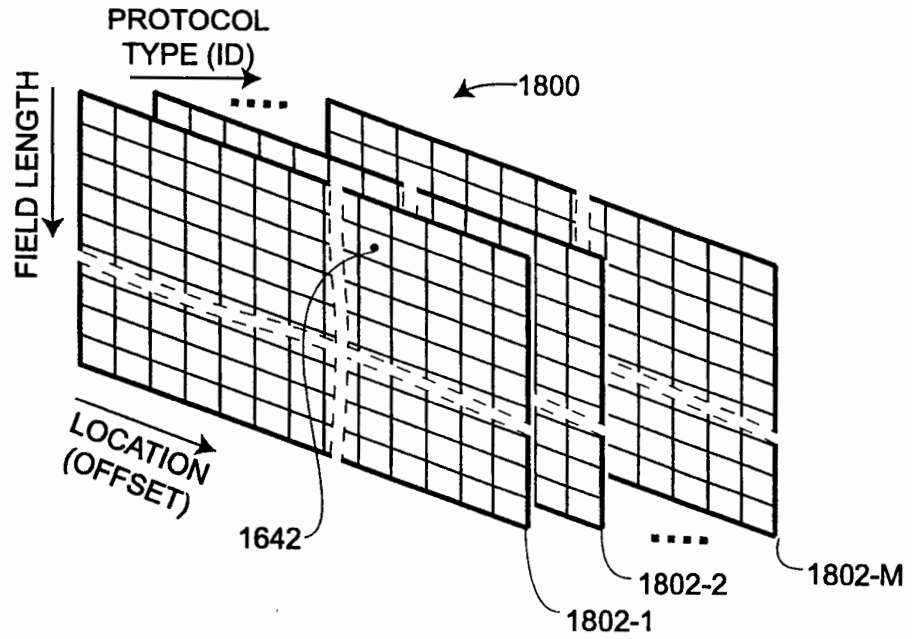


FIG. 18A

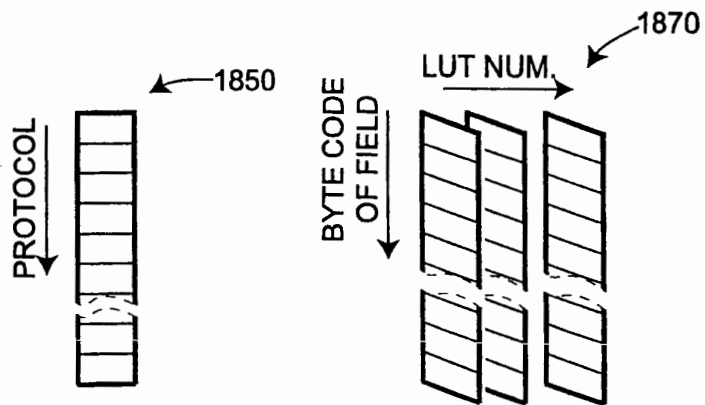


FIG. 18B

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## METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

### CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Ser. No.: 60/141,903 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK to inventors Dietz, et al., filed Jun. 30, 1999, the contents of which are incorporated herein by reference.

This application is related to the following U.S. patent applications, each filed concurrently with the present application, and each assigned to Apptitude, Inc., the assignee of the present invention:

U.S. patent application Ser. No. 09/609,179 for PROCESSING PROTOCOL SPECIFIC INFORMATION IN PACKETS SPECIFIED BY A PROTOCOL DESCRIPTION LANGUAGE, to inventors Koppenhaver, et al., filed Jun. 30, 2000, still pending, and incorporated herein by reference. U.S. patent application Ser. No. 09/608,126 for RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING, to inventors Dietz, et al., filed Jun. 30, 2000, still pending, and incorporated herein by reference. U.S. patent application Ser. No. 09/608,266 for ASSOCIATIVE CACHE STRUCTURE FOR LOOK-UPS AND UPDATES OF FLOW RECORDS IN A NETWORK MONITOR, to inventors Sarkissian, et al., filed Jun. 30, 2000, still pending, and incorporated herein by reference. U.S. patent application Ser. No. 09/608,267 for STATE PROCESSOR FOR PATTERN MATCHING IN A NETWORK MONITOR DEVICE, to inventors Sarkissian, et al., filed Jun. 30, 2000, still pending, and incorporated herein by reference.

### FIELD OF INVENTION

The present invention relates to computer networks, specifically to the real-time elucidation of packets communicated within a data network, including classification according to protocol and application program.

### BACKGROUND TO THE PRESENT INVENTION

There has long been a need for network activity monitors. This need has become especially acute, however, given the recent popularity of the Internet and other internets—an “internet” being any plurality of interconnected networks which forms a larger, single network. With the growth of networks used as a collection of clients obtaining services from one or more servers on the network, it is increasingly important to be able to monitor the use of those services and to rate them accordingly. Such objective information, for example, as which services (i.e., application programs) are being used, who is using them, how often they have been accessed, and for how long, is very useful in the maintenance and continued operation of these networks. It is especially important that selected users be able to access a network remotely in order to generate reports on network use in real time. Similarly, a need exists for a real-time network monitor that can provide alarms notifying selected users of problems that may occur with the network or site.

One prior art monitoring method uses log files. In this method, selected network activities may be analyzed retrospectively by reviewing log files, which are maintained by

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network servers and gateways. Log file monitors must access this data and analyze (“mine”) its contents to determine statistics about the server or gateway. Several problems exist with this method, however. First, log file information does not provide a map of real-time usage; and secondly, log file mining does not supply complete information. This method relies on logs maintained by numerous network devices and servers, which requires that the information be subjected to refining and correlation. Also, sometimes information is simply not available to any gateway or server in order to make a log file entry.

One such case, for example, would be information concerning NetMeeting® (Microsoft Corporation, Redmond, Washington) sessions in which two computers connect directly on the network and the data is never seen by a server or a gateway.

Another disadvantage of creating log files is that the process requires data logging features of network elements to be enabled, placing a substantial load on the device, which results in a subsequent decline in network performance. Additionally, log files can grow rapidly, there is no standard means of storage for them, and they require a significant amount of maintenance.

Though Netflow® (Cisco Systems, Inc., San Jose, Calif.), RMON2, and other network monitors are available for the real-time monitoring of networks, they lack visibility into application content and are typically limited to providing network layer level information.

Pattern-matching parser techniques wherein a packet is parsed and pattern filters are applied are also known, but these too are limited in how deep into the protocol stack they can examine packets.

Some prior art packet monitors classify packets into connection flows. The term “connection flow” is commonly used to describe all the packets involved with a single connection. A conversational flow, on the other hand, is the sequence of packets that are exchanged in any direction as a result of an activity—for instance, the running of an application on a server as requested by a client. It is desirable to be able to identify and classify conversational flows rather than only connection flows. The reason for this is that some conversational flows involve more than one connection, and some even involve more than one exchange of packets between a client and server. This is particularly true when using client/server protocols such as RPC, DCOMP, and SAP, which enable a service to be set up or defined prior to any use of that service.

An example of such a case is the SAP (Service Advertising Protocol), a NetWare (Novell Systems, Provo, Utah) protocol used to identify the services and addresses of servers attached to a network. In the initial exchange, a client might send a SAP request to a server for print service. The server would then send a SAP reply that identifies a particular address—for example, SAP#5—as the print service on that server. Such responses might be used to update a table in a router, for instance, known as a Server Information Table. A client who has inadvertently seen this reply or who has access to the table (via the router that has the Service Information Table) would know that SAP#5 for this particular server is a print service. Therefore, in order to print data on the server, such a client would not need to make a request for a print service, but would simply send data to be printed specifying SAP#5. Like the previous exchange, the transmission of data to be printed also involves an exchange between a client and a server, but requires a second connection and is therefore independent of the initial exchange.

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In order to eliminate the possibility of disjointed conversational exchanges, it is desirable for a network packet monitor to be able to "virtually concatenate"—that is, to link—the first exchange with the second. If the clients were the same, the two packet exchanges would then be correctly identified as being part of the same conversational flow.

Other protocols that may lead to disjointed flows, include RPC (Remote Procedure Call); DCOM (Distributed Component Object Model), formerly called Network OLE (Microsoft Corporation, Redmond, Wash.); and CORBA (Common Object Request Broker Architecture). RPC is a programming interface from Sun Microsystems (Palo Alto, Calif.) that allows one program to use the services of another program in a remote machine. DCOM, Microsoft's counterpart to CORBA, defines the remote procedure call that allows those objects—objects are self-contained software modules—to be run remotely over the network. And CORBA, a standard from the Object Management Group (OMG) for communicating between distributed objects, provides a way to execute programs (objects) written in different programming languages running on different platforms regardless of where they reside in a network.

What is needed, therefore, is a network monitor that makes it possible to continuously analyze all user sessions on a heavily trafficked network. Such a monitor should enable non-intrusive, remote detection, characterization, analysis, and capture of all information passing through any point on the network (i.e., of all packets and packet streams passing through any location in the network). Not only should all the packets be detected and analyzed, but for each of these packets the network monitor should determine the protocol (e.g., http, ftp, H.323, VPN, etc.), the application/use within the protocol (e.g., voice, video, data, real-time data, etc.), and an end user's pattern of use within each application or the application context (e.g., options selected, service delivered, duration, time of day, data requested, etc.). Also, the network monitor should not be reliant upon server resident information such as log files. Rather, it should allow a user such as a network administrator or an Internet service provider (ISP) the means to measure and analyze network activity objectively; to customize the type of data that is collected and analyzed; to undertake real time analysis; and to receive timely notification of network problems.

Considering the previous SAP example again, because one feature of the invention is to correctly identify the second exchange as being associated with a print service on that server, such exchange would even be recognized if the clients were not the same. What distinguishes this invention from prior art network monitors is that it has the ability to recognize disjointed flows as belonging to the same conversational flow.

The data value in monitoring network communications has been recognized by many inventors. Chiu, et al., describe a method for collecting information at the session level in a computer network in U.S. Pat. No. 5,101,402, titled "APPARATUS AND METHOD FOR REAL-TIME MONITORING OF NETWORK SESSIONS AND A LOCAL AREA NETWORK" (the "402 patent"). The 402 patent specifies fixed locations for particular types of packets to extract information to identify session of a packet. For example, if a DECnet packet appears, the 402 patent looks at six specific fields (at 6 locations) in the packet in order to identify the session of the packet. If, on the other hand, an IP packet appears, a different set of six different locations is specified for an IP packet. With the proliferation of protocols, clearly the specifying of all the possible places to look to determine the session becomes more and more

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difficult. Likewise, adding a new protocol or application is difficult. In the present invention, the locations examined and the information extracted from any packet are adaptively determined from information in the packet for the particular type of packet. There is no fixed definition of what to look for and where to look in order to form an identifying signature. A monitor implementation of the present invention, for example, adapts to handle differently IEEE 802.3 packet from the older Ethernet Type 2 (or Version 2) DIX (Digital-Intel-Xerox) packet.

The 402 patent system is able to recognize up to the session layer. In the present invention, the number of levels examined varies for any particular protocol. Furthermore, the present invention is capable of examining up to whatever level is sufficient to uniquely identify to a required level, even all the way to the application level (in the OSI model).

Other prior art systems also are known. Phael describes a network activity monitor that processes only randomly selected packets in U.S. Pat. No. 5,315,580, titled "NETWORK MONITORING DEVICE AND SYSTEM." Nakamura teaches a network monitoring system in U.S. Pat. No. 4,891,639, titled "MONITORING SYSTEM OF NETWORK." Ross, et al., teach a method and apparatus for analyzing and monitoring network activity in U.S. Pat. No. 5,247,517, titled "METHOD AND APPARATUS FOR ANALYSIS NETWORKS," McCreery, et al., describe an Internet activity monitor that decodes packet data at the Internet protocol level layer in U.S. Pat. No. 5,787,253, titled "APPARATUS AND METHOD OF ANALYZING INTERNET ACTIVITY." The McCreery method decodes IP-packets. It goes through the decoding operations for each packet, and therefore uses the processing overhead for both recognized and unrecognized flows. In a monitor implementation of the present invention, a signature is built for every flow such that future packets of the flow are easily recognized. When a new packet in the flow arrives, the recognition process can commence from where it last left off, and a new signature built to recognize new packets of the flow.

#### SUMMARY

In its various embodiments the present invention provides a network monitor that can accomplish one or more of the following objects and advantages:

Recognize and classify all packets that are exchanges between a client and server into respective client/server applications.

Recognize and classify at all protocol layer levels conversational flows that pass in either direction at a point in a network.

Determine the connection and flow progress between clients and servers according to the individual packets exchanged over a network.

Be used to help tune the performance of a network according to the current mix of client/server applications requiring network resources.

Maintain statistics relevant to the mix of client/server applications using network resources.

Report on the occurrences of specific sequences of packets used by particular applications for client/server network conversational flows.

Other aspects of embodiments of the invention are:

Properly analyzing each of the packets exchanged between a client and a server and maintaining information relevant to the current state of each of these conversational flows. p1 Providing a flexible process-



ing system that can be tailored or adapted as new applications enter the client/server market.

Maintaining statistics relevant to the conversational flows in a client/server network as classified by an individual application.

Reporting a specific identifier, which may be used by other network-oriented devices to identify the series of packets with a specific application for a specific client/server network conversational flow.

In general, the embodiments of the present invention overcome the problems and disadvantages of the art.

As described herein, one embodiment analyzes each of the packets passing through any point in the network in either direction, in order to derive the actual application used to communicate between a client and a server. Note that there could be several simultaneous and overlapping applications executing over the network that are independent and asynchronous.

A monitor embodiment of the invention successfully classifies each of the individual packets as they are seen on the network. The contents of the packets are parsed and selected parts are assembled into a signature (also called a key) that may then be used identify further packets of the same conversational flow, for example to further analyze the flow and ultimately to recognize the application program. Thus the key is a function of the selected parts, and in the preferred embodiment, the function is a concatenation of the selected parts. The preferred embodiment forms and remembers the state of any conversational flow, which is determined by the relationship between individual packets and the entire conversational flow over the network. By remembering the state of a flow in this way, the embodiment determines the context of the conversational flow, including the application program it relates to and parameters such as the time, length of the conversational flow, data rate, etc.

The monitor is flexible to adapt to future applications developed for client/server networks. New protocols and protocol combinations may be incorporated by compiling files written in a high-level protocol description language.

The monitor embodiment of the present invention is preferably implemented in application-specific integrated circuits (ASIC) or field programmable gate arrays (FPGA). In one embodiment, the monitor comprises a parser subsystem that forms a signature from a packet. The monitor further comprises an analyzer subsystem that receives the signature from the parser subsystem.

A packet acquisition device such as a media access controller (MAC) or a segmentation and reassemble module is used to provide packets to the parser subsystem of the monitor.

In a hardware implementation, the parsing subsystem comprises two sub-parts, the pattern analysis and recognition engine (PRE), and an extraction engine (slicer). The PRE interprets each packet, and in particular, interprets individual fields in each packet according to a pattern database.

The different protocols that can exist in different layers may be thought of as nodes of one or more trees of linked nodes. The packet type is the root of a tree. Each protocol is either a parent node or a terminal node. A parent node links a protocol to other protocols (child protocols) that can be at higher layer levels. For example, An Ethernet packet (the root node) may be an Ethernertype packet—also called an Ethernet Type/Version 2 and a DIX (DIGITAL-Intel-Xerox packet)—or an IEEE 802.3 packet. Continuing with the IEEE 802.3-type packet, one of the children nodes may be the IP protocol, and one of the children of the IP protocol may be the TCP protocol.

The pattern database includes a description of the different headers of packets and their contents, and how these relate to the different nodes in a tree. The PRE traverses the tree as far as it can. If a node does not include a link to a deeper level, pattern matching is declared complete. Note that protocols can be the children of several parents. If a unique node was generated for each of the possible parent/child trees, the pattern database might become excessively large. Instead, child nodes are shared among multiple parents, thus compacting the pattern database.

Finally the PRE can be used on its own when only protocol recognition is required.

For each protocol recognized, the slicer extracts important packet elements from the packet. These form a signature (i.e., key) for the packet. The slicer also preferably generates a hash for rapidly identifying a flow that may have this signature from a database of known flows.

The flow signature of the packet, the hash and at least some of the payload are passed to an analyzer subsystem. In a hardware embodiment, the analyzer subsystem includes a unified flow key buffer (UFKB) for receiving parts of packets from the parser subsystem and for storing signatures in process, a lookup/update engine (LUE) to lookup a database of flow records for previously encountered conversational flows to determine whether a signature is from an existing flow, a state processor (SP) for performing state processing, a flow insertion and deletion engine (FIDE) for inserting new flows into the database of flows, a memory for storing the database of flows, and a cache for speeding up access to the memory containing the flow database. The LUE, SP, and FIDE are all coupled to the UFKB, and to the cache.

The unified flow key buffer thus contains the flow signature of the packet, the hash and at least some of the payload for analysis in the analyzer subsystem. Many operations can be performed to further elucidate the identity of the application program content of the packet involved in the client/server conversational flow while a packet signature exists in the unified flow signature buffer. In the particular hardware embodiment of the analyzer subsystem several flows may be processed in parallel, and multiple flow signatures from all the packets being analyzed in parallel may be held in the one UFKB.

The first step in the packet analysis process of a packet from the parser subsystem is to lookup the instance in the current database of known packet flow signatures. A lookup/update engine (LUE) accomplishes this task using first the hash, and then the flow signature. The search is carried out in the cache and if there is no flow with a matching signature in the cache, the lookup engine attempts to retrieve the flow from the flow database in the memory. The flow-entry for previously encountered flows preferably includes state information, which is used in the state processor to execute any operations defined for the state, and to determine the next state. A typical state operation may be to search for one or more known reference strings in the payload of the packet stored in the UFKB.

Once the lookup processing by the LUE has been completed a flag stating whether it is found or is new is set within the unified flow signature buffer structure for this packet flow signature. For an existing flow, the flow-entry is updated by a calculator component of the LUE that adds values to counters in the flow-entry database used to store one or more statistical measures of the flow. The counters are used for determining network usage metrics on the flow.

After the packet flow signature has been looked up and contents of the current flow signature are in the database, a

state processor can begin analyzing the packet payload to further elucidate the identity of the application program component of this packet. The exact operation of the state processor and functions performed by it will vary depending on the current packet sequence in the stream of a conversational flow. The state processor moves to the next logical operation stored from the previous packet seen with this same flow signature. If any processing is required on this packet, the state processor will execute instructions from a database of state instruction for this state until there are either no more left or the instruction signifies processing.

In the preferred embodiment, the state processor functions are programmable to provide for analyzing new application programs, and new sequences of packets and states that can arise from using such application.

If during the lookup process for this particular packet flow signature, the flow is required to be inserted into the active database, a flow insertion and deletion engine (FIDE) is initiated. The state processor also may create new flow signatures and thus may instruct the flow insertion and deletion engine to add a new flow to the database as a new item.

In the preferred hardware embodiment, each of the LUE, state processor, and FIDE operate independently from the other two engines.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Although the present invention is better understood by referring to the detailed preferred embodiments, these should not be taken to limit the present invention to any specific embodiment because such embodiments are provided only for the purposes of explanation. The embodiments, in turn, are explained with the aid of the following figures.

FIG. 1 is a functional block diagram of a network embodiment of the present invention in which a monitor is connected to analyze packets passing at a connection point.

FIG. 2 is a diagram representing an example of some of the packets and their formats that might be exchanged in starting, as an illustrative example, a conversational flow between a client and server on a network being monitored and analyzed. A pair of flow signatures particular to this example and to embodiments of the present invention is also illustrated. This represents some of the possible flow signatures that can be generated and used in the process of analyzing packets and of recognizing the particular server applications that produce the discrete application packet exchanges.

