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☐ The term of this patent subsequent to _____ (date) has been disclaimed.	_____ (Assistant Examiner) _____ (Date)			NOTICE OF ALLOWANCE MAILED: 6-4-04	
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** CONTINUING DATA **********

THIS APPLN CLAIMS BENEFIT OF 60/141,903 06/30/1999

** FOREIGN APPLICATIONS **********

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Re-using information from data transactions for maintaining statistics in network monitoring

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RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

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I hereby certify that this application and all attachments are being deposited with the United States Postal Service as Express Mail (Express Mail Label: EI417961927US in an envelope addressed to Box Patent Application, Assistant Commissioner for Patents, Washington, D.C. 20231 on.

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RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Serial No.: 60/141,903 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK to inventors Dietz, et al., filed June 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 Serial No. 09/608237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK, to inventors Dietz, et al., filed June 30, 2000, Attorney/Agent Reference Number APPT-001-1, and incorporated herein by reference.

U.S. Patent Application Serial No. 09/609179 for PROCESSING PROTOCOL SPECIFIC INFORMATION IN PACKETS SPECIFIED BY A PROTOCOL DESCRIPTION LANGUAGE, to inventors Koppenhaver, et al., filed June 30, 2000, Attorney/Agent Reference Number APPT-001-2, and incorporated herein by reference.

U.S. Patent Application Serial No. 09/608266 for ASSOCIATIVE CACHE STRUCTURE FOR LOOKUPS AND UPDATES OF FLOW RECORDS IN A NETWORK MONITOR, to inventors Sarkissian, et al., filed June 30, 2000, Attorney/Agent Reference Number APPT-001-4, and incorporated herein by reference.

U.S. Patent Application Serial No. 09/608267 for STATE PROCESSOR FOR PATTERN MATCHING IN A NETWORK MONITOR DEVICE, to inventors Sarkissian, et al., filed June 30, 2000, Attorney/Agent Reference Number APPT-001-5, 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.

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BACKGROUND

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 interconnected networks. In particular, there is a need for a real-time network monitor that can provide details as to the application programs being used. 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.

Related and incorporated by reference U.S. Patent application 09/608237 for *METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK*, to

inventors Dietz, et al, Attorney/Agent Docket APPT-001-1, describes a network monitor that includes carrying out protocol specific operations on individual packets including extracting information from header fields in the packet to use for building a signature for identifying the conversational flow of the packet and for recognizing future packets as belonging to a previously encountered flow. A parser subsystem includes a parser for recognizing different patterns in the packet that identify the protocols used. For each protocol recognized, a 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.

Each flow-entry includes one or more statistical measures, e.g., the packet count related to the flow, the time of arrival of a packet, the time differential.

In the preferred hardware embodiment, each of the LUE, state processor, and FIDE operate independently from the other two engines. The state processor performs one or more operations specific to the state of the flow.

It is advantageous to collect statistics on packets passing through a point in a network rather than to simply count each and every packet. By maintaining statistical measures in the flow-entries related to a conversational flow, embodiments of the present invention enable specific metrics to be collected in real-time that otherwise would not be possible. For example, it is desirable to maintain metrics related to bi-directional conversations based on the entire flow for each exchange in the conversation. By maintaining the state of flow, embodiments of the present invention also enable certain

metrics related to the states of flows to be determined.

Most prior-art network traffic monitors that use statistical metrics collect only end-point and end-of-session related statistics. Examples of such commonly used metrics include packet counts, byte counts, session connection time, session timeouts, session and transport response times and others. All of these deal with events that can be directly related to an event in a single packet. These prior-art systems cannot collect some important performance metrics that are related to a complete sequence of packets of a flow or to several disjointed sequences of the same flow in a network.

Time based metrics on application data packets are important. Such metrics could be determined if all the timestamps and related data could be stored and forwarded for later analysis. However when faced with thousands or millions of conversations per second on ever faster networks, storing all the data, even if compressed, would take too much processing, memory, and manager down load time to be practical.

Thus there is a need for maintaining and reporting time-base metrics from statistical measures accumulated from packets in a flow.

Network data is properly modeled as a population and not a sample. Thus, all the data needs to be processed. Because of the nature of application protocols, just sampling some of the packets may not give good measured related to flows. Missing just one critical packet, such as one the specified an additional port that data will be transmitted on, or what application will be run, can cause valid data to be lost.

Thus there is also a need for maintaining and reporting time-base metrics from statistical measures accumulated from *every* packet in a flow.

There also is a need to determine metrics related to a sequence of events. A good example is relative jitter. Measuring the time from the end of one packet in one direction to another packet with the same signature in the same direction collects data that relates normal jitter. This type of jitter metric is good for measuring broad signal quality in a packet network. However, it is not specific to the payload or data item being transported in a cluster of packets.

Using the state processing described herein, because the state processor can

search for specific data payloads, embodiments of monitor 300 can be programmed to collect the same jitter metric for a group of packets in a flow that are all related to a specific data payload. This allows the inventive system to provide metrics more focused on the type of quality related to a set of packets. This in general is more desirable than metrics related to single packets when evaluating the performance of a system in a network.

Specifically, the monitor system 300 can be programmed to maintain any type of metric at any state of a conversational flow. Also the system 300 can have the actual statistics programmed into the state at any point. This enables embodiments of the monitor system to collect metrics related to network usage and performance, as well as metrics related to specific states or sequences of packets.

Some of the specific metrics that can be collected only with states are events related to a group of traffic in one direction, events related to the status of a communication sequence in one or both directions, events related to the exchange of packets for a specific application in a specific sequence. This is only a small sample of the metrics that requires an engine that can relate the state of a flow to a set of metrics.

In addition, because the monitor 300 provides greater visibility to the specific application in a conversation or flow, the monitor 300 can be programmed to collect metrics that may be specific to that type of application or service. In other word, if a flow is for an Oracle Database server, an embodiment of monitor 300 could collect the number of packets required to complete a transaction. Only with both state and application classification can this type of metric be derived from the network.

Because the monitor 300 can be programmed to collect a diverse set of metrics, the system can be used as a data source for metrics required in a number of environments. In particular, the metrics may be used to monitor and analyze the quality and performance of traffic flows related to a specific set of applications. Other implementation could include metrics related to billing and charge-back for specific traffic flow and events with the traffic flows. Yet other implementations could be programmed to provide metrics useful for troubleshooting and capacity planning and related directly to a focused application and service.

SUMMARY

Another aspect of the invention is determining quality of service metrics based on each and every packet. A method of and monitor apparatus for analyzing a flow of packets passing through a connection point on a computer network are disclosed that may include such quality of service metrics. The method includes receiving a packet from a packet acquisition device, and looking up a flow-entry database containing flow-entries for previously encountered conversational flows. The looking up to determine if the received packet is of an existing flow. Each and every packet is processed. If the packet is of an existing flow, the method updates the flow-entry of the existing flow, including storing one or more statistical measures kept in the flow-entry. 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 storing one or more statistical measures kept in the flow-entry. The statistical measures are used to determine metrics related to the flow. The metrics may be base metrics from which quality of service metrics are determined, or may be the quality of service metrics.

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 than 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 Ethertype 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 Ethertype 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 table 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 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 multilevel 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 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 an 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 none 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 if 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 form 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 operations 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 (jump 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.

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 Ethertype 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.

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 Ethertype packet 1700. For an Ethertype 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 Ethertype 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 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 timestamps; 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 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. 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 form 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 be 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 exists 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, MIB 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, California) 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_1". If such address identifies the server 110 (shown also as server 204), the label used in the drawing is "S_1". The first two fields 214 and 215 in packet 206 are "S_1" and C_1" because packet 206 is provided from the server 110 and is destined for the client 106. Suppose for this example, "S_1" is an address numerically less than address "C_1". A third field "p^1" 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^1" 219 is an element that is being requested by the client from the server. A seventh field denoted "s_1a" 220 is the service requested by the client from server 110. The following eighth field "QA" 221 (for question mark) indicates that the client 106 wants to know what to use to access application "s_1a". 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_1" and "S_1", 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^1" is used as indicated in field 226. The request "i^1" is in field 229. Values have been filled in for the application port number, *e.g.*, in field 233 and protocol ""p^2"" 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_1"<"C_1", the order is address "S_1" followed by client address "C_1". 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^1". 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^1 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^1" (Sun RPC Bind Lookup), and a next-state that the state processor should proceed to for more complex recognition jobs, denoted as state "st_D" 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_D". The operations for state "st_D" 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_1" followed by (the numerically higher address) client "C_1". A protocol field 252 defines the protocol to be used, *e.g.,* "p^2" 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^2". 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^1". 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^2". 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_1" followed by client "C_1". 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_1 and C_1, in a pair of fields 260 and 261. A field 262 defines the protocol as "p^2", 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^2" 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_1" 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.

Re-Using Information from Flows for Maintaining Metrics

The flow-entry of each flow stores a set of statistical measures for the flow, including the total number of packets in the flow, the time of arrival, and the differential time from the last arrival.

Referring again to FIG. 3, the state processing process 328 performs operations defined for the state of the flow, for example for the particular protocol so far identified for the flow. One aspect of the invention is that from time to time, a set of one or more metrics related t the flow may be determined using one or more of the statistical measures stored in the flow-entry. Such metric determining may be carried out, for example, by the state processor running instructions in the state processor instruction and pattern database 326. Such metrics may then be sent by the analyzer subsystem to a host computer connected to the monitor. Alternatively, such metric determining may be carried out by a processor connected to the flow-entry database 324. In our preferred hardware implementation shown in FIG. 10, an analyzer host interface and control 1118 may be configured to configured to access flow-entry records via cache system 1115 to output to a processor via the host bus interface. The processor may then do the reporting

of the base metrics.

Fig. 15 describes how the monitor system can be set up with a host computer 1504. The monitor 300 sends metrics from time to time to the host computer 1504, and the host computer 1504 carries out part of the analysis.

This following section describes how the monitor of the invention can be used to monitor the Quality of Service (QOS) by providing QOS Metrics.

Quality of Service Traffic Statistics (Metrics)

This next section defines the common structure that may be applied for the Quality of Service (QOS) Metrics according to one aspect of the invention. It also defines the "original" (or "base") set of metrics that may be determined in an embodiment of the invention to support QOS. The base metrics are determined as part of state processing or by a processor connected to monitor 300, and the QOS metrics are determined from the base metrics by the host computer 1504. The main reason for the breakdown is that the complete QOS metrics may be computationally complex, involving square roots and other functions requiring more computational resources than may be available in real time. The base functions are chosen to be simple to calculate in real time and from which complete QOS metrics may be determined. Other breakdowns of functions clearly are possible within the scope of the invention.

Such metric determining may be carried out, for example, by the state processor running instructions in the state processor instruction and pattern database 326. Such base metrics may then be sent by the analyzer subsystem via a microprocessor or logic circuit connected to the monitor. Alternatively, such metric determining may be carried out by a microprocessor (or some other logic) connected to the flow-entry database 324. In our preferred hardware implementation shown in FIGS. 10 and 11, such a microprocessor is connected cache system 1115 via an analyzer host interface and control 1118 and host bus interface. These components may be configured to access flow-entry records via cache system 1115 to enable the microprocessor to determine and report the base metrics.

The QOS Metrics may broken into the following Metrics Groups. The names are descriptive. The list is not exhaustive, and other metrics may be used. The QOS metrics

below include client-to-server (CS) and server-to-client (SC) metrics.

Traffic Metrics such as CSTraffic and SCTraffic.

Jitter Metrics such as CSTraffic and CS Traffic.

Exchange Response Metrics such as CSExchangeResponseTimeStartToStart, CSExchangeResponseTimeEndToStart, CSExchangeResponseTimeStartToEnd, SCExchangeResponseTimeStartToStart, SCExchangeResponseTimeEndToStart, and SCExchangeResponseTimeStartToEnd.

Transaction Response Metrics such as CSTransactionResponseTimeStartToStart, CSApplicationResponseTimeEndToStart, CSApplicationResponseTimeStartToEnd, SCTransactionResponseTimeStartToStart, SCApplicationResponseTimeEndToStart, and SCApplicationResponseTimeStartToEnd.

Connection Metrics such as ConnectionEstablishment and ConnectionGracefulTermination, and ConnectionTimeoutTermination.

Connection Sequence Metrics such as CSConnectionRetransmissions, SCConnectionRetransmissions, and CSConnectionOutOfOrders, SCConnectionOutOfOrders.

Connection Window Metrics, CSConnectionWindow, SCConnectionWindow, CSConnectionFrozenWindows, SCConnectionFrozenWindows, CSConnectionClosedWindows, and SCConnectionClosedWindows

QOS Base Metrics

The simplest means of representing a group of data is by frequency distributions in sub-ranges. In the preferred embodiment, there are some rules in creating the sub-ranges. First the range needs to be known. Second a sub-range size needs to be determined. Fixed sub-range sizes are preferred, alternate embodiments may use variable sub-range sizes.

Determining complete frequency distributions may be computationally expensive. Thus, the preferred embodiment uses metrics determined by summation functions on the individual data elements in a population.

The metrics reporting process provides data that can be used to calculate useful statistical measurements. In one embodiment, the metrics reporting process is part of the state processing that is carried out from time to time according to the state, and in another embodiment, the metrics reporting process carried out from time to time by a microprocessor having access to flow records. Preferably, the metrics reporting process provides base metrics and the final QOS metrics calculations are carried out by the host computer 1504. In addition to keeping the real time state processing simple, the partitioning of the tasks in this way provides metrics that are scalable. For example, the base metrics from two intervals may be combined to metrics for larger intervals.

Consider, for example is the arithmetic mean defined as the sum of the data divided by the number of data elements.

$$\overline{X} = \frac{\sum x}{N}$$

Two base metrics provided by the metrics reporting process are the sum of the x, and the number of elements N. The host computer 1504 performs the division to obtain the average. Furthermore, two sets base metrics for two intervals may be combined by adding the sum of the x's and by adding the number of elements to get a combined sum and number of elements. The average formula then works just the same.

The base metrics have been chosen to maximize the amount of data available while minimizing the amount of memory needed to store the metric and minimizing the processing requirement needed to generate the metric. The base metrics are provided in a metric data structure that contains five unsigned integer values.

- N count of the number of data points for the metric.
- ΣX sum of all the data point values for the metric.
- $\Sigma (X^2)$ sum of all the data point values squared for the metric.
- X_{max} maximum data point value for the metric.
- X_{min} minimum data point value for the metric.

A metric is used to describe events over a time interval. The base metrics are

determined from statistical measures maintained in flow-entries. It is not necessary to cache all the events and then count them at the end of the interval. The base metrics have also been designed to be easily scaleable in terms of combining adjacent intervals.

The following rules are applied when combining base metrics for contiguous time intervals.

- N ΣN
- ΣX $\Sigma(\Sigma (X))$
- $\Sigma (X^2)$ $\Sigma(\Sigma (X^2))$
- X_{max} $MAX(X_{max})$
- X_{min} $MIN(X_{min})$

In addition to the above five values, a "trend" indicator is included in the preferred embodiment data structure. This is provided by an enumerated type. The reason for this is that the preferred method of generating trend information is by subtract an initial first value for the interval from the final value for the interval. Only the sign of the resulting number may have value, for example, to determine an indication of trend.

Typical operations that may be performed on the base metrics include:

- Number N.
- Frequency $\frac{N}{TimeInterval}$.
- Maximum X_{max}.
- Minimum X_{min}.
- Range $R = X_{max} - X_{min}$.
- Arithmetic Mean $\overline{X} = \frac{\sum X}{N}$.
- Root Mean Square $RMS = \sqrt{\frac{\sum (X^2)}{N}}$.

- Variance $\sigma^2 = \frac{\sum(X-\bar{X})^2}{N} = \frac{(\sum X^2) - 2\bar{X}(\sum X) + N(\bar{X}^2)}{N}$.

- Standard Deviation $\sigma = \sqrt{\frac{\sum((X-\bar{X})^2)}{N}} = \sqrt{\frac{(\sum(X^2)) - 2\bar{X}(\sum X) + N(\bar{X}^2)}{N}}$.

- Trend information, which may be the trend between polled intervals and the trend within an interval. Trending between polled intervals is a management application function. Typically the management station would trend on the average of the reported interval. The trend within an interval is presented as an enumerated type and can easily be generated by subtracting the first value in the interval from the last and assigning trend based on the sign value.

Alternate Embodiments

One or more of the following different data elements may be included in various implementation of the metric.

- Sum of the deltas (i.e., differential values). The trend enumeration can be based on this easy calculation.

- Sum of the absolute values of the delta values. This would provide a measurement of the overall movement within an interval.

- Sum of positive delta values and sum of the negative delta values. Expanding each of these with an associated count and maximum would give nice information.

- The statistical measurement of skew can be obtained by adding $\Sigma(X^3)$ to the existing metric.

- The statistical measurement of kurtosis can be obtained by adding $\Sigma(X^3)$ and $\Sigma(X^4)$ to the existing metric.

- Data to calculate a slope of a least-squares line through the data..

Various metrics are now described in more detail.

Traffic Metrics

CSTraffic

Definition

This metric contains information about the volume of traffic measured for a given application and either a specific Client-Server Pair or a specific Server and all of its clients.

This information duplicates, somewhat, that which may be found in the standard, RMON II, AL/NL Matrix Tables. It has been included here for convenience to applications and the associated benefit of improved performance by avoiding the need to access different functional RMON areas when performing QOS Analysis.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Packets	Count of the # of Packets from the Client(s) to the Server
Σ	Applicable	Octets	Sum total of the # of Octets in these packets from the Client(s) to the Server.
Maximum	Not Applicable		
Minimum	Not Applicable		

SCTraffic

Definition

This metric contains information about the volume of traffic measured for a given application and either a specific Client-Server Pair or a specific Server and all of its clients.

This information duplicates, somewhat, that which may be found in the standard, RMON II, AL/NL Matrix Tables. It has been included here for convenience to applications and the associated benefit of improved performance by avoiding the need to access different functional RMON areas when performing QOS Analysis.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Packets	Count of the # of Packets from the Server to the Client(s)
Σ	Applicable	Octets	Sum total of the # of Octets in these packets from the Server to the Client(s).
Maximum	Not Applicable		
Minimum	Not Applicable		

Jitter Metrics

CSJitter

Definition

This metric contains information about the Jitter (e.g. Inter-packet Gap) measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSJitter* measures the Jitter for Data Messages from the Client to the Server.

A Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. Client to Server Inter-packet Gaps are measured between Data packets within the Message. Note that in our implementaions, ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets. The interval between the last packet in a Data Message from the Client to the Server and the 1st packet of the Next Message in the same direction is not interpreted as an Inter-Packet Gap.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Inter-Packet Gaps	Count of the # of Inter-Packet Gaps measured for Data from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Delta Times in these Inter-Packet Gaps
Maximum	Applicable	uSeconds	The maximum Delta Time of Inter-Packet Gaps measured
Minimum	Applicable	uSeconds	The minimum Delta Time of Inter-Packet Gaps measured.

SCJitter

Definition

This metric contains information about the Jitter (e.g. Inter-packet Gap) measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCJitter* measures the Jitter for Data Messages from the Client to the Server.

A Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. Server to Client Inter-packet Gaps are measured between Data packets within the Message. Note that in our implementaions, ACKnowledgements are not considered within the measurement of this metric.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Inter-Packet Gaps	Count of the # of Inter-Packet Gaps measured for Data from the Server to the Client(s).
Σ	Applicable	uSeconds	Sum total of the Delta Times in these Inter-Packet Gaps.
Maximum	Applicable	uSeconds	The maximum Delta Time of Inter-Packet Gaps measured
Minimum	Applicable	uSeconds	The minimum Delta Time of Inter-Packet Gaps measured.

Exchange Response Metrics

CSExchangeResponseTimeStartToStart

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSExchangeResponseTimeStartToStart* measures the response time between **start** of Data Messages from the Client to the Server and the **start** of their subsequent response Data Messages from the Server to the Client.

A Client->Server Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The total time between the start of the Client->Server Data Message and the start of the Server->Client Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client-> Server Messages	Count of the # Client->Server Messages measured for Data Exchanges from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Start-to-Start Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-Start Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-Start Delta Time of these Exchange Response Times

CSExchangeResponseTimeEndToStart

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair

or a specific Server and all of its clients. Specifically, *CSExchangeResponseTimeEndToStart* measures the response time between **end** of Data Messages from the Client to the Server and the **start** of their subsequent response Data Messages from the Server to the Client.

A Client->Server Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The total time between the end of the Client->Server Data Message and the start of the Server->Client Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client-> Server Messages	Count of the # Client->Server Messages measured for Data Exchanges from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the End-to-Start Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum End-to-Start Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum End-to-Start Delta Time of these Exchange Response Times

CSExchangeResponseTimeStartToEnd

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSExchangeResponseTimeEndToStart* measures the response time between **Start** of Data Messages from the Client to the Server and the **End** of their subsequent response Data Messages from the Server to the Client.

A Client->Server Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The end of the Response Message in the other direction (e.g. from the Server to the Client) is demarcated by the last data of the Message prior to the 1st data packet of the **next** Client to Server Message. The total time between the start of the Client->Server Data Message and the end of the Server->Client Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client-> Server Message Exchanges	Count of the # Client->Server and Server-> Client Exchange message pairs measured for Data Exchanges from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Start-to-End Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-End Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-End Delta Time of these Exchange Response Times

SCExchangeResponseTimeStartToStart

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCExchangeResponseTimeStartToStart* measures the response time between **start** of Data Messages from the Server to the Client and the **start** of their subsequent response Data Messages from the Client to the Server.

A Server->Client Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The total time between the start of the

Server->Client Data Message and the start of the Client->Sever Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Server-> Client Messages	Count of the # Server->Client Messages measured for Data Exchanges from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Start-to-Start Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-Start Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-Start Delta Time of these Exchange Response Times

SCExchangeResponseTimeEndToStart

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCExchangeResponseTimeEndToStart* measures the response time between **end** of Data Messages from the Server to the Client and the **start** of their subsequent response Data Messages from the Client to the Server.

A Server->Client Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The total time between the end of the Server->Client Data Message and the start of the Client->Server Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-

order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Server-> Client Messages	Count of the # Server->Client Messages measured for Data Exchanges from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the End-to-Start Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum End-to-Start Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum End-to-Start Delta Time of these Exchange Response Times

SCExchangeResponseTimeStartToEnd

Definition

This metric contains information about the Transport-level response time measured for data packets for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCExchangeResponseTimeEndToStart* measures the response time between **Start** of Data Messages from the Server to the Client and the **End** of their subsequent response Data Messages from the Client to the Server.

A Server->Client Data Message starts with the 1st Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1st subsequent Data Packet in the other direction. The end of the Response Message in the other direction (e.g. from the Server to the Client) is demarcated by the last data of the Message prior to the 1st data packet of the **next** Server to Client Message. The total time between the start of the Server->Client Data Message and the end of the Client->Server Data Message is measured with this metric. Note that ACKnowledgements are not considered within the measurement of this metric.

Also, there is no consideration in the measurement for retransmissions or out-of-order data packets.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client-Server Message Exchanges	Count of the # Server->Client and Client->Server Exchange message pairs measured for Data Exchanges from the Server to the Client(s)
Σ	Applicable	uSeconds	Sum total of the Start-to-End Delta Times in these Exchange Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-End Delta Time of these Exchange Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-End Delta Time of these Exchange Response Times

Transaction Response Metrics

CSTransactionResponseTimeStartToStart

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSTransactionResponseTimeStartToStart* measures the response time between **start** of an application transaction from the Client to the Server and the **start** of their subsequent transaction response from the Server to the Client.

A Client->Server transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Client to the Server and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request. The total time between the start of the Client->Server transaction request and the start of the actual transaction response from the Server->Client is measured with this metric.

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *CSExchangeResponseTimeStartToStart.*

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client->Svr Transaction Requests	Count of the # Client->Server Transaction Requests measured for Application requests from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Start-to-Start Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-Start Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-Start Delta Time of these Application Response Times

CSApplicationResponseTimeEndToStart

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSApplicationResponseTimeEndToStart* measures the response time between **end** of an application transaction from the Client to the Server and the **start** of their subsequent transaction response from the Server to the Client.

A Client->Server transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Client to the Server and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request The total time between the end of the Client->Server transaction request and the start of the actual transaction response from the Server->Client is measured with this metric

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *CSExchangeResponseTimeEndToStart.*

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client->Svr Transaction Requests	Count of the # Client->Server Transaction Requests measured for Application requests from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the End-to-Start Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum End-to-Start Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum End-to-Start Delta Time of these Application Response Times

CSApplicationResponseTimeStartToEnd

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *CSTransactionResponseTimeStartToEnd* measures the response time between **Start** of an application transaction from the Client to the Server and the **End** of their subsequent transaction response from the Server to the Client.

A Client->Server transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) a transaction request from the Client to the Server and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request. The end of the Transaction Response in the other direction (e.g. from the Server to the Client) is demarcated by the last data of the transaction response prior to the 1st data of the **next** Client to Server Transaction Request. The total time between the start of the Client->Server transaction request and the end of the Server->Client transaction response is measured with this metric.

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *CSExchangeResponseTimeStartToEnd.*

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Client-> Server Transactions	Count of the # Client<->Server request/response pairs measured for transactions from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Start-to-End Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-End Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-End Delta Time of these Application Response Times

SCTransactionResponseTimeStartToStart

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCTransactionResponseTimeStartToStart* measures the response time between **start** of an application transaction from the Server to the Client and the **start** of their subsequent transaction response from the Client to the Server.

A Server->Client transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Server to the Client and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request. The total time between the start of the Server->Client transaction request and the start of the actual transaction response from the Client->Server is measured with this metric.

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *SCExchangeResponseTimeStartToStart.*

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Svr->Client Transaction Requests	Count of the # Server->Client Transaction Requests measured for Application requests from the Server to the Client(s)
Σ	Applicable	uSeconds	Sum total of the Start-to-Start Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-Start Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-Start Delta Time of these Application Response Times

SCApplicationResponseTimeEndToStart

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCApplicationResponseTimeEndToStart* measures the response time between **end** of an application transaction from the Server to the Client and the **start** of their subsequent transaction response from the Client to the Server.

A Server->Client transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Server to the Client and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request The total time between the end of the Server->Client transaction request and the start of the actual transaction response from the Client->Server is measured with this metric

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *SCExchangeResponseTimeEndToStart*.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Svr->Client Transaction Requests	Count of the # Server->Client Transaction Requests measured for Application requests from the Server to the Client(s)
Σ	Applicable	uSeconds	Sum total of the End-to-Start Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum End-to-Start Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum End-to-Start Delta Time of these Application Response Times

SCApplicationResponseTimeStartToEnd

Definition

This metric contains information about the **Application-level response time** measured for application transactions for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *SCTransactionResponseTimeStartToEnd* measures the response time between **Start** of an application transaction from the Server to the Client and the **End** of their subsequent transaction response from the Client to the Server.

A Server->Client transaction starts with the 1st Transport Protocol Data Packet/Unit (TPDU) a transaction request from the Server to the Client and is demarcated (or terminated) by 1st subsequent data packet of the response to the transaction request. The end of the Transaction Response in the other direction (e.g. from the Client to the Server) is demarcated by the last data of the transaction response prior to the 1st data of the **next** Server to Client Transaction Request. The total time between the start of the Server->Client transaction request and the end of the Client->Server transaction response is measured with this metric.

This metric is considered a "best-effort" measurement. Systems implementing this metric should make a "best-effort" to demarcate the start and end of requests and responses with the specific application's definition of a logical transaction. The lowest level of support for this metric would make this metric the equivalent of *SCExchangeResponseTimeStartToEnd.*

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Server-> Client Transactions	Count of the # Server<->Client request/response pairs measured for transactions from the Server to the Client(s)
Σ	Applicable	uSeconds	Sum total of the Start-to-End Delta Times in these Application Response Times
Maximum	Applicable	uSeconds	The maximum Start-to-End Delta Time of these Application Response Times
Minimum	Applicable	uSeconds	The minimum Start-to-End Delta Time of these Application Response Times

Connection Metrics

ConnectionEstablishment

Definition

This metric contains information about the transport-level connection establishment for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *ConnectionsEstablishment* measures number of connections established the Client(s) to the Server. The information contain, in essence, includes:

- # Transport Connections Successfully established
- Set-up Times of the established connections
- Max. # of Simultaneous established connections.
- # Failed Connection establishment attempts (due to either timeout or rejection)

Note that the "# of CURRENT Established Transport Connections" may be derived from this metric along with the *ConnectionGracefulTermination* and *ConnectionTimeoutTermination* metrics, as follows:

current connections :== "# successfully established"
- "# terminated gracefully"
- "# terminated by time-out"

The set-up time of a connection is defined to be the delta time between the first transport-level, Connection Establishment Request (*i.e.*, SYN, CR-TPDU, etc.) and the first Data Packet exchanged on the connection.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Connections	Count of the # Connections Established from the Client(s) to the Server
Σ	Applicable	uSeconds	Sum total of the Connection Set-up Times in these Established connections
Maximum	Applicable	Connections	Count of the MAXIMUM simultaneous # Connections Established from the Client(s) to the Server
Minimum	Not Applicable	Connections	Count of the Failed simultaneous # Connections Established from the Client(s) to the Server

ConnectionGracefulTermination

Definition

This metric contains information about the transport-level connections terminated gracefully for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *ConnectionsGracefulTermination* measures gracefully terminated connections both in volume and summary connection duration. The information contain, in essence, includes:

- # Gracefully terminated Transport Connections
- Durations (lifetimes) of gracefully terminated connections.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Connections	Count of the # Connections Gracefully Terminated between Client(s) to the Server
Σ	Applicable	mSeconds	Sum total of the Connection Durations (Lifetimes) of these terminated connections
Maximum	Not Applicable		
Minimum	Not Applicable		

ConnectionTimeoutTermination

Definition

This metric contains information about the transport-level connections terminated non-gracefully (e.g. Timed-Out) for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, *ConnectionsTimeoutTermination* measures previously established and timed-out connections both in volume and summary connection duration. The information contain, in essence, includes:

- # Timed-out Transport Connections
- Durations (lifetimes) of timed-out terminated connections.

The duration factor of this metric is considered a "best-effort" measurement. Independent network monitoring devices cannot really know when network entities actually detect connection timeout conditions and hence may need to extrapolate or estimate when connection timeouts actually occur.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Connections	Count of the # Connections Timed-out between Client(s) to the Server
Σ	Applicable	mSeconds	Sum total of the Connection Durations (Lifetimes) of these terminated connections
Maximum	Not Applicable		
Minimum	Not Applicable		

Connection Sequence Metrics

CSConnectionRetransmissions

Definition

This metric contains information about the transport-level connection health for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, CS*ConnectionRetransmissions* measures number of actual events within established connection lifetimes in which Transport, data-bearing PDUs (packets) from the Client->Server were retransmitted.

Note that retransmission events as seen by the Network Monitoring device indicate the "duplicate" presence of a TPDU as observed on the network.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # Data TPDU retransmissions from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

SCConnectionRetransmissions

Definition

This metric contains information about the transport-level connection health for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, SC*ConnectionRetransmissions* measures number of actual

events within established connection lifetimes in which Transport, data-bearing PDUs (packets) from the Server->Client were retransmitted.

Note that retransmission events as seen by the Network Monitoring device indicate the "duplicate" presence of a TPDU as observed on the network.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # Data TPDU retransmissions from the Server to the Client(s)
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

CSConnectionOutOfOrders

Definition

This metric contains information about the transport-level connection health for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, CS*ConnectionOutOfOrders* measures number of actual events within established connection lifetimes in which Transport, data-bearing PDUs (packets) from the Client->Server were detected as being out of sequential order.

Note that retransmissions (or duplicates) are considered to be different than out-of-order events and are tracked separately in the CS*ConnectionRetransmissions* metric.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # Out-of-Order TPDU events from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

SCConnectionOutOfOrders

Definition

This metric contains information about the transport-level connection health for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, SC*ConnectionOutOfOrders* measures number of actual events within established connection lifetimes in which Transport, data-bearing PDUs (packets) from the Server->Client were detected as being out of sequential order.

Note that retransmissions (or duplicates) are considered to be different than out-of-order events and are tracked separately in the SC*ConnectionRetransmissions* metric.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # Out-of-Order TPDU events from the Server to the Client(s)
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

Connection Window Metrics

CSConnectionWindow

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, CS*ConnectionWindow* measures number of Transport-level Acknowledges within established connection lifetimes and their relative sizes from the Client->Server.

Note that the number of DATA TPDUs (packets) may be estimated by differencing the Acknowledge count of this metric and the overall traffic from the Client to the Server (see *CSTraffic* above). A slight error in this calculation may occur due to Connection Establishment and Termination TPDUS, but it should not be significant.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU retransmissions from the Client(s) to the Server
Σ	Not Applicable	Increments	Sum total of the Window Sizes of the Acknowledges
Maximum	Not Applicable	Increments	The maximum Window Size of these Acknowledges
Minimum	Not Applicable	Increments	The minimum Window Size of these Acknowledges

SCConnectionWindow

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, SS*ConnectionWindow* measures number of Transport-level Acknowledges within established connection lifetimes and their relative sizes from the Server->Client.

Note that the number of DATA TPDUs (packets) may be estimated by differencing the Acknowledge count of this metric and the overall traffic from the Client to the Server (see *SCTraffic* above).. A slight error in this calculation may occur due to Connection Establishment and Termination TPDUS, but it should not be significant.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU retransmissions from the Server to the Client(s)
Σ	Applicable	Increments	Sum total of the Window Sizes of the Acknowledges
Maximum	Applicable	Increments	The maximum Window Size of these Acknowledges
Minimum	Applicable	Increments	The minimum Window Size of these Acknowledges

CSConnectionFrozenWindows

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, CS*ConnectionWindow* measures number of Transport-level Acknowledges from Client->Server within established connection lifetimes which validly acknowledge data, but either

- failed to increase the upper window edge,
- reduced the upper window edge

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU with frozen/reduced windows from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

SCConnectionFrozenWindows

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, SC*ConnectionWindow* measures number of Transport-level Acknowledges from Server->Client within established connection lifetimes which validly acknowledge data, but either

- failed to increase the upper window edge,
- reduced the upper window edge

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU with frozen/reduced windows from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

CSConnectionClosedWindows

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, CS*ConnectionWindow* measures number of Transport-level Acknowledges from Client->Server within established connection lifetimes which fully closed the acknowledge/sequence window.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU with Closed windows from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

SCConnectionClosedWindows

Definition

This metric contains information about the transport-level connection windows for a given application and either a specific Client-Server Pair or a specific Server and all of its clients. Specifically, SC*ConnectionWindow* measures number of Transport-level Acknowledges from Server->Client within established connection lifetimes which fully closed the acknowledge/sequence window.

Metric Specification

Metric	Applicability	Units	Description
N	Applicable	Events	Count of the # ACK TPDU with Closed windows from the Client(s) to the Server
Σ	Not Applicable		
Maximum	Not Applicable		
Minimum	Not Applicable		

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 or 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.

CLAIMS

What is claimed is:

1. A method of analyzing a flow of packets passing through a connection point on a computer network, the method comprising:

(a) receiving a packet from a packet acquisition device;

(b) looking up a flow-entry database comprising none or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow;

(d) if the packet is of an existing flow, updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry; and

(e) if the packet is of a new flow, storing a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry,

wherein every packet passing though the connection point is received by the packet acquisition device.

2. A method according to claim 1, further including:

extracting identifying portions from the packet,

wherein the looking up uses a function of the identifying portions.

3. A method according to claim 1, wherein the steps are carried out in real time on each packet passing through the connection point.

4. A method according to claim 1, wherein the one or more statistical measures include measures selected from the set consisting of the total packet count for the flow, the time, and a differential time from the last entered time to the present time.

5. A method according to claim 1, further including reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry.

6. A method according to claim 7, wherein the metrics include one or more quality of service (QOS) metrics.

7. A method according to claim 5, wherein the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time.

8. A method according to claim 7, further comprising calculating one or more quality of service (QOS) metrics from the base metrics.

9. A method according to claim 7, wherein the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to determine respective metrics for the combined interval.

10. A method according to claim 1, wherein step (d) includes if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow; and wherein step (e) includes if the packet is of a new flow, performing any state operations required for the initial state of the new flow.

11. A method according to claim 10, further including reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry.

12. A method according to claim 11, wherein the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time.

13. A method according to claim 12, wherein the reporting is part of the state operations for the state of the flow.

14. A method according to claim 10, wherein the state operations include updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry.

15. A method according to claim 14, further including receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow.

16. A method according to claim 15, wherein one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow.

17. A packet monitor for examining packets passing through a connection point on a computer network, each packets conforming to one or more protocols, the monitor comprising:

(a) a packet acquisition device coupled to the connection point and configured to receive packets passing through the connection point;

(b) a memory for storing a database comprising none or more flow-entries for previously encountered conversational flows to which a received packet may belong; and

(c) an analyzer subsystem coupled to the packet acquisition device configured to lookup whether a received packet belongs to a flow-entry in the flow-entry database, to update the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry in the case that the packet is of an existing flow, and to store a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry if the packet is of a new flow.

18. A packet monitor according to claim 17, further comprising:

a parser subsystem coupled to the packet acquisition device and to the analyzer subsystem configured to extract identifying information from a received packet,

wherein each flow-entry is identified by identifying information stored in the flow-entry, and wherein the cache lookup uses a function of the extracted identifying information.

19. A packet monitor according to claim 17, wherein the one or more statistical measures include measures selected from the set consisting of the total packet count for the flow, the time, and a differential time from the last entered time to the present time.

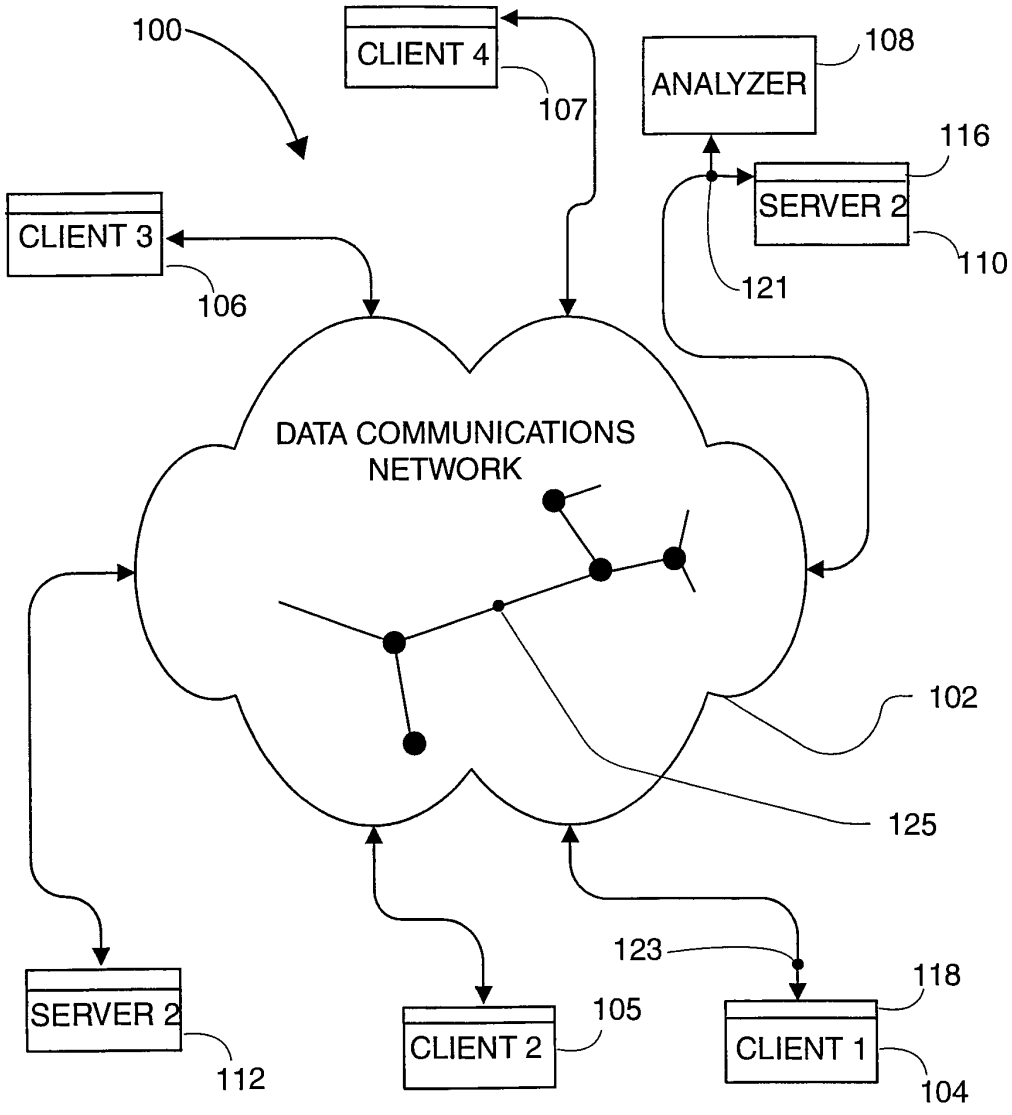
20. A packet monitor according to claim 17, further including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow.

21. A packet monitor according to claim 20, wherein the statistical processor determine and reports the one or more metrics from time to time.

ABSTRACT

A method of and monitor apparatus for analyzing a flow of packets passing through a connection point on a computer network. The method includes receiving a packet from a packet acquisition device, and looking up a flow-entry database containing flow-entries for previously encountered conversational flows. The looking up to determine if the received packet is of an existing flow. Each and every packet is processed. If the packet is of an existing flow, the method updates the flow-entry of the existing flow, including storing one or more statistical measures kept in the flow-entry. 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 storing one or more statistical measures kept in the flow-entry. The statistical measures are used to determine metrics related to the flow. The metrics may be base metrics from which quality of service metrics are determined, or may be the quality of service metrics.

1/18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CLIENT 4
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ANALYZER
108
116
SERVER 2
110
121
CLIENT 3
106
DATA COMMUNICATIONS NETWORK
102
125
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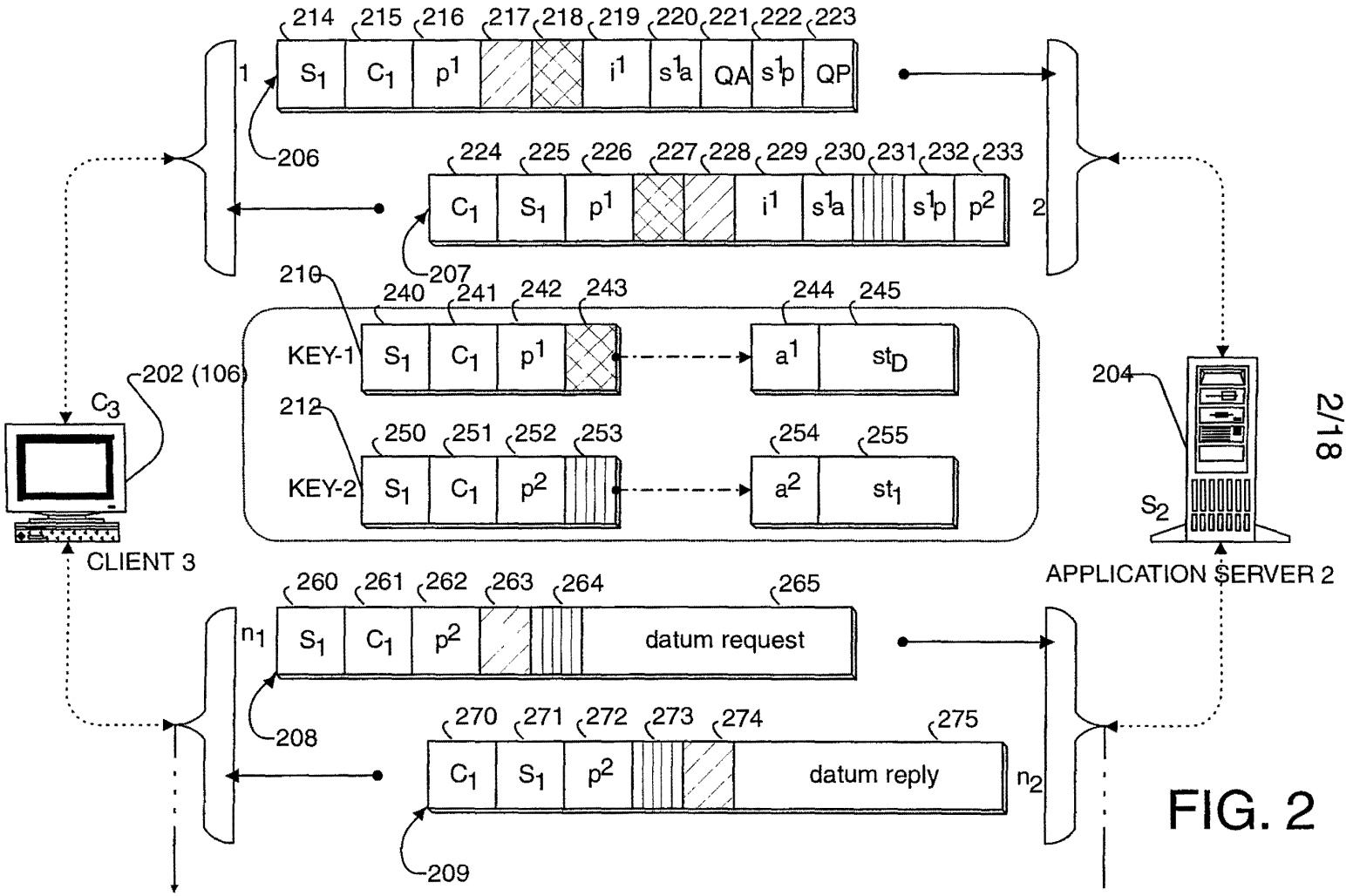
SERVER 2
112
CLIENT 2
105
CLIENT 1
104

FIG. 1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206
224 225 226 227 228 229 230 231 232 233
C1 S1 p1 i1 s1a s1p p2
2
207
210
240 241 242 243 244 245
KEY-1 S1 C1 p1 a1 stD
212
250 251 252 253 254 255
KEY-2 S1 C1 p2 a2 st1
202 (106)
C3
CLIENT 3
204
S2
APPLICATION SERVER 2
260 261 262 263 264 265
n1
S1 C1 p2 datum request
208
270 271 272 273 274 275
C1 S1 p2 datum reply
n2
209

FIG. 2

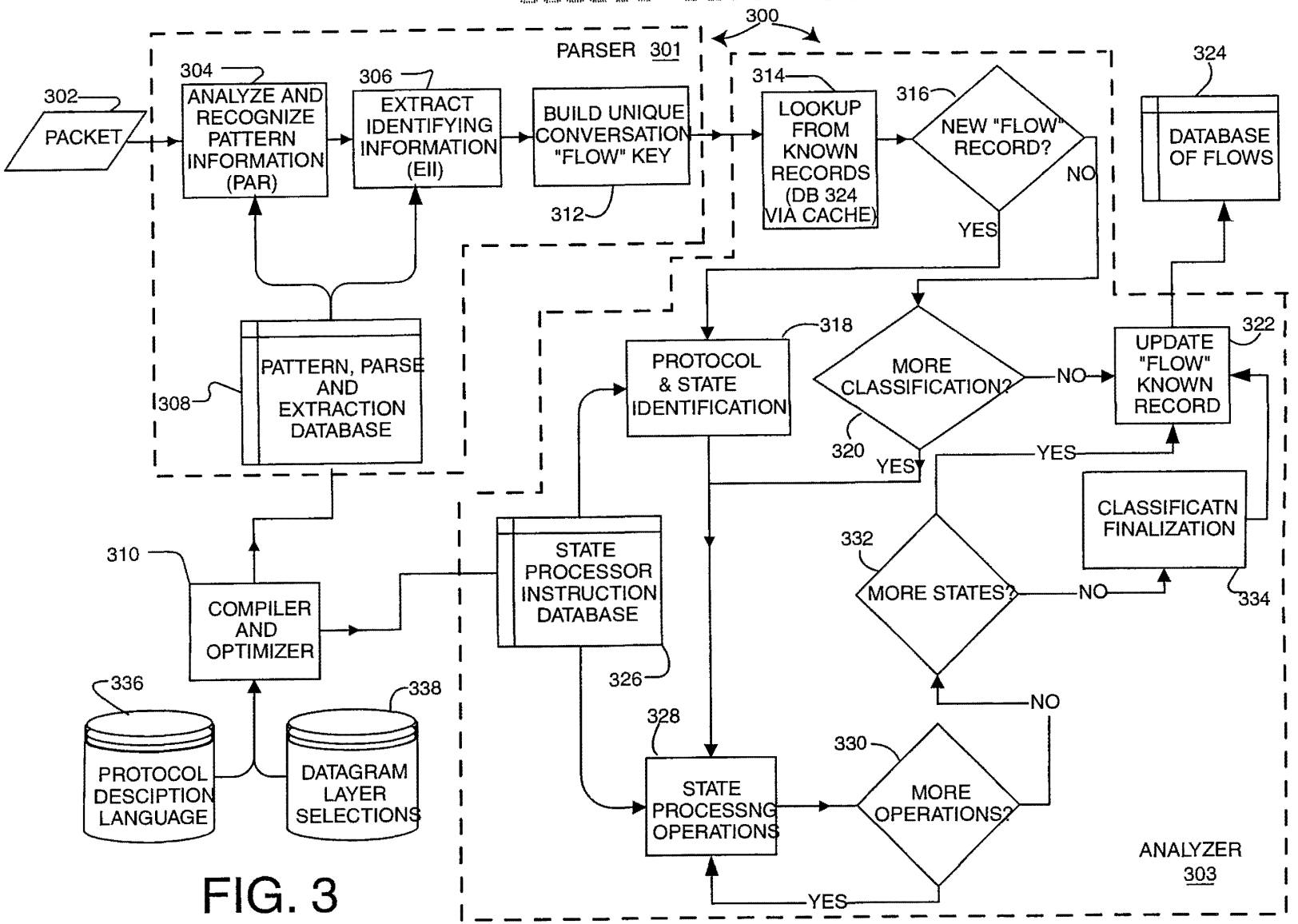

300
PARSER 301
302
PACKET
304
ANALYZE AND RECOGNIZE PATTERN INFORMATION (PAR)
306
EXTRACT IDENTIFYING INFORMATION (EII)
BUILD UNIQUE CONVERSATION "FLOW" KEY
312
314
LOOKUP FROM KNOWN RECORDS (DB 324 VIA CACHE)
316
NEW "FLOW" RECORD?
NO
YES
324
DATABASE OF FLOWS
308
PATTERN, PARSE AND EXTRACTION DATABASE
318
PROTOCOL & STATE IDENTIFICATION
MORE CLASSIFICATION?
320
NO
YES
322
UPDATE "FLOW" KNOWN RECORD
YES
CLASSIFICATN FINALIZATION
334
310
COMPILER AND OPTIMIZER
STATE PROCESSOR INSTRUCTION DATABASE
326
332
MORE STATES?
NO
336
PROTOCOL DESCIPTION LANGUAGE
338
DATAGRAM LAYER SELECTIONS
328
NO
330
STATE PROCESSNG OPERATIONS
MORE OPERATIONS?
YES
ANALYZER 303

FIG. 3

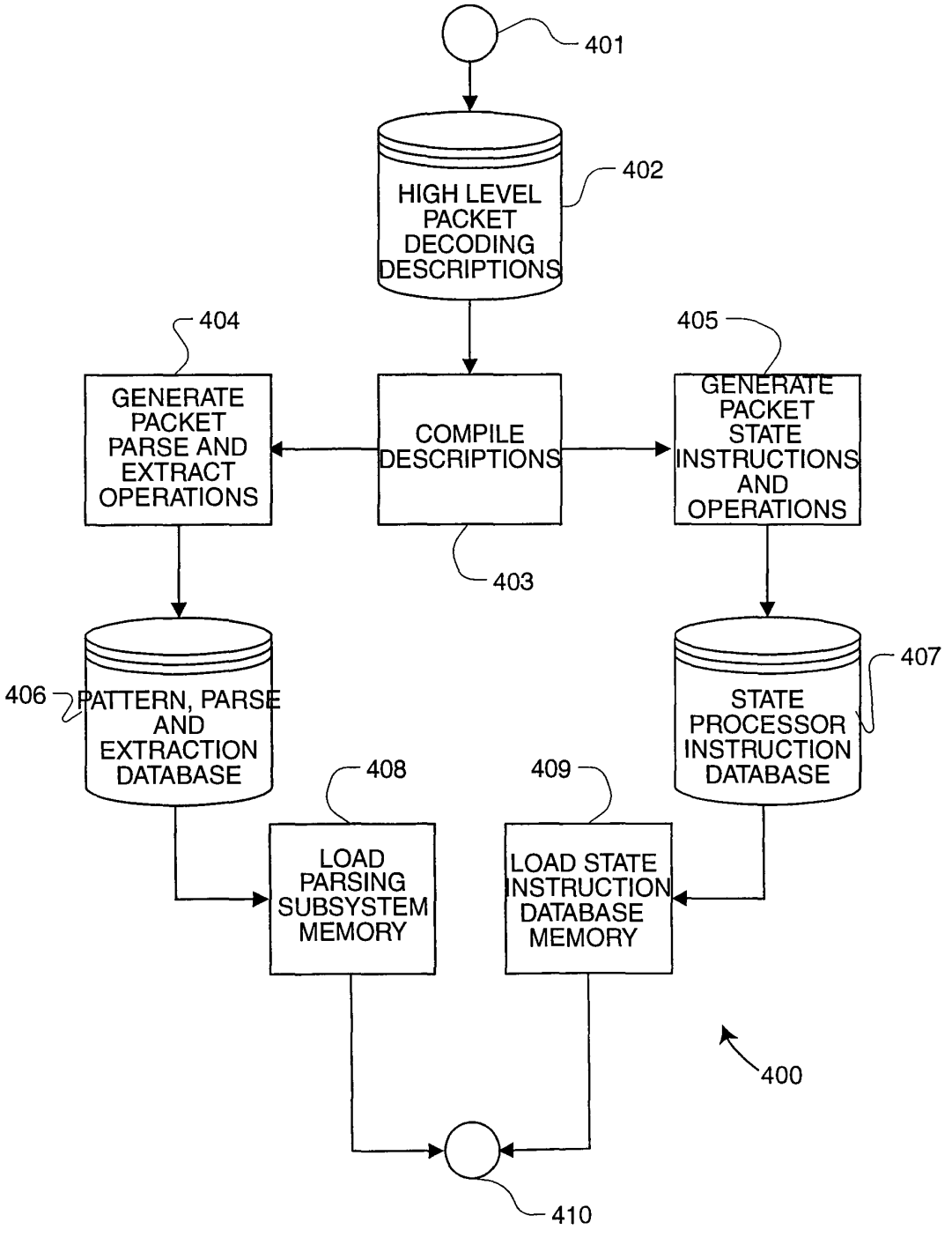
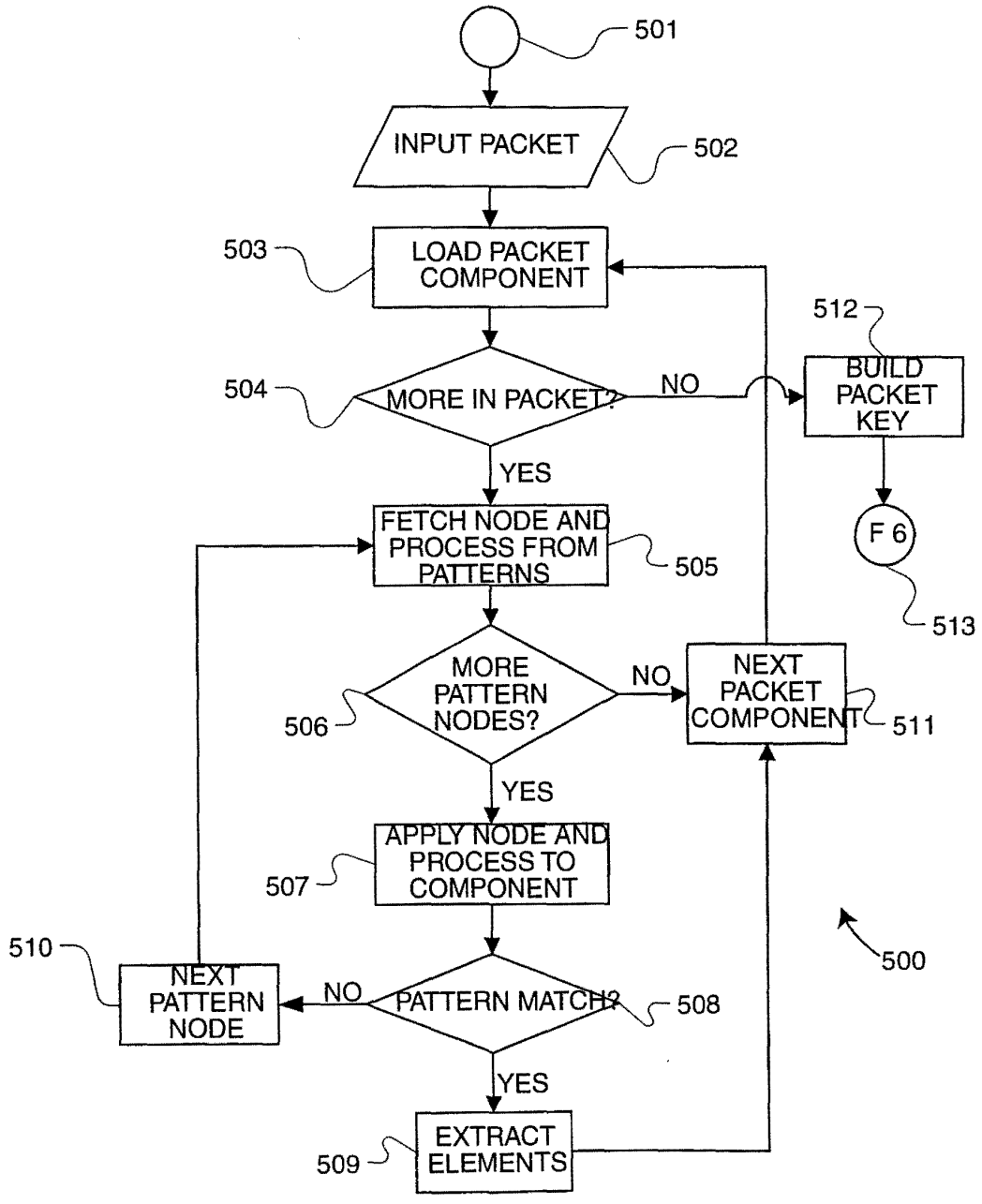