FIG. 3 is a functional block diagram of a process embodiment of the present invention that can operate as the packet monitor shown in FIG. 1. This process may be implemented in software or hardware.

FIG. 4 is a flowchart of a high-level protocol language compiling and optimization process, which in one embodiment may be used to generate data for monitoring packets according to versions of the present invention.

FIG. 5 is a flowchart of a packet parsing process used as part of the parser in an embodiment of the inventive packet monitor.

FIG. 6 is a flowchart of a packet element extraction process that is used as part of the parser in an embodiment of the inventive packet monitor.

FIG. 7 is a flowchart of a flow-signature building process that is used as part of the parser in the inventive packet monitor.

FIG. 8 is a flowchart of a monitor lookup and update process that is used as part of the analyzer in an embodiment of the inventive packet monitor.

FIG. 9 is a flowchart of an exemplary Sun Microsystems Remote Procedure Call application that may be recognized by the inventive packet monitor.

FIG. 10 is a functional block diagram of a hardware parser subsystem including the pattern recognizer and extractor that can form part of the parser module in an embodiment of the inventive packet monitor.

FIG. 11 is a functional block diagram of a hardware analyzer including a state processor that can form part of an embodiment of the inventive packet monitor.

FIG. 12 is a functional block diagram of a flow insertion and deletion engine process that can form part of the analyzer in an embodiment of the inventive packet monitor.

FIG. 13 is a flowchart of a state processing process that can form part of the analyzer in an embodiment of the inventive packet monitor.

FIG. 14 is a simple functional block diagram of a process embodiment of the present invention that can operate as the packet monitor shown in FIG. 1. This process may be implemented in software.

FIG. 15 is a functional block diagram of how the packet monitor of FIG. 3 (and FIGS. 10 and 11) may operate on a network with a processor such as a microprocessor.

FIG. 16 is an example of the top (MAC) layer of an Ethernet packet and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. 17A is an example of the header of an Ethernet type of Ethernet packet of FIG. 16 and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. 17B is an example of an IP packet, for example, of the Ethernet packet shown in FIGS. 16 and 17A, and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. 18A is a three dimensional structure that can be used to store elements of the pattern, parse and extraction database used by the parser subsystem in accordance to one embodiment of the invention.

FIG. 18B is an alternate form of storing elements of the pattern, parse and extraction database used by the parser subsystem in accordance to another embodiment of the invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Note that this document includes hardware diagrams and descriptions that may include signal names. In most cases, the names are sufficiently descriptive, in other cases however the signal names are not needed to understand the operation and practice of the invention.

##### Operation in a Network

FIG. 1 represents a system embodiment of the present invention that is referred to herein by the general reference numeral 100. The system 100 has a computer network 102 that communicates packets (e.g., IP datagrams) between various computers, for example between the clients 104-107 and servers 110 and 112. The network is shown schematically as a cloud with several network nodes and links shown in the interior of the cloud. A monitor 108 examines the packets passing in either direction past its connection point 121 and, according to one aspect of the invention, can elucidate what application programs are associated with

each packet. The monitor 108 is shown examining packets (i.e., datagrams) between the network interface 116 of the server 110 and the network. The monitor can also be placed at other points in the network, such as connection point 123 between the network 102 and the interface 118 of the client 104, or some other location, as indicated schematically by connection point 125 somewhere in network 102. Not shown is a network packet acquisition device at the location 123 on the network for converting the physical information on the network into packets for input into monitor 108. Such packet acquisition devices are common.

Various protocols may be employed by the network to establish and maintain the required communication, e.g., TCP/IP, etc. Any network activity—for example an application program run by the client 104 (CLIENT 1) communicating with another running on the server 110 (SERVER 2)—will produce an exchange of a sequence of packets over network 102 that is characteristic of the respective programs and of the network protocols. Such characteristics may not be completely revealing at the individual packet level. It may require the analyzing of many packets by the monitor 108 to have enough information needed to recognize particular application programs. The packets may need to be parsed then analyzed in the context of various protocols, for example, the transport through the application session layer protocols for packets of a type conforming to the ISO layered network model.

Communication protocols are layered, which is also referred to as a protocol stack. The ISO (International Standardization Organization) has defined a general model that provides a framework for design of communication protocol layers. This model, shown in tables form below, serves as a basic reference for understanding the functionality of existing communication protocols.

ISO MODEL		
Layer	Functionality	Example
7	Application	Telnet, NFS, Novell NCP, HTTP, H.323
6	Presentation	XDR
5	Session	RPC, NETBIOS, SNMP, etc
4	Transport	TCP, Novel SPX, UDP, etc.
3	Network	IP, Novell IPX, VIP, AppleTalk, etc.
2	Data Link	Network Interface Card (Hardware Interface), MAC layer
1	Physical	Ethernet, Token Ring, Frame Relay, ATM, T1 (Hardware Connection)

Different communication protocols employ different levels of the ISO model or may use a layered model that is similar to but which does not exactly conform to the ISO model. A protocol in a certain layer may not be visible to protocols employed at other layers. For example, an application (Level 7) may not be able to identify the source computer for a communication attempt (Levels 2-3).

In some communication arts, the term "frame" generally refers to encapsulated data at OSI layer 2, including a destination address, control bits for flow control, the data or payload, and CRC (cyclic redundancy check) data for error checking. The term "packet" generally refers to encapsulated data at OSI layer 3. In the TCP/IP world, the term "datagram" is also used. In this specification, the term "packet" is intended to encompass packets, datagrams, frames, and cells. In general, a packet format or frame format refers to how data is encapsulated with various fields

and headers for transmission across a network. For example, a data packet typically includes an address destination field, a length field, an error correcting code (ECC) field, or cyclic redundancy check (CRC) field, as well as headers and footers to identify the beginning and end of the packet. The terms "packet format" and "frame format," also referred to as "cell format," are generally synonymous.

Monitor 108 looks at every packet passing the connection point 121 for analysis. However, not every packet carries the same information useful for recognizing all levels of the protocol. For example, in a conversational flow associated with a particular application, the application will cause the server to send a type-A packet, but so will another. If, though, the particular application program always follows a type-A packet with the sending of a type-B packet, and the other application program does not, then in order to recognize packets of that application's conversational flow, the monitor can be available to recognize packets that match the type-B packet to associate with the type-A packet. If such is recognized after a type-A packet, then the particular application program's conversational flow has started to reveal itself to the monitor 108.

Further packets may need to be examined before the conversational flow can be identified as being associated with the application program. Typically, monitor 108 is simultaneously also in partial completion of identifying other packet exchanges that are parts of conversational flows associated with other applications. One aspect of monitor 108 is its ability to maintain the state of a flow. The state of a flow is an indication of all previous events in the flow that lead to recognition of the content of all the protocol levels, e.g., the ISO model protocol levels. Another aspect of the invention is forming a signature of extracted characteristic portions of the packet that can be used to rapidly identify packets belonging to the same flow.

In real-world uses of the monitor 108, the number of packets on the network 102 passing by the monitor 108's connection point can exceed a million per second. Consequently, the monitor has very little time available to analyze and type each packet and identify and maintain the state of the flows passing through the connection point. The monitor 108 therefore masks out all the unimportant parts of each packet that will not contribute to its classification. However, the parts to mask-out will change with each packet depending on which flow it belongs to and depending on the state of the flow.

The recognition of the packet type, and ultimately of the associated application programs according to the packets that their executions produce, is a multi-step process within the monitor 108. At a first level, for example, several application programs will all produce a first kind of packet. A first "signature" is produced from selected parts of a packet that will allow monitor 108 to identify efficiently any packets that belong to the same flow. In some cases, that packet type may be sufficiently unique to enable the monitor to identify the application that generated such a packet in the conversational flow. The signature can then be used to efficiently identify all future packets generated in traffic related to that application.

In other cases, that first packet only starts the process of analyzing the conversational flow, and more packets are necessary to identify the associated application program. In such a case, a subsequent packet of a second type—but that potentially belongs to the same conversational flow—is recognized by using the signature. At such a second level, then, only a few of those application programs will have

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conversational flows that can produce such a second packet type. At this level in the process of classification, all application programs that are not in the set of those that lead to such a sequence of packet types may be excluded in the process of classifying the conversational flow that includes these two packets. Based on the known patterns for the protocol and for the possible applications, a signature is produced that allows recognition of any future packets that may follow in the conversational flow.

It may be that the application is now recognized, or recognition may need to proceed to a third level of analysis using the second level signature. For each packet, therefore, the monitor parses the packet and generates a signature to determine if this signature identified a previously encountered flow, or shall be used to recognize future packets belonging to the same conversational flow. In real time, the packet is further analyzed in the context of the sequence of previously encountered packets (the state), and of the possible future sequences such a past sequence may generate in conversational flows associated with different applications. A new signature for recognizing future packets may also be generated. This process of analysis continues until the applications are identified. The last generated signature may then be used to efficiently recognize future packets associated with the same conversational flow. Such an arrangement makes it possible for the monitor 108 to cope with millions of packets per second that must be inspected.

Another aspect of the invention is adding eavesdropping. In alternative embodiments of the present invention capable of eavesdropping, once the monitor 108 has recognized the executing application programs passing through some point in the network 102 (for example, because of execution of the applications by the client 105 or server 110), the monitor sends a message to some general purpose processor on the network that can input the same packets from the same location on the network, and the processor then loads its own executable copy of the application program and uses it to read the content being exchanged over the network. In other words, once the monitor 108 has accomplished recognition of the application program, eavesdropping can commence.

#### The Network Monitor

FIG. 3 shows a network packet monitor 300, in an embodiment of the present invention that can be implemented with computer hardware and/or software. The system 300 is similar to monitor 108 in FIG. 1. A packet 302 is examined, e.g., from a packet acquisition device at the location 121 in network 102 (FIG. 1), and the packet evaluated, for example in an attempt to determine its characteristics, e.g., all the protocol information in a multi-level model, including what server application produced the packet.

The packet acquisition device is a common interface that converts the physical signals and then decodes them into bits, and into packets, in accordance with the particular network (Ethernet, frame relay, ATM, etc.). The acquisition device indicates to the monitor 108 the type of network of the acquired packet or packets.

Aspects shown here include: (1) the initialization of the monitor to generate what operations need to occur on packets of different types—accomplished by compiler and optimizer 310, (2) the processing—parsing and extraction of selected portions—of packets to generate an identifying signature—accomplished by parser subsystem 301, and (3) the analysis of the packets—accomplished by analyzer 303.

The purpose of compiler and optimizer 310 is to provide protocol specific information to parser subsystem 301 and to

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analyzer subsystem 303. The initialization occurs prior to operation of the monitor, and only needs to re-occur when new protocols are to be added.

A flow is a stream of packets being exchanged between any two addresses in the network. For each protocol there are known to be several fields, such as the destination (recipient), the source (the sender), and so forth, and these and other fields are used in monitor 300 to identify the flow. There are other fields not important for identifying the flow, such as checksums, and those parts are not used for identification.

Parser subsystem 301 examines the packets using pattern recognition process 304 that parses the packet and determines the protocol types and associated headers for each protocol layer that exists in the packet 302. An extraction process 306 in parser subsystem 301 extracts characteristic portions (signature information) from the packet 302. Both the pattern information for parsing and the related extraction operations, e.g., extraction masks, are supplied from a parsing-pattern-structures and extraction-operations database (parsing/extractions database) 308 filled by the compiler and optimizer 310.

The protocol description language (PDL) files 336 describes both patterns and states of all protocols that occur at any layer, including how to interpret header information, how to determine from the packet header information the protocols at the next layer, and what information to extract for the purpose of identifying a flow, and ultimately, applications and services. The layer selections database 338 describes the particular layering handled by the monitor. That is, what protocols run on top of what protocols at any layer level. Thus 336 and 338 combined describe how one would decode, analyze, and understand the information in packets, and, furthermore, how the information is layered. This information is input into compiler and optimizer 310.

When compiler and optimizer 310 executes, it generates two sets of internal data structures. The first is the set of parsing/extraction operations 308. The pattern structures include parsing information and describe what will be recognized in the headers of packets; the extraction operations are what elements of a packet are to be extracted from the packets based on the patterns that get matched. Thus, database 308 of parsing/extraction operations includes information describing how to determine a set of one or more protocol dependent extraction operations from data in the packet that indicate a protocol used in the packet.

The other internal data structure that is built by compiler 310 is the set of state patterns and processes 326. These are the different states and state transitions that occur in different conversational flows, and the state operations that need to be performed (e.g., patterns that need to be examined and new signatures that need to be built) during any state of a conversational flow to further the task of analyzing the conversational flow.

Thus, compiling the PDL files and layer selections provides monitor 300 with the information it needs to begin processing packets. In an alternate embodiment, the contents of one or more of databases 308 and 326 may be manually or otherwise generated. Note that in some embodiments the layering selections information is inherent rather than explicitly described. For example, since a PDL file for a protocol includes the child protocols, the parent protocols also may be determined.

In the preferred embodiment, the packet 302 from the acquisition device is input into a packet buffer. The pattern recognition process 304 is carried out by a pattern analysis

and recognition (PAR) engine that analyzes and recognizes patterns in the packets. In particular, the PAR locates the next protocol field in the header and determines the length of the header, and may perform certain other tasks for certain types of protocol headers. An example of this is type and length comparison to distinguish an IEEE 802.3 (Ethernet) packet from the older type 2 (or Version 2) Ethernet packet, also called a DIGITAL-Intel-Xerox (DIX) packet. The PAR also uses the pattern structures and extraction operations database 308 to identify the next protocol and parameters associated with that protocol that enables analysis of the next protocol layer. Once a pattern or a set of patterns has been identified, it/they will be associated with a set of one or more extraction operations. These extraction operations (in the form of commands and associated parameters) are passed to the extraction process 306 implemented by an extracting and information identifying (EII) engine that extracts selected parts of the packet, including identifying information from the packet as required for recognizing this packet as part of a flow. The extracted information is put in sequence and then processed in block 312 to build a unique flow signature (also called a "key") for this flow. A flow signature depends on the protocols used in the packet. For some protocols, the extracted components may include source and destination addresses. For example, Ethernet frames have end-point addresses that are useful in building a better flow signature. Thus, the signature typically includes the client and server address pairs. The signature is used to recognize further packets that are or may be part of this flow.

In the preferred embodiment, the building of the flow key includes generating a hash of the signature using a hash function. The purpose of using such a hash is conventional—to spread flow-entries identified by the signature across a database for efficient searching. The hash generated is preferably based on a hashing algorithm and such hash generation is known to those in the art.

In one embodiment, the parser passes data from the packet—a parser record—that includes the signature (i.e., selected portions of the packet), the hash, and the packet itself to allow for any state processing that requires further data from the packet. An improved embodiment of the parser subsystem might generate a parser record that has some predefined structure and that includes the signature, the hash, some flags related to some of the fields in the parser record, and parts of the packet's payload that the parser subsystem has determined might be required for further processing, e.g., for state processing.

Note that alternate embodiments may use some function other than concatenation of the selected portions of the packet to make the identifying signature. For example, some "digest function" of the concatenated selected portions may be used.

The parser record is passed onto lookup process 314 which looks in an internal data store of records of known flows that the system has already encountered, and decides (in 316) whether or not this particular packet belongs to a known flow as indicated by the presence of a flow-entry matching this flow in a database of known flows 324. A record in database 324 is associated with each encountered flow.

The parser record enters a buffer called the unified flow key buffer (UFKB). The UFKB stores the data on flows in a data structure that is similar to the parser record, but that includes a field that can be modified. In particular, one or the UFKB record fields stores the packet sequence number, and another is filled with state information in the form of a

program counter for a state processor that implements state processing 328.

The determination (316) of whether a record with the same signature already exists is carried out by a lookup engine (LUE) that obtains new UFKB records and uses the hash in the UFKB record to lookup if there is a matching known flow. In the particular embodiment, the database of known flows 324 is in an external memory. A cache is associated with the database 324. A lookup by the LUE for a known record is carried out by accessing the cache using the hash, and if the entry is not already present in the cache, the entry is looked up (again using the hash) in the external memory.

The flow-entry database 324 stores flow-entries that include the unique flow-signature, state information, and extracted information from the packet for updating flows, and one or more statistical about the flow. Each entry completely describes a flow. Database 324 is organized into bins that contain a number, denoted N, of flow-entries (also called flow-entries, each a bucket), with N being 4 in the preferred embodiment. Buckets (i.e., flow-entries) are accessed via the hash of the packet from the parser subsystem 301 (i.e., the hash in the UFKB record). The hash spreads the flows across the database to allow for fast lookups of entries, allowing shallower buckets. The designer selects the bucket depth N based on the amount of memory attached to the monitor, and the number of bits of the hash data value used. For example, in one embodiment, each flow-entry is 128 bytes long, so for 128K flow-entries, 16 Mbytes are required. Using a 16-bit hash gives two flow-entries per bucket. Empirically, this has been shown to be more than adequate for the vast majority of cases. Note that another embodiment uses flow-entries that are 256 bytes long.

Herein, whenever an access to database 324 is described, it is to be understood that the access is via the cache, unless otherwise stated or clear from the context.

If there is no flow-entry found matching the signature, i.e., the signature is for a new flow, then a protocol and state identification process 318 further determines the state and protocol. That is, process 318 determines the protocols and where in the state sequence for a flow for this protocol's this packet belongs. Identification process 318 uses the extracted information and makes reference to the database 326 of state patterns and processes. Process 318 is then followed by any state operations that need to be executed on this packet by a state processor 328.

If the packet is found to have a matching flow-entry in the database 324 (e.g., in the cache), then a process 320 determines, from the looked-up flow-entry, if more classification by state processing of the flow signature is necessary. If not, a process 322 updates the flow-entry in the flow-entry database 324 (e.g., via the cache). Updating includes updating one or more statistical measures stored in the flow-entry. In our embodiment, the statistical measures are stored in counters in the flow-entry.

If state processing is required, state process 328 is commenced. State processor 328 carries out any state operations specified for the state of the flow and updates the state to the next state according to a set of state instructions obtained from the state pattern and processes database 326.

The state processor 328 analyzes both new and existing flows in order to analyze all levels of the protocol stack, ultimately classifying the flows by application (level 7 in the ISO model). It does this by proceeding from state-to-state based on predefined state transition rules and state opera-

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tions as specified in state processor instruction database 326. A state transition rule is a rule typically containing a test followed by the next-state to proceed to if the test result is true. An operation is an operation to be performed while the state processor is in a particular state—for example, in order to evaluate a quantity needed to apply the state transition rule. The state processor goes through each rule and each state process until the test is true, or there are no more tests to perform.

In general, the set of state operations may be none or more operations on a packet, and carrying out the operation or operations may leave one in a state that causes exiting the system prior to completing the identification, but possibly knowing more about what state and state processes are needed to execute next, i.e., when a next packet of this flow is encountered. As an example, a state process (set of state operations) at a particular state may build a new signature for future recognition packets of the next state.

By maintaining the state of the flows and knowing that new flows may be set up using the information from previously encountered flows, the network traffic monitor 300 provides for (a) single-packet protocol recognition of flows, and (b) multiple-packet protocol recognition of flows. Monitor 300 can even recognize the application program from one or more disjointed sub-flows that occur in server announcement type flows. What may seem to prior art monitors to be some unassociated flow, may be recognized by the inventive monitor using the flow signature to be a sub-flow associated with a previously encountered sub-flow.

Thus, state processor 328 applies the first state operation to the packet for this particular flow-entry. A process 330 decides if more operations need to be performed for this state. If so, the analyzer continues looping between block 330 and 328 applying additional state operations to this particular packet until all those operations are completed—that is, there are no more operations for this packet in this state. A process 332 decides if there are further states to be analyzed for this type of flow according to the state of the flow and the protocol, in order to fully characterize the flow. If not, the conversational flow has now been fully characterized and a process 334 finalizes the classification of the conversational flow for the flow.