401
HIGH LEVEL PACKET DECODING DESCRIPTIONS
402
404
GENERATE PACKET PARSE AND EXTRACT OPERATIONS
COMPILE DESCRIPTIONS
403
405
GENERATE PACKET STATE INSTRUCTIONS AND OPERATIONS
406
PATTERN, PARSE AND EXTRACTION DATABASE
407
STATE PROCESSOR INSTRUCTION DATABASE
408
LOAD PARSING SUBSYSTEM MEMORY
409
LOAD STATE INSTRUCTION DATABASE MEMORY
400
410

FIG. 4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INPUT PACKET
502
503
LOAD PACKET COMPONENT
504
MORE IN PACKET?
NO
512
BUILD PACKET KEY
F 6
513
YES
FETCH NODE AND PROCESS FROM PATTERNS
505
MORE PATTERN NODES?
506
NO
NEXT PACKET COMPONENT
511
YES
APPLY NODE AND PROCESS TO COMPONENT
507
500
510
NEXT PATTERN NODE
NO
PATTERN MATCH?
508
YES
EXTRACT ELEMENTS
509

FIG. 5

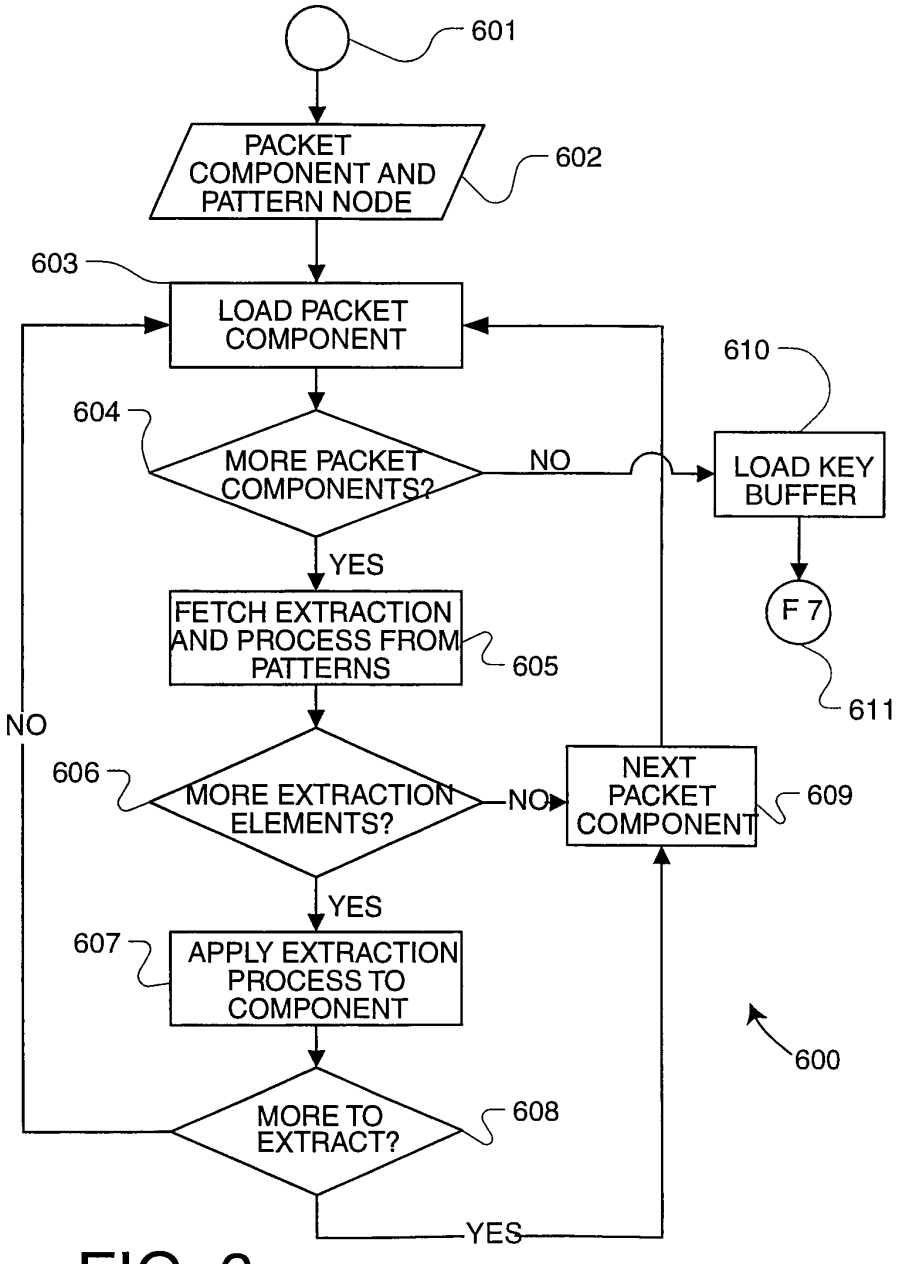

601
PACKET COMPONENT AND PATTERN NODE
602
603
LOAD PACKET COMPONENT
610
604
MORE PACKET COMPONENTS?
NO
LOAD KEY BUFFER
YES
F 7
611
FETCH EXTRACTION AND PROCESS FROM PATTERNS
605
NO
606
MORE EXTRACTION ELEMENTS?
NO
NEXT PACKET COMPONENT
609
YES
607
APPLY EXTRACTION PROCESS TO COMPONENT
600
MORE TO EXTRACT?
608
YES

FIG. 6

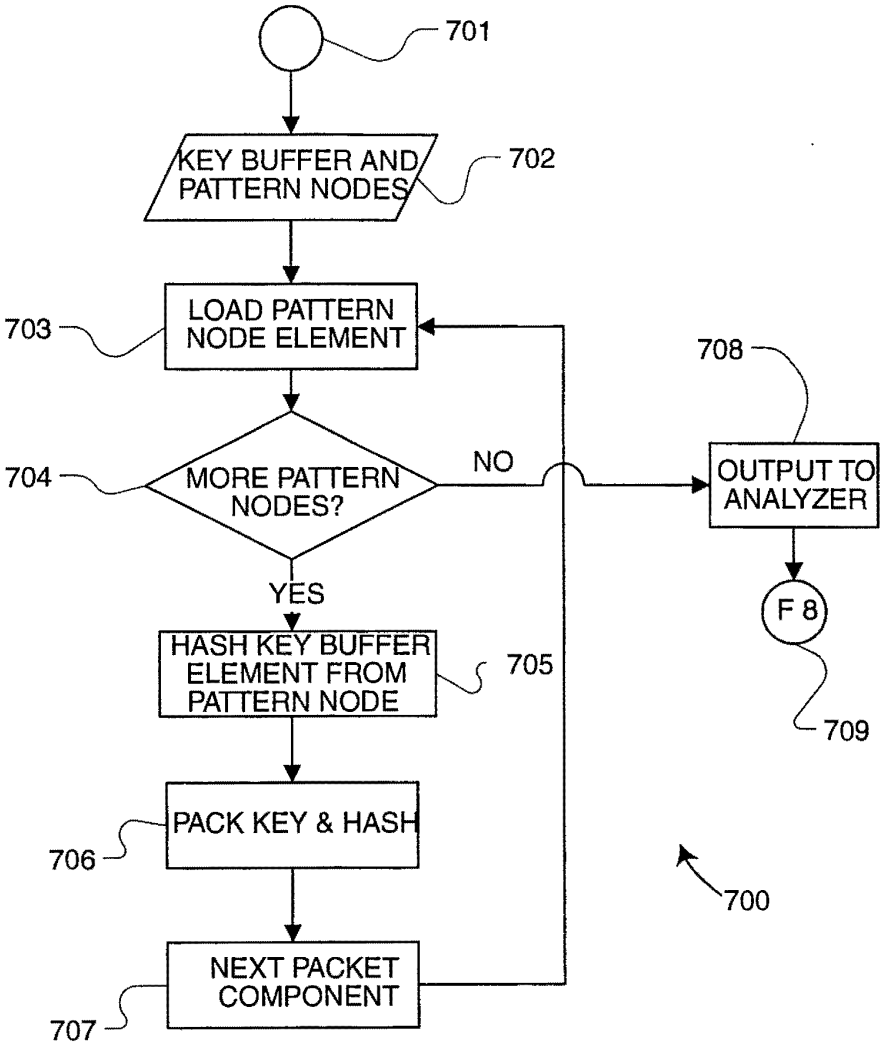

701
KEY BUFFER AND PATTERN NODES
702
LOAD PATTERN NODE ELEMENT
703
MORE PATTERN NODES?
704
NO
YES
OUTPUT TO ANALYZER
708
F 8
709
HASH KEY BUFFER ELEMENT FROM PATTERN NODE
705
PACK KEY & HASH
706
NEXT PACKET COMPONENT
707
700

FIG. 7

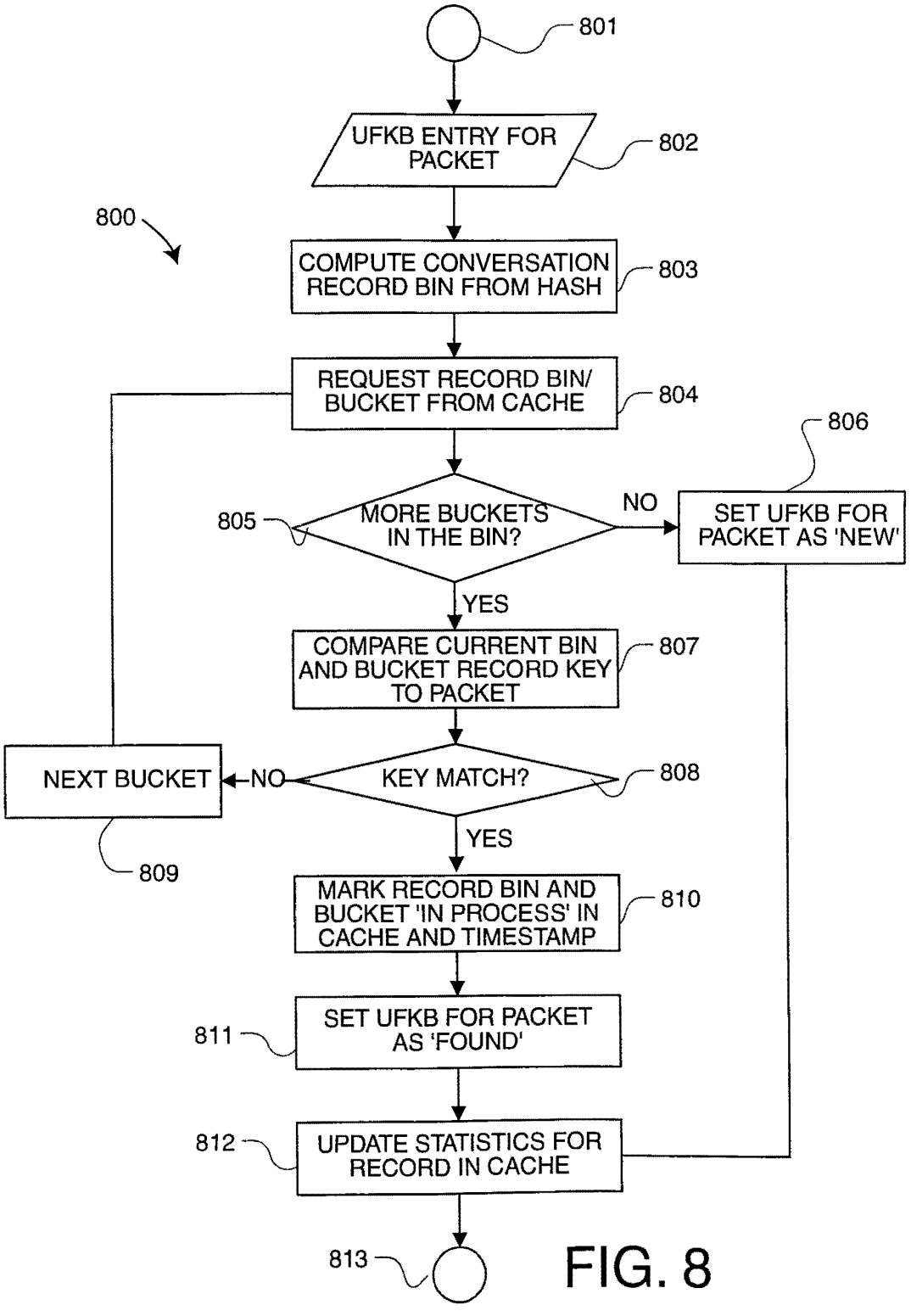

801
UFKB ENTRY FOR PACKET
802
800
COMPUTE CONVERSATION RECORD BIN FROM HASH
803
REQUEST RECORD BIN/ BUCKET FROM CACHE
804
806
805
MORE BUCKETS IN THE BIN?
NO
SET UFKB FOR PACKET AS 'NEW'
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
807
NEXT BUCKET
NO
KEY MATCH?
808
YES
809
MARK RECORD BIN AND BUCKET 'IN PROCESS' IN CACHE AND TIMESTAMP
810
SET UFKB FOR PACKET AS 'FOUND'
811
812
UPDATE STATISTICS FOR RECORD IN CACHE
813

FIG. 8

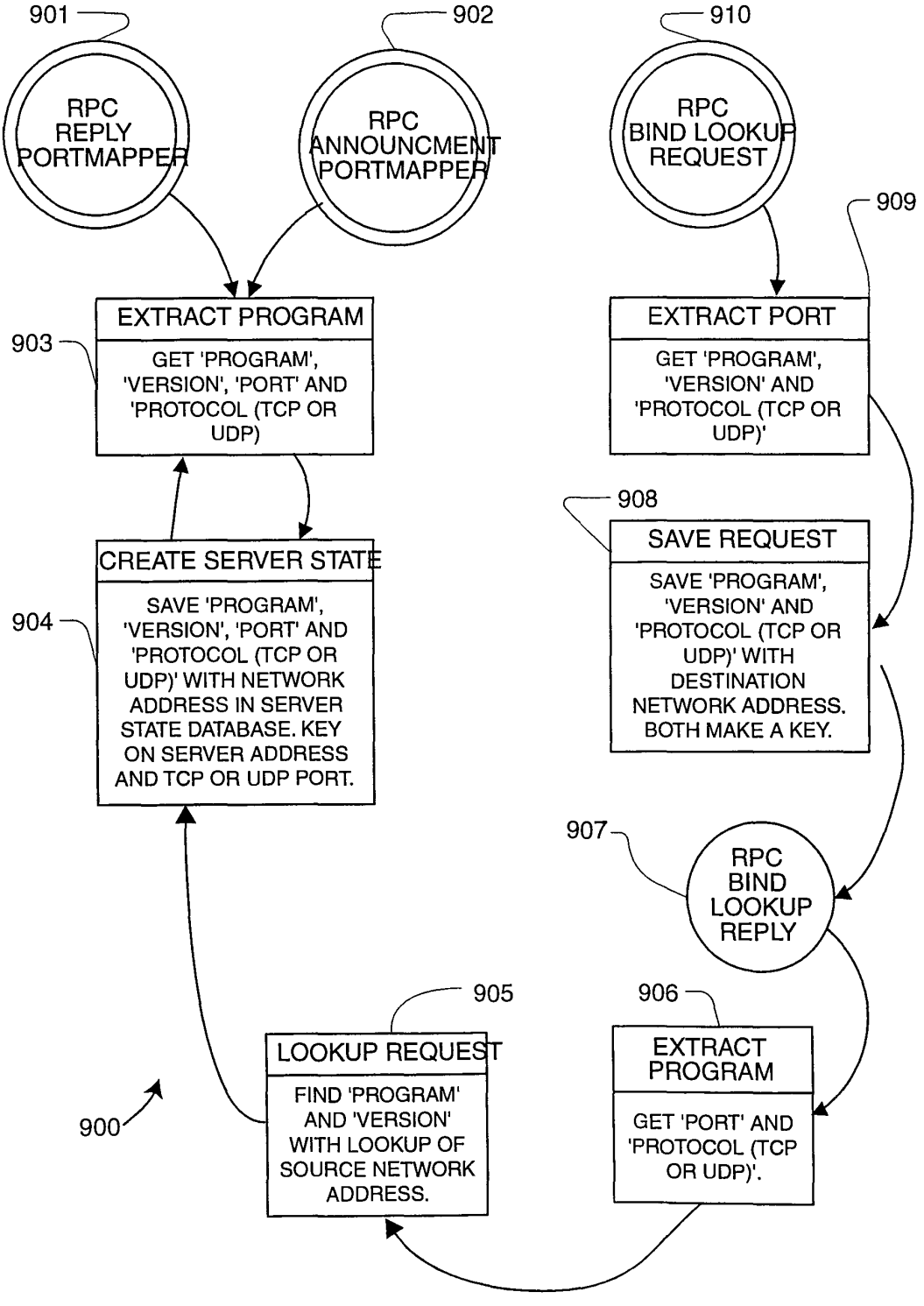

901
RPC REPLY PORTMAPPER
902
RPC ANNOUNCMENT PORTMAPPER
910
RPC BIND LOOKUP REQUEST
909
EXTRACT PROGRAM
GET 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)
903
EXTRACT PORT
GET 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'
908
SAVE REQUEST
SAVE 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)' WITH DESTINATION NETWORK ADDRESS. BOTH MAKE A KEY.
CREATE SERVER STATE
SAVE 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)' WITH NETWORK ADDRESS IN SERVER STATE DATABASE. KEY ON SERVER ADDRESS AND TCP OR UDP PORT.
904
907
RPC BIND LOOKUP REPLY
905
906
LOOKUP REQUEST
FIND 'PROGRAM' AND 'VERSION' WITH LOOKUP OF SOURCE NETWORK ADDRESS.
EXTRACT PROGRAM
GET 'PORT' AND 'PROTOCOL (TCP OR UDP)'.
900

FIG. 9

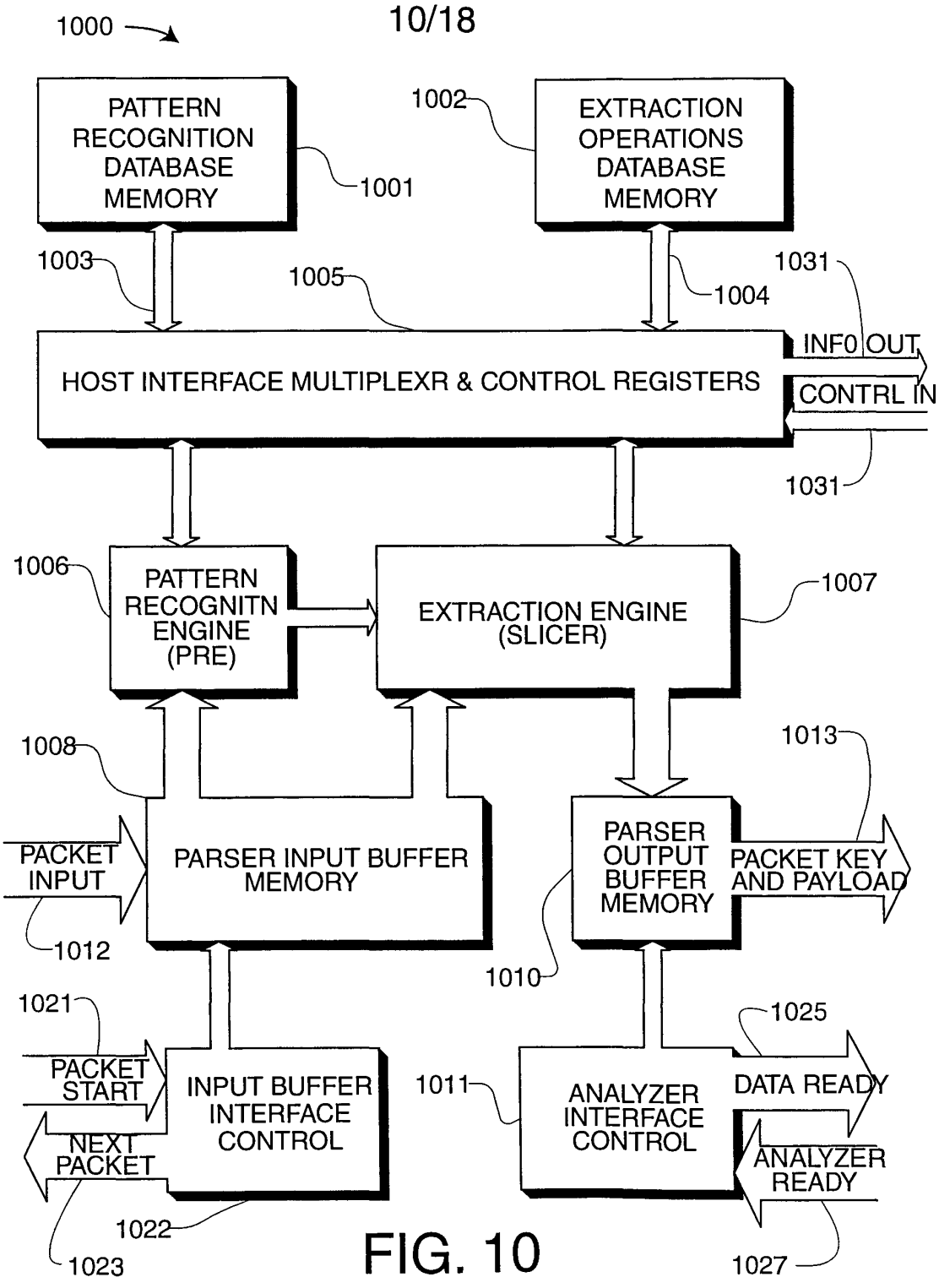

1000
PATTERN RECOGNITION DATABASE MEMORY
1001
1002
EXTRACTION OPERATIONS DATABASE MEMORY
1003
1005
1004
1031
INFO OUT
HOST INTERFACE MULTIPLEXR & CONTROL REGISTERS
CONTRL IN
1031
1006
PATTERN RECOGNITN ENGINE (PRE)
EXTRACTION ENGINE (SLICER)
1007
1008
1013
PACKET INPUT
PARSER INPUT BUFFER MEMORY
PARSER OUTPUT BUFFER MEMORY
PACKET KEY AND PAYLOAD
1012
1010
1021
1025
PACKET START
INPUT BUFFER INTERFACE CONTROL
1011
ANALYZER INTERFACE CONTROL
DATA READY
NEXT PACKET
ANALYZER READY
1022
1023
1027

FIG. 10

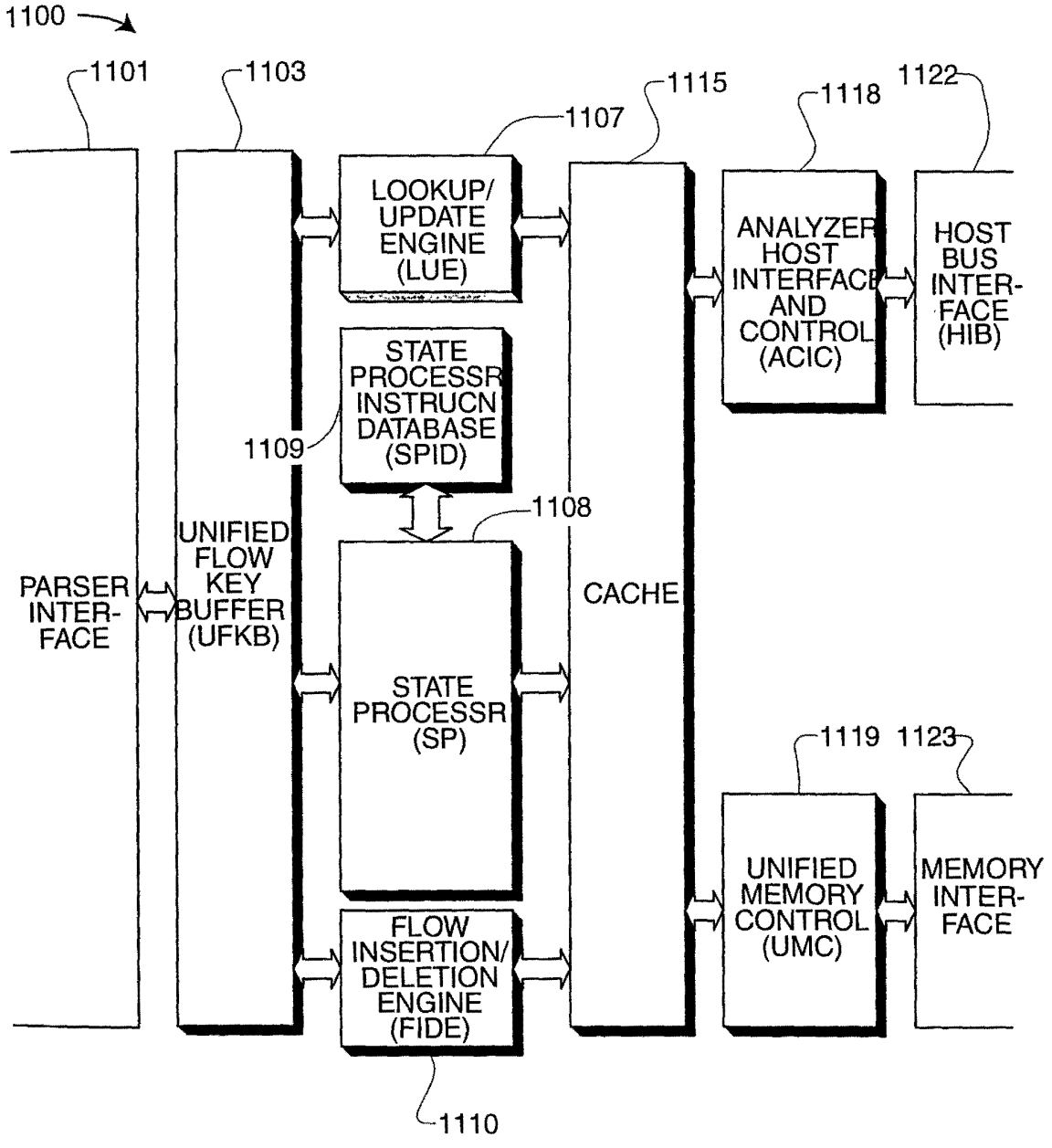

1100
1101
1103
1107
1115
1118
1122
LOOKUP/ UPDATE ENGINE (LUE)
ANALYZER HOST INTERFACE AND CONTROL (ACIC)
HOST BUS INTER-FACE (HIB)
STATE PROCESSR INSTRUCN DATABASE (SPID)
1109
1108
PARSER INTER-FACE
UNIFIED FLOW KEY BUFFER (UFKB)
STATE PROCESSR (SP)
CACHE
1119
1123
UNIFIED MEMORY CONTROL (UMC)
MEMORY INTER-FACE
FLOW INSERTION/ DELETION ENGINE (FIDE)
1110

FIG. 11

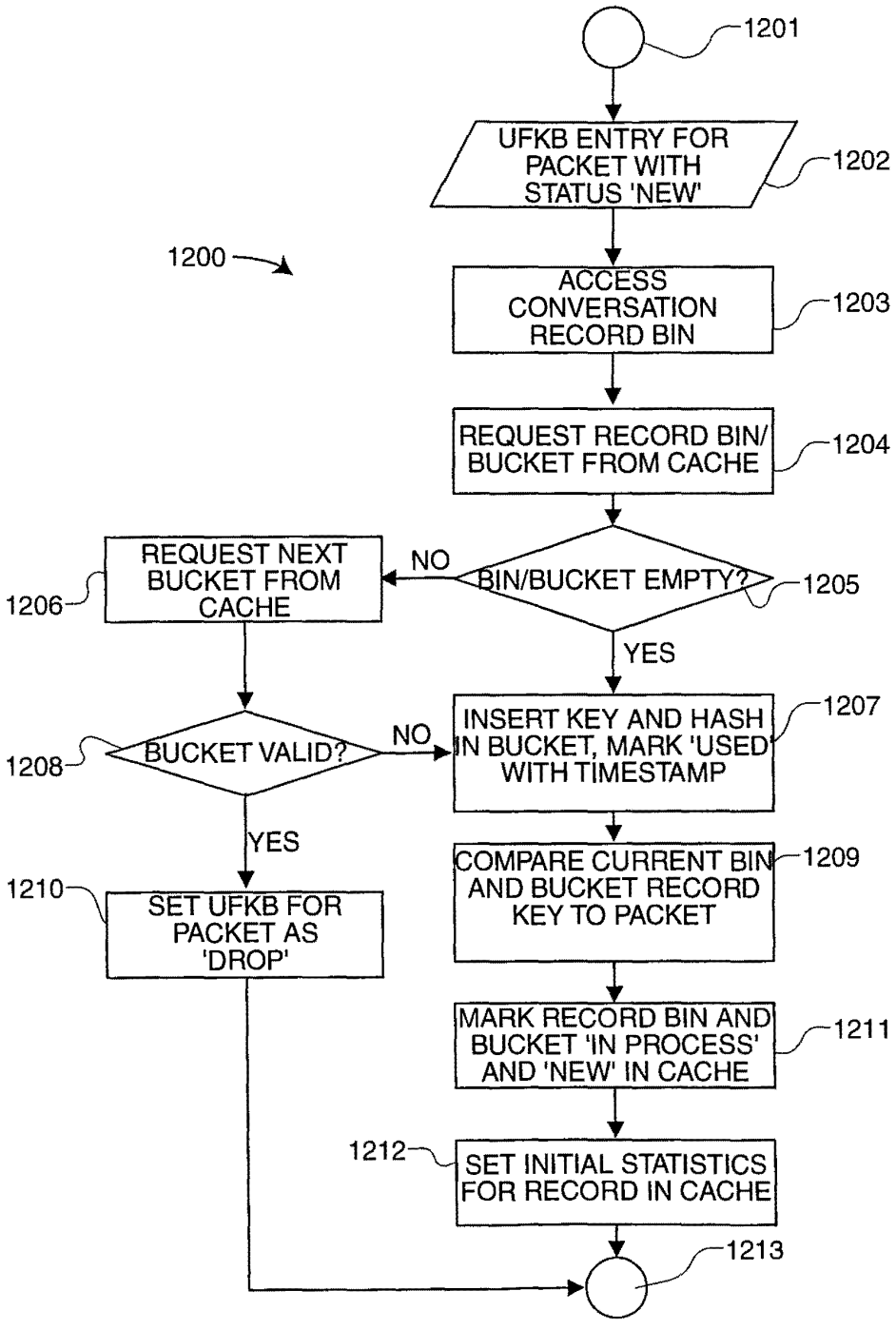

1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
BIN/BUCKET EMPTY?
1205
NO
REQUEST NEXT BUCKET FROM CACHE
1206
YES
INSERT KEY AND HASH IN BUCKET, MARK 'USED' WITH TIMESTAMP
1207
BUCKET VALID?
1208
NO
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
1209
SET UFKB FOR PACKET AS 'DROP'
1210
MARK RECORD BIN AND BUCKET 'IN PROCESS' AND 'NEW' IN CACHE
1211
SET INITIAL STATISTICS FOR RECORD IN CACHE
1212
1213

FIG. 12

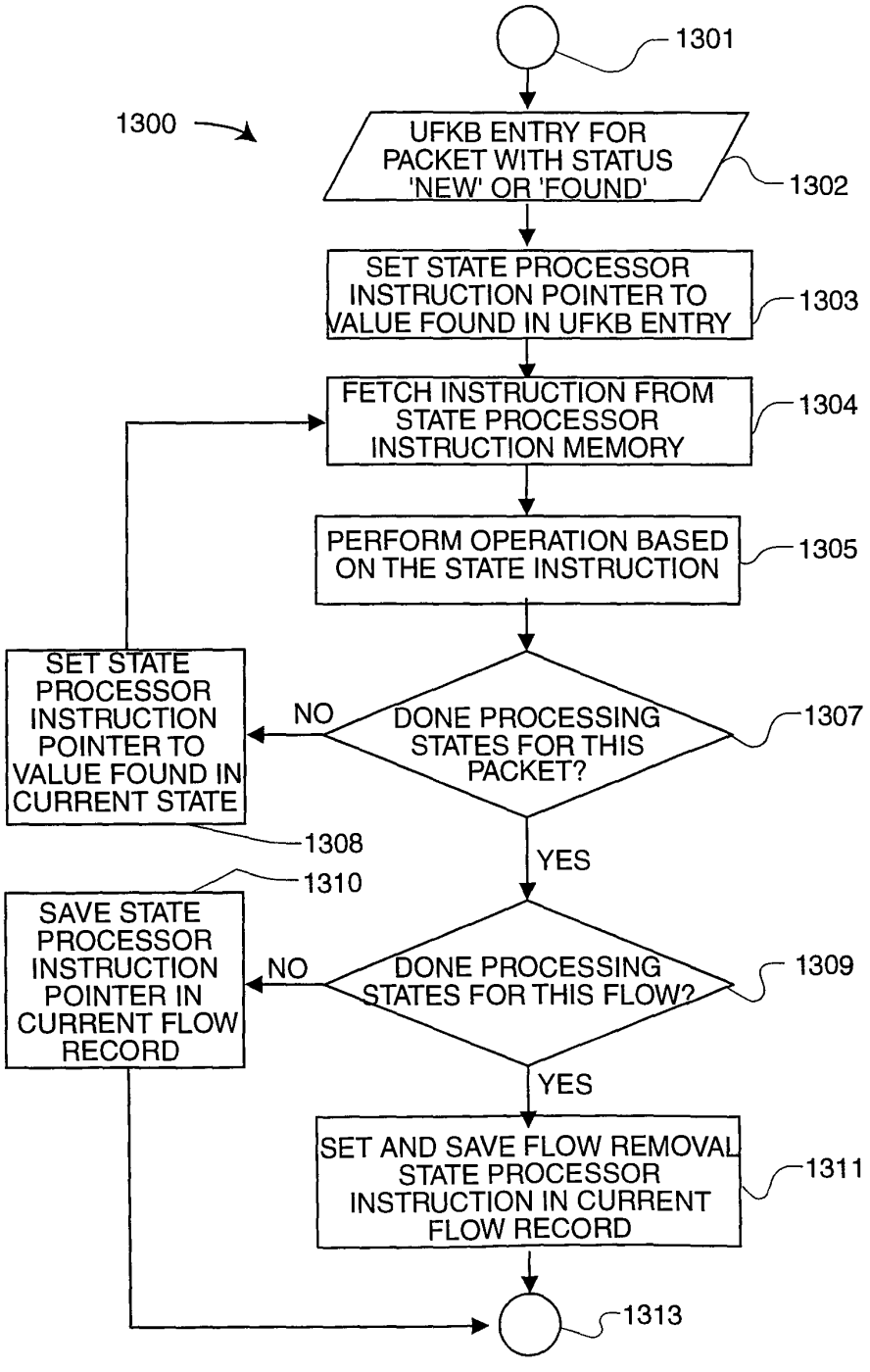

1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
DONE PROCESSING STATES FOR THIS PACKET?
1307
NO
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN CURRENT STATE
1308
YES
1310
DONE PROCESSING STATES FOR THIS FLOW?
1309
NO
SAVE STATE PROCESSOR INSTRUCTION POINTER IN CURRENT FLOW RECORD
YES
SET AND SAVE FLOW REMOVAL STATE PROCESSOR INSTRUCTION IN CURRENT FLOW RECORD
1311
1313

FIG. 13

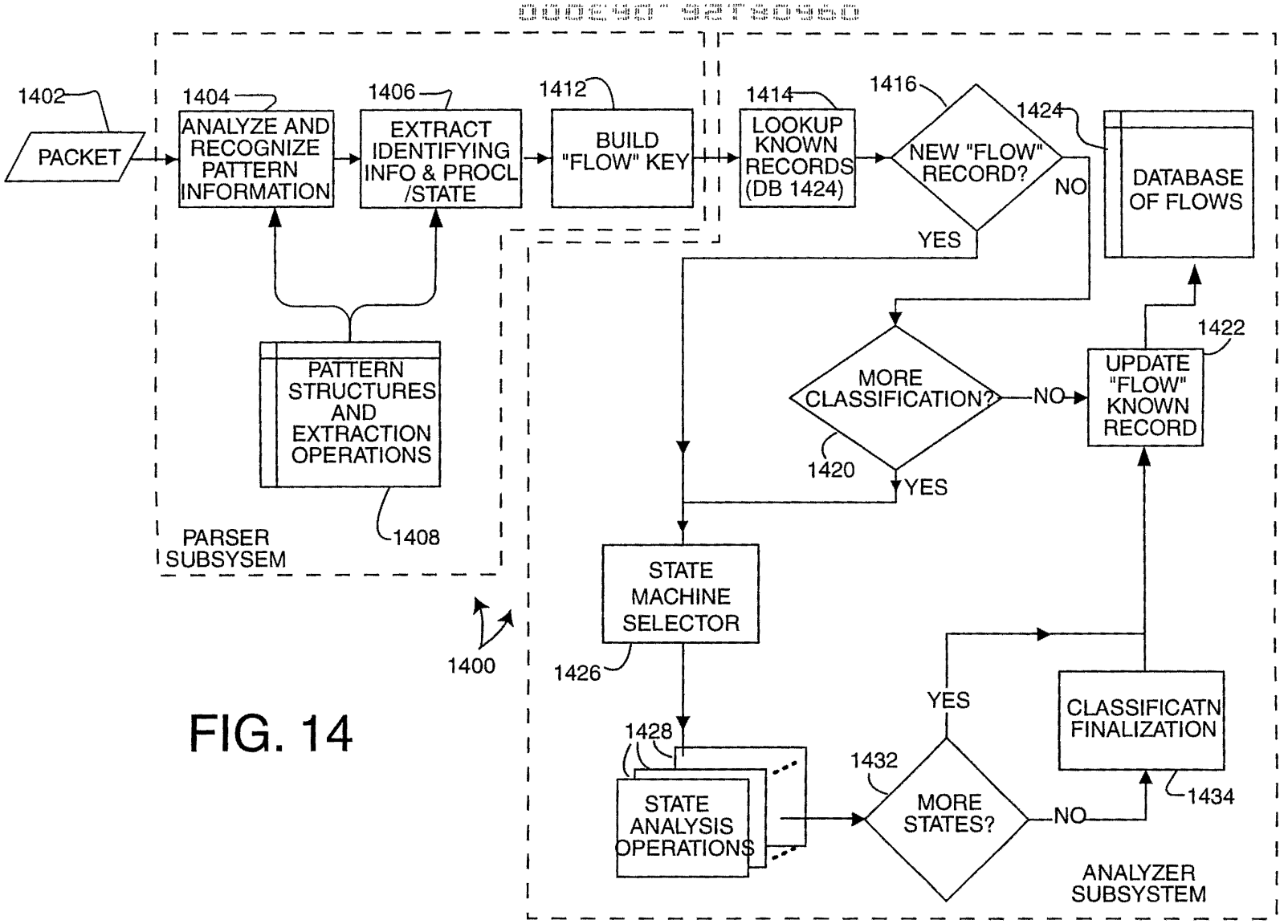

1402
PACKET
1404
ANALYZE AND RECOGNIZE PATTERN INFORMATION
1406
EXTRACT IDENTIFYING INFO & PROCL /STATE
1412
BUILD "FLOW" KEY
1414
LOOKUP KNOWN RECORDS (DB 1424)
1416
NEW "FLOW" RECORD?
NO
YES
1424
DATABASE OF FLOWS
PATTERN STRUCTURES AND EXTRACTION OPERATIONS
1408
PARSER SUBSYSEM
MORE CLASSIFICATION?
NO
1420
YES
1422
UPDATE "FLOW" KNOWN RECORD
STATE MACHINE SELECTOR
1426
1400
1428
STATE ANALYSIS OPERATIONS
1432
MORE STATES?
YES
NO
CLASSIFICATN FINALIZATION
1434
ANALYZER SUBSYSTEM

FIG. 14

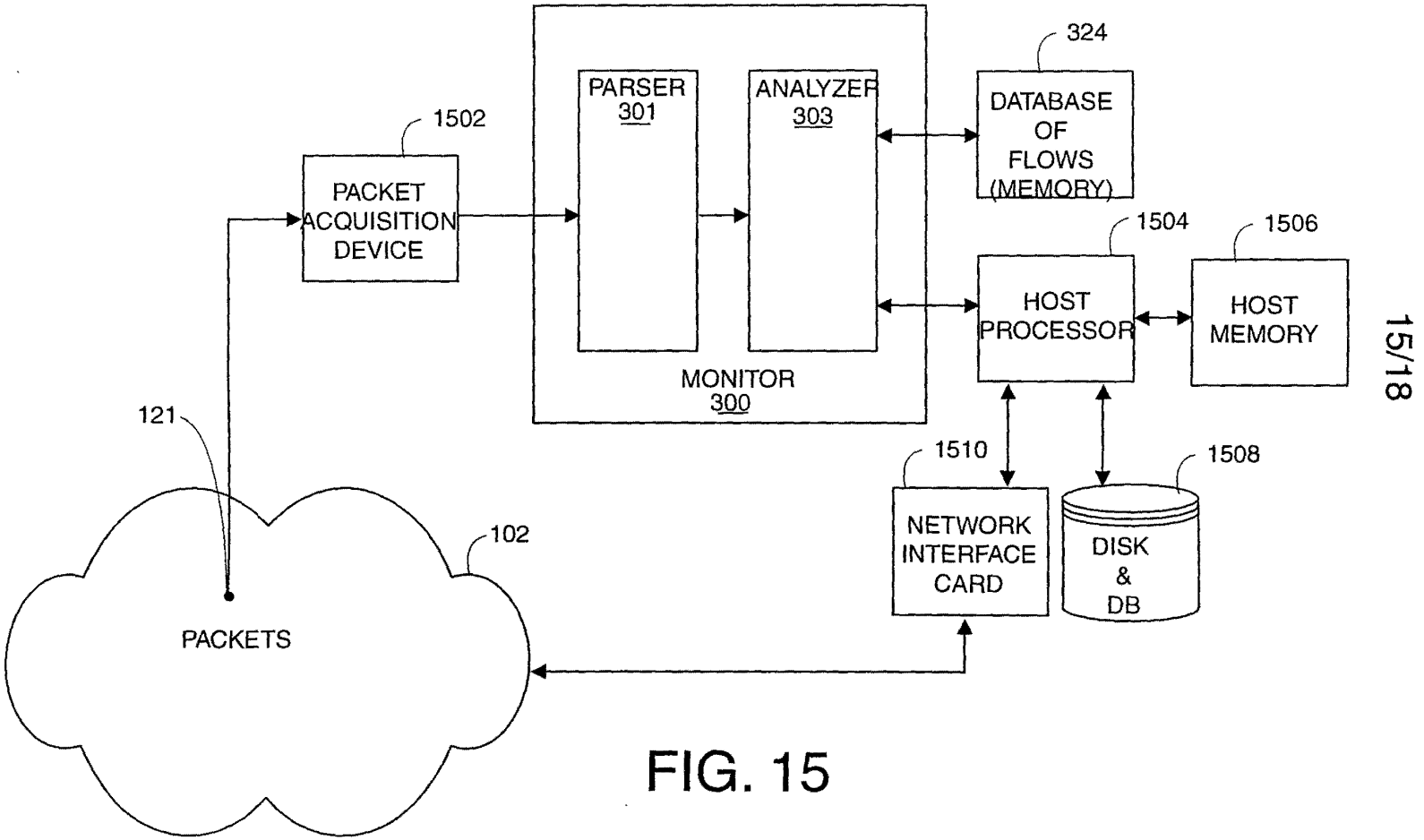

PACKET ACQUISITION DEVICE
1502
PARSER 301
ANALYZER 303
MONITOR 300
DATABASE OF FLOWS (MEMORY)
324
HOST PROCESSOR
1504
HOST MEMORY
1506
NETWORK INTERFACE CARD
1510
DISK & DB
1508
121
PACKETS
102

FIG. 15

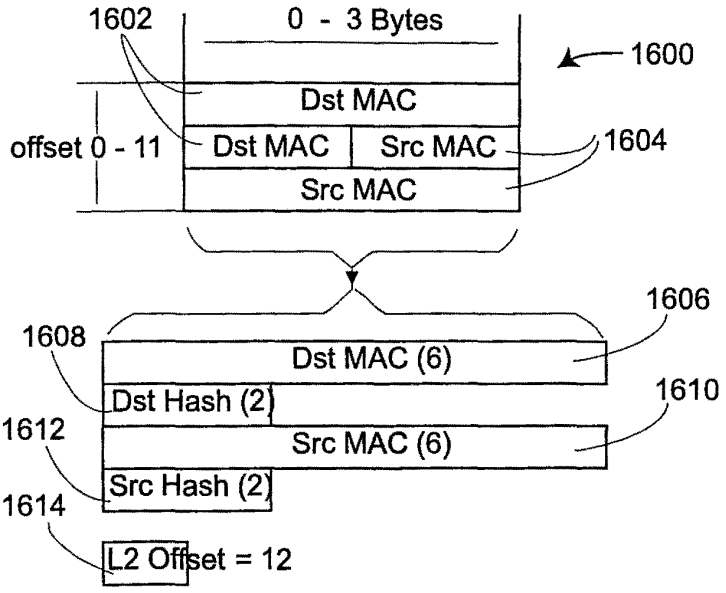

1602
0 - 3 Bytes
1600
Dst MAC
offset 0 - 11
Dst MAC
Src MAC
1604
Src MAC
1606
1608
Dst MAC (6)
Dst Hash (2)
1610
1612
Src MAC (6)
Src Hash (2)
1614
L2 Offset = 12

FIG. 16

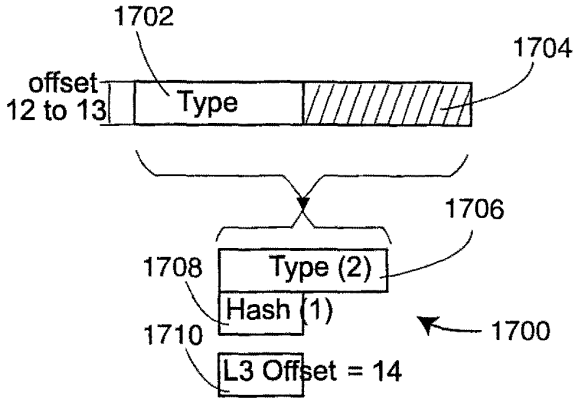


FIG. 17A

1712

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

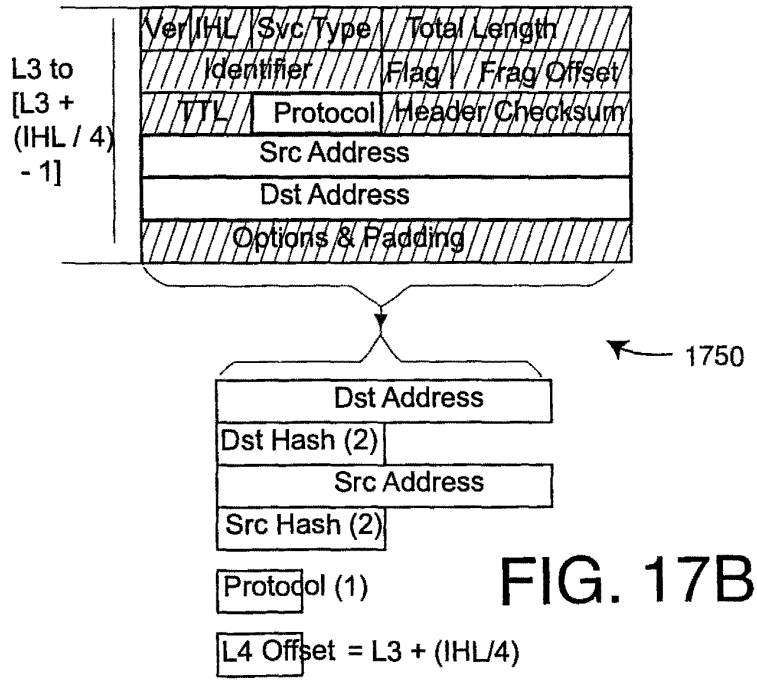


FIG. 17B

1752

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

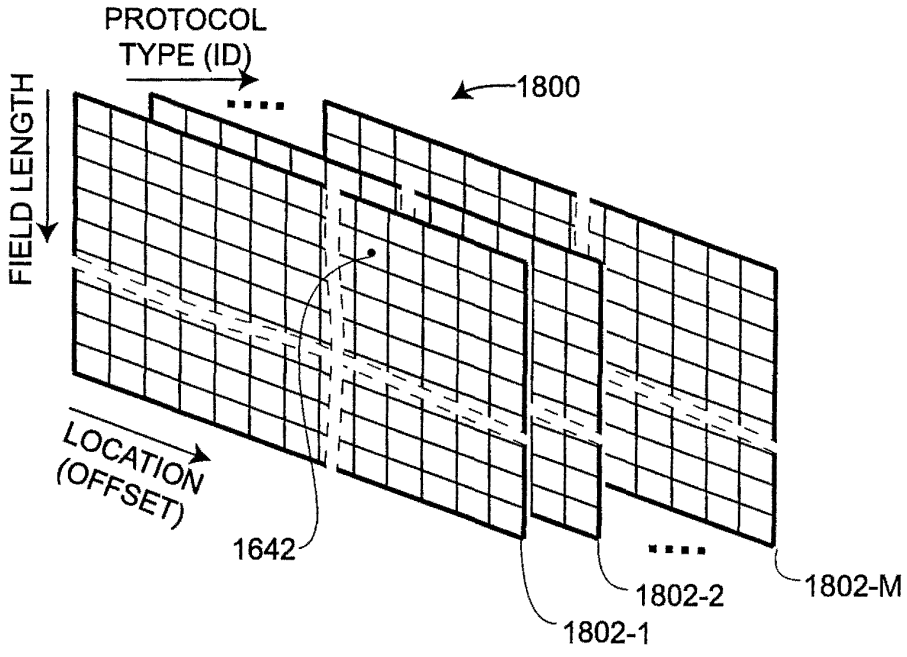


FIG. 18A

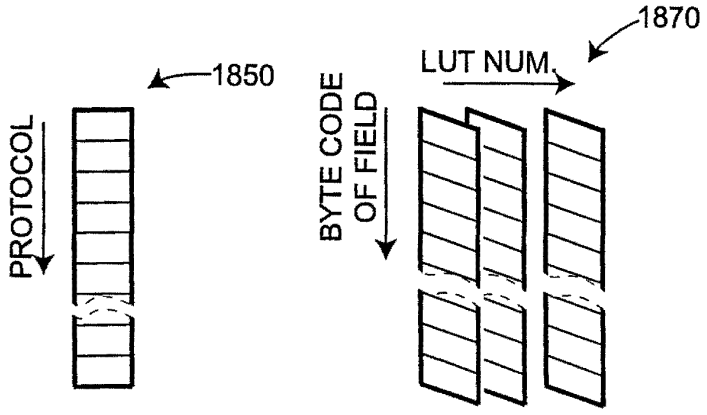


FIG. 18B

Our Ref./Docket No: APPT-001-3 Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.* Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	Group Art Unit: unassigned Examiner: unassigned

LETTER TO OFFICIAL DRAFTSPERSON SUBMISSION OF FORMAL DRAWINGS

The Assistant Commissioner for Patents
Washington, DC 20231
ATTN: Official Draftsperson

Dear Sir or Madam:

Attached please find 18 sheets of formal drawings to be made of record for the above identified patent application submitted herewith.

Respectfully Submitted,

June 30, 2000
Date

Dov Rosenfeld, Reg. No. 38687

Address for correspondence and attorney for applicant(s):
Dov Rosenfeld, Reg. No. 38,687
5507 College Avenue, Suite 2
Oakland, CA 94618
Telephone: (510) 547-3378; Fax: (510) 653-7992

Certificate of Mailing under 37 CFR 1.10

I hereby certify that this application and all attachments are being deposited with the United States Postal Service as Express Mail (Express Mail Label: EI417961927US in an envelope addressed to Box Patent Application, Assistant Commissioner for Patents, Washington, D.C. 20231 on.