In the particular embodiment, the state processor 328 starts the state processing by using the last protocol recognized by the parser as an offset into a jump table (ump vector). The jump table finds the state processor instructions to use for that protocol in the state patterns and processes database 326. Most instructions test something in the unified flow key buffer, or the flow-entry in the database of known flows 324, if the entry exists. The state processor may have to test bits, do comparisons, add, or subtract to perform the test. For example, a common operation carried out by the state processor is searching for one or more patterns in the payload part of the UFKB.

Thus, in 332 in the classification, the analyzer decides whether the flow is at an end state. If not at an end state, the flow-entry is updated (or created if a new flow) for this flow-entry in process 322.

Furthermore, if the flow is known and if in 332 it is determined that there are further states to be processed using later packets, the flow-entry is updated in process 322.

The flow-entry also is updated after classification finalization so that any further packets belonging to this flow will be readily identified from their signature as belonging to this fully analyzed conversational flow.

After updating, database 324 therefore includes the set of all the conversational flows that have occurred.

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Thus, the embodiment of present invention shown in FIG. 3 automatically maintains flow-entries, which in one aspect includes storing states. The monitor of FIG. 3 also generates characteristic parts of packets—the signatures—that can be used to recognize flows. The flow-entries may be identified and accessed by their signatures. Once a packet is identified to be from a known flow, the state of the flow is known and this knowledge enables state transition analysis to be performed in real time for each different protocol and application. In a complex analysis, state transitions are traversed as more and more packets are examined. Future packets that are part of the same conversational flow have their state analysis continued from a previously achieved state. When enough packets related to an application of interest have been processed, a final recognition state is ultimately reached, i.e., a set of states has been traversed by state analysis to completely characterize the conversational flow. The signature for that final state enables each new incoming packet of the same conversational flow to be individually recognized in real time.

In this manner, one of the great advantages of the present invention is realized. Once a particular set of state transitions has been traversed for the first time and ends in a final state, a short-cut recognition pattern—a signature—can be generated that will key on every new incoming packet that relates to the conversational flow. Checking a signature involves a simple operation, allowing high packet rates to be successfully monitored on the network.

In improved embodiments, several state analyzers are run in parallel so that a large number of protocols and applications may be checked for. Every known protocol and application will have at least one unique set of state transitions, and can therefore be uniquely identified by watching such transitions.

When each new conversational flow starts, signatures that recognize the flow are automatically generated on-the-fly, and as further packets in the conversational flow are encountered, signatures are updated and the states of the set of state transitions for any potential application are further traversed according to the state transition rules for the flow. The new states for the flow—those associated with a set of state transitions for one or more potential applications—are added to the records of previously encountered states for easy recognition and retrieval when a new packet in the flow is encountered.

#### Detailed Operation

FIG. 4 diagrams an initialization system 400 that includes the compilation process. That is, part of the initialization generates the pattern structures and extraction operations database 308 and the state instruction database 328. Such initialization can occur off-line or from a central location.

The different protocols that can exist in different layers may be thought of as nodes of one or more trees of linked nodes. The packet type is the root of a tree (called level 0). Each protocol is either a parent node or a terminal node. A parent node links a protocol to other protocols (child protocols) that can be at higher layer levels. Thus a protocol may have zero or more children. Ethernet packets, for example, have several variants, each having a basic format that remains substantially the same. An Ethernet packet (the root or level 0 node) may be an Ethernertype packet—also called an Ethernet Type/Version 2 and a DIX (DIGITAL-Intel-Xerox packet)—or an IEEE 803.2 packet. Continuing with the IEEE 802.3 packet, one of the children nodes may be the IP protocol, and one of the children of the IP protocol may be the TCP protocol.

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FIG. 16 shows the header 1600 (base level 1) of a complete Ethernet frame (i.e., packet) of information and includes information on the destination media access control address (Dst MAC 1602) and the source media access control address (Src MAC 1604). Also shown in FIG. 16 is some (but not all) of the information specified in the PDL files for extraction the signature.

FIG. 17A now shows the header information for the next level (level-2) for an Ethernets packet 1700. For an Ethernets packet 1700, the relevant information from the packet that indicates the next layer level is a two-byte type field 1702 containing the child recognition pattern for the next level. The remaining information 1704 is shown hatched because it not relevant for this level. The list 1712 shows the possible children for an Ethernets packet as indicated by what child recognition pattern is found offset 12. FIG. 17B shows the structure of the header of one of the possible next levels, that of the IP protocol. The possible children of the IP protocol are shown in table 1752.

The pattern, parse, and extraction database (pattern recognition database, or PRD) 308 generated by compilation process 310, in one embodiment, is in the form of a three dimensional structure that provides for rapidly searching packet headers for the next protocol. FIG. 18A shows such a 3-D representation 1800 (which may be considered as an indexed set of 2-D representations). A compressed form of the 3-D structure is preferred.

An alternate embodiment of the data structure used in database 308 is illustrated in FIG. 18B. Thus, like the 3-D structure of FIG. 18A, the data structure permits rapid searches to be performed by the pattern recognition process 304 by indexing locations in a memory rather than performing address link computations. In this alternate embodiment, the PRD 308 includes two parts, a single protocol table 1850 (PT) which has an entry for each protocol known for the monitor, and a series of Look Up Tables 1870 (LUT's) that are used to identify known protocols and their children. The protocol table includes the parameters needed by the pattern analysis and recognition process 304 (implemented by PRE 1006) to evaluate the header information in the packet that is associated with that protocol, and parameters needed by extraction process 306 (implemented by slicer 1007) to process the packet header. When there are children, the PT describes which bytes in the header to evaluate to determine the child protocol. In particular, each PT entry contains the header length, an offset to the child, a slicer command, and some flags.

The pattern matching is carried out by finding particular "child recognition codes" in the header fields, and using these codes to index one or more of the LUT's. Each LUT entry has a node code that can have one of four values, indicating the protocol that has been recognized, a code to indicate that the protocol has been partially recognized (more LUT lookups are needed), a code to indicate that this is a terminal node, and a null node to indicate a null entry. The next LUT to lookup is also returned from a LUT lookup.

Compilation process is described in FIG. 4. The source-code information in the form of protocol description files is shown as 402. In the particular embodiment, the high level decoding descriptions includes a set of protocol description files 336, one for each protocol, and a set of packet layer selections 338, which describes the particular layering (sets of trees of protocols) that the monitor is to be able to handle.

A compiler 403 compiles the descriptions. The set of packet parse-and-extract operations 406 is generated (404), and a set of packet state instructions and operations 407 is

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generated (405) in the form of instructions for the state processor that implements state processing process 328. Data files for each type of application and protocol to be recognized by the analyzer are downloaded from the pattern, parse, and extraction database 406 into the memory systems of the parser and extraction engines. (See the parsing process 500 description and FIG. 5; the extraction process 600 description and FIG. 6; and the parsing subsystem hardware description and FIG. 10). Data files for each type of application and protocol to be recognized by the analyzer are also downloaded from the state-processor instruction database 407 into the state processor. (see the state processor 1108 description and FIG. 11.).

Note that generating the packet parse and extraction operations builds and links the three dimensional structure (one embodiment) or the or all the lookup tables for the PRD.

Because of the large number of possible protocol trees and subtrees, the compiler process 400 includes optimization that compares the trees and subtrees to see which children share common parents. When implemented in the form of the LUT's, this process can generate a single LUT from a plurality of LUT's. The optimization process further includes a compaction process that reduces the space needed to store the data of the PRD.

As an example of compaction, consider the 3-D structure of FIG. 18A that can be thought of as a set of 2-D structures each representing a protocol. To enable saving space by using only one array per protocol which may have several parents, in one embodiment, the pattern analysis subprocess keeps a "current header" pointer. Each location (offset) index for each protocol 2-D array in the 3-D structure is a relative location starting with the start of header for the particular protocol. Furthermore, each of the two-dimensional arrays is sparse. The next step of the optimization, is checking all the 2-D arrays against all the other 2-D arrays to find out which ones can share memory. Many of these 2-D arrays are often sparsely populated in that they each have only a small number of valid entries. So, a process of "folding" is next used to combine two or more 2-D arrays together into one physical 2-D array without losing the identity of any of the original 2-D arrays (i.e., all the 2-D arrays continue to exist logically). Folding can occur between any 2-D arrays irrespective of their location in the tree as long as certain conditions are met. Multiple arrays may be combined into a single array as long as the individual entries do not conflict with each other. A fold number is then used to associate each element with its original array. A similar folding process is used for the set of LUTs 1850 in the alternate embodiment of FIG. 18B.

In 410, the analyzer has been initialized and is ready to perform recognition.

FIG. 5 shows a flowchart of how actual parser subsystem 301 functions. Starting at 501, the packet 302 is input to the packet buffer in step 502. Step 503 loads the next (initially the first) packet component from the packet 302. The packet components are extracted from each packet 302 one element at a time. A check is made (504) to determine if the load-packet-component operation 503 succeeded, indicating that there was more in the packet to process. If not, indicating all components have been loaded, the parser subsystem 301 builds the packet signature (512)—the next stage (FIG. 6).

If a component is successfully loaded in 503, the node and processes are fetched (505) from the pattern, parse and extraction database 308 to provide a set of patterns and

processes for that node to apply to the loaded packet component. The parser subsystem 301 checks (506) to determine if the fetch pattern-node operation 505 completed successfully, indicating there was a pattern node that loaded in 505. If not, step 511 moves to the next packet component. If yes, then the node and pattern matching process are applied in 507 to the component extracted in 503. A pattern match obtained in 507 (as indicated by test 508) means the parser subsystem 301 has found a node in the parsing elements; the parser subsystem 301 proceeds to step 509 to extract the elements.

If applying the node process to the component does not produce a match (test 508), the parser subsystem 301 moves (510) to the next pattern node from the pattern database 308 and to step 505 to fetch the next node and process. Thus, there is an "applying patterns" loop between 508 and 505. Once the parser subsystem 301 completes all the patterns and has either matched or not, the parser subsystem 301 moves to the next packet component (511).

Once all the packet components have been the loaded and processed from the input packet 302, then the load packet will fail (indicated by test 504), and the parser subsystem 301 moves to build a packet signature which is described in FIG. 6

FIG. 6 is a flow chart for extracting the information from which to build the packet signature. The flow starts at 601, which is the exit point 513 of FIG. 5. At this point parser subsystem 301 has a completed packet component and a pattern node available in a buffer (602). Step 603 loads the packet component available from the pattern analysis process of FIG. 5. If the load completed (test 604), indicating that there was indeed another packet component, the parser subsystem 301 fetches in 605 the extraction and process elements received from the pattern node component in 602. If the fetch was successful (test 606), indicating that there are extraction elements to apply, the parser subsystem 301 in step 607 applies that extraction process to the packet component based on an extraction instruction received from that pattern node. This removes and saves an element from the packet component.

In step 608, the parser subsystem 301 checks if there is more to extract from this component, and if not, the parser subsystem 301 moves back to 603 to load the next packet component at hand and repeats the process. If the answer is yes, then the parser subsystem 301 moves to the next packet component ratchet. That new packet component is then loaded in step 603. As the parser subsystem 301 moved through the loop between 608 and 603, extra extraction processes are applied either to the same packet component if there is more to extract, or to a different packet component if there is no more to extract.

The extraction process thus builds the signature, extracting more and more components according to the information in the patterns and extraction database 308 for the particular packet. Once loading the next packet component operation 603 fails (test 604), all the components have been extracted. The built signature is loaded into the signature buffer (610) and the parser subsystem 301 proceeds to FIG. 7 to complete the signature generation process.

Referring now to FIG. 7, the process continues at 701. The signature buffer and the pattern node elements are available (702). The parser subsystem 301 loads the next pattern node element. If the load was successful (test 704) indicating there are more nodes, the parser subsystem 301 in 705 hashes the signature buffer element based on the hash elements that are found in the pattern node that is in the

element database. In 706 the resulting signature and the hash are packed. In 707 the parser subsystem 301 moves on to the next packet component which is loaded in 703.

The 703 to 707 loop continues until there are no more patterns of elements left (test 704). Once all the patterns of elements have been hashed, processes 304, 306 and 312 of parser subsystem 301 are complete. Parser subsystem 301 has generated the signature used by the analyzer subsystem 303.

A parser record is loaded into the analyzer, in particular, into the UFKB in the form of a UFKB record which is similar to a parser record, but with one or more different fields.

FIG. 8 is a flow diagram describing the operation of the lookup/update engine (LUE) that implements lookup operation 314. The process starts at 801 from FIG. 7 with the parser record that includes a signature, the hash and at least parts of the payload. In 802 those elements are shown in the form of a UFKB-entry in the buffer. The LUE, the lookup engine 314 computes a "record bin number" from the hash for a flow-entry. A bin herein may have one or more "buckets" each containing a flow-entry. The preferred embodiment has four buckets per bin.

Since preferred hardware embodiment includes the cache, all data accesses to records in the flowchart of FIG. 8 are stated as being to or from the cache.

Thus, in 804, the system looks up the cache for a bucket from that bin using the hash. If the cache successfully returns with a bucket from the bin number, indicating there are more buckets in the bin, the lookup/update engine compares (807) the current signature (the UFKB-entry's signature) from that in the bucket (i.e., the flow-entry signature). If the signatures match (test 808), that record (in the cache) is marked in step 810 as "in process" and a timestamp added. Step 811 indicates to the UFKB that the UFKB-entry in 802 has a status of "found." The "found" indication allows the state processing 328 to begin processing this UFKB element. The preferred hardware embodiment includes one or more state processors, and these can operate in parallel with the lookup/update engine.

In the preferred embodiment, a set of statistical operations is performed by a calculator for every packet analyzed. The statistical operations may include one or more of counting the packets associated with the flow; determining statistics related to the size of packets of the flow; compiling statistics on differences between packets in each direction, for example using times tamps; and determining statistical relationships of timestamps of packets in the same direction. The statistical measures are kept in the flow-entries. Other statistical measures also may be compiled. These statistics may be used singly or in combination by a statistical processor component to analyze many different aspects of the flow. This may include determining network usage metrics from the statistical measures, for example to ascertain the network's ability to transfer information for this application. Such analysis provides for measuring the quality of service of a conversation, measuring how well an application is performing in the network, measuring network resources consumed by an application, and so forth.

To provide for such analyses, the lookup/update engine updates one or more counters that are part of the flow-entry (in the cache) in step 812. The process exits at 813. In our embodiment, the counters include the total packets of the flow, the time, and a differential time from the last timestamp to the present timestamp.

It may be that the bucket of the bin did not lead to a signature match (test 808). In such a case, the analyzer in



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809 moves to the next bucket for this bin. Step 804 again looks up the cache for another bucket from that bin. The lookup/update engine thus continues lookup up buckets of the bin until there is either a match in 808 or operation 804 is not successful (test 805), indicating that there are no more buckets in the bin and no match was found.

If no match was found, the packet belongs to a new (not previously encountered) flow. In 806 the system indicates that the record in the unified flow key buffer for this packet is new, and in 812, any statistical updating operations are performed for this packet by updating the flow-entry in the cache. The update operation exits at 813. A flow insertion/deletion engine (FIDE) creates a new record for this flow (again via the cache).

Thus, the update/lookup engine ends with a UFKB-entry for the packet with a "new" status or a "found" status.

Note that the above system uses a hash to which more than one flow-entry can match. A longer hash may be used that corresponds to a single flow-entry. In such an embodiment, the flow chart of FIG. 8 is simplified as would be clear to those in the art.

#### The Hardware System

Each of the individual hardware elements through which the data flows in the system are now described with reference to FIGS. 10 and 11. Note that while we are describing a particular hardware implementation of the invention embodiment of FIG. 3, it would be clear to one skilled in the art that the flow of FIG. 3 may alternatively be implemented in software running on one or more general-purpose processors, or only partly implemented in hardware. An implementation of the invention that can operate in software is shown in FIG. 14. The hardware embodiment (FIGS. 10 and 11) can operate at over a million packets per second, while the software system of FIG. 14 may be suitable for slower networks. To one skilled in the art it would be clear that more and more of the system may be implemented in software as processors become faster.

FIG. 10 is a description of the parsing subsystem (301, shown here as subsystem 1000) as implemented in hardware. Memory 1001 is the pattern recognition database memory, in which the patterns that are going to be analyzed are stored. Memory 1002 is the extraction-operation database memory, in which the extraction instructions are stored. Both 1001 and 1002 correspond to internal data structure 308 of FIG. 3. Typically, the system is initialized from a microprocessor (not shown) at which time these memories are loaded through a host interface multiplexor and control register 1005 via the internal buses 1003 and 1004. Note that the contents of 1001 and 1002 are preferably obtained by compiling process 310 of FIG. 3.

A packet enters the parsing system via 1012 into a parser input buffer memory 1008 using control signals 1021 and 1023, which control an input buffer interface controller 1022. The buffer 1008 and interface control 1022 connect to a packet acquisition device (not shown). The buffer acquisition device generates a packet start signal 1021 and the interface control 1022 generates a next packet (i.e., ready to receive data) signal 1023 to control the data flow into parser input buffer memory 1008. Once a packet starts loading into the buffer memory 1008, pattern recognition engine (PRE) 1006 carries out the operations on the input buffer memory described in block 304 of FIG. 3. That is, protocol types and associated headers for each protocol layer that exist in the packet are determined.

The PRE searches database 1001 and the packet in buffer 1008 in order to recognize the protocols the packet contains.

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In one implementation, the database 1001 includes a series of linked lookup tables. Each lookup table uses eight bits of addressing. The first lookup table is always at address zero. The Pattern Recognition Engine uses a base packet offset from a control register to start the comparison. It loads this value into a current offset pointer (COP). It then reads the byte at base packet offset from the parser input buffer and uses it as an address into the first lookup table.

Each lookup table returns a word that links to another lookup table or it returns a terminal flag. If the lookup produces a recognition event the database also returns a command for the slicer. Finally it returns the value to add to the COP.

The PRE 1006 includes of a comparison engine. The comparison engine has a first stage that checks the protocol type field to determine if it is an 802.3 packet and the field should be treated as a length. If it is not a length, the protocol is checked in a second stage. The first stage is the only protocol level that is not programmable. The second stage has two full sixteen bit content addressable memories (CAMs) defined for future protocol additions.

Thus, whenever the PRE recognizes a pattern, it also generates a command for the extraction engine (also called a "slicer") 1007. The recognized patterns and the commands are sent to the extraction engine 1007 that extracts information from the packet to build the parser record. Thus, the operations of the extraction engine are those carried out in blocks 306 and 312 of FIG. 3. The commands are sent from PRE 1006 to slicer 1007 in the form of extraction instruction pointers which tell the extraction engine 1007 where to a find the instructions in the extraction operations database memory (i.e., slicer instruction database) 1002.

Thus, when the PRE 1006 recognizes a protocol it outputs both the protocol identifier and a process code to the extractor. The protocol identifier is added to the flow signature and the process code is used to fetch the first instruction from the instruction database 1002. Instructions include an operation code and usually source and destination offsets as well as a length. The offsets and length are in bytes. A typical operation is the MOVE instruction. This instruction tells the slicer 1007 to copy n bytes of data unmodified from the input buffer 1008 to the output buffer 1010. The extractor contains a byte-wise barrel shifter so that the bytes moved can be packed into the flow signature. The extractor contains another instruction called HASH. This instruction tells the extractor to copy from the input buffer 1008 to the HASH generator.

Thus these instructions are for extracting selected element (s) of the packet in the input buffer memory and transferring the data to a parser output buffer memory 1010. Some instructions also generate a hash.

The extraction engine 1007 and the PRE operate as a pipeline. That is, extraction engine 1007 performs extraction operations on data in input buffer 1008 already processed by PRE 1006 while more (i.e., later arriving) packet information is being simultaneously parsed by PRE 1006. This provides high processing speed sufficient to accommodate the high arrival rate speed of packets.