Date: June 30, 2000

Signed:

Name: Dov Rosenfeld, Reg. No. 38687

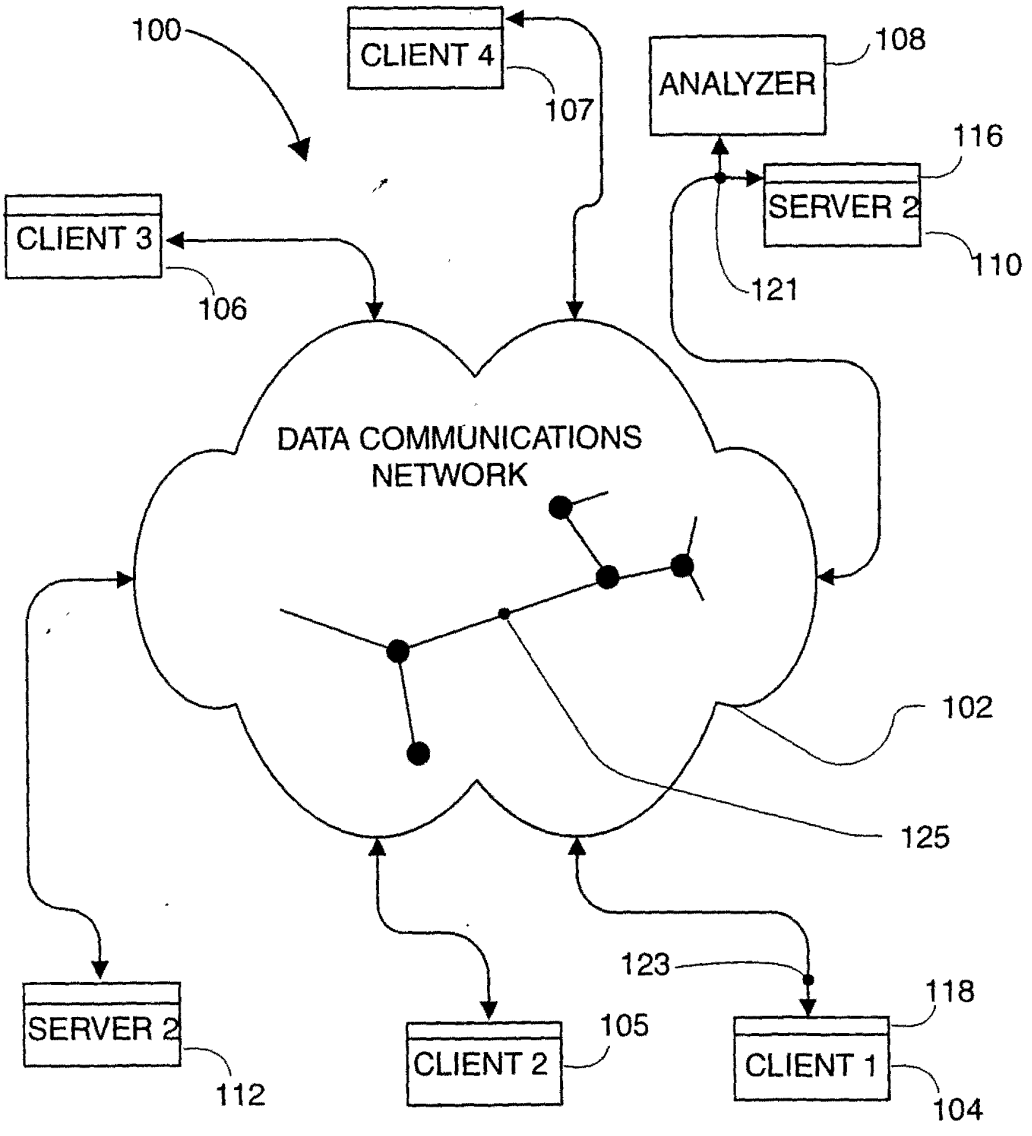


FIG. 1

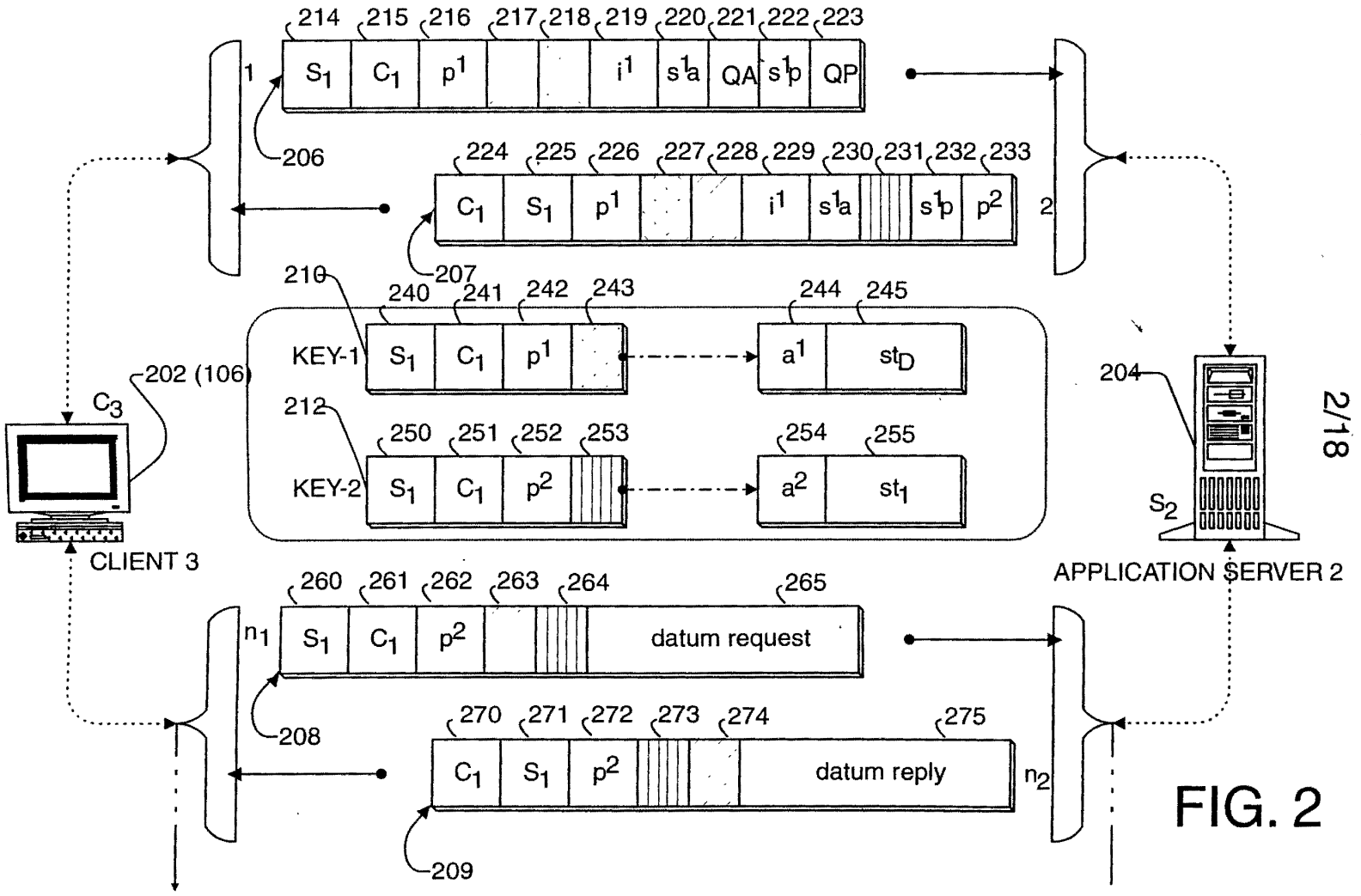


FIG. 2

2/18

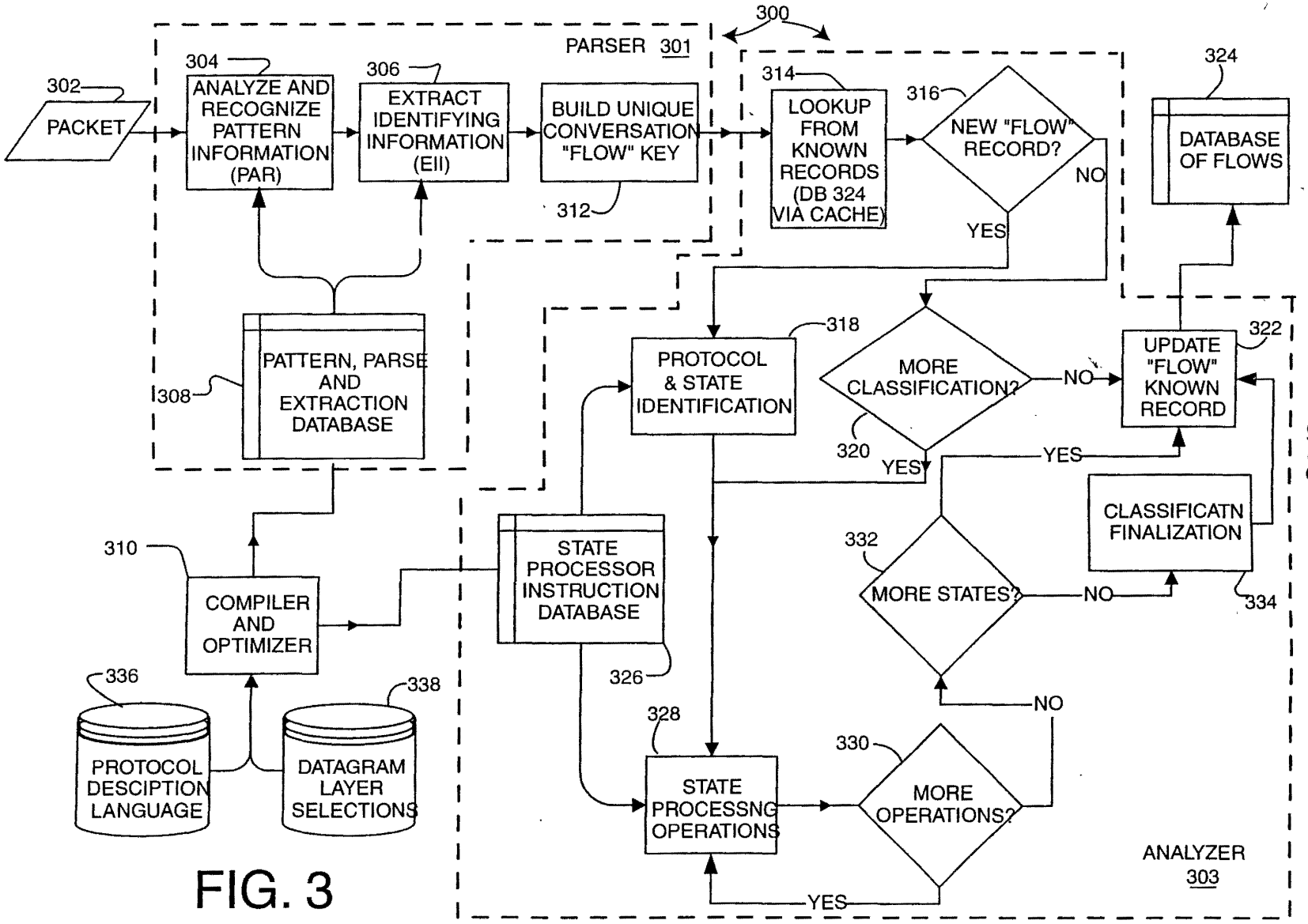


FIG. 3

3/18

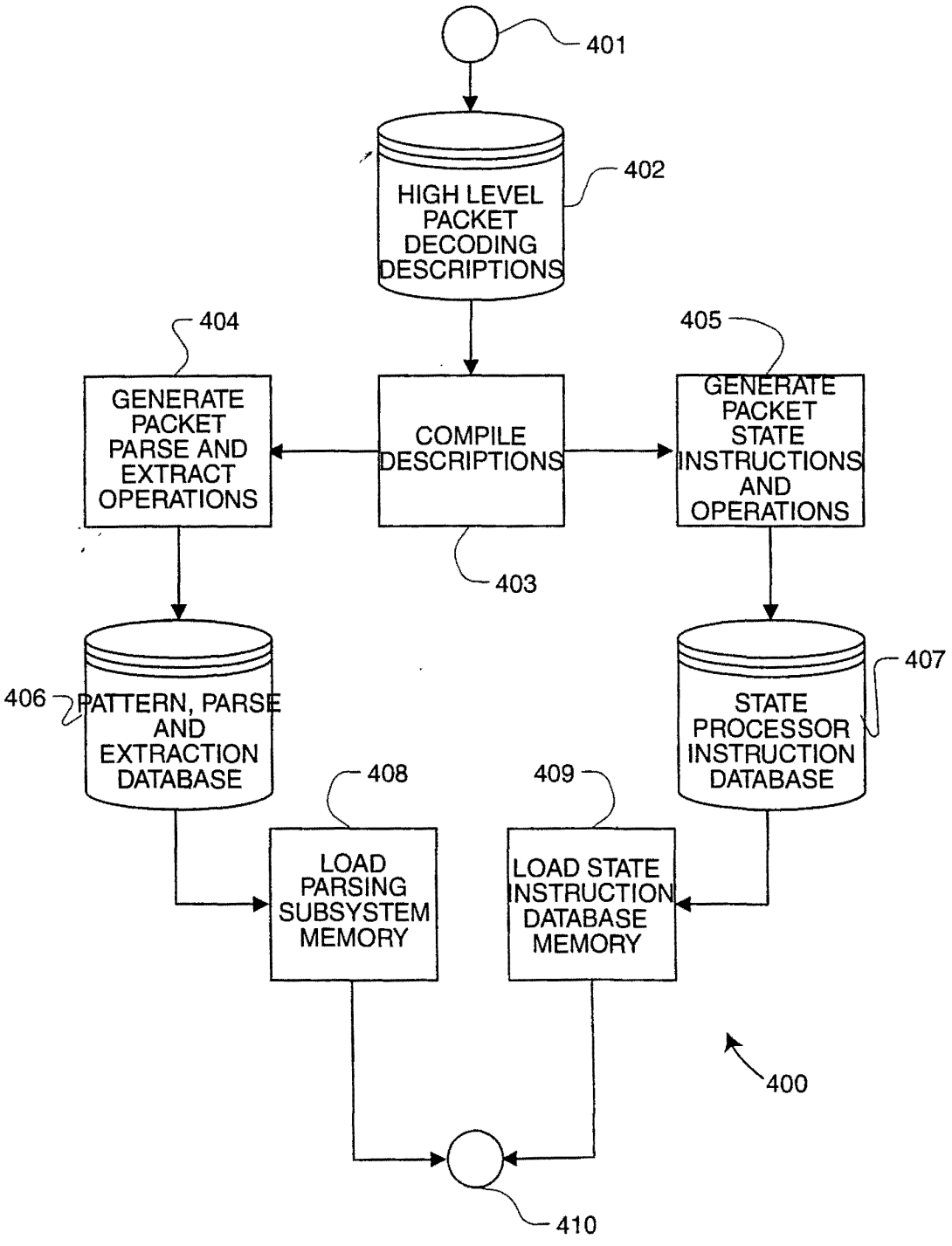


FIG. 4

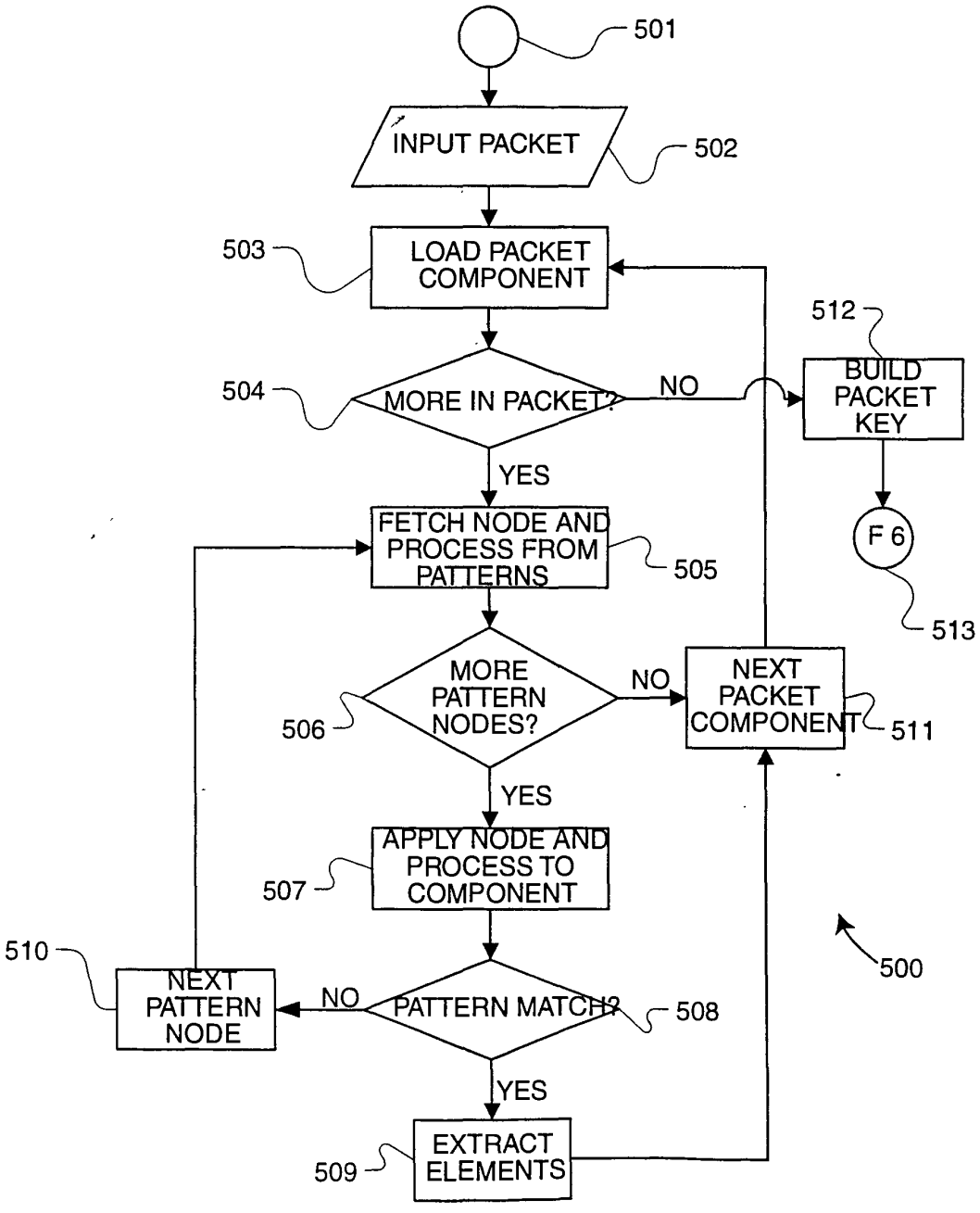


FIG. 5

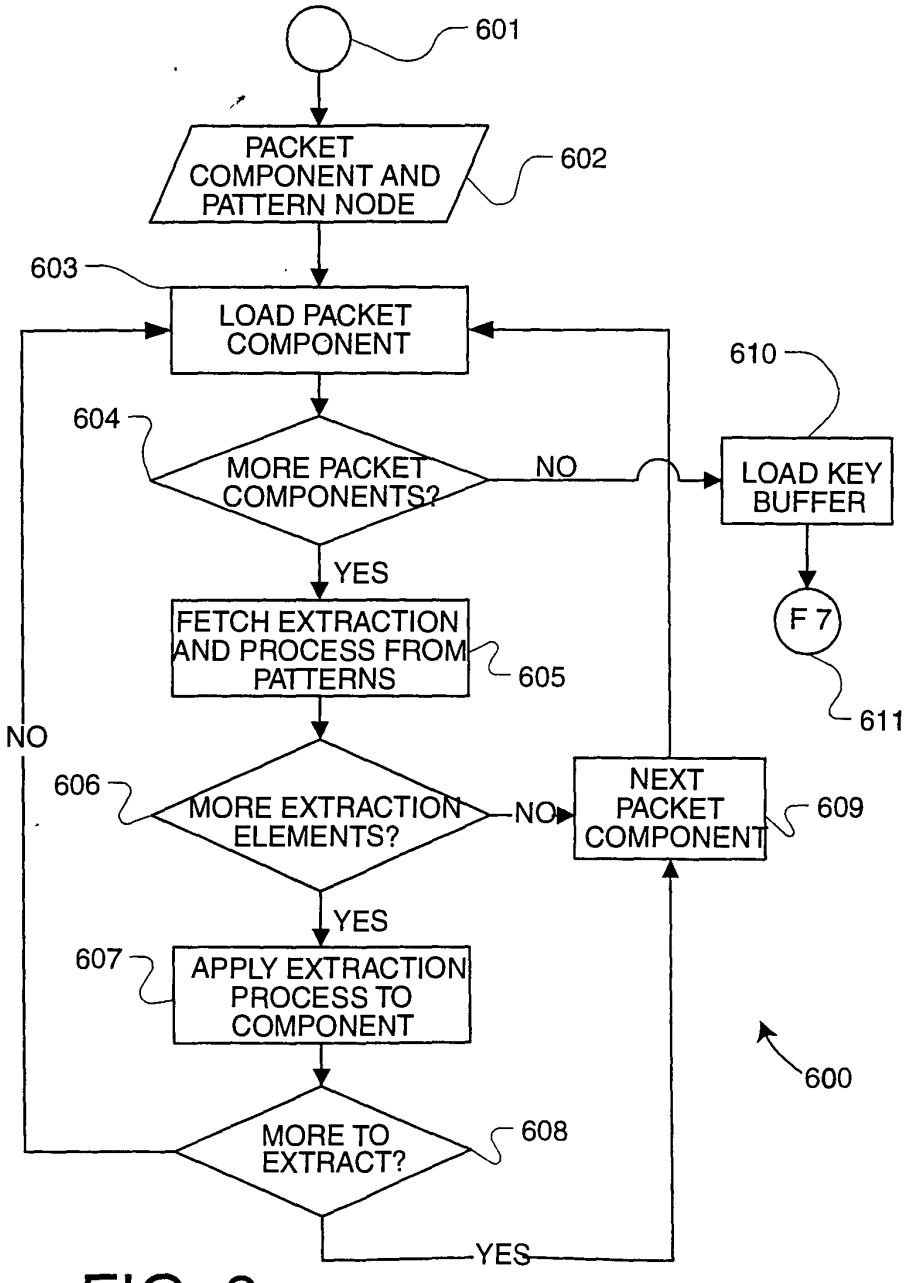


FIG. 6

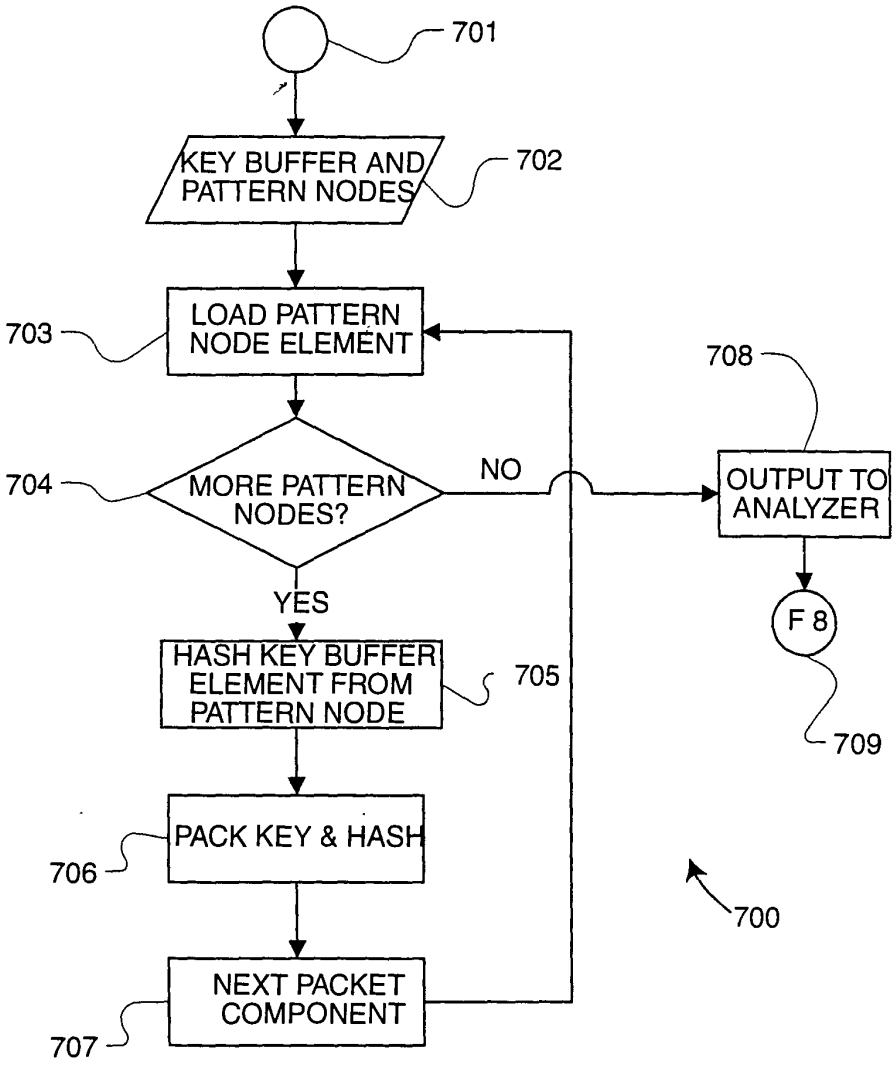


FIG. 7

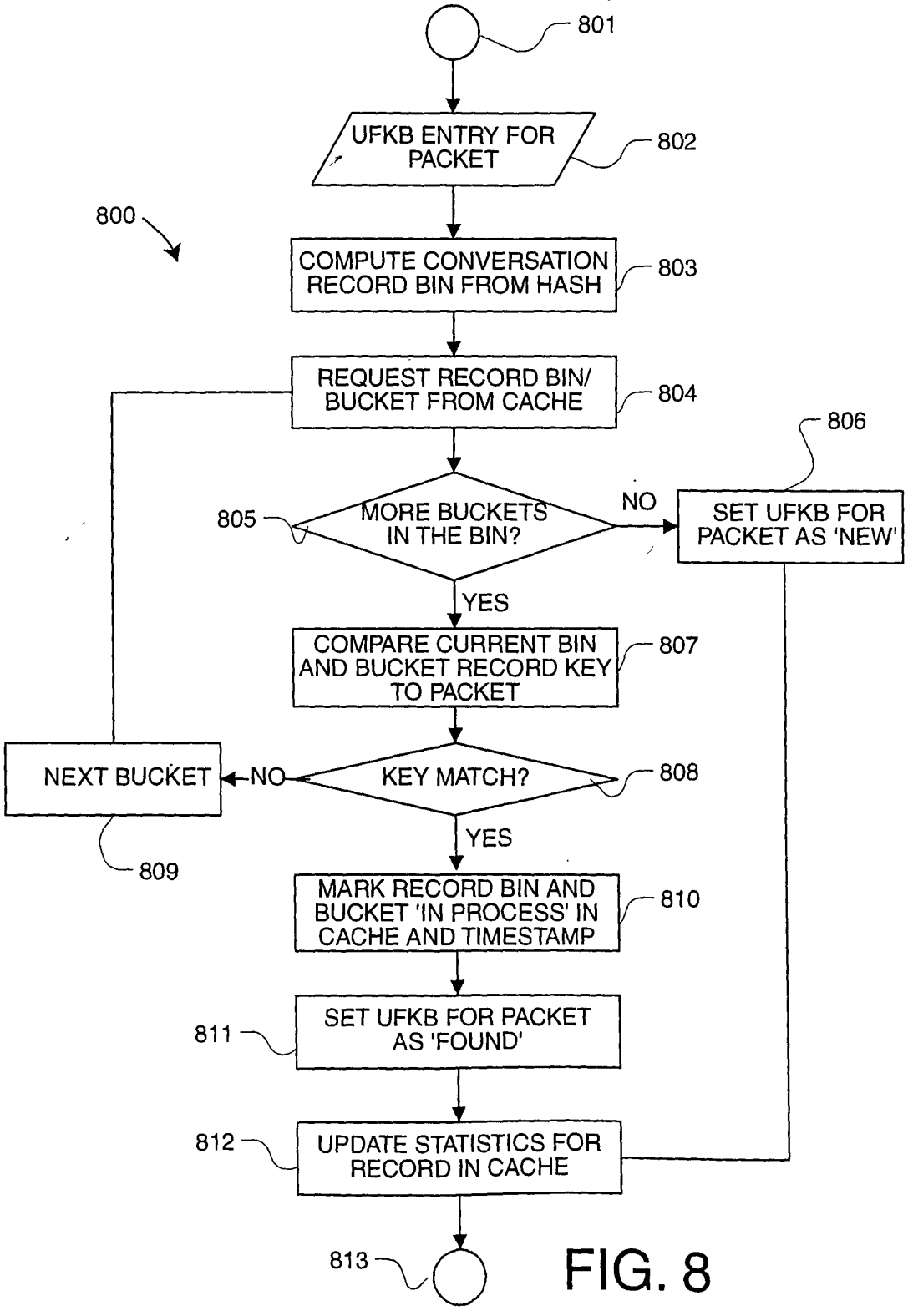


FIG. 8

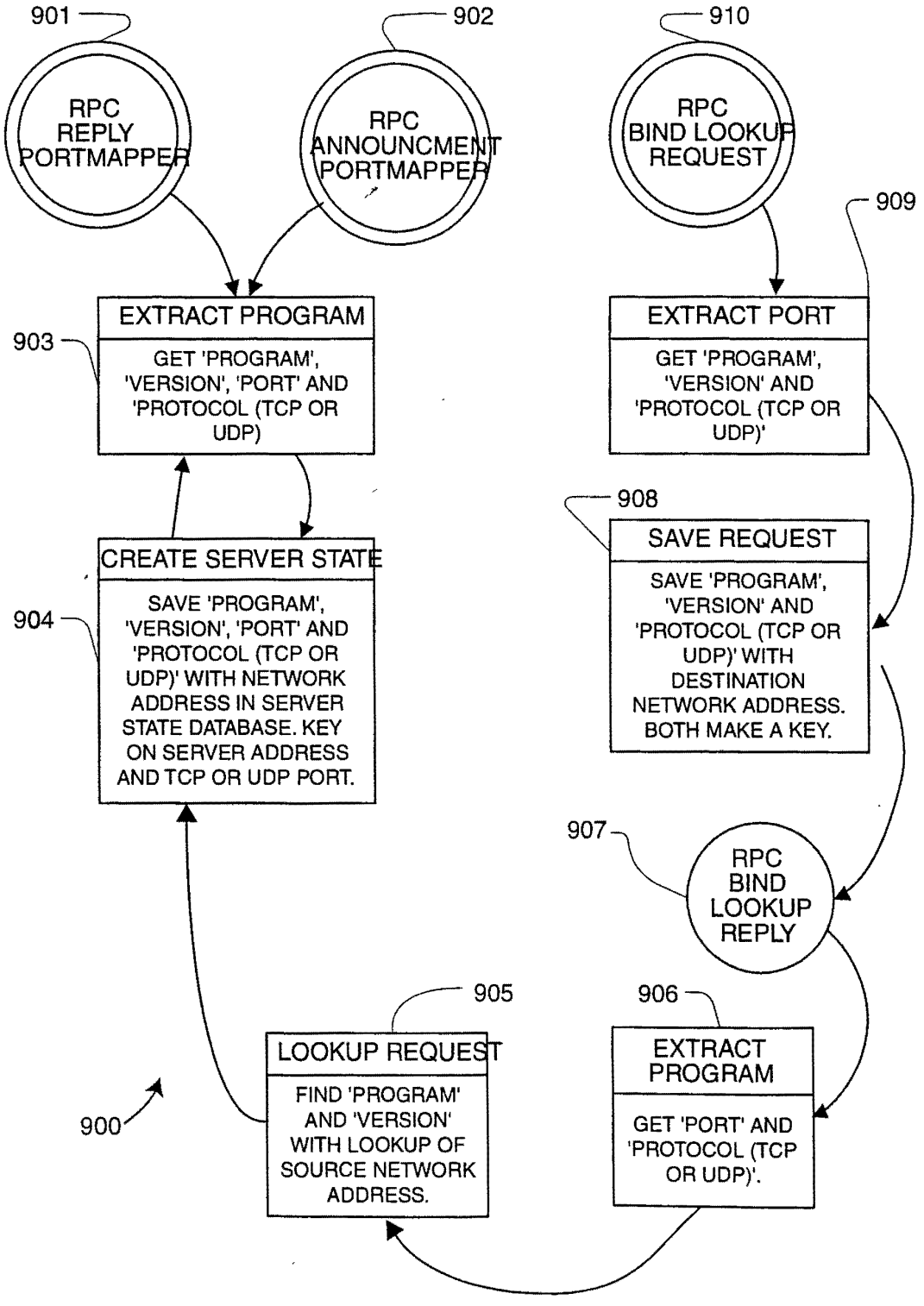


FIG. 9

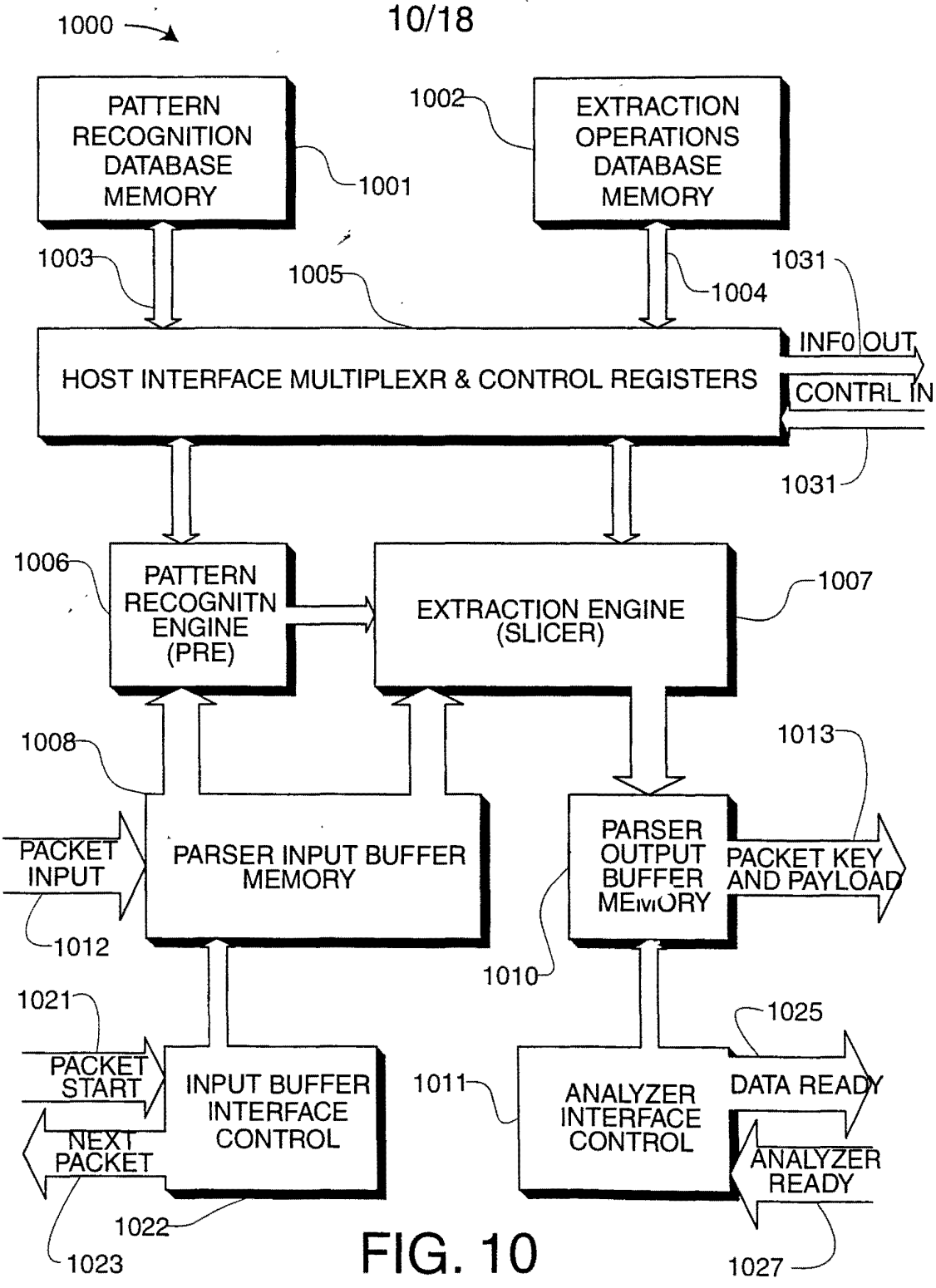


FIG. 10

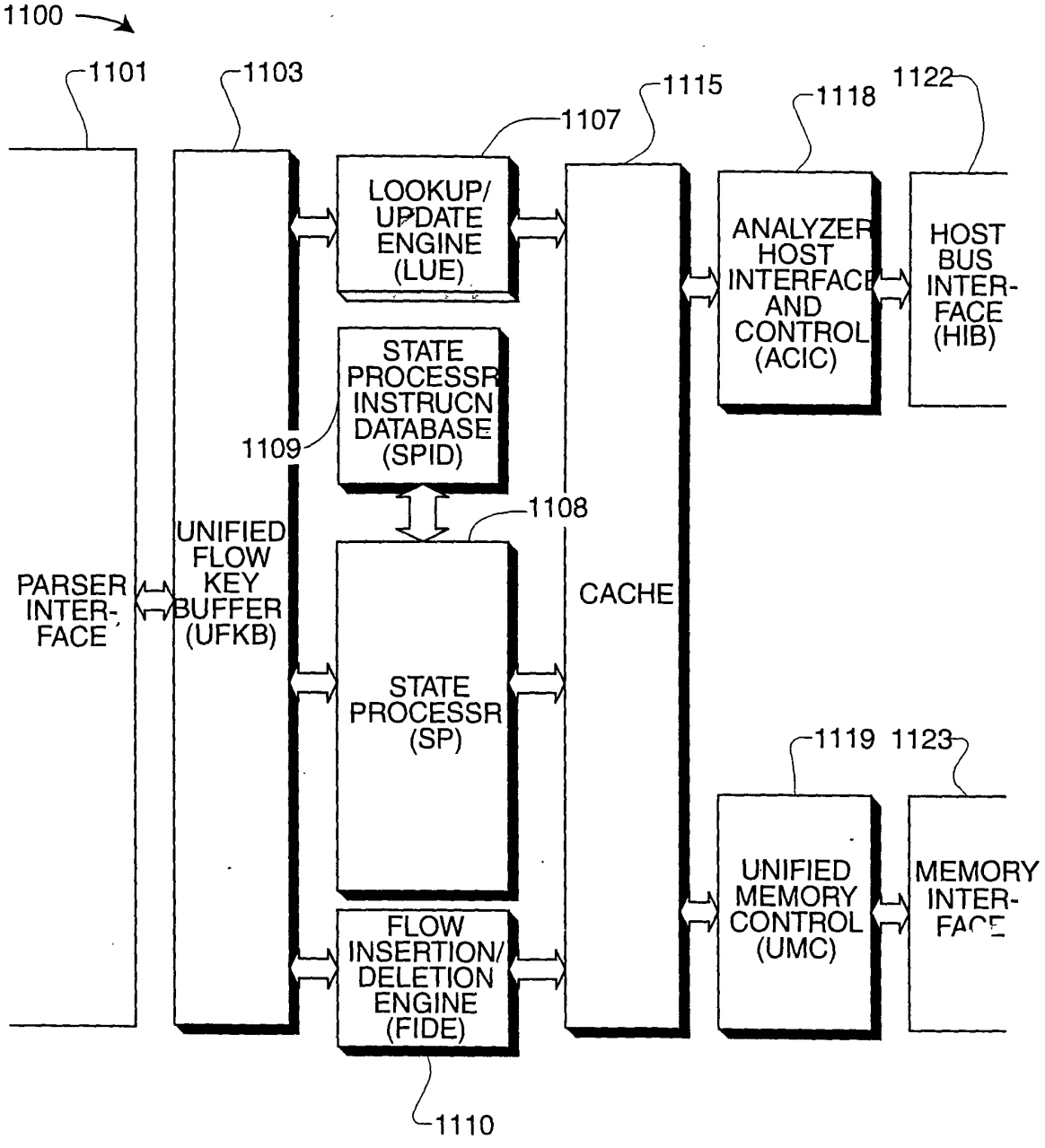


FIG. 11

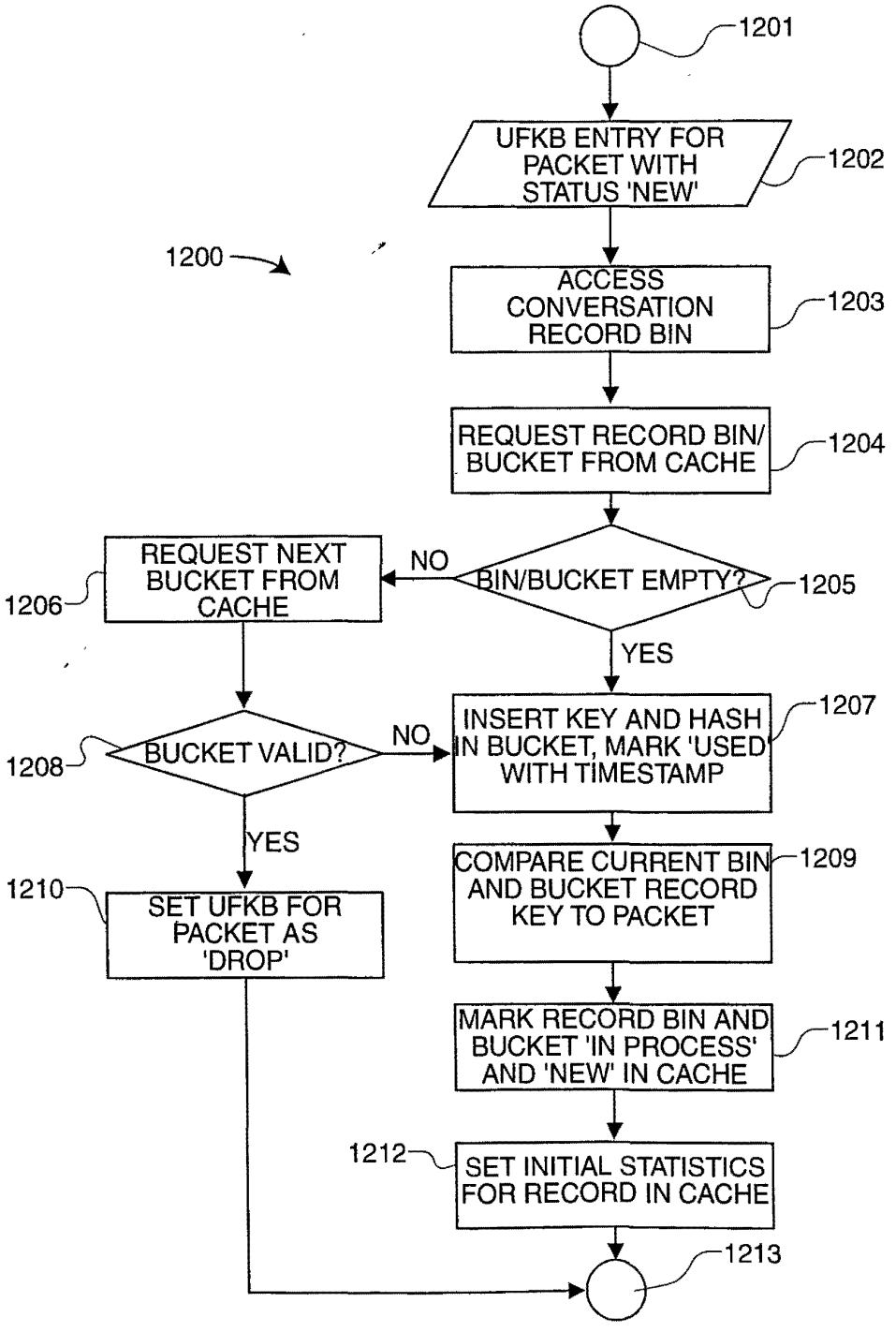

1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
REQUEST NEXT BUCKET FROM CACHE
NO
BIN/BUCKET EMPTY?
1205
1206
YES
INSERT KEY AND HASH IN BUCKET, MARK 'USED WITH TIMESTAMP
1207
BUCKET VALID?
NO
1208
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
1209
1210
SET UFKB FOR PACKET AS 'DROP'
MARK RECORD BIN AND BUCKET 'IN PROCESS' AND 'NEW' IN CACHE
1211
1212
SET INITIAL STATISTICS FOR RECORD IN CACHE
1213

FIG. 12

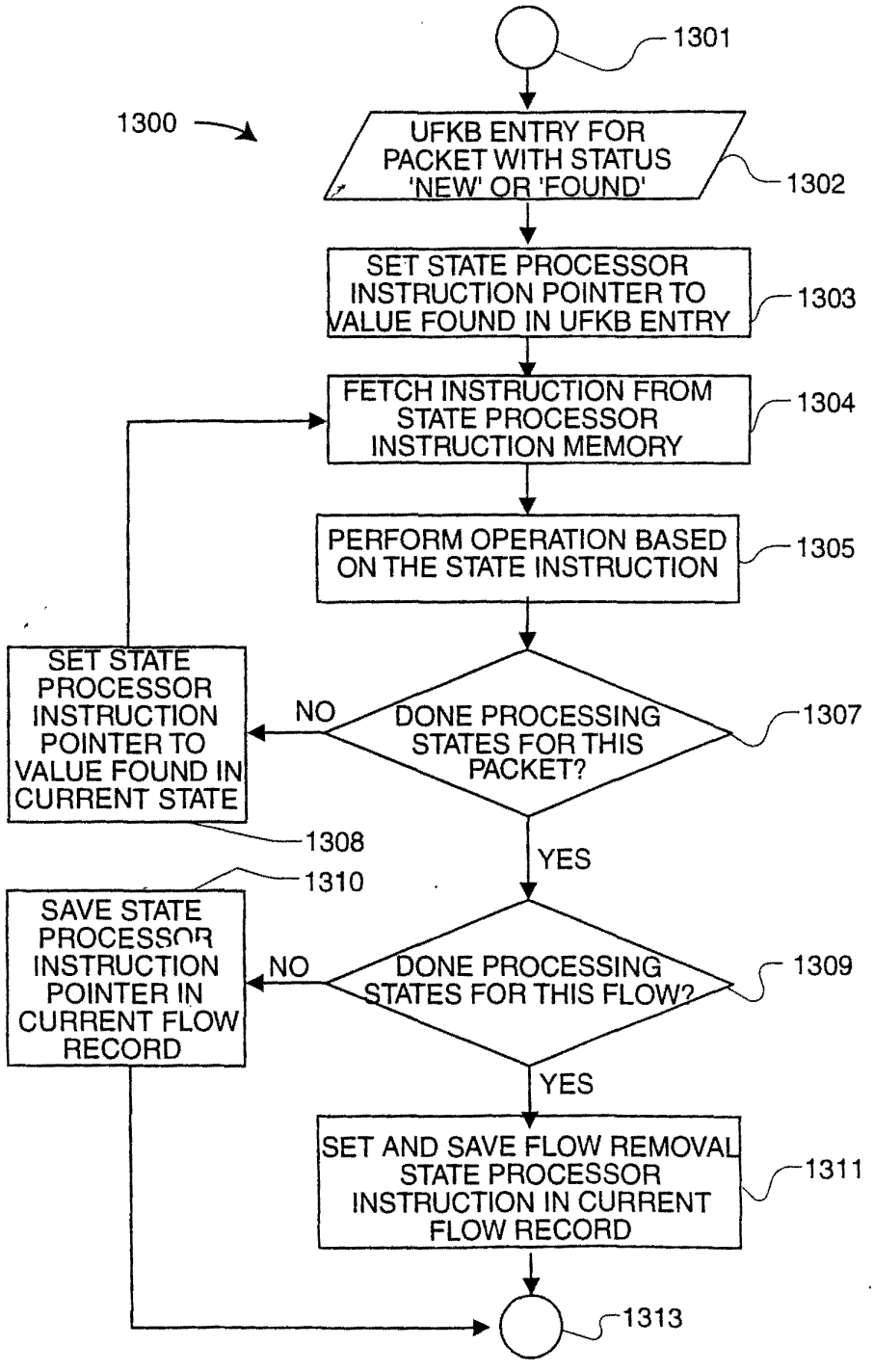

1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
DONE PROCESSING STATES FOR THIS PACKET?
1307
NO
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN CURRENT STATE
1308
YES
DONE PROCESSING STATES FOR THIS FLOW?
1309
NO
SAVE STATE PROCESSOR INSTRUCTION POINTER IN CURRENT FLOW RECORD
1310
YES
SET AND SAVE FLOW REMOVAL STATE PROCESSOR INSTRUCTION IN CURRENT FLOW RECORD
1311
1313