Once all the selected parts of the packet used to form the signature are extracted, the hash is loaded into parser output buffer memory 1010. Any additional payload from the packet that is required for further analysis is also included. The parser output memory 1010 is interfaced with the analyzer subsystem by analyzer interface control 1011. Once all the information of a packet is in the parser output buffer memory 1010, a data ready signal 1025 is asserted by

analyzer interface control. The data from the parser subsystem 1000 is moved to the analyzer subsystem via 1013 when an analyzer ready signal 1027 is asserted.

FIG. 11 shows the hardware components and dataflow for the analyzer subsystem that performs the functions of the analyzer subsystem 303 of FIG. 3. The analyzer is initialized prior to operation, and initialization includes loading the state processing information generated by the compilation process 310 into a database memory for the state processing, called state processor instruction database (SPID) memory 1109.

The analyzer subsystem 1100 includes a host bus interface 1122 using an analyzer host interface controller 1118, which in turn has access to a cache system 1115. The cache system has bi-directional access to and from the state processor of the system 1108. State processor 1108 is responsible for initializing the state processor instruction database memory 1109 from information given over the host bus interface 1122.

With the SPID 1109 loaded, the analyzer subsystem 1100 receives parser records comprising packet signatures and payloads that come from the parser into the unified flow key buffer (UFKB) 1103. UFKB is comprised of memory set up to maintain UFKB records. A UFKB record is essentially a parser record; the UFKB holds records of packets that are to be processed or that are in process. Furthermore, the UFKB provides for one or more fields to act as modifiable status flags to allow different processes to run concurrently.

Three processing engines run concurrently and access records in the UFKB 1103: the lookup/update engine (LUE) 1107, the state processor (SP) 1108, and the flow insertion and deletion engine (FIDE) 1110. Each of these is implemented by one or more finite state machines (FSM's). There is bi-directional access between each of the finite state machines and the unified flow key buffer 1103. The UFKB record includes a field that stores the packet sequence number, and another that is filled with state information in the form of a program counter for the state processor 1108 that implements state processing 328. The status flags of the UFKB for any entry includes that the LUE is done and that the LUE is transferring processing of the entry to the state processor. The LUE done indicator is also used to indicate what the next entry is for the LUE. There also is provided a flag to indicate that the state processor is done with the current flow and to indicate what the next entry is for the state processor. There also is provided a flag to indicate the state processor is transferring processing of the UFKB-entry to the flow insertion and deletion engine.

A new UFKB record is first processed by the LUE 1107. A record that has been processed by the LUE 1107 may be processed by the state processor 1108, and a UFKB record data may be processed by the flow insertion/deletion engine 1110 after being processed by the state processor 1108 or only by the LUE. Whether or not a particular engine has been applied to any unified flow key buffer entry is determined by status fields set by the engines upon completion. In one embodiment, a status flag in the UFKB-entry indicates whether an entry is new or found. In other embodiments, the LUE issues a flag to pass the entry to the state processor for processing, and the required operations for a new record are included in the SP instructions.

Note that each UFKB-entry may not need to be processed by all three engines. Furthermore, some UFKB entries may need to be processed more than once by a particular engine.

Each of these three engines also has bi-directional access to a cache subsystem 1115 that includes a caching engine.

Cache 1115 is designed to have information flowing in and out of it from five different points within the system: the three engines, external memory via a unified memory controller (UMC) 1119 and a memory interface 1123, and a microprocessor via analyzer host interface and control unit (ACIC) 1118 and host interface bus (HIB) 1122. The analyzer microprocessor (or dedicated logic processor) can thus directly insert or modify data in the cache.

The cache subsystem 1115 is an associative cache that includes a set of content addressable memory cells (CAMs) each including an address portion and a pointer portion pointing to the cache memory (e.g., RAM) containing the cached flow-entries. The CAMs are arranged as a stack ordered from a top CAM to a bottom CAM. The bottom CAM's pointer points to the least recently used (LRU) cache memory entry. Whenever there is a cache miss, the contents of cache memory pointed to by the bottom CAM are replaced by the flow-entry from the flow-entry database 324. This now becomes the most recently used entry, so the contents of the bottom CAM are moved to the top CAM and all CAM contents are shifted down. Thus, the cache is an associative cache with a true LRU replacement policy.

The LUE 1107 first processes a UFKB-entry, and basically performs the operation of blocks 314 and 316 in FIG. 3. A signal is provided to the LUE to indicate that a "new" UFKB-entry is available. The LUE uses the hash in the UFKB-entry to read a matching bin of up to four buckets from the cache. The cache system attempts to obtain the matching bin. If a matching bin is not in the cache, the cache 1115 makes the request to the UMC 1119 to bring in a matching bin from the external memory.

When a flow-entry is found using the hash, the LUE 1107 looks at each bucket and compares it using the signature to the signature of the UFKB-entry until there is a match or there are no more buckets.

If there is no match, or if the cache failed to provide a bin of flow-entries from the cache, a time stamp in set in the flow key of the UFKB record, a protocol identification and state determination is made using a table that was loaded by compilation process 310 during initialization, the status for the record is set to indicate the LUE has processed the record, and an indication is made that the UFKB-entry is ready to start state processing. The identification and state determination generates a protocol identifier which in the preferred embodiment is a "jump vector" for the state processor which is kept by the UFKB for this UFKB-entry and used by the state processor to start state processing for the particular protocol. For example, the jump vector jumps to the subroutine for processing the state.

If there was a match, indicating that the packet of the UFKB-entry is for a previously encountered flow, then a calculator component enters one or more statistical measures stored in the flow-entry, including the timestamp. In addition, a time difference from the last stored timestamp may be stored, and a packet count may be updated. The state of the flow is obtained from the flow-entry is examined by looking at the protocol identifier stored in the flow-entry of database 324. If that value indicates that no more classification is required, then the status for the record is set to indicate the LUE has processed the record. In the preferred embodiment, the protocol identifier is a jump vector for the state processor to a subroutine to state processing the protocol, and no more classification is indicated in the preferred embodiment by the jump vector being zero. If the protocol identifier indicates more processing, then an indication is made that the UFKB-entry is ready to start state

processing and the status for the record is set to indicate the LUE has processed the record.

The state processor 1108 processes information in the cache system according to a UFKB-entry after the LUE has completed. State processor 1108 includes a state processor program counter SPPC that generates the address in the state processor instruction database 1109 loaded by compiler process 310 during initialization. It contains an Instruction Pointer (SPIP) which generates the SPID address. The instruction pointer can be incremented or loaded from a Jump Vector Multiplexor which facilitates conditional branching. The SPIP can be loaded from one of three sources: (1) A protocol identifier from the UFKB, (2) an immediate jump vector from the currently decoded instruction, or (3) a value provided by the arithmetic logic unit (SPALU) included in the state processor.

Thus, after a Flow Key is placed in the UFKB by the LUE with a known protocol identifier, the Program Counter is initialized with the last protocol recognized by the Parser. This first instruction is a jump to the subroutine which analyzes the protocol that was decoded.

The State Processor ALU (SPALU) contains all the Arithmetic, Logical and String Compare functions necessary to implement the State Processor instructions. The main blocks of the SPALU are: The A and B Registers, the Instruction Decode & State Machines, the String Reference Memory the Search Engine, an Output Data Register and an Output Control Register.

The Search Engine in turn contains the Target Search Register set, the Reference Search Register set, and a Compare block which compares two operands by exclusive-or-ing them together.

Thus, after the UFKB sets the program counter, a sequence of one or more state operations are executed in state processor 1108 to further analyze the packet that is in the flow key buffer entry for this particular packet.

FIG. 13 describes the operation of the state processor 1108. The state processor is entered at 1301 with a unified flow key buffer entry to be processed. The UFKB-entry is new or corresponding to a found flow-entry. This UFKB-entry is retrieved from unified flow key buffer 1103 in 1301. In 1303, the protocol identifier for the UFKB-entry is used to set the state processor's instruction counter. The state processor 1108 starts the process by using the last protocol recognized by the parser subsystem 301 as an offset into a jump table. The jump table takes us to the instructions to use for that protocol. Most instructions test something in the unified flow key buffer or the flow-entry if it exists. The state processor 1108 may have to test bits, do comparisons, add or subtract to perform the test.

The first state processor instruction is fetched in 1304 from the state processor instruction database memory 1109. The state processor performs the one or more fetched operations (1304). In our implementation, each single state processor instruction is very primitive (e.g., a move, a compare, etc.), so that many such instructions need to be performed on each unified flow key buffer entry. One aspect of the state processor is its ability to search for one or more (up to four) reference strings in the payload part of the UFKB entry. This is implemented by a search engine component of the state processor responsive to special searching instructions.

In 1307, a check is made to determine if there are any more instructions to be performed for the packet. If yes, then in 1308 the system sets the state processor instruction pointer (SPIP) to obtain the next instruction. The SPIP may

be set by an immediate jump vector in the currently decoded instruction, or by a value provided by the SPALU during processing.

The next instruction to be performed is now fetched (1304) for execution. This state processing loop between 1304 and 1307 continues until there are no more instructions to be performed.

At this stage, a check is made in 1309 if the processing on this particular packet has resulted in a final state. That is, is the analyzer is done processing not only for this particular packet, but for the whole flow to which the packet belongs, and the flow is fully determined. If indeed there are no more states to process for this flow, then in 1311 the processor finalizes the processing. Some final states may need to put a state in place that tells the system to remove a flow—for example, if a connection disappears from a lower level connection identifier. In that case, in 1311, a flow removal state is set and saved in the flow-entry. The flow removal state may be a NOP (no-op) instruction which means there are no removal instructions.

Once the appropriate flow removal instruction as specified for this flow (a NOP or otherwise) is set and saved, the process is exited at 1313. The state processor 1108 can now obtain another unified flow key buffer entry to process.

If at 1309 it is determined that processing for this flow is not completed, then in 1310 the system saves the state processor instruction pointer in the current flow-entry in the current flow-entry. That will be the next operation that will be performed the next time the LRE 1107 finds packet in the UFKB that matches this flow. The processor now exits processing this particular unified flow key buffer entry at 1313.

Note that state processing updates information in the unified flow key buffer 1103 and the flow-entry in the cache. Once the state processor is done, a flag is set in the UFKB for the entry that the state processor is done. Furthermore, if the flow needs to be inserted or deleted from the database of flows, control is then passed on to the flow insertion/deletion engine 1110 for that flow signature and packet entry. This is done by the state processor setting another flag in the UFKB for this UFKB-entry indicating that the state processor is passing processing of this entry to the flow insertion and deletion engine.

The flow insertion and deletion engine 1110 is responsible for maintaining the flow-entry database. In particular, for creating new flows in the flow database, and deleting flows from the database so that they can be reused.

The process of flow insertion is now described with the aid of FIG. 12. Flows are grouped into bins of buckets by the hash value. The engine processes a UFKB-entry that may be new or that the state processor otherwise has indicated needs to be created. FIG. 12 shows the case of a new entry being created. A conversation record bin (preferably containing 4 buckets for four records) is obtained in 1203. This is a bin that matches the hash of the UFKB, so this bin may already have been sought for the UFKB-entry by the LUE. In 1204 the FIDE 1110 requests that the record bin/bucket be maintained in the cache system 1115. If in 1205 the cache system 1115 indicates that the bin/bucket is empty, step 1207 inserts the flow signature (with the hash) into the bucket and the bucket is marked "used" in the cache engine of cache 1115 using a timestamp that is maintained throughout the process. In 1209, the FIDE 1110 compares the bin and bucket record flow signature to the packet to verify that all the elements are in place to complete the record. In 1211 the system marks the record bin and bucket as "in process" and as "new" in the

cache system (and hence in the external memory). In 1212, the initial statistical measures for the flow-record are set in the cache system. This in the preferred embodiment clears the set of counters used to maintain statistics, and may perform other procedures for statistical operations requires by the analyzer for the first packet seen for a particular flow.

Back in step 1205, if the bucket is not empty, the FIDE 1110 requests the next bucket for this particular bin in the cache system. If this succeeds, the processes of 1207, 1209, 1211 and 1212 are repeated for this next bucket. If at 1208, there is no valid bucket, the unified flow key buffer entry for the packet is set as "drop," indicating that the system cannot process the particular packet because there are no buckets left in the system. The process exits at 1213. The FIDE 1110 indicates to the UFKB that the flow insertion and deletion operations are completed for this UFKB-entry. This also lets the UFKB provide the FIDE with the next UFKB record.

Once a set of operations is performed on a unified flow key buffer entry by all of the engines required to access and manage a particular packet and its flow signature, the unified flow key buffer entry is marked as "completed." That element will then be used by the parser interface for the next packet and flow signature coming in from the parsing and extracting system.

All flow-entries are maintained in the external memory and some are maintained in the cache 1115. The cache system 1115 is intelligent enough to access the flow database and to understand the data structures that exist on the other side of memory interface 1123. The lookup/update engine 1107 is able to request that the cache system pull a particular flow or "buckets" of flows from the unified memory controller 1119 into the cache system for further processing. The state processor 1108 can operate on information found in the cache system once it is looked up by means of the lookup/update engine request, and the flow insertion/deletion engine 1110 can create new entries in the cache system if required based on information in the unified flow key buffer 1103. The cache retrieves information as required from the memory through the memory interface 1123 and the unified memory controller 1119, and updates information as required in the memory through the memory controller 1119.

There are several interfaces to components of the system external to the module of FIG. 11 for the particular hardware implementation. These include host bus interface 1122, which is designed as a generic interface that can operate with any kind of external processing system such as a microprocessor or a multiplexor (MUX) system. Consequently, one can connect the overall traffic classification system of FIGS. 11 and 12 into some other processing system to manage the classification system and to extract data gathered by the system.

The memory interface 1123 is designed to interface to any of a variety of memory systems that one may want to use to store the flow-entries. One can use different types of memory systems like regular dynamic random access memory (DRAM), synchronous DRAM, synchronous graphic memory (SGRAM), static random access memory (SRAM), and so forth.

FIG. 10 also includes some "generic" interfaces. There is a packet input interface 1012—a general interface that works in tandem with the signals of the input buffer interface control 1022. These are designed so that they can be used with any kind of generic systems that can then feed packet information into the parser. Another generic interface is the interface of pipes 1031 and 1033 respectively out of and into host interface multiplexor and control registers 1005. This

enables the parsing system to be managed by an external system, for example a microprocessor or another kind of external logic, and enables the external system to program and otherwise control the parser.

The preferred embodiment of this aspect of the invention is described in a hardware description language (HDL) such as VHDL or Verilog. It is designed and created in an HDL so that it may be used as a single chip system or, for instance, integrated into another general-purpose system that is being designed for purposes related to creating and analyzing traffic within a network. Verilog or other HDL implementation is only one method of describing the hardware.

In accordance with one hardware implementation, the elements shown in FIGS. 10 and 11 are implemented in a set of six field programmable logic arrays (FPGA's). The boundaries of these FPGA's are as follows. The parsing subsystem of FIG. 10 is implemented as two FPGAs; one FPGA, and includes blocks 1006, 1008 and 1012, parts of 1005, and memory 1001. The second FPGA includes 1002, 1007, 1013, 1011 parts of 1005. Referring to FIG. 11, the unified look-up buffer 1103 is implemented as a single FPGA. State processor 1108 and part of state processor instruction database memory 1109 is another FPGA. Portions of the state processor instruction database memory 1109 are maintained in external SRAM's. The lookup/update engine 1107 and the flow insertion/deletion engine 1110 are in another FPGA. The sixth FPGA includes the cache system 1115, the unified memory control 1119, and the analyzer host interface and control 1118.

Note that one can implement the system as one or more VSLI devices, rather than as a set of application specific integrated circuits (ASIC's) such as FPGA's. It is anticipated that in the future device densities will continue to increase, so that the complete system may eventually form a sub-unit (a "core") of a larger single chip unit.

#### Operation of the Invention

FIG. 15 shows how an embodiment of the network monitor 300 might be used to analyze traffic in a network 102. Packet acquisition device 1502 acquires all the packets from a connection point 121 on network 102 so that all packets passing point 121 in either direction are supplied to monitor 300. Monitor 300 comprises the parser sub-system 301, which determines flow signatures, and analyzer sub-system 303 that analyzes the flow signature of each packet. A memory 324 is used to store the database of flows that are determined and updated by monitor 300. A host computer 1504, which might be any processor, for example, a general-purpose computer, is used to analyze the flows in memory 324. As is conventional, host computer 1504 includes a memory, say RAM, shown as host memory 1506. In addition, the host might contain a disk. In one application, the system can operate as an RMON probe, in which case the host computer is coupled to a network interface card 1510 that is connected to the network 102.

The preferred embodiment of the invention is supported by an optional Simple Network Management Protocol (SNMP) implementation. FIG. 15 describes how one would, for example, implement an RMON probe, where a network interface card is used to send RMON information to the network. Commercial SNMP implementations also are available, and using such an implementation can simplify the process of porting the preferred embodiment of the invention to any platform.

In addition, MEB Compilers are available. An MIB Compiler is a tool that greatly simplifies the creation and maintenance of proprietary MIB extensions.

## Examples of Packet Elucidation

Monitor 300, and in particular, analyzer 303 is capable of carrying out state analysis for packet exchanges that are commonly referred to as "server announcement" type exchanges. Server announcement is a process used to ease communications between a server with multiple applications that can all be simultaneously accessed from multiple clients. Many applications use a server announcement process as a means of multiplexing a single port or socket into many applications and services. With this type of exchange, messages are sent on the network, in either a broadcast or multicast approach, to announce a server and application, and all stations in the network may receive and decode these messages. The messages enable the stations to derive the appropriate connection point for communicating that particular application with the particular server. Using the server announcement method, a particular application communicates using a service channel, in the form of a TCP or UDP socket or port as in the IP protocol suite, or using a SAP as in the Novell IPX protocol suite.

The analyzer 303 is also capable of carrying out "in-stream analysis" of packet exchanges. The "in-stream analysis" method is used either as a primary or secondary recognition process. As a primary process, in-stream analysis assists in extracting detailed information which will be used to further recognize both the specific application and application component. A good example of in-stream analysis is any Web-based application. For example, the commonly used PointCast Web information application can be recognized using this process; during the initial connection between a PointCast server and client, specific key tokens exist in the data exchange that will result in a signature being generated to recognize PointCast.

The in-stream analysis process may also be combined with the server announcement process. In many cases in-stream analysis will augment other recognition processes. An example of combining in-stream analysis with server announcement can be found in business applications such as SAP and BAAN.

"Session tracking" also is known as one of the primary processes for tracking applications in client/server packet exchanges. The process of tracking sessions requires an initial connection to a predefined socket or port number. This method of communication is used in a variety of transport layer protocols. It is most commonly seen in the TCP and UDP transport protocols of the IP protocol.

During the session tracking, a client makes a request to a server using a specific port or socket number. This initial request will cause the server to create a TCP or UDP port to exchange the remainder of the data between the client and the server. The server then replies to the request of the client using this newly created port. The original port used by the client to connect to the server will never be used again during this data exchange.

One example of session tracking is TFTP (Trivial File Transfer Protocol), a version of the TCP/IP FTP protocol that has no directory or password capability. During the client/server exchange process of TFTP, a specific port (port number 69) is always used to initiate the packet exchange. Thus, when the client begins the process of communicating, a request is made to UDP port 69. Once the server receives this request, a new port number is created on the server. The server then replies to the client using the new port. In this example, it is clear that in order to recognize TFTP, network monitor 300 analyzes the initial request from the client and generates a signature for it. Monitor 300 uses that signature

to recognize the reply. Monitor 300 also analyzes the reply from the server with the key port information, and uses this to create a signature for monitoring the remaining packets of this data exchange.