FIG. 13

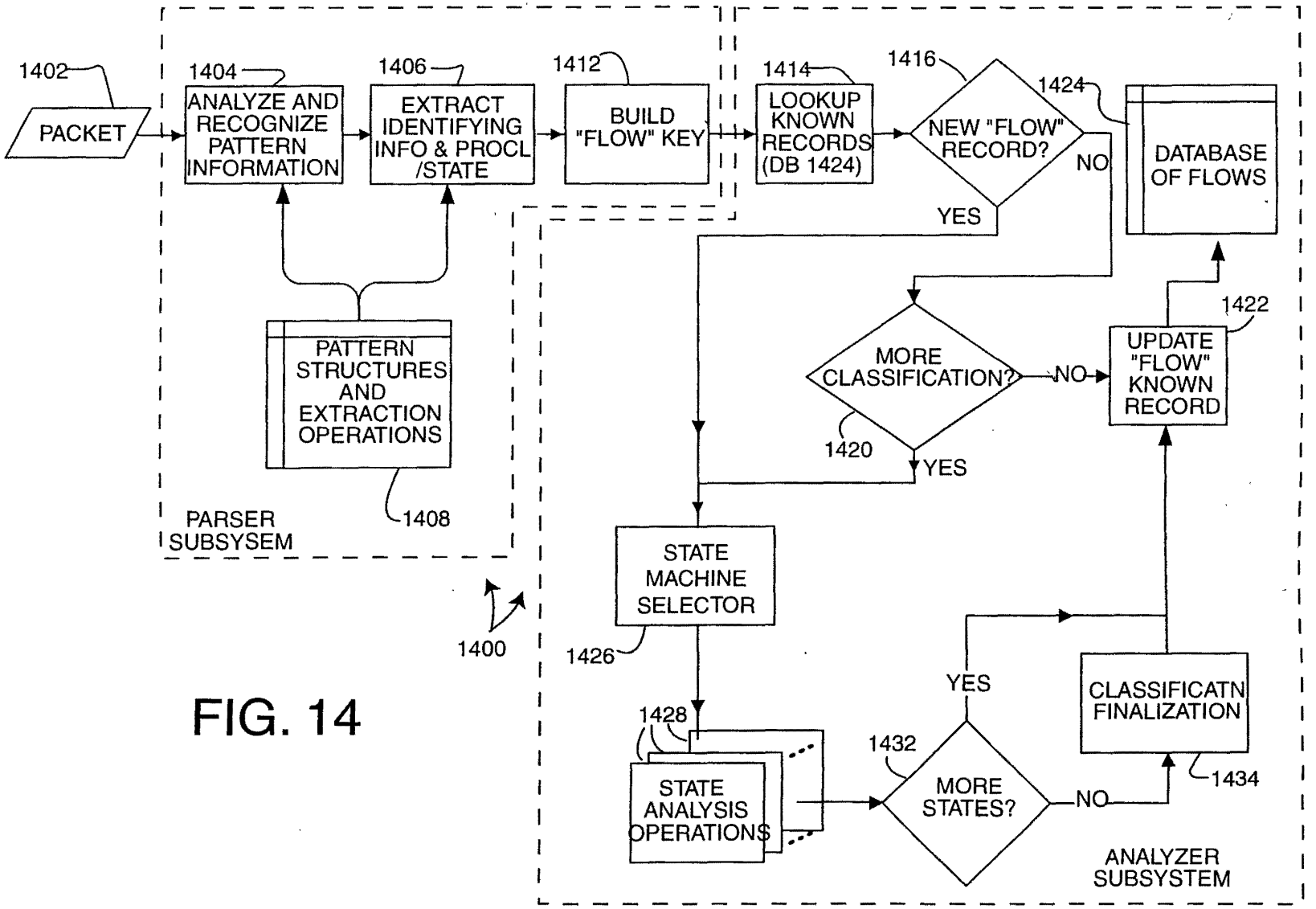


FIG. 14

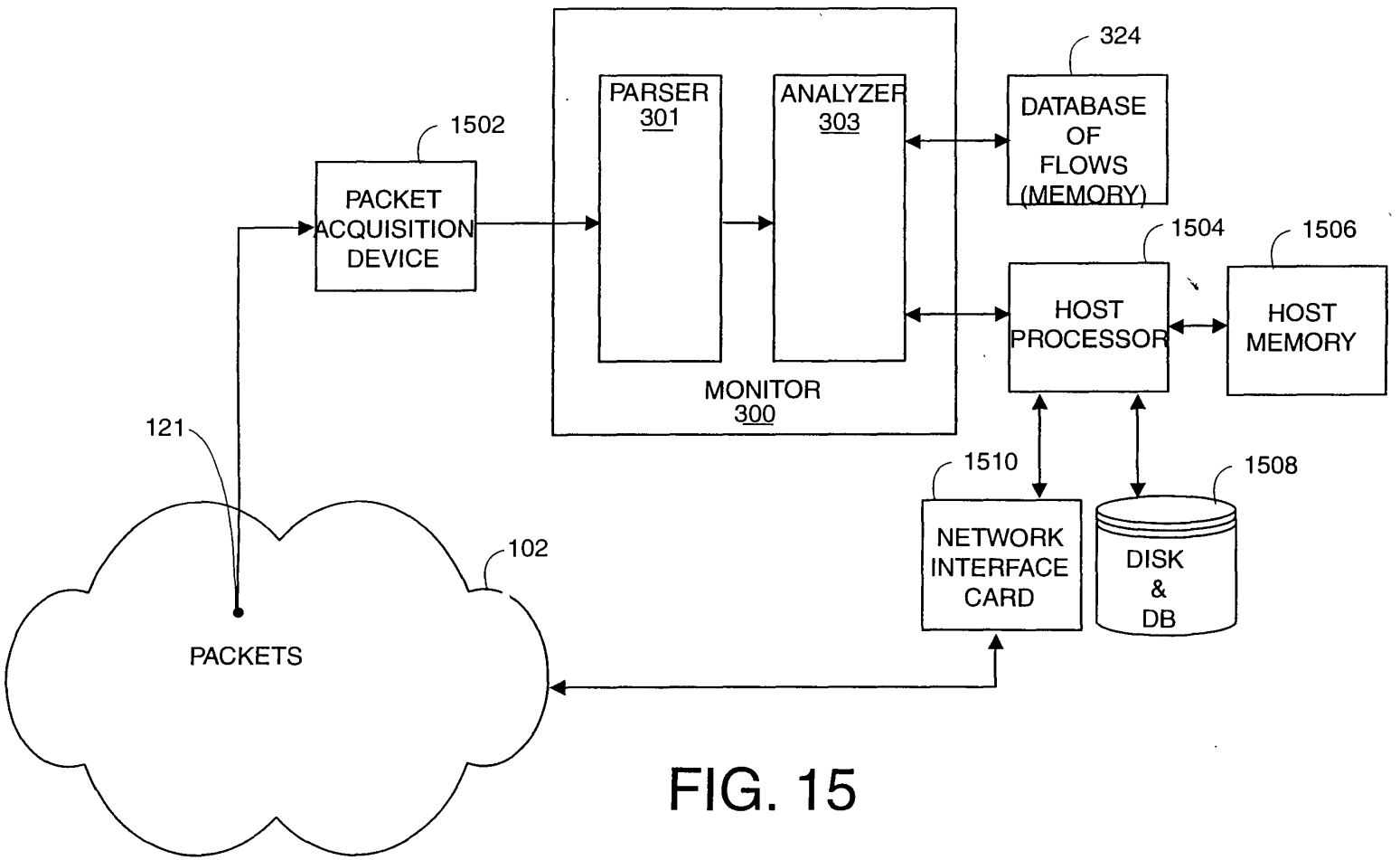


FIG. 15

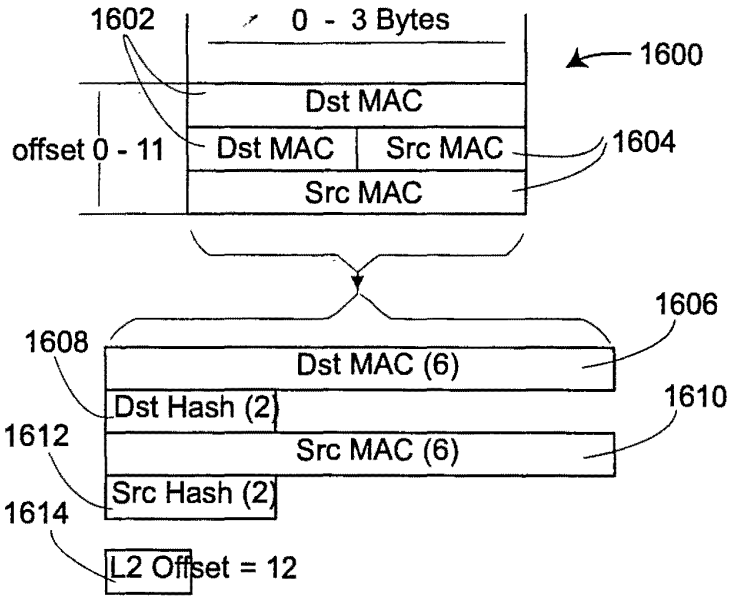


FIG. 16

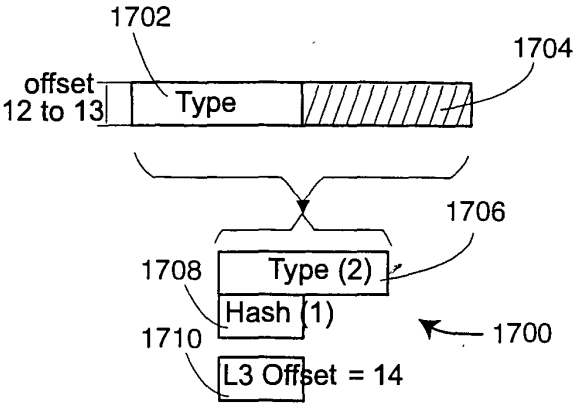


FIG. 17A

1712

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

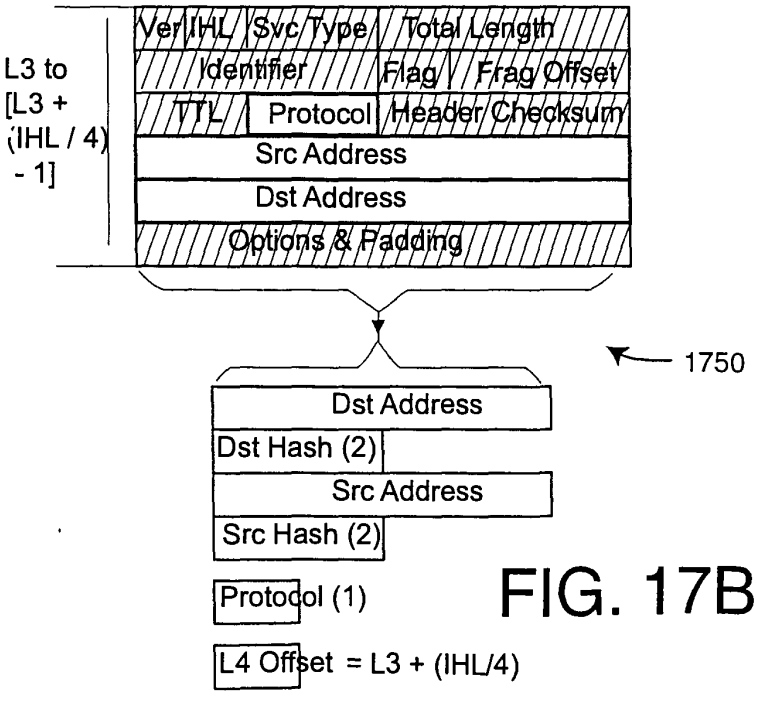


FIG. 17B

1752

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

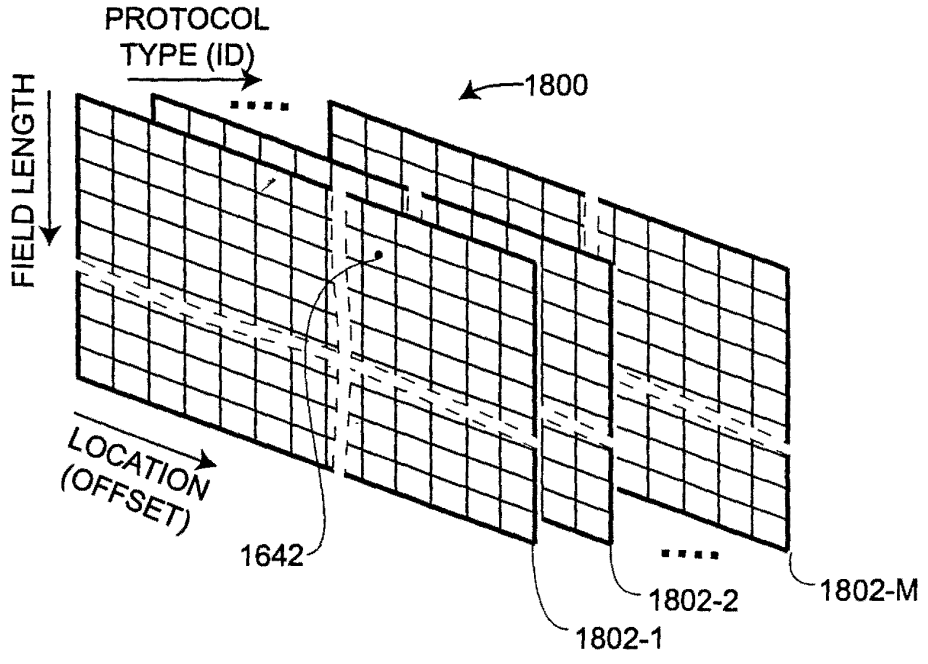


FIG. 18A

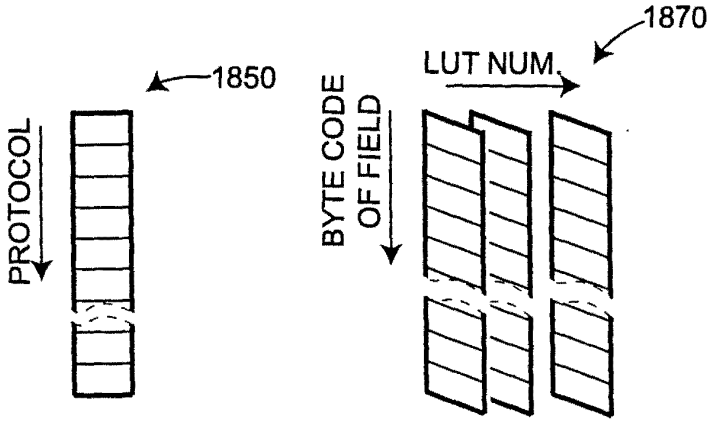


FIG. 18B

UNITED STATES PATENT AND TRADEMARK OFFICE

COMMISSIONER FOR PATENTS
UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. 20231
www.uspto.gov

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
09/608,126	06/30/2000	Russell S. Dietz	APPT-001-3

FORMALITIES LETTER

OC000000005444855

Dov Rosenfeld
Suite 2
5507 College Avenue
Oakland, CA 94618

Date Mailed: 10/02/2000

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given TWO MONTHS from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
  Applicant must submit **$ 690** *to complete the basic filing fee and/or file a small entity statement claiming such status (37 CFR 1.27).*
- Total additional claim fee(s) for this application is $18.
  - **$18** for **1** total claims over 20.
- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
- To avoid abandonment, a late filing fee or oath or declaration surcharge as set forth in 37 CFR 1.16(e) of $130 for a non-small entity, must be submitted with the missing items identified in this letter.

- **The balance due by applicant is $ 838.**

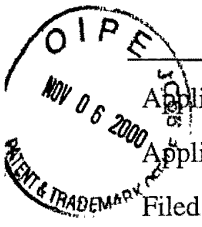
A copy of this notice MUST be returned with the reply.

Customer Service Center
Initial Patent Examination Division (703) 308-1202
PART 3 - OFFICE COPY

SEC JDR.

Our Ref./Docket No: APPT-0C

Patent



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.* Application No.: 09/608126 Filed: June 30, 2000 Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	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:

__X__ Executed Declaration and Power of Attorney. The above-identified application is the same application which the inventor executed by signing the enclosed declaration;

__X__ Executed Assignment with assignment cover sheet.

__X__ A credit card payment form in the amount of $ 898.00 is attached, being for:

- __X__ Statutory basic filing fee: $ 710
- __X__ Additional claim fee of $ 18
- __X__ Assignment recordation fee of $ 40
- ____ Extension Fee (1st Month) of $ 110
- __X__ Missing Parts Surcharge $130

__X__ 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

__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

Dov Rosenfeld, Reg. No. 38687

Address for correspondence:
Dov Rosenfeld
5507 College Avenue, Suite 2
Oakland, CA 94618
Tel. (510) 547-3378; Fax: (510) 653-7992

PATENT APPLICATION

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION — ATTORNEY DOCKET NO. APPT-001-3

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

the specification of which is attached hereto unless the following box is checked:

(X) was filed on June 30, 2000 as US Application Serial No. 09/608126 or PCT International Application Number ____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

Foreign Application(s) and/or Claim of Foreign Priority

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35
			YES: ___ NO: ___
			YES: ___ NO: ___

Provisional Application

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE
60/141,903	June 30, 1999

U.S. Priority Claim

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS(patented/pending/abandoned)

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

Dov Rosenfeld, Reg. No. 38,687

Send Correspondence to:	**Direct Telephone Calls To:**
Dov Rosenfeld 5507 College Avenue, Suite 2 Oakland, CA 94618	Dov Rosenfeld, Reg. No. 38,687 Tel: (510) 547-3378

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of First Inventor: Russell S. Dietz **Citizenship:** USA

Residence: 6146 Ostenberg Drive, San Jose, CA 95120-2736

Post Office Address: Same

First Inventor's Signature **Date** 10/9/00

APPT-001-3

ADDITIONAL INVENTOR SIGNATURES:

Name of Second Inventor: Joseph R. Maixner **Citizenship:** USA

Residence: 121 Driftwood Court, Aptos, CA 95003

Post Office Address: Same

_____ _____

Inventor's Signature **Date**

Name of Third Inventor: Andrew A. Koppenhaver **Citizenship:** USA

Residence: 10400 Kenmore Drive, Fairfax, VA 22030

Post Office Address: Same

_____ _____

Inventor's Signature **Date**

PATENT APPLICATION

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION — **ATTORNEY DOCKET NO. APPT-001-3**

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

the specification of which is attached hereto unless the following box is checked:

(X) was filed on June 30, 2000 as US Application Serial No. 09/608126 or PCT International Application Number _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

Foreign Application(s) and/or Claim of Foreign Priority

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COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35
			YES: ___ NO: ___
			YES: ___ NO: ___

Provisional Application

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE
60/141,903	June 30, 1999

U.S. Priority Claim

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS(patented/pending/abandoned)

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

Dov Rosenfeld, Reg. No. 38,687

Send Correspondence to:	**Direct Telephone Calls To:**
Dov Rosenfeld 5507 College Avenue, Suite 2 Oakland, CA 94618	Dov Rosenfeld, Reg. No. 38,687 Tel: (510) 547-3378

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of First Inventor: Russell S. Dietz **Citizenship:** USA

Residence: 6146 Ostenberg Drive, San Jose, CA 95120-2736

Post Office Address: Same

_____ _____

First Inventor's Signature **Date**

PATENT APPLICATION

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION — **ATTORNEY DOCKET NO. APPT-001-3**

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

the specification of which is attached hereto unless the following box is checked:

(X) was filed on June 30, 2000 as US Application Serial No. 09/608126 or PCT International Application Number ____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

Foreign Application(s) and/or Claim of Foreign Priority

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COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35
			YES: NO:
			YES: NO:

Provisional Application

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE
60/141,903	June 30, 1999

U.S. Priority Claim

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APPLICATION SERIAL NUMBER	FILING DATE	STATUS(patented/pending/abandoned)

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

Dov Rosenfeld, Reg. No. 38,687

Send Correspondence to:	**Direct Telephone Calls To:**
Dov Rosenfeld	Dov Rosenfeld, Reg. No. 38,687
5507 College Avenue, Suite 2	Tel: (510) 547-3378
Oakland, CA 94618	

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of First Inventor: Russell S. Dietz **Citizenship:** USA

Residence: 6146 Ostenberg Drive, San Jose, CA 95120-2736

Post Office Address: Same

_____ _____

First Inventor's Signature **Date**

ADDITIONAL INVENTOR SIGNATURES:

Name of Second Inventor: Joseph R. Maixner **Citizenship:** USA

Residence: 121 Driftwood Court, Aptos, CA 95003

Post Office Address: Same

Joseph R. Maixner
Inventor's Signature

10/23/2000
Date

Name of Third Inventor: Andrew A. Koppenhaver **Citizenship:** USA

Residence: 10400 Kenmore Drive, Fairfax, VA 22030

Post Office Address: Same

_____
Inventor's Signature

_____
Date

PATENT APPLICATION

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

ATTORNEY DOCKET NO. APPT-001-3

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING

the specification of which is attached hereto unless the following box is checked:

(X) was filed on June 30, 2000 as US Application Serial No. 09/608126 or PCT International Application Number _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

Foreign Application(s) and/or Claim of Foreign Priority

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35
			YES: NO:
			YES: NO:

Provisional Application

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE
60/141,903	June 30, 1999

U.S. Priority Claim

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS(patented/pending/abandoned)

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

Dov Rosenfeld, Reg. No. 38,687

Send Correspondence to:	**Direct Telephone Calls To:**
Dov Rosenfeld	Dov Rosenfeld, Reg. No. 38,687
5507 College Avenue, Suite 2	Tel: (510) 547-3378
Oakland, CA 94618	

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of First Inventor: Russell S. Dietz **Citizenship:** USA

Residence: 6146 Ostenberg Drive, San Jose, CA 95120-2736

Post Office Address: Same

_____ _____

First Inventor's Signature **Date**

Declaration and Power of Attorney (Continued)
Case No; «Case CaseNumber»
Page 2 APPT-001-3

ADDITIONAL INVENTOR SIGNATURES:

Name of Second Inventor: Joseph R. Maixner **Citizenship:** USA

Residence: 121 Driftwood Court, Aptos, CA 95003

Post Office Address: Same

_____ _____

Inventor's Signature **Date**

Name of Third Inventor: Andrew A. Koppenhaver **Citizenship:** USA

Residence: 9325 W. Hinsdale Place, Littleton, CO 80128

Post Office Address: Same

_____ 10/10/2000

Inventor's Signature **Date**

Our Ref./Docket No: APPT-6[illegible]3 Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.* Application No.: 09/608126 Filed: June 30, 2000 Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	Group Art Unit: Examiner: (Unassigned)

REQUEST FOR RECORDATION OF ASSIGNMENT

Assistant Commissioner for Patents
Washington, D.C. 20231
Attn: Box Assignment

Dear Assistant Commissioner:

Enclosed herewith for recordation in the records of the U.S. Patent and Trademark Office is an original Assignment, an Assignment Cover Sheet, and $40.00. Please record and return the Assignment.

Respectfully Submitted,

Nov 1, 2000
Date

Dov Rosenfeld, Reg. No. 38687

Address for correspondence:

Dov Rosenfeld
5507 College Avenue, Suite 2
Oakland, CA 94618
Tel. (510) 547-3378; Fax: (510) 653-7992

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

UNITED STATES PATENT AND TRADEMARK OFFICE

COMMISSIONER FOR PATENTS
UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. 20231
www.uspto.gov

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
09/608,126	06/30/2000	Russell S. Dietz	APPT-001-3

FORMALITIES LETTER

OC000000005444855

Dov Rosenfeld
Suite 2
5507 College Avenue
Oakland, CA 94618

Date Mailed: 10/02/2000

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given TWO MONTHS from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
  Applicant must submit **$ ~~690~~** *to complete the basic filing fee and/or file a small entity statement claiming such status (37 CFR 1.27).* 710
- Total additional claim fee(s) for this application is $18.
  - **$18** for **1** total claims over 20.
- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
- To avoid abandonment, a late filing fee or oath or declaration surcharge as set forth in 37 CFR 1.16(e) of $130 for a non-small entity, must be submitted with the missing items identified in this letter.

- **The balance due by applicant is $ 838.**

858+40 = 898

11/03/2000 KZEWDIE 00000036 09608126
01 FC:101 710.00 DP
02 FC:105 130.00 DP
03 FC:103 18.00 DP

*A copy of this notice **MUST** be returned with the reply.*

Customer Service Center
Initial Patent Examination Division (703) 308-1202
PART 2 - COPY TO BE RETURNED WITH RESPONSE

Our Docket/Ref. No.: APPT-0[illegible]-3

Patent 2755 2151

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz et al. Serial No.: 09/608126 Filed: June 30, 2000 Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	Group Art Unit: Examiner:

Commissioner for Patents
Washington, D.C. 20231

TRANSMITTAL: INFORMATION DISCLOSURE STATEMENT

Dear Commissioner:

Transmitted herewith are:

X 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.

X Return postcard.

X 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

Date: 30 Mar 2002

Respectfully submitted,

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

#5

Our Docket/Ref. No.: APPT-001-3 Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz et al. Serial No.: 09/608126 Filed: June 30, 2000 Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	Group Art Unit: 2755 Examiner:

Commissioner for Patents
Washington, D.C. 20231

INFORMATION DISCLOSURE STATEMENT

Dear Commissioner:

This Information Disclosure Statement is submitted:

X under 37 CFR 1.97(b), or
(Within three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)

X Applicant(s) submit herewith Form PTO 1449-Information Disclosure Citation together with copies, of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56.

X (Certification) Each item of information contained in this information disclosure statement was first cited in a formal communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of this information disclosure statement (written opinion from PCT mailed Jan 11,2002).

It is expressly requested that the cited information be made of record in the application and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR 1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no representation is

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

being made that a search has been conducted or that this statement encompasses all the possible relevant information.

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

...M - 1449 _____ _____ SHEET 1 OF 1.

ATTY. DOCKET NO.	SERIAL NO.
APPT-001-3	09/608126
APPLICANT: Dietz et al.	
FILING DATE: 6/30/2000	GROUP: 2755 2142

INFORMATION DISCLOSURE STATEMENT

(Use several sheets if necessary)

U.S. PATENT DOCUMENTS

*EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS	SUB-CLASS	FILING DATE IF APPROPRIATE
Uh	AA	5,703,877	Dec. 30, 1997	Nuber et al.	370	395	Nov. 22, 1995
Uh	AB	5,892,754	Apr.6, 1999	Kompella et al.	370	236	Jun. 7, 1996
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	AJ						
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FOREIGN PATENT DOCUMENTS

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OTHER DISCLOSURES (Including Author, Title, Date, Pertinent Pages, Place of Publication, Etc.)

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EXAMINER: Uh DATE CONSIDERED: 6/19/03

*EXAMINER: initial if citation considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include a copy of this form with next communication to Applicant.

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United States Patent [19]

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[45] Date of Patent: *Dec. 30, 1997

[54] **ACQUISITION AND ERROR RECOVERY OF AUDIO DATA CARRIED IN A PACKETIZED DATA STREAM**

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[73] Assignee: **General Instrument Corporation of Delaware**, Chicago, Ill.

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,517,250.

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[51] **Int. Cl.**[6] **H04J 3/06**; H04N 7/12

[52] **U.S. Cl.** **370/395**; 370/510; 370/514; 375/366; 348/423; 348/462; 348/466; 348/467

[58] **Field of Search** 370/389, 395, 370/503, 509, 510, 514, 516; 375/362, 365, 366, 368, 371; 348/423, 461, 462, 464, 466, 467

[56] **References Cited**

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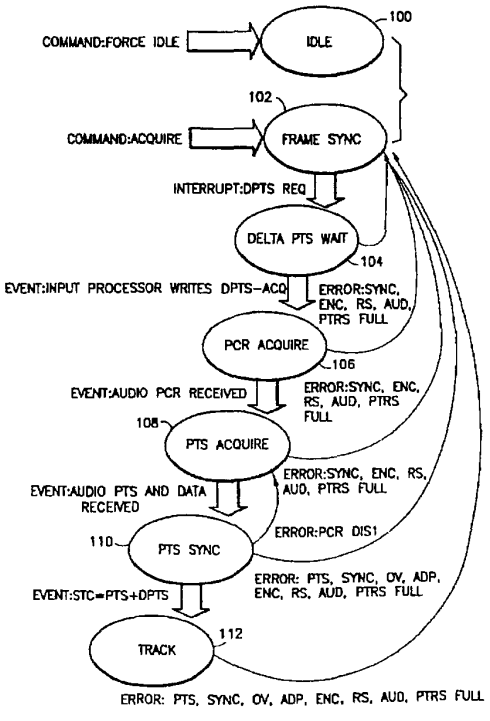
Attorney, Agent, or Firm—Barry R. Lipsitz

[57] **ABSTRACT**

Audio data is processed from a packetized data stream carrying digital television information in a succession of fixed length transport packets. Some of the packets contain a presentation time stamp (PTS) indicative of a time for commencing the output of associated audio data. After the audio data stream has been acquired, the detected audio packets are monitored to locate subsequent PTS's for adjusting the timing at which audio data is output, thereby providing proper lip synchronization with associated video. Errors in the audio data are processed in a manner which attempts to maintain synchronization of the audio data stream while masking the errors. In the event that the synchronization condition cannot be maintained, for example in the presence of errors over more than one audio frame, the audio data stream is reacquired while the audio output is concealed. An error condition is signaled to the audio decoder by altering the audio synchronization word associated with the audio frame in which the error has occurred.

25 Claims, 4 Drawing Sheets



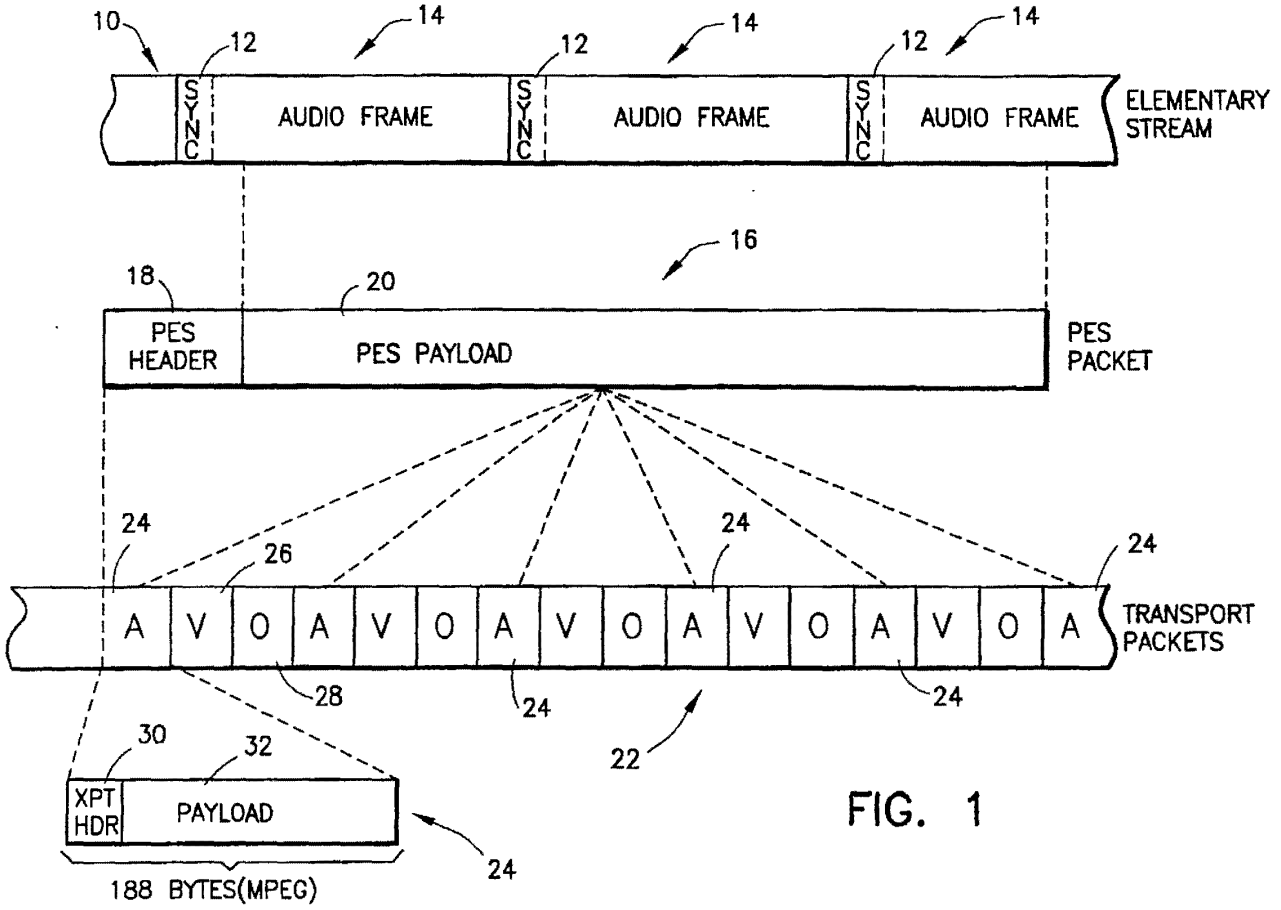

10
12
14
SYNC
AUDIO FRAME
ELEMENTARY STREAM
16
18
20
PES HEADER
PES PAYLOAD
PES PACKET
24
26
28
22
A
V
O
TRANSPORT PACKETS
30
32
XPT HDR
PAYLOAD
188 BYTES(MPEG)