Network monitor 300 can also understand the current state of particular connections in the network. Connection-oriented exchanges often benefit from state tracking to correctly identify the application. An example is the common TCP transport protocol that provides a reliable means of sending information between a client and a server. When a data exchange is initiated, a TCP request for synchronization message is sent. This message contains a specific sequence number that is used to track an acknowledgement from the server. Once the server has acknowledged the synchronization request, data may be exchanged between the client and the server. When communication is no longer required, the client sends a finish or complete message to the server, and the server acknowledges this finish request with a reply containing the sequence numbers from the request. The states of such a connection-oriented exchange relate to the various types of connection and maintenance messages.

## Server Announcement Example

The individual methods of server announcement protocols vary. However, the basic underlying process remains similar. A typical server announcement message is sent to one or more clients in a network. This type of announcement message has specific content, which, in another aspect of the invention, is salvaged and maintained in the database of flow-entries in the system. Because the announcement is sent to one or more stations, the client involved in a future packet exchange with the server will make an assumption that the information announced is known, and an aspect of the inventive monitor is that it too can make the same assumption.

Sun-RPC is the implementation by Sun Microsystems, Inc. (Palo Alto, Calif.) of the Remote Procedure Call (RPC), a programming interface that allows one program to use the services of another on a remote machine. A Sun-RPC example is now used to explain how monitor 300 can capture server announcements.

A remote program or client that wishes to use a server or procedure must establish a connection, for which the RPC protocol can be used.

Each server running the Sun-RPC protocol must maintain a process and database called the port Mapper. The port Mapper creates a direct association between a Sun-RPC program or application and a TCP or UDP socket or port (for TCP or UDP implementations). An application or program number is a 32-bit unique identifier assigned by ICANN (the Internet Corporation for Assigned Names and Numbers, www.icann.org), which manages the huge number of parameters associated with Internet protocols (port numbers, router protocols, multicast addresses, etc.) Each port Mapper on a Sun-RPC server can present the mappings between a unique program number and a specific transport socket through the use of specific request or a directed announcement. According to ICANN, port number 111 is associated with Sun RPC.

As an example, consider a client (e.g., CLIENT 3 shown as 106 in FIG. 1) making a specific request to the server (e.g., SERVER 2 of FIG. 1, shown as 110) on a predefined UDP or TCP socket. Once the port Mapper process on the sun RPC server receives the request, the specific mapping is returned in a directed reply to the client.

1. A client (CLIENT 3, 106 in FIG. 1) sends a TCP packet to SERVER 2 (110 in FIG. 1) on port 111, with an RPC Bind

Lookup Request (rpcBindLookup). TCP or UDP port 111 is always associated Sun RPC. This request specifies the program (as a program identifier), version, and might specify the protocol (UDP or TCP).

2. The server SERVER 2 (110 in FIG. 1) extracts the program identifier and version identifier from the request. The server also uses the fact that this packet came in using the TCP transport and that no protocol was specified, and thus will use the TCP protocol for its reply.

3. The server 110 sends a TCP packet to port number 111, with an RPC Bind Lookup Reply. The reply contains the specific port number (e.g., port number 'port') on which future transactions will be accepted for the specific RPC program identifier (e.g., Program 'program') and the protocol (UDP or TCP) for use.

It is desired that from now on every time that port number 'port' is used, the packet is associated with the application program 'program' until the number 'port' no longer is to be associated with the program 'program'. Network monitor 300 by creating a flow-entry and a signature includes a mechanism for remembering the exchange so that future packets that use the port number 'port' will be associated by the network monitor with the application program 'program'.

In addition to the Sun RPC Bind Lookup request and reply, there are other ways that a particular program—say 'program'—might be associated with a particular port number, for example number 'port'. One is by a broadcast announcement of a particular association between an application service and a port number, called a Sun RPC portMapper Announcement. Another, is when some server—say the same SERVER 2—replies to some client—say CLIENT 1—requesting some portMapper assignment with a RPC portMapper Reply. Some other client—say CLIENT 2—might inadvertently see this request, and thus know that for this particular server, SERVER 2, port number 'port' is associated with the application service 'program'. It is desirable for the network monitor 300 to be able to associate any packets to SERVER 2 using port number 'port' with the application program 'program'.

FIG. 9 represents a dataflow 900 of some operations in the monitor 300 of FIG. 3 for Sun Remote Procedure Call. Suppose a client 106 (e.g., CLIENT 3 in FIG. 1) is communicating via its interface to the network 118 to a server 110 (e.g., SERVER 2 in FIG. 1) via the server's interface to the network 116. Further assume that Remote Procedure Call is used to communicate with the server 110. One path in the data flow 900 starts with a step 910 that a Remote Procedure Call bind lookup request is issued by client 106 and ends with the server state creation step 904. Such RPC bind lookup request includes values for the 'program,' 'version,' and 'protocol' to use, e.g., TCP or UDP. The process for Sun RPC analysis in the network monitor 300 includes the following aspects:

Process 909: Extract the 'program,' 'version,' and 'protocol' (UDP or TCP).

Extract the TCP or UDP port (process 909) which is 111 indicating Sun RPC.

Process 908: Decode the Sun RPC packet. Check RPC type field for ID. If value is portMapper, save paired socket (i.e., dest for destination address, src for source address). Decode ports and mapping, save ports with socket/addr key. There may be more than one pairing per mapper packet. Form a signature (e.g., a key). A flow-entry is created in database 324. The saving of the request is now complete.

At some later time, the server (process 907) issues a RPC bind lookup reply. The packet monitor 300 will extract a signature from the packet and recognize it from the previously stored flow. The monitor will get the protocol port number (906) and lookup the request (905). A new signature (i.e., a key) will be created and the creation of the server state (904) will be stored as an entry identified by the new signature in the flow-entry database. That signature now may be used to identify packets associated with the server.

The server state creation step 904 can be reached not only from a Bind Lookup Request/Reply pair, but also from a RPC Reply portMapper packet shown as 901 or an RPC Announcement portMapper shown as 902. The Remote Procedure Call protocol can announce that it is able to provide a particular application service. Embodiments of the present invention preferably can analyze when an exchange occurs between a client and a server, and also can track those stations that have received the announcement of a service in the network.

The RPC Announcement portMapper announcement 902 is a broadcast. Such causes various clients to execute a similar set of operations, for example, saving the information obtained from the announcement. The RPC Reply portMapper step 901 could be in reply to a portMapper request, and is also broadcast. It includes all the service parameters.

Thus monitor 300 creates and saves all such states for later classification of flows that relate to the particular service 'program'.

FIG. 2 shows how the monitor 300 in the example of Sun RPC builds a signature and flow states. A plurality of packets 206-209 are exchanged, e.g., in an exemplary Sun Microsystems Remote Procedure Call protocol. A method embodiment of the present invention might generate a pair of flow signatures, "signature-1" 210 and "signature-2" 212, from information found in the packets 206 and 207 which, in the example, correspond to a Sun RPC Bind Lookup request and reply, respectively.

Consider first the Sun RPC Bind Lookup request. Suppose packet 206 corresponds to such a request sent from CLIENT 3 to SERVER 2. This packet contains important information that is used in building a signature according to an aspect of the invention. A source and destination network address occupy the first two fields of each packet, and according to the patterns in pattern database 308, the flow signature (shown as KEY1 230 in FIG. 2) will also contain these two fields, so the parser subsystem 301 will include these two fields in signature KEY 1 (230). Note that in FIG. 2, if an address identifies the client 106 (shown also as 202), the label used in the drawing is "C<sub>1</sub>". If such address identifies the server 110 (shown also as server 204), the label used in the drawing is "S<sub>1</sub>". The first two fields 214 and 215 in packet 206 are "S<sub>1</sub>" and "C<sub>1</sub>" because packet 206 is provided from the server 110 and is destined for the client 106. Suppose for this example, "S<sub>1</sub>" is an address numerically less than address "C<sub>1</sub>". A third field "p" 216 identifies the particular protocol being used, e.g., TCP, UDP, etc.

In packet 206, a fourth field 217 and a fifth field 218 are used to communicate port numbers that are used. The conversation direction determines where the port number field is. The diagonal pattern in field 217 is used to identify a source-port pattern, and the hash pattern in field 218 is used to identify the destination-port pattern. The order indicates the client-server message direction. A sixth field denoted "i" 219 is an element that is being requested by the client from the server. A seventh field denoted "s<sub>1</sub>a" 220 is the service requested by the client from server 110. The

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following eighth field "QA" 221 (for question mark) indicates that the client 106 wants to know what to use to access application "s<sub>1</sub>a". A tenth field "QP" 223 is used to indicate that the client wants the server to indicate what protocol to use for the particular application.

Packet 206 initiates the sequence of packet exchanges, e.g., a RPC Bind Lookup Request to SERVER 2. It follows a well-defined format, as do all the packets, and is transmitted to the server 110 on a well-known service connection identifier (port 111 indicating Sun RPC).

Packet 207 is the first sent in reply to the client 106 from the server. It is the RPC Bind Lookup Reply as a result of the request packet 206.

Packet 207 includes ten fields 224-233. The destination and source addresses are carried in fields 224 and 225, e.g., indicated "C<sub>1</sub>" and "S<sub>1</sub>", respectively. Notice the order is now reversed, since the client-server message direction is from the server 110 to the client 106. The protocol "p<sup>1</sup>" is used as indicated in field 226. The request "i<sup>1</sup>" is in field 229. Values have been filled in for the application port number, e.g., in field 233 and protocol "p<sup>2</sup>" in field 233.

The flow signature and flow states built up as a result of this exchange are now described. When the packet monitor 300 sees the request packet 206 from the client, a first flow signature 210 is built in the parser subsystem 301 according to the pattern and extraction operations database 308. This signature 210 includes a destination and a source address 240 and 241. One aspect of the invention is that the flow keys are built consistently in a particular order no matter what the direction of conversation. Several mechanisms may be used to achieve this. In the particular embodiment, the numerically lower address is always placed before the numerically higher address. Such least to highest order is used to get the best spread of signatures and hashes for the lookup operations. In this case, therefore, since we assume "S<sub>1</sub>" < "C<sub>1</sub>", the order is address "S<sub>1</sub>" followed by client address "C<sub>1</sub>". The next field used to build the signature is a protocol field 242 extracted from packet 206's field 216, and thus is the protocol "p<sup>1</sup>". The next field used for the signature is field 243, which contains the destination source port number shown as a crosshatched pattern from the field 218 of the packet 206. This pattern will be recognized in the payload of packets to derive how this packet or sequence of packets exists as a flow. In practice, these may be TCP port numbers, or a combination of TCP port numbers. In the case of the Sun RPC example, the crosshatch represents a set of port numbers of UDS for p<sup>1</sup> that will be used to recognize this flow (e.g., port 111). Port 111 indicates this is Sun RPC. Some applications, such as the Sun RPC Bind Lookups, are directly determinable ("known") at the parser level. So in this case, the signature KEY-1 points to a known application denoted "a<sup>1</sup>" (Sun RPC Bind Lookup), and a next-state that the state processor should proceed to for more complex recognition jobs, denoted as state "st<sub>D</sub>" is placed in the field 245 of the flow-entry.

When the Sun RPC Bind Lookup reply is acquired, a flow signature is again built by the parser. This flow signature is identical to KEY-1. Hence, when the signature enters the analyzer subsystem 303 from the parser subsystem 301, the complete flow-entry is obtained, and in this flow-entry indicates state "st<sub>D</sub>". The operations for state "st<sub>D</sub>" in the state processor instruction database 326 instructs the state processor to build and store a new flow signature, shown as KEY-2 (212) in FIG. 2. This flow signature built by the state processor also includes the destination and a source addresses 250 and 251, respectively, for server "S<sub>1</sub>" followed by (the numerically higher address) client "C<sub>1</sub>". A

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protocol field 252 defines the protocol to be used, e.g., "p<sup>2</sup>" which is obtained from the reply packet. A field 253 contains a recognition pattern also obtained from the reply packet. In this case, the application is Sun RPC, and field 254 indicates this application "a<sup>2</sup>". A next-state field 255 defines the next state that the state processor should proceed to for more complex recognition jobs, e.g., a state "st<sup>1</sup>". In this particular example, this is a final state. Thus, KEY-2 may now be used to recognize packets that are in any way associated with the application "a<sup>2</sup>". Two such packets 208 and 209 are shown, one in each direction. They use the particular application service requested in the original Bind Lookup Request, and each will be recognized because the signature KEY-2 will be built in each case.

The two flow signatures 210 and 212 always order the destination and source address fields with server "S<sub>1</sub>" followed by client "C<sub>1</sub>". Such values are automatically filled in when the addresses are first created in a particular flow signature. Preferably, large collections of flow signatures are kept in a lookup table in a least-to-highest order for the best spread of flow signatures and hashes.

Thereafter, the client and server exchange a number of packets, e.g., represented by request packet 208 and response packet 209. The client 106 sends packets 208 that have a destination and source address S<sub>1</sub> and C<sub>1</sub>, in a pair of fields 260 and 261. A field 262 defines the protocol as "p<sup>2</sup>", and a field 263 defines the destination port number.

Some network-server application recognition jobs are so simple that only a single state transition has to occur to be able to pinpoint the application that produced the packet.

Others require a sequence of state transitions to occur in order to match a known and predefined climb from state-to-state.

Thus the flow signature for the recognition of application "a<sup>2</sup>" is automatically set up by predefining what packet-exchange sequences occur for this example when a relatively simple Sun Microsystems Remote Procedure Call bind lookup request instruction executes. More complicated exchanges than this may generate more than two flow signatures and their corresponding states. Each recognition may involve setting up a complex state transition diagram to be traversed before a "final" resting state such as "st<sub>1</sub>" in field 255 is reached. All these are used to build the final set of flow signatures for recognizing a particular application in the future.

Embodiments of the present invention automatically generate flow signatures with the necessary recognition patterns and state transition climb procedure. Such comes from analyzing packets according to parsing rules, and also generating state transitions to search for. Applications and protocols, at any level, are recognized through state analysis of sequences of packets.

Note that one in the art will understand that computer networks are used to connect many different types of devices, including network appliances such as telephones, "Internet" radios, pagers, and so forth. The term computer as used herein encompasses all such devices and a computer network as used herein includes networks of such computers.

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that the disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those of ordinary skill in the art after having read the above disclosure. Accordingly, it is intended that the claims be interpreted as covering all alterations and modifications as fall within the true spirit and scope of the present invention.

What is claimed is:

1. A packet monitor for examining packets passing through a connection point on a computer network in real-time, the packets provided to the packet monitor via a packet acquisition device connected to the connection point, the packet monitor comprising:

- (a) a packet-buffer memory configured to accept a packet from the packet acquisition device;
- (b) a parsing/extraction operations memory configured to store a database of parsing/extraction operations that includes information describing how to determine at least one of the protocols used in a packet from data in the packet;
- (c) a parser subsystem coupled to the packet buffer and to the pattern/extraction operations memory, the parser subsystem configured to examine the packet accepted by the buffer, extract selected portions of the accepted packet, and form a function of the selected portions sufficient to identify that the accepted packet is part of a conversational flow-sequence;
- (d) a memory storing a flow-entry database including a plurality of flow-entries for conversational flows encountered by the monitor;
- (e) a lookup engine connected to the parser subsystem and to the flow-entry database, and configured to determine using at least some of the selected portions of the accepted packet if there is an entry in the flow-entry database for the conversational flow sequence of the accepted packet;
- (f) a state patterns/operations memory configured to store a set of predefined state transition patterns and state operations such that traversing a particular transition pattern as a result of a particular conversational flow-sequence of packets indicates that the particular conversational flow-sequence is associated with the operation of a particular application program, visiting each state in a traversal including carrying out none or more predefined state operations;
- (g) a protocol/state identification mechanism coupled to the state patterns/operations memory and to the lookup engine, the protocol/state identification engine configured to determine the protocol and state of the conversational flow of the packet; and
- (h) a state processor coupled to the flow-entry database, the protocol/state identification engine, and to the state patterns/operations memory, the state processor, configured to carry out any state operations specified in the state patterns/operations memory for the protocol and state of the flow of the packet, the carrying out of the state operations furthering the process of identifying which application program is associated with the conversational flow-sequence of the packet, the state processor progressing through a series of states and state operations until there are no more state operations to perform for the accepted packet, in which case the state processor updates the flow-entry, or until a final state is reached that indicates that no more analysis of the flow is required, in which case the result of the analysis is announced.

2. A packet monitor according to claim 1, wherein the flow-entry includes the state of the flow, such that the protocol/state identification mechanism determines the state of the packet from the flow-entry in the case that the lookup engine finds a flow-entry for the flow of the accepted packet.

3. A packet monitor according to claim 1, wherein the parser subsystem includes a mechanism for building a hash from the selected portions, and wherein the hash is used by the lookup engine to search the flow-entry database, the hash designed to spread the flow-entries across the flow-entry database.

4. A packet monitor according to claim 1, further comprising:

a compiler processor coupled to the parsing/extraction operations memory, the compiler processor configured to run a compilation process that includes: receiving commands in a high-level protocol description language that describe the protocols that may be used in packets encountered by the monitor, and translating the protocol description language commands into a plurality of parsing/extraction operations that are initialized into the parsing/extraction operations memory.

5. A packet monitor according to claim 4, wherein the protocol description language commands also describe a correspondence between a set of one or more application programs and the state transition patterns/operations that occur as a result of particular conversational flow-sequences associated with an application program, wherein the compiler processor is also coupled to the state patterns/operations memory, and wherein the compilation process further includes translating the protocol description language commands into a plurality of state patterns and state operations that are initialized into the state patterns/operations memory.

6. A packet monitor according to claim 1, further comprising:

a cache memory coupled to and between the lookup engine and the flow-entry database providing for fast access of a set of likely-to-be-accessed flow-entries from the flow-entry database.

7. A packet monitor according to claim 6, wherein the cache functions as a fully associative, least-recently-used cache memory.

8. A packet monitor according to claim 7, wherein the cache functions as a fully associative, least-recently-used cache memory and includes content addressable memories configured as a stack.

9. A packet monitor according to claim 1, wherein one or more statistical measures about a flow are stored in each flow-entry, the packet monitor further comprising:

a calculator for updating the statistical measures in a flow-entry of the accepted packet.

10. A packet monitor according to claim 9, wherein, when the application program of a flow is determined, one or more network usage metrics related to said application and determined from the statistical measures are presented to a user for network performance monitoring.

\* \* \* \* \*



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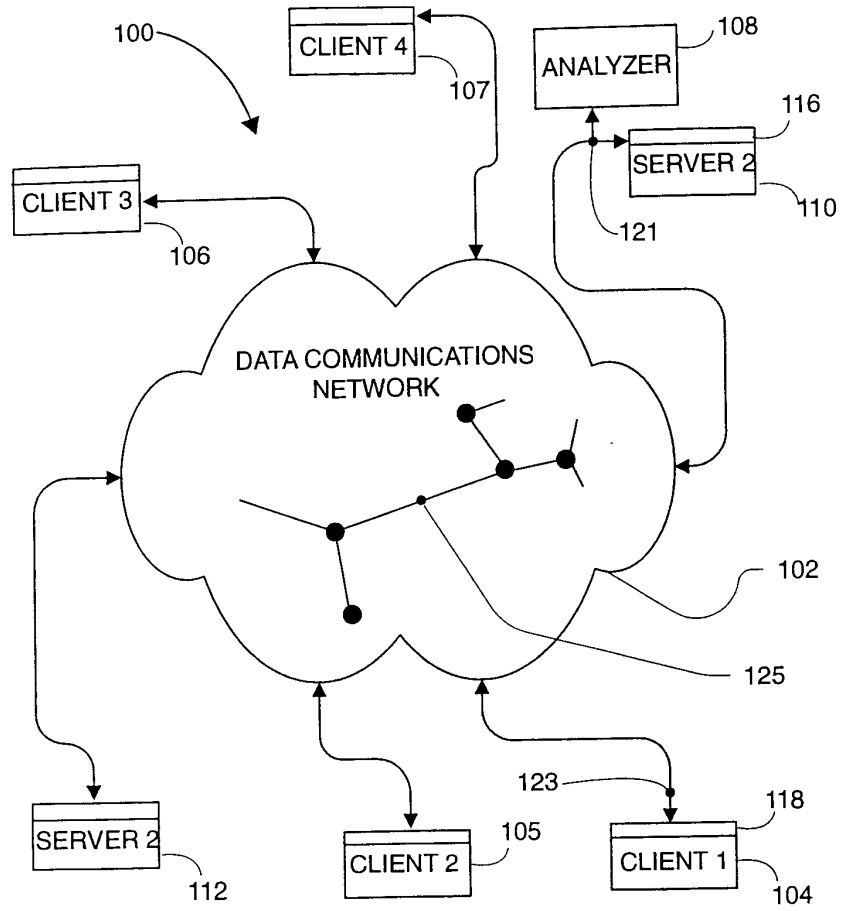


FIG. 1

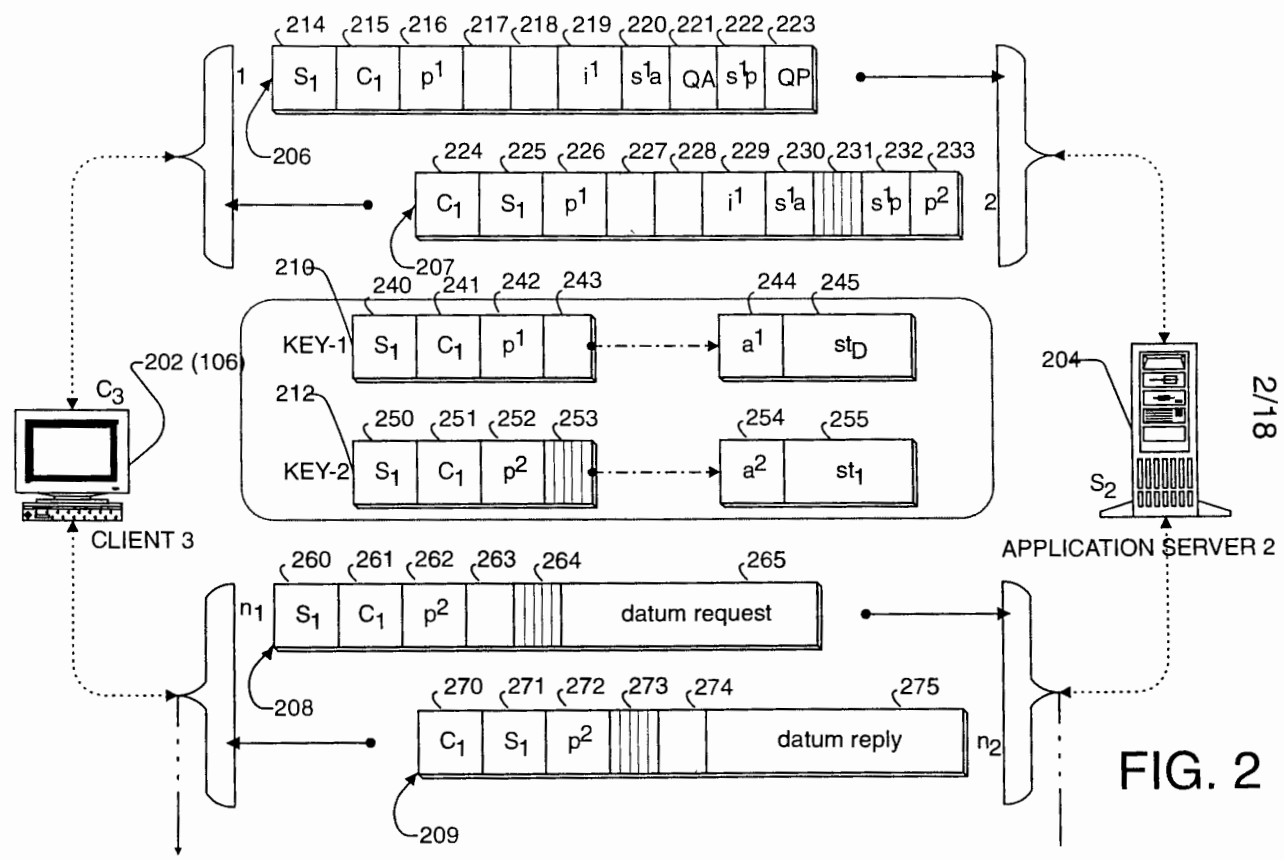


FIG. 2

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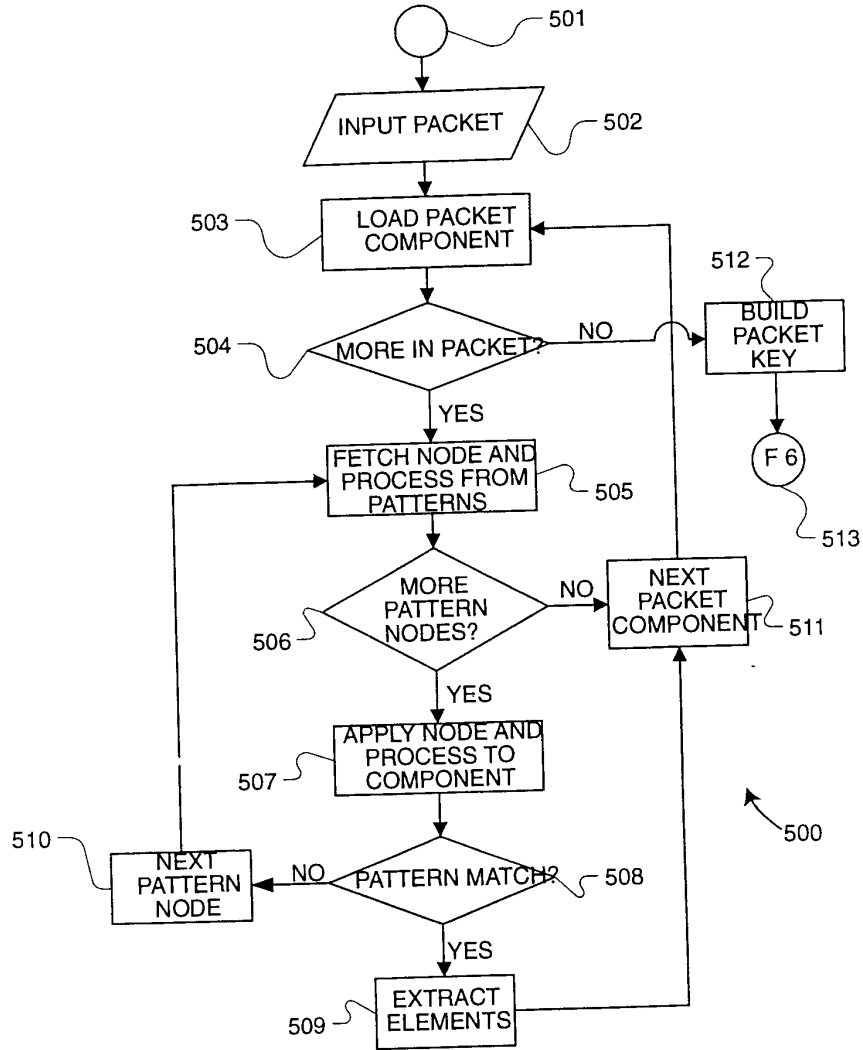


FIG. 5

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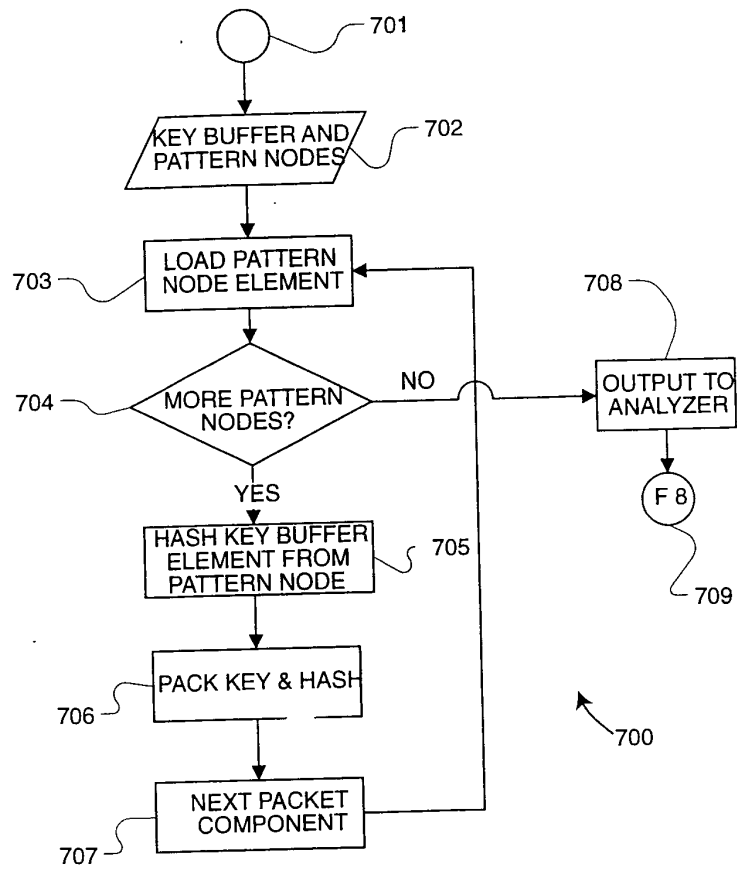


FIG. 7

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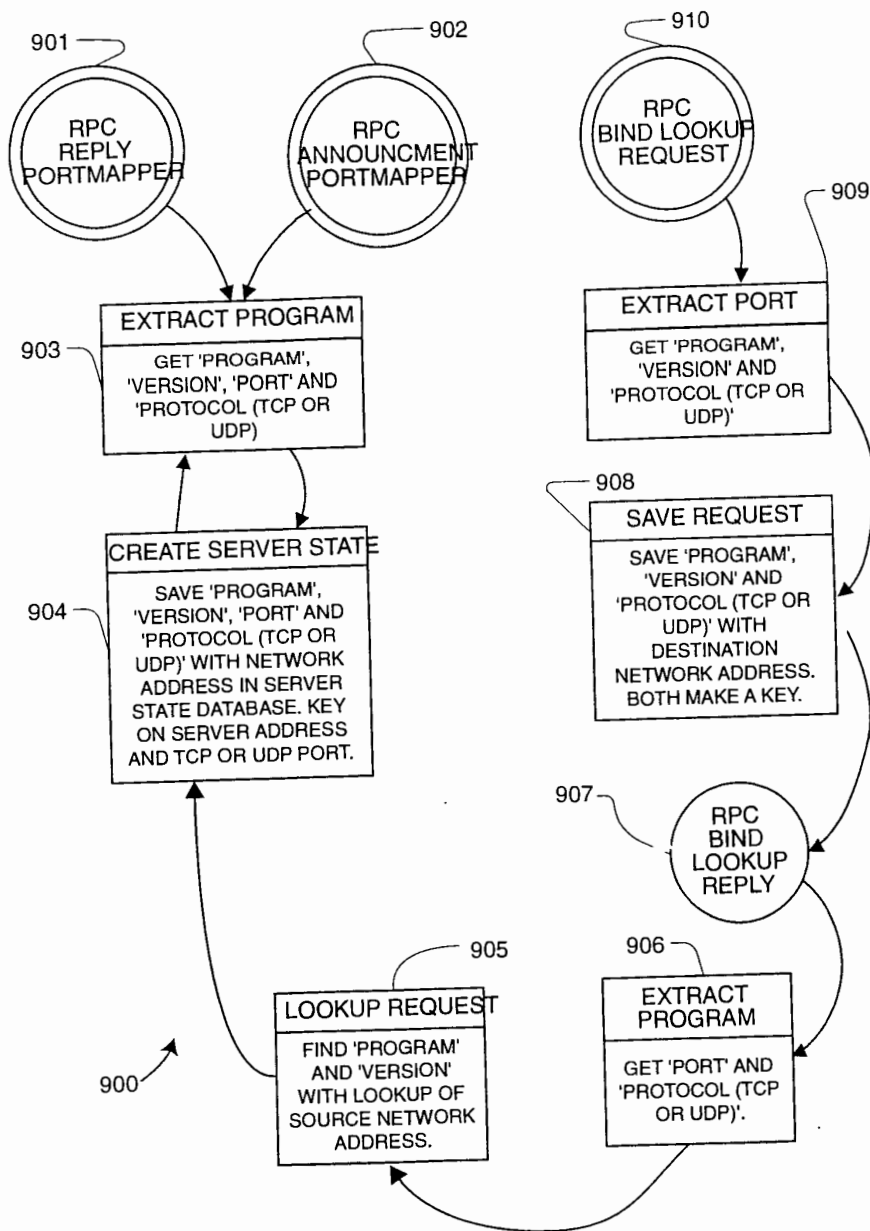


FIG. 9

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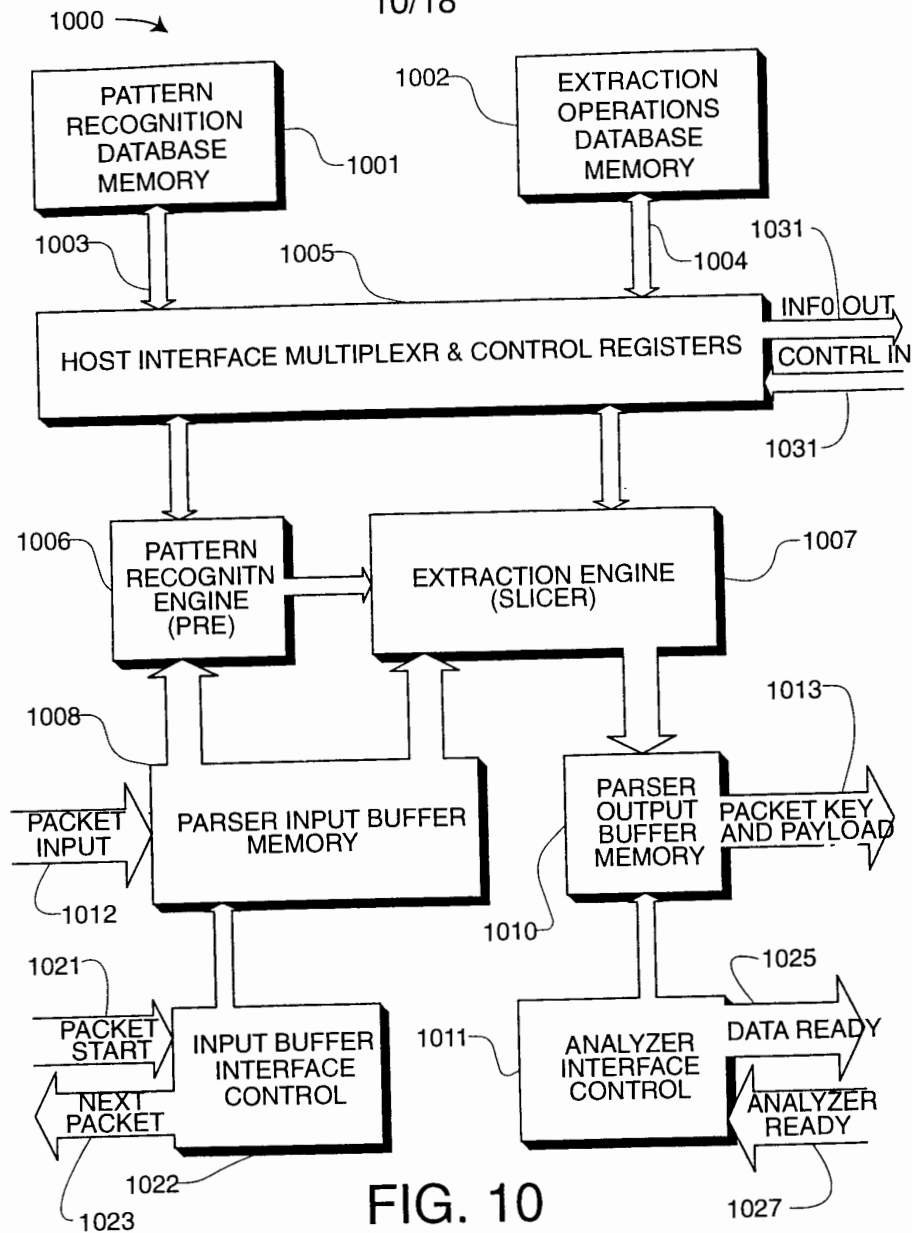


FIG. 10

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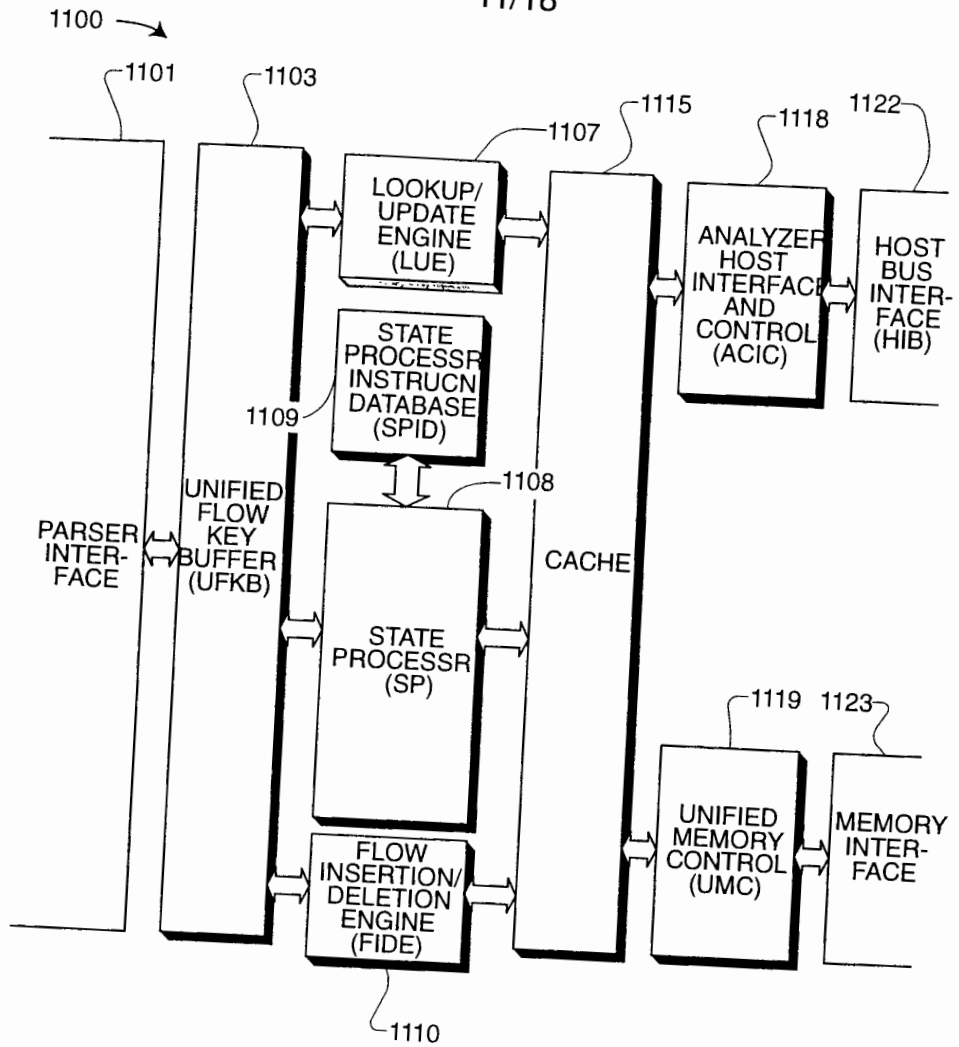


FIG. 11



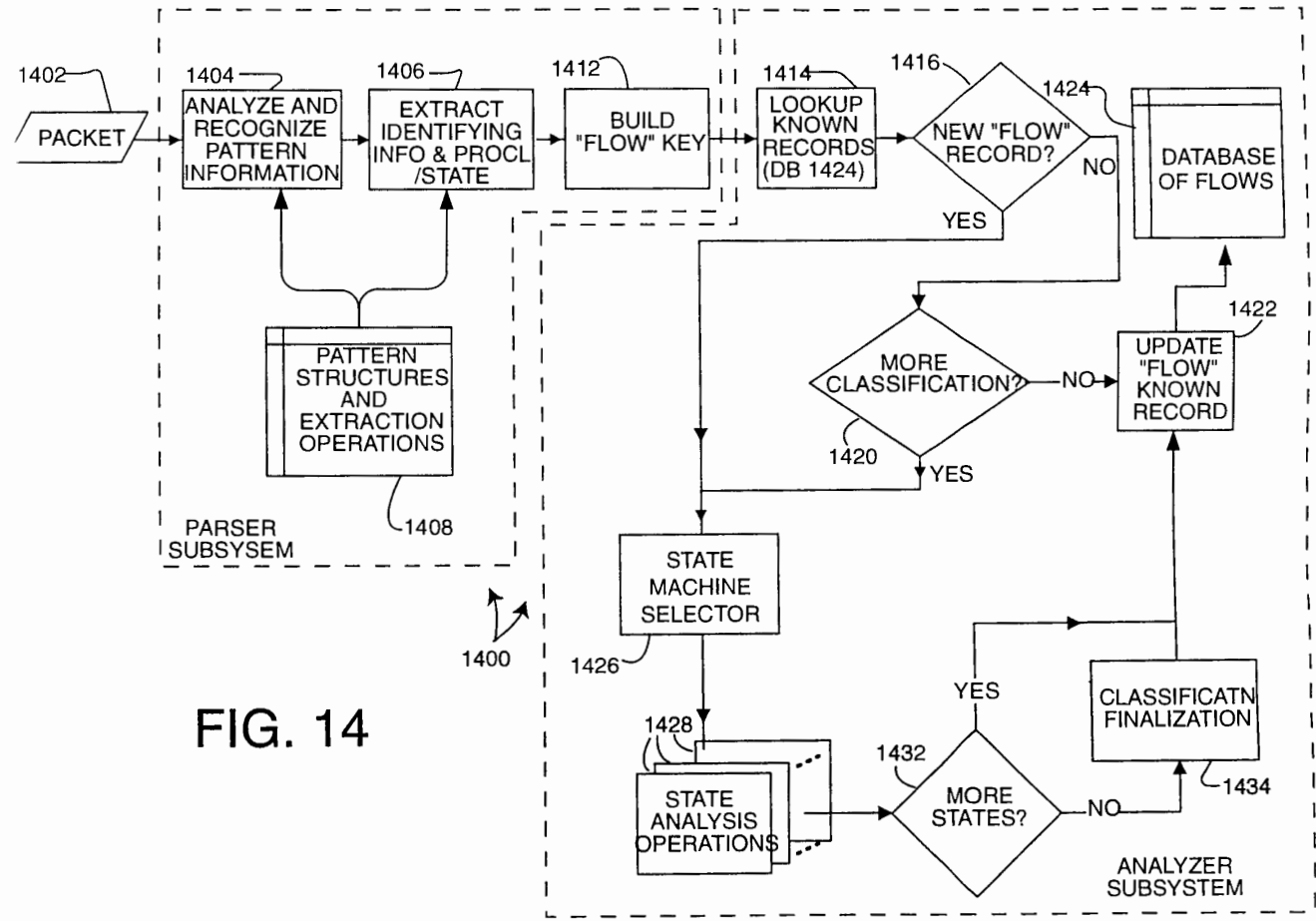


FIG. 14

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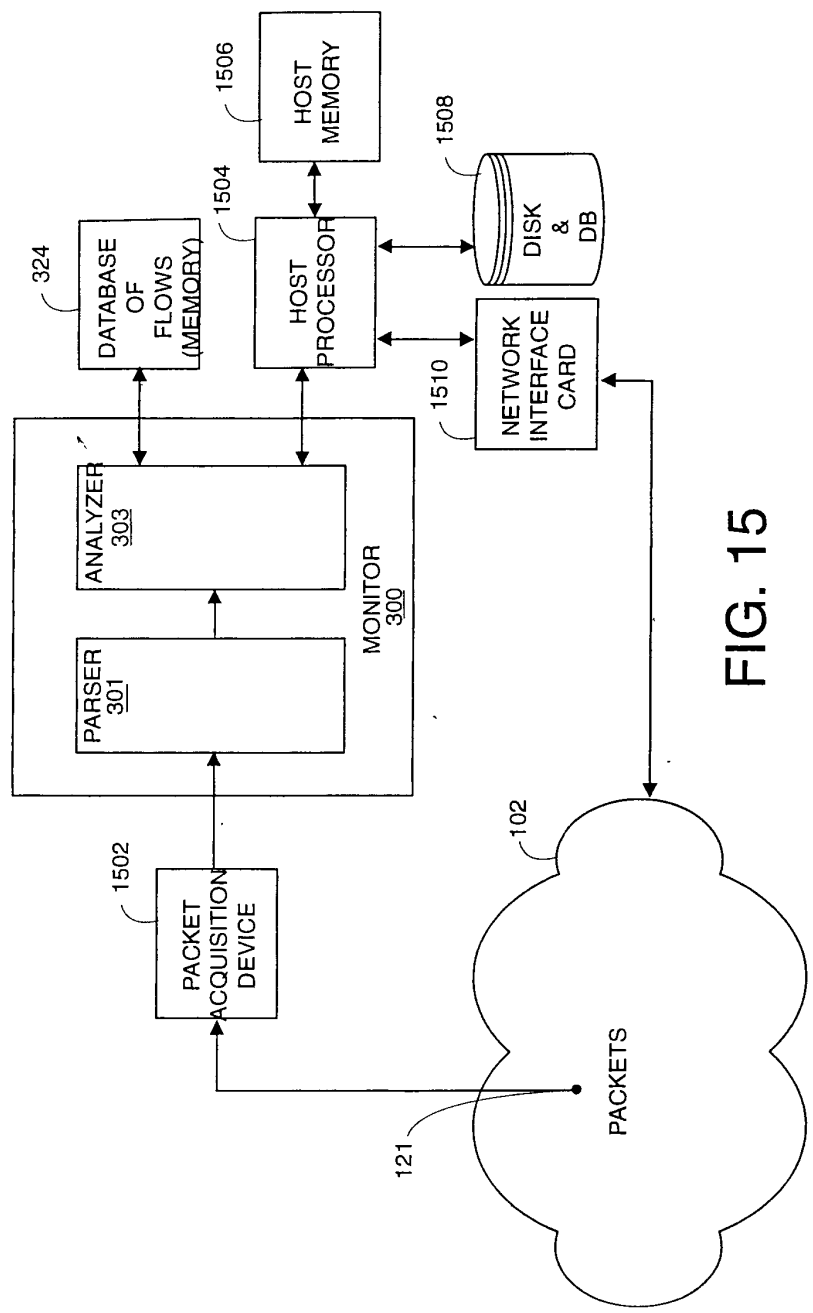


FIG. 15

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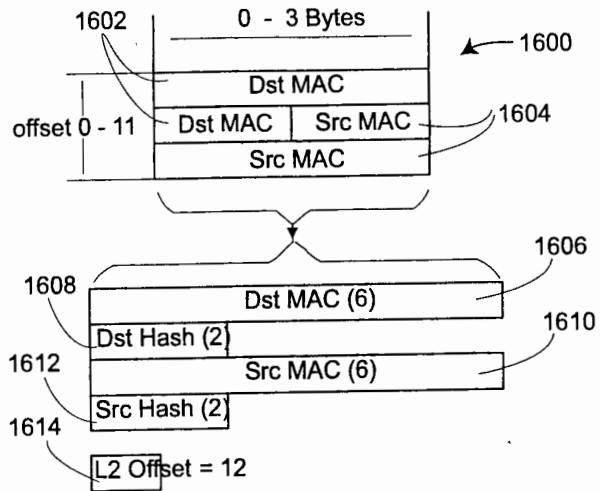


FIG. 16

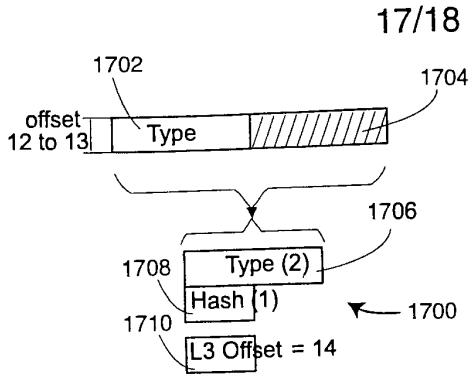


FIG. 17A

- IDP = 0x0600\*
  - IP = 0x0800\*
  - CHAOSNET = 0x0804
  - ARP = 0x0806
  - VIP = 0x0BAD\*
  - VLOOP = 0x0BAE
  - VECHO = 0x0BAF
  - NETBIOS-3COM = 0x3C00 - 0x3C0D#
  - DEC-MOP = 0x6001
  - DEC-RC = 0x6002
  - DEC-DRP = 0x6003\*
  - DEC-LAT = 0x6004
  - DEC-DIAG = 0x6005
  - DEC-LAVC = 0x6007
  - RARP = 0x8035
  - ATALK = 0x809B\*
  - VLOOP = 0x80C4
  - VECHO = 0x80C5
  - SNA-TH = 0x80D5\*
  - ATALKARP = 0x80F3
  - IPX = 0x8137\*
  - SNMP = 0x814C#
  - IPv6 = 0x86DD\*
  - LOOPBACK = 0x9000
  - Apple = 0x080007
- \* L3 Decoding  
 # L5 Decoding

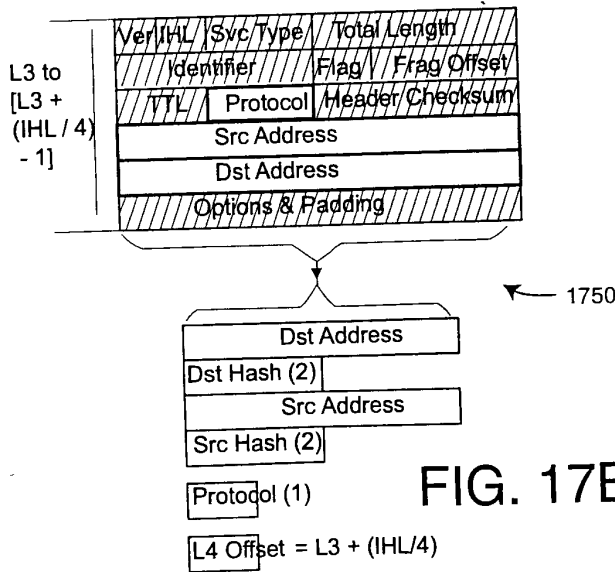


FIG. 17B

- ICMP = 1
  - IGMP = 2
  - GGP = 3
  - TCP = 6\*
  - EGP = 8
  - IGRP = 9
  - PUP = 12
  - CHAOS = 16
  - UDP = 17\*
  - IDP = 22#
  - ISO-TP4 = 29
  - DDP = 37#
  - ISO-IP = 80
  - VIP = 83#
  - EIGRP = 88
  - OSPF = 89
- \* L4 Decoding  
 # L3 Re-Decoding

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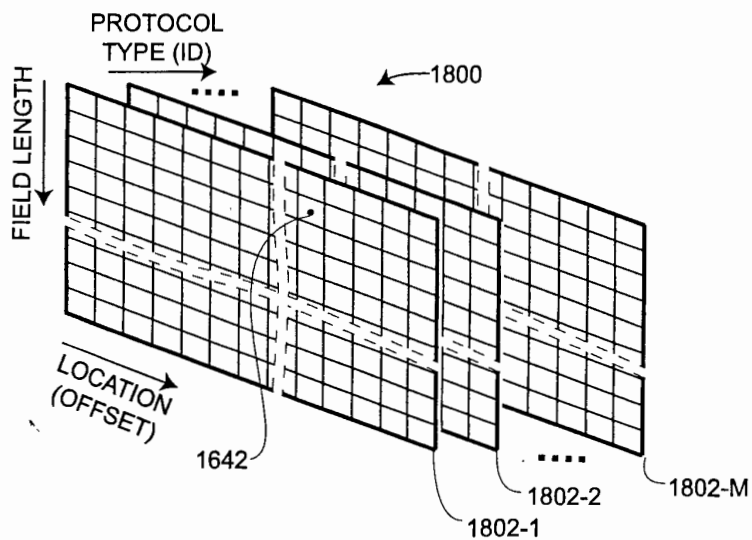


FIG. 18A

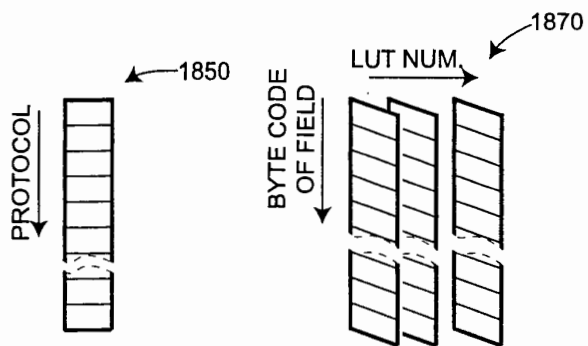


FIG. 18B

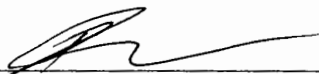
Application 09/608237, Page 2

X The Commissioner is hereby authorized to charge payment of any missing fees associated with this communication or credit any overpayment to Deposit Account No. 50-0292

(A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED):

Respectfully Submitted,

Nov 1, 2000  
Date

  
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Our Docket/Ref. No.: APPT-C-1

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE



Applicant(s): Dietz et al.

Serial No.: 09/608237

File Date: June 30, 2000

Title: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

Group Art Unit: 2755

Examiner:

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APR 16 2001

Technology Center 2100

Commissioner for Patents  
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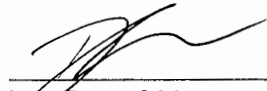
Transmitted herewith are:

- An Information Disclosure Statement for the above referenced patent application, together with PTO form 1449 and a copy of each reference cited in form 1449.
- A check for petition fees.
- Return postcard.
- The commissioner is hereby authorized to charge payment of any missing fee associated with this communication or credit any overpayment to Deposit Account 50-0292.

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Respectfully submitted,

Date: April 9, 2001

  
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Docket/Ref. No.: APPT-00

Patent

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Applicant(s): Dietz et al.

Serial No.: 09/608237

Filed: June 30, 2000

Title: METHOD AND APPARATUS FOR  
MONITORING TRAFFIC IN A  
NETWORK

Group Art Unit: 2755

Examiner:

RECEIVED  
APR 22 2002  
Technology Center 2100

Commissioner for Patents  
Washington, D.C. 20231

**TRANSMITTAL: INFORMATION DISCLOSURE STATEMENT**

Dear Commissioner:

Transmitted herewith are:

- An Information Disclosure Statement for the above referenced patent application, together with PTO form 1449 and a copy of each reference cited in form 1449.
- A check for petition fees.
- Return postcard.
- The commissioner is hereby authorized to charge payment of any missing fee associated with this communication or credit any overpayment to Deposit Account 50-0292.

A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED

Respectfully submitted,

Date: 30 Mar 2002

Dov Rosenfeld  
Attorney/Agent for Applicant(s)  
Reg. No. 38687

Correspondence Address:

Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618  
Telephone No.: +1-510-547-3378

**Certificate of Mailing under 37 CFR 1.18**

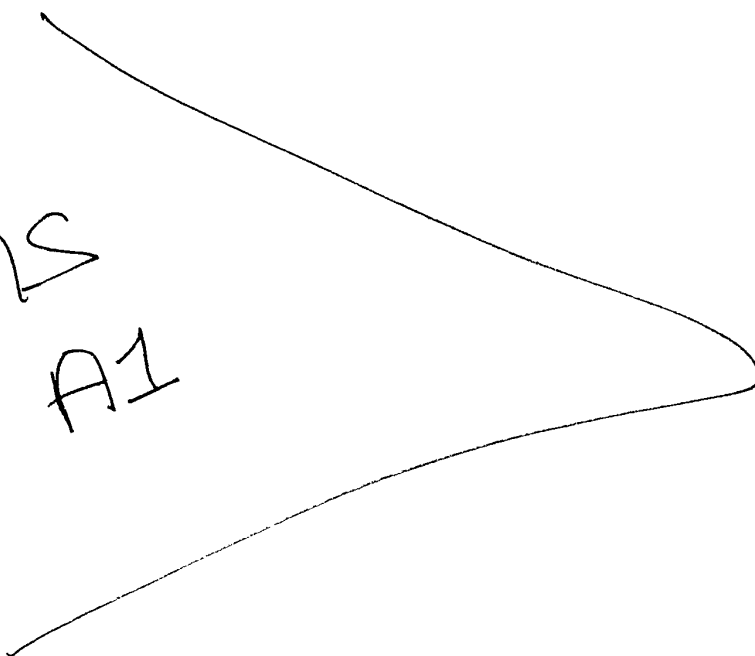
I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, Washington, D.C. 20231.

Date of Deposit: 30 Mar 2002 Signature:

Dov Rosenfeld, Reg. No. 38,687



INS  
A1





Patent Ref./Docket No: 2000-APPT-001-1

Patent

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

<p>Inventor(s): Dietz, <i>et al.</i></p> <p>Assignee: Hi/fn, Inc.</p> <p>Patent No: 6651099</p> <p>Issue Date: November, 18, 2003</p> <p>Application No.: 09/608237</p> <p>Filed: June 30, 2000</p> <p>Title: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK</p>	
--	--

**REQUEST FOR CERTIFICATE OF CORRECTIONS**

Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

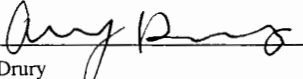
The above patent contains significant error as indicated on the attached Certificate of Correction form (submitted in duplicate).

X Such error arose through the fault of the Patent and Trademark Office. It is requested that the certificate be issued at no cost to the applicant.

However, if it is determined that the error arose through the fault of applicant(s), please note that such error is of clerical error or minor nature and occurred in good faith and therefore issuance of the certificate of Correction is respectfully requested. The Commissioner is authorized to charge Deposit Account No. 50-0292 any required fee. A duplicate of this request is attached.

Such errors specifically:

- In col. 3, line 14, delete the word "lo"
- In col. 15, line 45, kindly replace "ump" with --jump--
- In col. 28, line 65, change "MEB" to --MIB--.


<b>Certificate of Mailing under 37 CFR 1.8</b>	
I hereby certify that this response is being deposited with the United States Postal Service as first class mail in an envelope addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on.	
Date: <u>Feb. 25, 2004</u>	Signed: <u></u>
	Name: Amy Drury

The undersigned requests being contacted at (510) 547-3378 if there are any questions or clarifications, or if there are any problems with issuance of the Certificate of Correction.

Respectfully Submitted,

Feb. 25, 2004

Date

  
Dov Rosenfeld, Reg. No. 38687  
Agent of Record.

Address for correspondence:

Dov Rosenfeld  
5507 College Avenue, Suite 2,  
Oakland, CA 94618  
Tel. 510-547-3378; Fax: 510-291-2985

# INVENTEK

## Fax

Dov Rosenfeld  
 5507 College Avenue, Suite 2  
 Oakland, CA 94618, USA  
 Phone: (510)547-3378; Fax: (510)653-7992  
 dov@inventek.com

**Patent Application Ser. No.:** 09/608237

**Ref./Docket No:** APPT-001-1

**Applicant(s):** Dietz, et al.

**Examiner.:** Moustafa M. Meky

**Filing Date:** June 30, 2000

**Art Unit:** 2157

### FAX COVER PAGE

**TO:** Commissioner for Patents  
 P.O. Box 1450  
 Alexandria, VA 22313-1450

United States Patent and Trademark Office  
 (Examiner Moustafa M. Meky, Art Unit 2157)

**Fax No.:** ~~703-308-9052~~ 746-7239

**DATE:** July 08, 2003

**FROM:** Dov Rosenfeld, Reg. No. 38687

**RE:** Response to Office Action

*Number of pages including cover: 13*

OFFICIAL COMMUNICATION

PLEASE URGENTLY DELIVER A COPY OF  
 THIS RESPONSE TO  
 EXAMINER MOUSTAFA M. MEKY, ART UNIT  
 2157

#### Certificate of Facsimile Transmission under 37 CFR 1.8

I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark Office at telephone number ~~703-308-9052~~ <sup>746-7239</sup> addressed the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on.

Date: 7/8/03

Signed: 

Name: Dov Rosenfeld, Reg. No. 38687

<b>TRANSMITTAL FORM</b> <i>(to be used for all correspondence after initial filing)</i>	Application Number	09/608237  7/8/03
	Filing Date	30 Jun 2000
	First Named Inventor	Dietz, Russell S.
	Group Art Unit	2157
	Examiner Name	Moustafa M. Meky
		Attorney Docket Number APPT-001-1

<b>ENCLOSURES (check all that apply)</b>		
<input type="checkbox"/> Fee Transmittal Form <input type="checkbox"/> Fee Attached <input checked="" type="checkbox"/> Amendment / Response <input type="checkbox"/> <input type="checkbox"/> After Final <input type="checkbox"/> <input type="checkbox"/> Affidavits/declaration(s) <input type="checkbox"/> Extension of Time Request <input type="checkbox"/> Express Abandonment Request <input type="checkbox"/> Information Disclosure Statement <input type="checkbox"/> Certified Copy of Priority Document(s) <input type="checkbox"/> Response to Missing Parts/ Incomplete Application <input type="checkbox"/> <input type="checkbox"/> Response to Missing Parts under 37 CFR 1.52 or 1.53	<input type="checkbox"/> Assignment Papers (for an Application) <input type="checkbox"/> Drawing(s) <input type="checkbox"/> Licensing-related Papers <input type="checkbox"/> Petition Routing Slip (PTO/SB/69) and Accompanying Petition <input type="checkbox"/> To Convert a Provisional Application <input type="checkbox"/> Power of Attorney, Revocation Change of Correspondence Address <input type="checkbox"/> Terminal Disclaimer <input type="checkbox"/> Small Entity Statement <input type="checkbox"/> Request of Refund	<input type="checkbox"/> After Allowance Communication to Group <input type="checkbox"/> Appeal Communication to Board of Appeals and Interferences <input type="checkbox"/> Appeal Communication to Group (Appeal Notice, Brief, Reply Brief) <input type="checkbox"/> Proprietary Information <input type="checkbox"/> Status Letter <input type="checkbox"/> Additional Enclosure(s) (please identify below): <input type="checkbox"/> Return Postcard <input type="checkbox"/> <input type="checkbox"/>
Remarks		

<b>SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT/ CORRESPONDENCE ADDRESS</b>	
Firm or Individual name	Dov Rosenfeld, Reg. No. 38687
Signature	
Date	July 8, 2003
<b>ADDRESS FOR CORRESPONDENCE</b>	
Firm or Individual name	Dov Rosenfeld 5507 College Avenue, Suite 2 Oakland, CA 94618, Tel: +1-510-547-3378

<b>CERTIFICATE OF FACSIMILE TRANSMISSION</b>			
I hereby certify that this correspondence is being facsimile transmitted with the United States Patent and Trademark Office at Telephone number 703-746-7239 addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA			
			July 8, 2003
Type or printed name	Dov Rosenfeld, Reg. No. 38687		
Signature		Date	July 8, 2003

Our Ref./Docket No: APPT-001-1

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Patent  
7/8/03

<p>Applicant(s): Dietz, <i>et al.</i>          Application No.: 09/608237          Filed: June 30, 2000          Title: METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK</p>	<p>Group Art Unit: 2157          Examiner: Moustafa M. Meky</p>
--	---

**TRANSMITTAL: RESPONSE TO OFFICE ACTION**

Mail Stop Non Fee Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

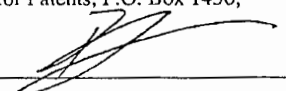
Transmitted herewith is a response to an office action for the above referenced application. Included with the response are:

\_\_\_\_\_ formal drawings (with separate letter);

This application has:

\_\_\_\_\_ a small entity status. If a claim for such status has not earlier been made, consider this as a claim for small entity status.

X  No additional fee is required.

<b>Certificate of Facsimile Transmission under 37 CFR 1.8</b>	
I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark Office at telephone number <del>703-908-9052</del> addressed the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on. <del>703-746-7239</del>	
Date: <u>7/8/03</u>	Signed: 
	Name: Dov Rosenfeld, Reg. No. 38687

S/N 09/608237

Page 4

APPT-001-1

Applicant(s) believe(s) that no Extension of Time is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition for an extension of time.

Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:

one months (\$110)  two months (\$410)

two months (\$930)  four months (\$1450)

If an additional extension of time is required, please consider this as a petition therefor.

A credit card payment form for the required fee(s) is attached.

The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 50-0292 (A DUPLICATE OF THIS TRANSMITTAL IS ATTACHED):

Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.

Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

7/8/03  
Date

  
Dov Rosenfeld, Reg. No. 38687

Address for correspondence:  
Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618  
Tel. +1-510-547-3378; Fax: +1-510-291-2985

7/8/03

Our Ref./Docket No: APPT-001-1

Patent

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

<p>Applicant(s): Dietz, <i>et al.</i>          Application No.: 09/608237          Filed: June 30, 2000          Title: METHOD AND APPARATUS FOR          MONITORING TRAFFIC IN A NETWORK</p>	<p>Group Art Unit: 2157          Examiner: Moustafa M. Meko</p>
---	---

**TRANSMITTAL: RESPONSE TO OFFICE ACTION**

Mail Stop No Fee Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Commissioner:

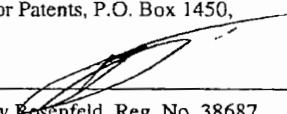
Transmitted herewith is a response to an office action for the above referenced application. Included with the response are:

formal drawings (with separate letter);

This application has:

a small entity status. If a claim for such status has not earlier been made, consider this as a claim for small entity status.

No additional fee is required.

<b>Certificate of Facsimile Transmission under 37 CFR 1.8</b>	
I hereby certify that this response is being facsimile transmitted to the United States Patent and Trademark Office at telephone number 703- <del>308-9052</del> addressed the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on. 746-7239	
Date: <u>7/8/03</u>	Signed: 
	Name: Dov Rosenfeld, Reg. No. 38687



S/N 09/608237

Page 6

APPT-001-1

Applicant(s) believe(s) that no Extension of Time is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition for an extension of time.

Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:

- one months (\$110)                       two months (\$410)
- two months (\$930)                       four months (\$1450)

If an additional extension of time is required, please consider this as a petition therefor.

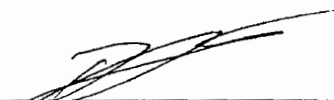
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- Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.
- Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

7/8/03  
Date

  
Dov Rosenfeld, Reg. No. 38687

Address for correspondence:  
Dov Rosenfeld  
5507 College Avenue, Suite 2  
Oakland, CA 94618  
Tel. +1-510-547-3378; Fax: +1-510-291-2985

1 A 29 54

**PATENT APPLICATION FEE DETERMINATION RECORD**

Effective December 29, 1999

Application or Docket Number

**CLAIMS AS FILED - PART I**

(Column 1) (Column 2)

FOR	NUMBER FILED	NUMBER EXTRA
BASIC FEE		
TOTAL CLAIMS	59 minus 20=	* 39
INDEPENDENT CLAIMS	4 minus 3 =	* 1
MULTIPLE DEPENDENT CLAIM PRESENT		

\* If the difference in column 1 is less than zero, enter "0" in column 2

**CLAIMS AS AMENDED - PART II**

(Column 1) (Column 2) (Column 3)

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*	0	Minus	**
Independent	*		Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*		Minus	**
Independent	*		Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					

AMENDMENT C		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*		Minus	**
Independent	*		Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					

\* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.  
 \*\* If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."  
 \*\*\* If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."  
 The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

SMALL ENTITY TYPE  OR

OTHER THAN SMALL ENTITY

RATE	FEE	OR	RATE	FEE
	345.00			690.00
X\$ 9=			X\$18=	702
X39=			X78=	98
+130=			+260=	
TOTAL			TOTAL	1472

SMALL ENTITY OR

OTHER THAN SMALL ENTITY

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X\$ 9=			X\$18=	
X39=			X78=	
+130=			+260=	
TOTAL ADDIT. FEE			TOTAL ADDIT. FEE	

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X\$ 9=			X\$18=	
X39=			X78=	
+130=			+260=	
TOTAL ADDIT. FEE			TOTAL ADDIT. FEE	

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X\$ 9=			X\$18=	
X39=			X78=	
+130=			+260=	
TOTAL ADDIT. FEE			TOTAL ADDIT. FEE	

ISSUE SLIP STAPLE AREA (for additional cross references)

5/11/10  
8/2/10

POSITION	INITIALS	ID NO.	DATE
FEE DETERMINATION	WJA		7/11/10
C.I.P.E. CLASSIFIER			7/11/10
FORMALITY REVIEW	-Z	JCS51	08-21-0
RESPONSE FORMALITY REVIEW			

INDEX OF CLAIMS

- ✓ ..... Rejected
- ..... Allowed
- (Through numeral) ..... Canceled
- + ..... Restricted
- N ..... Non-elected
- I ..... Interference
- A ..... Appeal
- O ..... Objected

Claim	Date	Claim	Date	Claim	Date
Final		Final		Final	
Original		Original		Original	
1	6/23/2003	1	6/22/2003	101	
2	7/16/2003	2		102	
3		3		103	
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5		5		105	
6		6		106	
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49		49		149	
50		50		150	

If more than 150 claims or 10 actions  
staple additional sheet here

OFFICE

SEARCHED			
Class	Sub.	Date	Exmr.
709	200 } 201 } 220 } 223 } 224 } 231 } 232 } 236 } 238 } 239 } 240 } 246 } 370 } 389 } 392 } 395.32 }	6/21/2003	MMM
update		7/16/2003	MMM

INTERFERENCE SEARCHED			
Class	Sub.	Date	Exmr.
709	224 } 370 } 389 }	7/16/2003	MMM

SEARCH NOTES (INCLUDING SEARCH STRATEGY)		
	Date	Exmr.
West	6/21/2003	MMM

(RIGHT OUTSIDE)

09608237  
1439F  
RET 232724102-000004  
SF  
RT ID: VD

PATENT APPLICATION



09608237

09/608237  
06/30/00

INITIALS *PH*

CONTENTS

	Date Received (Incl. C. of M.) or Date Mailed		Date Received (Incl. C. of M.) or Date Mailed
1. Application <i>18 pmt</i> papers.		42.	
2. <i>Force Dec missing 08-25-00</i>		43.	
3. <i>Decl, fees, EDT 11-10-00</i>		44.	
4. <i>IDS 4/12/01</i>		45.	
5. <i>I. D.S. w/References 4-18-02</i>		46.	
6. <i>3 Rejection-3 mos 6-25-03</i>		47.	
7. <i>Amend A 7-8-03</i>		48.	
8. <i>Notice of Allowability 7-17-03</i>		49.	
9. <i>Req for C&amp;C 2-27-04</i>		50.	
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41.		82.	

(LEFT OUTSIDE)

Our Ref./Docket No: AF/T-001-1

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.*

Application No.: 09/608237

Filed: June 30, 2000

Title: METHOD AND APPARATUS FOR  
MONITORING TRAFFIC IN A NETWORK



Group Art Unit: 2755

Examiner: (Unassigned)

RESPONSE TO NOTICE TO FILE MISSING PARTS OF APPLICATION

Assistant Commissioner for Patents  
Washington, D.C. 20231  
Attn: Box Missing Parts

Dear Assistant Commissioner:

This is in response to a Notice to File Missing Parts of Application under 37 CFR 1.53(f). Enclosed is a copy of said Notice and the following documents and fees to complete the filing requirements of the above-identified application:

- Executed Declaration and Power of Attorney. The above-identified application is the same application which the inventor executed by signing the enclosed declaration;
- Executed Assignment with assignment cover sheet.
- A credit card payment form in the amount of \$ 1772.00 is attached, being for:
  - Statutory basic filing fee: \$ 710
  - Additional claim fee of \$ 782
  - Assignment recordation fee of \$ 40
  - Extension Fee First Month of \$ 110
  - Missing Parts Surcharge \$ 130

Applicant(s) believe(s) that no Extension of Time is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition for an extension of time.

- Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:
  - one months (\$110)                       two months (\$380)
  - two months (\$870)                       four months (\$1360)

If an additional extension of time is required, please consider this as a petition therefor.

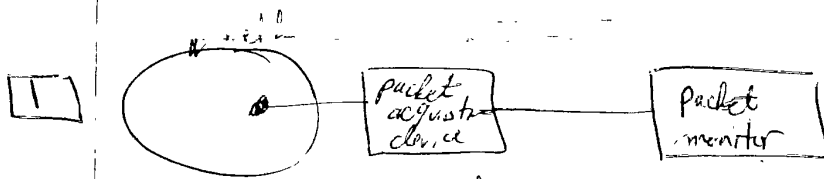
Certificate of Mailing under 37 CFR 1.8

I hereby certify that this response is being deposited with the United States Postal Service as first class mail in an envelope addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231 on.

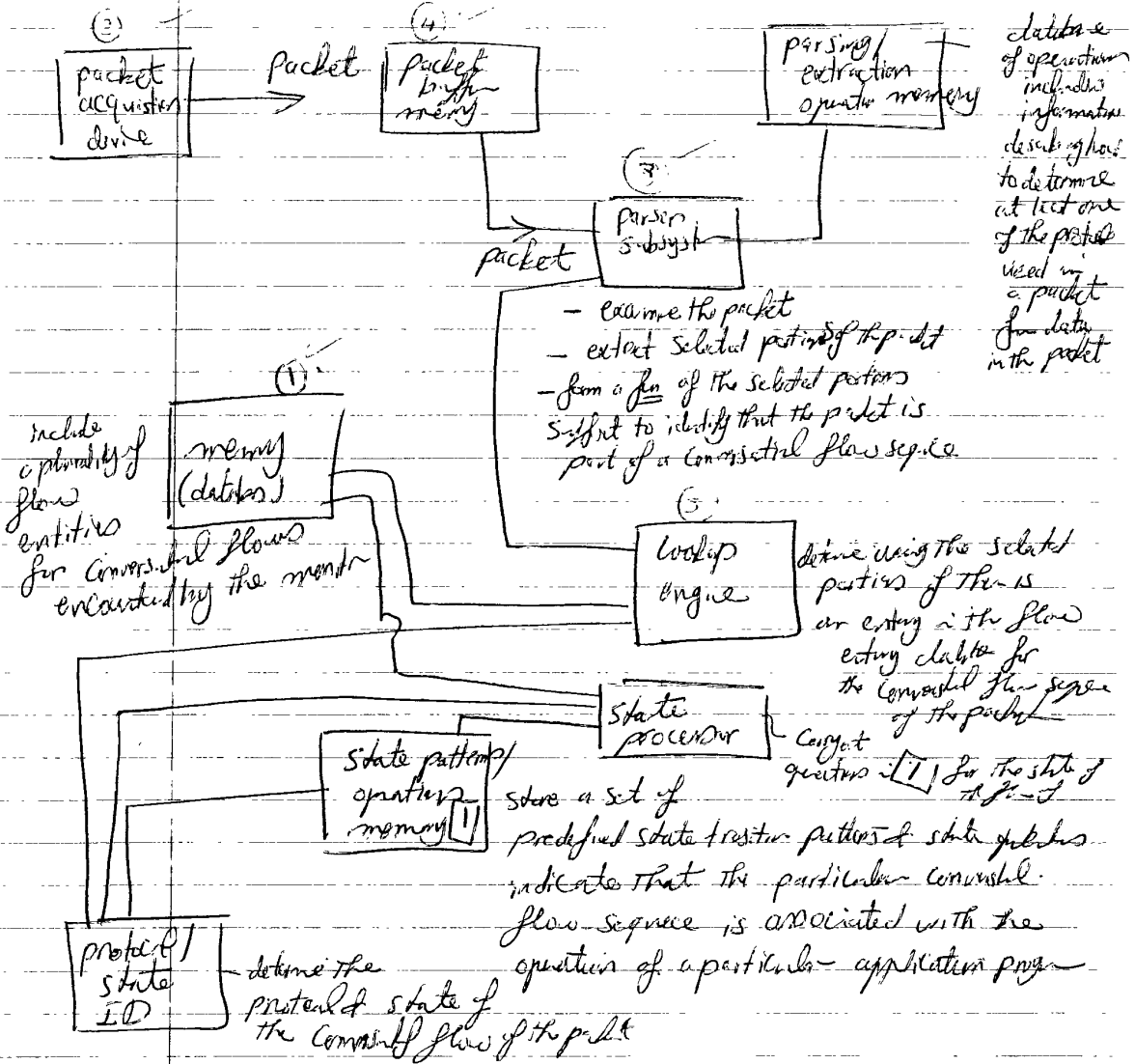
Date: Nov 1, 2000

Signed:

Name: Dov Rosenfeld, Reg No. 38687

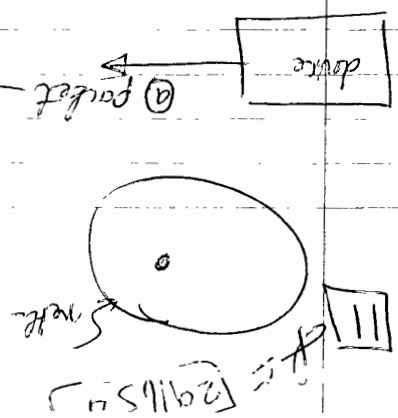


The packet monitor



- identify which application program is associated with the conversational flow sequence of the packet, update the flow entry

① perform parsing/evaluation operation on the packet to create a parser record comprising a list of selected portions of the packet  
 ② Looking up a flow-entry table having entry entries for previously encountered (comparable) flows, the looking up using at least some of the selected packet portions and determine if the packet is of an existing flow  
 → if the packet is of an existing flow, classify the packet as belonging to the existing flow  
 → if a new flow, store a new flow entry for the new flow entry table entry





# WEST

## Freeform Search

**Database:** US Patents Full-Text Database  
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 IBM Technical Disclosure Bulletins

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### Search History

DATE: Saturday, June 21, 2003 [Printable Copy](#) [Create Case](#)

<u>Set Name</u> <u>Query</u>	<u>Hit Count</u>	<u>Set Name</u>
side by side		result set
<i>DB=USPT; PLUR=YES; OP=ADJ</i>		
<u>L6</u> 14 same 15	50	<u>L6</u>
<u>L5</u> (packet or datagram) near5 flow	3376	<u>L5</u>
<u>L4</u> flow near3 (entry or entries)	4883	<u>L4</u>
<u>L3</u> 11 same L2	18	<u>L3</u>
<u>L2</u> (source or destination) adj3 address\$2	15666	<u>L2</u>
<u>L1</u> (packet or datagram) near3 signature	199	<u>L1</u>

END OF SEARCH HISTORY