FIG. 1

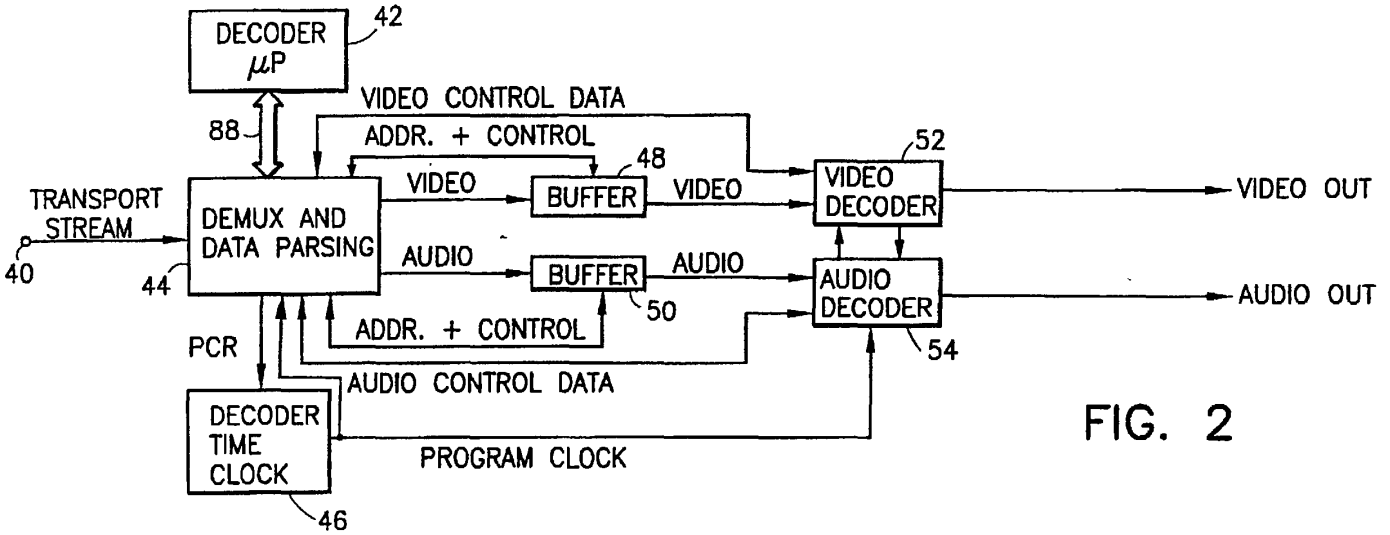

DECODER
μP
42
VIDEO CONTROL DATA
88
ADDR. + CONTROL
48
52
TRANSPORT
STREAM
40
DEMUX AND
DATA PARSING
44
VIDEO
BUFFER
VIDEO
VIDEO
DECODER
VIDEO OUT
AUDIO
BUFFER
AUDIO
AUDIO
DECODER
AUDIO OUT
50
ADDR. + CONTROL
54
PCR
AUDIO CONTROL DATA
DECODER
TIME
CLOCK
PROGRAM CLOCK
46

FIG. 2

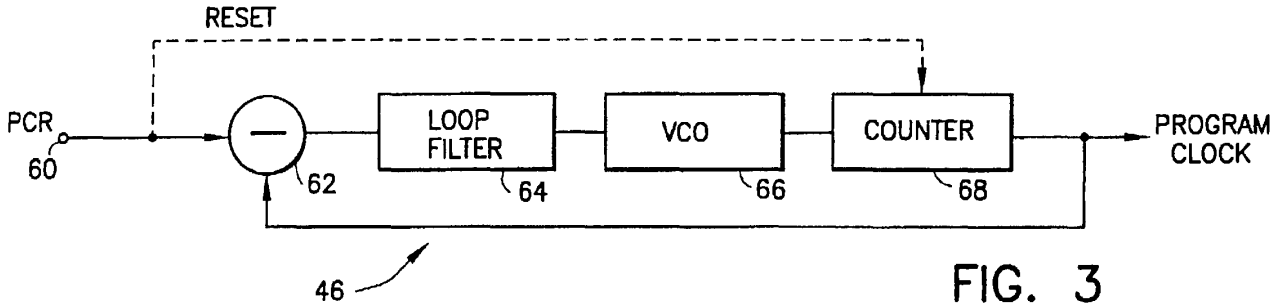
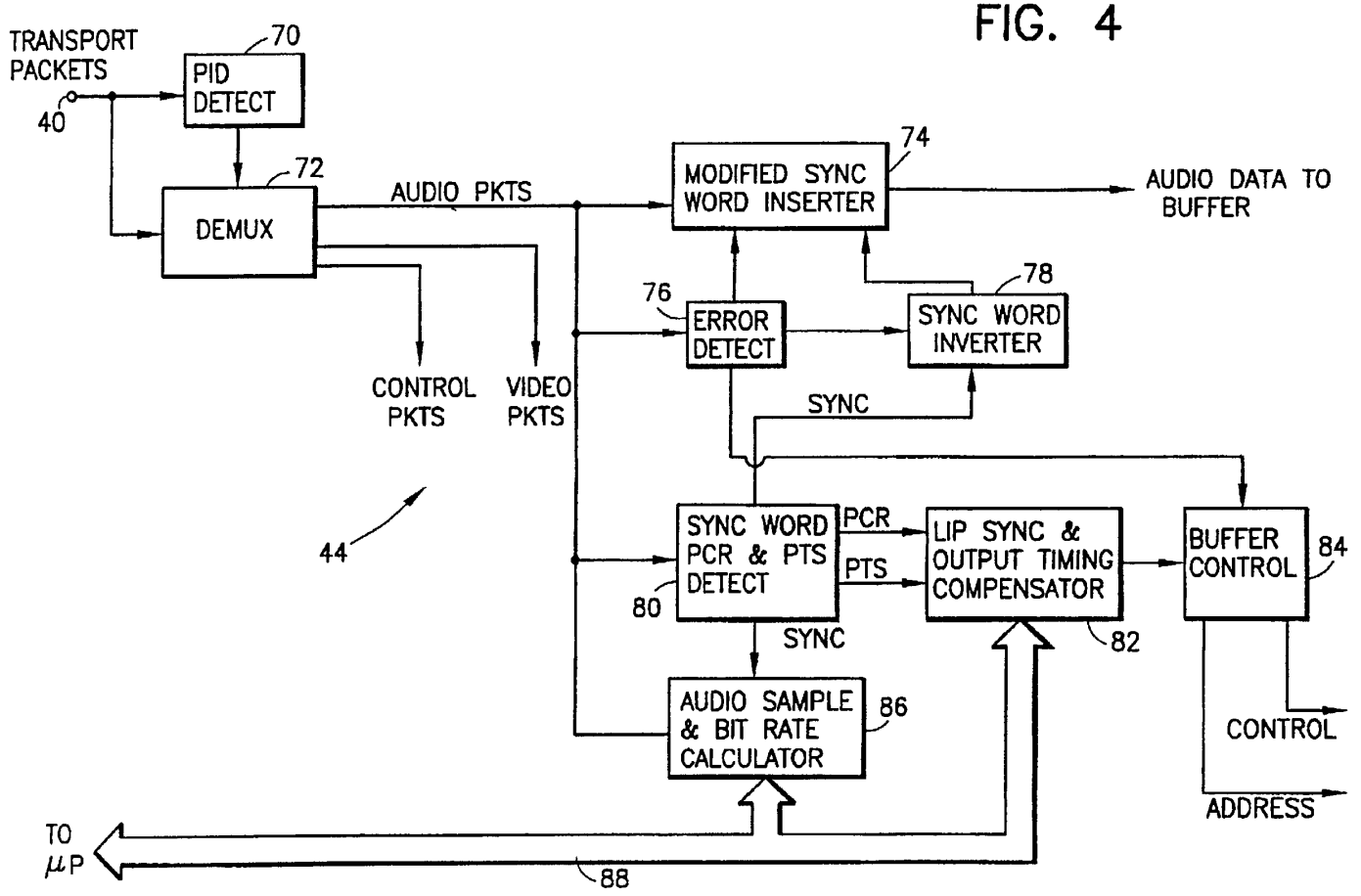

RESET
PCR
60
62
LOOP
FILTER
64
VCO
66
COUNTER
68
PROGRAM
CLOCK
46

FIG. 3

FIG. 4


TRANSPORT PACKETS
40
PID DETECT
70
DEMUX
72
AUDIO PKTS
MODIFIED SYNC WORD INSERTER
74
AUDIO DATA TO BUFFER
ERROR DETECT
76
SYNC WORD INVERTER
78
CONTROL PKTS
VIDEO PKTS
SYNC
44
SYNC WORD PCR & PTS DETECT
80
PCR
PTS
LIP SYNC & OUTPUT TIMING COMPENSATOR
82
BUFFER CONTROL
84
SYNC
AUDIO SAMPLE & BIT RATE CALCULATOR
86
CONTROL
ADDRESS
TO μP
88

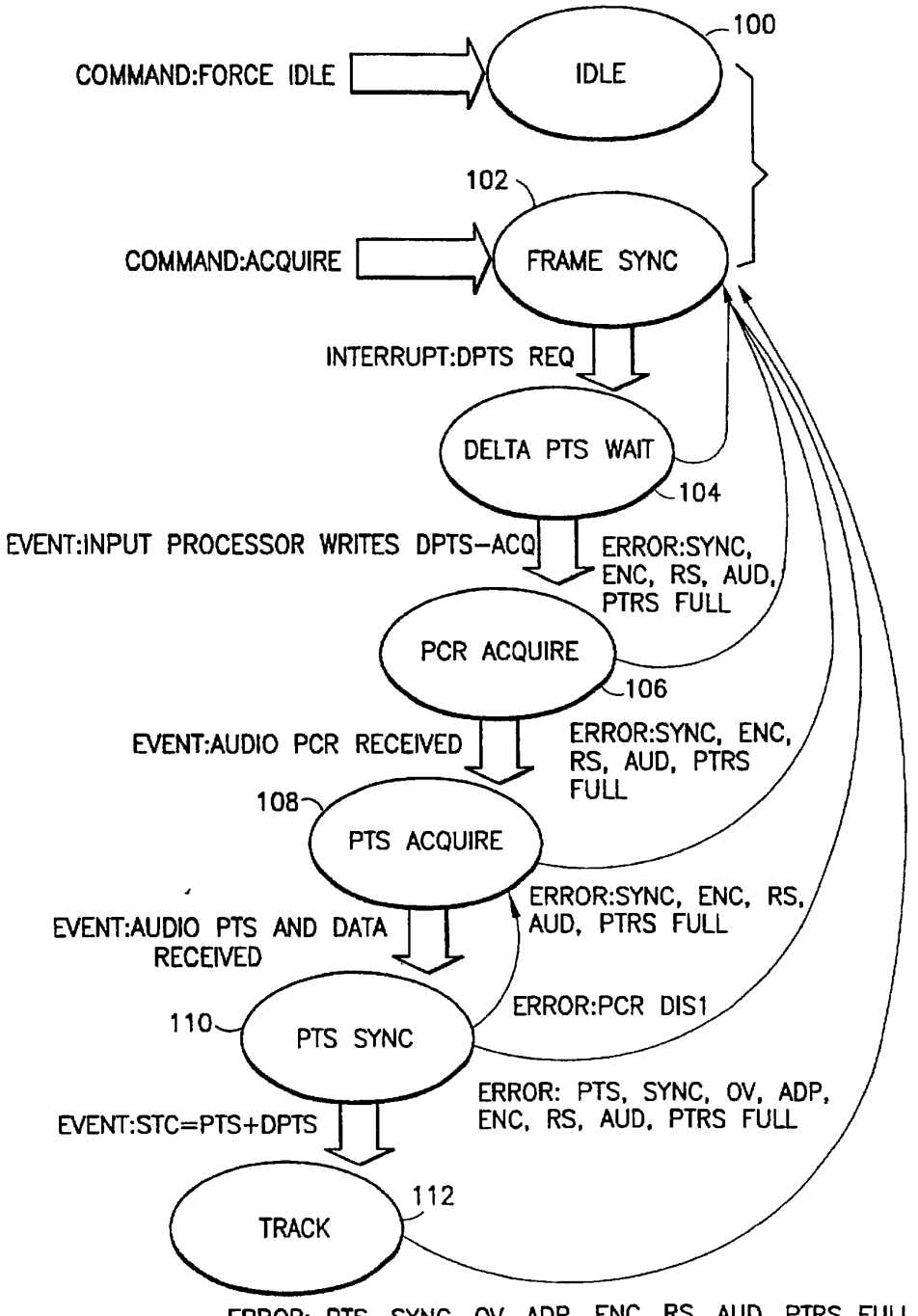

100
IDLE
COMMAND:FORCE IDLE
102
FRAME SYNC
COMMAND:ACQUIRE
INTERRUPT:DPTS REQ
DELTA PTS WAIT
104
EVENT:INPUT PROCESSOR WRITES DPTS-ACQ
ERROR:SYNC, ENC, RS, AUD, PTRS FULL
PCR ACQUIRE
106
EVENT:AUDIO PCR RECEIVED
ERROR:SYNC, ENC, RS, AUD, PTRS FULL
108
PTS ACQUIRE
ERROR:SYNC, ENC, RS, AUD, PTRS FULL
EVENT:AUDIO PTS AND DATA RECEIVED
ERROR:PCR DIS1
110
PTS SYNC
ERROR: PTS, SYNC, OV, ADP, ENC, RS, AUD, PTRS FULL
EVENT:STC=PTS+DPTS
112
TRACK
ERROR: PTS, SYNC, OV, ADP, ENC, RS, AUD, PTRS FULL

FIG. 5

ACQUISITION AND ERROR RECOVERY OF AUDIO DATA CARRIED IN A PACKETIZED DATA STREAM

BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for acquiring audio data from a packetized data stream and recovery from errors contained in such data.

Various standards have emerged for the transport of digital data, such as digital television data. Examples of such standards include the Moving Pictures Experts Group (MPEG) standards and the DigiCipher® II standard proprietary to General Instrument Corporation of Chicago, Ill., U.S.A., the assignee of the present invention. The DigiCipher® II standard extends the MPEG-2 systems and video standards, which are widely known and recognized as transport and video compression specifications specified by the International Standards Organization (ISO) in Document series ISO 13818. The MPEG-2 specification's systems "layer" provides a transmission medium independent coding technique to build bitstreams containing one or more MPEG programs. The MPEG coding technique uses a formal grammar ("syntax") and a set of semantic rules for the construction of bitstreams. The syntax and semantic rules include provisions for demultiplexing, clock recovery, elementary stream synchronization and error handling.

The MPEG transport stream is specifically designed for use with media that can generate data errors. Many programs, each comprised of one or more elementary streams, may be combined into a transport stream. Examples of services that can be provided using the MPEG format are television services broadcast over terrestrial, cable television and satellite networks as well as interactive telephony-based services. The primary mode of information carriage in MPEG broadcast applications will be the MPEG-2 transport stream. The syntax and semantics of the MPEG-2 transport stream are defined in International Organisation for Standardisation, ISO/IEC 13818-1, International Standard, 1994 entitled "Generic Coding of Moving Pictures and Associated Audio: Systems," recommendation H.222, incorporated herein by reference.

Multiplexing according to the MPEG-2 standard is accomplished by segmenting and packaging elementary streams such as compressed digital video and audio into packetized elementary stream (PES) packets which are then segmented and packaged into transport packets. As noted above, each MPEG transport packet is fixed at 188 bytes in length. The first byte is a synchronization byte having a specific eight-bit pattern, e.g., 01000111. The sync byte indicates the beginning of each transport packet.

Following the sync byte is a three-byte field which includes a one-bit transport packet error indicator, a one-bit payload unit start indicator, a one-bit transport priority indicator, a 13-bit packet identifier (PID), a two-bit transport scrambling control, a two-bit adaptation field control, and a four-bit continuity counter. The remaining 184 bytes of the packet may carry the data to be communicated. An optional adaptation field may follow the prefix for carrying both MPEG related and private information of relevance to a given transport stream or the elementary stream carried within a given transport packet. Provisions for clock recovery, such as a program clock reference (PCR), and bitstream splicing information are typical of the information carried in the adaptation field. By placing such information in an adaptation field, it becomes encapsulated with its associated data to facilitate remultiplexing and network routing operations. When an adaptation field is used, the payload is correspondingly shorter in length.

The PCR is a sample of the system time clock (STC) for the associated program at the time the PCR bytes are received at the decoder. The decoder uses the PCR values to synchronize a decoder system time clock (STC) with the encoder's system time clock. The lower nine bits of a 42-bit STC provide a modulo-300 counter that is incremented at a 27 MHz clock rate. At each modulo-300 rollover, the count in the upper 33 bits is incremented, such that the upper bits of the STC represent time in units of a 90 kHz clock period. This enables presentation time stamps (PTS) and decode time stamps (DTS) to be used to dictate the proper time for the decoder to decode access units and to present presentation units with the accuracy of one 90 kHz clock period. Since each program or service carried by the data stream may have its own PCR, the programs can be multiplexed asynchronously.

Synchronization of audio, video and data presentation within a program is accomplished using a time stamp approach. Presentation time stamps (PTSs) and/or decode time stamps (DTSs)are inserted into the transport stream for the separate video and audio packets. The PTS and DTS information is used by the decoder to determine when to decode and display a picture and when to play an audio segment. The PTS and DTS values are relative to the same system time clock sampled to generate the PCRs.

All MPEG video and audio data must be formatted into a packetized elementary stream (PES) formed from a succession of PES packets. Each PES packet includes a PES header followed by a payload. The PES packets are then divided into the payloads of successive fixed length transport packets.

PES packets are of variable and relatively long length. Various optional fields, such as the presentation time stamps and decode time stamps may be included in the PES header. When the transport packets are formed from the PES, the PES headers immediately follow the transport packet headers. A single PES packet may span many transport packets and the subsections of the PES packet must appear in consecutive transport packets of the same PID value. It should be appreciated, however, that these transport packets may be freely multiplexed with other transport packets having different PIDs and carrying data from different elementary streams within the constraints of the MPEG-2 Systems specification.

Video programs are carried by placing coded MPEG video streams into PES packets which are then divided into transport packets for insertion into a transport stream. Each video PES packet contains one or more coded video pictures, referred to as video "access units." A PTS and/or a DTS value may be placed into the PES packet header that encapsulates the associated access units. The DTS indicates when the decoder should decode the access unit into a presentation unit. The PTS is used to actuate the decoder to present the associated presentation unit.

Audio programs are provided in accordance with the MPEG Systems specification using the same specification of the PES packet layer. PTS values may be included in those PES packets that contain the first byte of an audio access unit (sync frame). The first byte of an audio access unit is part of an audio sync word. An audio frame is defined as the data between two consecutive audio sync words, including the preceding sync word and not including the succeeding sync word.

In DigiCipher® II, audio transport packets include one or both of an adaptation field and payload field. The adaptation field may be used to transport the PCR values. The payload field transports the audio PES, consisting of PES headers and PES data. PES headers are used to transport the audio PTS values. Audio PES data consists of audio frames as specified, e.g., by the Dolby® AC-3 or Musicam audio syntax specifications. The AC-3 specifications are set forth in a document entitled Digital Audio Compression (AC-3), ATSC Standard, Doc. A/52, United States Advanced Television Systems Committee. The Musicam specification can be found in the document entitled "Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 MBIT/s," *Part* 3 Audio, 11172-3 (MPEG-1) published by ISO. Each syntax specifies an audio sync frame as audio sync word, followed by audio information including audio sample rate, bit rate and/or frame size, followed by audio data.

In order to reconstruct a television signal from the video and audio information carried in an MPEG/DigiCipher® II transport stream, a decoder is required to process the video packets for output to a video decompression processor (VDP) and the audio packets for output to an audio decompression processor (ADP). In order to properly process the audio data, the decoder is required to synchronize to the audio data packet stream. In particular, this is required to enable audio data to be buffered for continuous output to the ADP and to enable the audio syntax to be read for audio rate information necessary to delay the audio output to achieve proper lip synchronization with respect to the video of the same program.

Several events can result in error conditions with respect to the audio processing. These include loss of audio transport packets due to transmission channel errors. Errors will also result from the receipt of audio packets which are not properly decrypted or are still encrypted. A decoder must be able to handle such errors without significantly degrading the quality of the audio output.

The decoder must also be able to handle changes in the audio sample rate and audio bit rate. The audio sample rate for a given audio elementary stream will rarely change. The audio bit rate, however, can often change at program boundaries, and at the start and end of commercials. It is difficult to maintain synchronization to the audio stream through such rate changes, since the size of the audio sync frames is dependent on the audio sample rate and bit rate. Handling undetected errors in the audio stream, particularly in systems where error detection is weak, complicates the tracking of the audio stream through rate changes. When a received bitstream indicates that an audio rate has changed, the rate may or may not have actually changed. If the decoder responds to an indication from the bitstream that the audio rate has changed when the indication is in error and the rate has not changed, a loss of audio synchronization will likely occur. This can result in an audio signal degradation that is noticeable to an end user.

To support an audio sample rate change, the audio clock rates utilized by the decoder must be changed. This process can take significant time, again degrading the quality of the audio output signal. Still further, such a sample rate change will require the audio buffers to be cleared to establish a different sample-rate-dependent lip sync delay. Thus, it may not be advantageous to trust a signal in the received bitstream indicating that the audio sample rate has changed.

With respect to bit rate changes, the relative frequency of such changes compared to undetected errors in the bit rate information will be dominated by whether the receiver has adequate error detection. Thus, it would be advantageous to provide a decoder having two modes of operation. In a robust error detection environment such as for satellite communications or cable media, where error detection is robust, a seamless mode of operation can be provided by trusting a bit rate change indication provided by the data. In a less robust error detection environment, indications of bit rate changes can be ignored, at the expense of requiring resynchronization of the audio in the event that the bit rate has actually changed.

It would be further advantageous to provide an audio decoder in which synchronization to the audio bitstream is maintained when the audio data contains errors. Such a decoder should conceal the audio for those sync frames in which an error has occurred, to minimize the aural impact of audio data errors.

It would be still further advantageous to provide a decoder in which the timing at which audio data is output from the decoder's audio buffer is adjusted on an ongoing basis. The intent of such adjustments would be to insure correct presentation time for audio elementary streams.

The present invention provides methods and apparatus for decoding digital audio data from a packetized transport stream having the aforementioned and other advantages.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method is provided for processing digital audio data from a packetized data stream carrying television information in a succession of fixed length transport packets. Each of the packets includes a packet identifier (PID). Some of the packets contain a program clock reference (PCR) value for synchronizing a decoder system time clock (STC). Some of the packets contain a presentation time stamp (PTS) indicative of a time for commencing the output of associated data for use in reconstructing a television signal. In accordance with the method, the PID's for the packets carried in the data stream are monitored to identify audio packets associated with the desired program. The audio packets are examined to locate the occurrence of at least one audio synchronization word therein for use in achieving a synchronization condition. The audio packets are monitored after the synchronization condition has been achieved to locate an audio PTS. After the PTS is located, the detected audio packets are searched to locate the next audio synchronization word. Audio data following the next audio synchronization word is stored in a buffer. The stored audio data is output from the buffer when the decoder system time clock reaches a specified time derived from the PTS. The detected audio packets are continually monitored to locate subsequent audio PTS's for adjusting the timing at which the stored audio data is output from the buffer on an ongoing basis.

A PTS pointer can be provided to maintain a current PTS value and an address of the buffer identifying where the sync word of an audio frame referred to by the current PTS is stored. In order to provide the timing adjustment, the PTS value in the PTS pointer is replaced with a new PTS value after data stored at the address specified by the PTS pointer has been output from the buffer. The address specified by the PTS pointer is then replaced with a new address corresponding to the sync word of an audio frame referred to by the new PTS value. The output of data from the buffer is suspended when the new buffer address is reached during the presentation process. The output of data from the buffer is recommenced when the decoder's system time clock reaches a specified time derived from the new PTS value.

In an illustrated embodiment, the output of data from the buffer is recommenced when the decoder's system time clock reaches the time indicated by the sum of the new PTS value and an offset value. The offset value provides proper lip synchronization by accounting for any decoder video signal processing delay. In this manner, after the audio and video data has been decoded, the audio data can be presented synchronously with the video data so that, for example, the movement of a person's lips in the video picture will be sufficiently synchronous to the sound reproduced.

The method of the present invention can comprise the further step of commencing a reacquisition of the audio synchronization condition if the decoder's system time clock is beyond the specified time derived from the new PTS value before the output of data from the buffer is recommenced. Thus, if a PTS designates that an audio frame should be presented at a time which has already passed, reacquisition of the audio data will automatically commence to correct the timing error, thus minimizing the duration of the resultant audio artifact.

In the illustrated embodiment, two consecutive audio synchronization words define an audio frame therebetween, including the preceding sync word, but not including the succeeding sync word. The occurrence of errors may be detected in the audio packets. Upon detecting a first audio packet of a current audio frame containing an error, the write pointer for the buffer is advanced by the maximum number of bytes (N) contained in one of the fixed length transport packets. At the same time, the current audio frame is designated as being in error. The subsequent audio packets of the current audio frame are monitored for the next audio synchronization word after the error has been detected. If the synchronization word is not received at the expected point in the audio elementary stream, subsequent data is not stored in the buffer until the sync word is located. Storage of audio data into the buffer is resumed with the next sync word if the next audio synchronization word is located within N bytes after the commencement of the search therefor. If the next audio synchronization word is not located within N bytes after the commencement of the search therefor, a reacquisition of the synchronization condition is commenced. These steps will insure the buffer is maintained at the correct fullness when as many as one transport packet is lost per audio sync frame, even with the sync frame size changes such as with a sample rate of 44.1 ksps, and will resynchronize the audio when too many audio transport packets are lost.

Whenever the audio data from which the television audio is being reconstructed is in error, it is preferable to conceal the error in the television audio. In the illustrated embodiment, a current audio frame is designated as being in error by altering the audio synchronization word for that frame. For example, every other bit of the audio synchronization word can be inverted. The error in the television audio for the corresponding audio frame may then be concealed in response to an altered synchronization word during the decoding and presentation process. This method allows the buffering and error detection process to signal the decoding and presentation process when errors occur via the data itself, without the need for additional interprocess signals.

The audio data can include information indicative of an audio sample rate and audio bit rate, at least one of which is variable. In such a situation, it is advantageous to maintain synchronization within the audio elementary stream during a rate change indicated by the audio data. This can be accomplished by ignoring an audio sample rate change indicated by the audio data on the assumption that the sample rate has not actually changed, and concealing the audio frame containing the data indicative of an audio sample rate change while attempting to maintain the synchronization condition. This strategy will properly respond to an event in which the audio sample rate change or bit rate change indication is the result of an error in the indication itself, as opposed to an actual rate change.

Similarly, audio data can be processed in accordance with a new rate indicated by the audio data in the absence of an error indication pertaining to the audio frame containing the new rate, while attempting to maintain the synchronization condition. The audio data is processed without changing the rate if an error indication pertains to the audio frame containing the new rate. At the same time, the audio frame to which the error condition pertains is concealed while the decoder attempts to maintain the synchronization condition. If the synchronization condition cannot be maintained, a reacquisition of the synchronization condition is commenced, as desired when the sample rate actually changes.

Apparatus in accordance with the present invention acquires audio information carried by a packetized data stream. The apparatus also handles errors contained in the audio information. Means are provided for identifying audio packets in the data stream. An audio elementary stream is recovered from the detected audio packets for storage in a buffer. An audio presentation time stamp (PTS) is located in the detected audio packets. Means responsive to the PTS are provided for commencing the output of audio data from the buffer at a specified time. Means are provided for monitoring the detected audio packets after the output of audio data from the buffer has commenced, in order to locate subsequent audio PTS's for use in governing the output of audio data from the buffer to insure audio is presented synchronous to any other elementary streams of the same program and to maintain correct buffer fullness.

The apparatus can further comprise means for maintaining a PTS pointer with a current PTS value and an address of the buffer identifying where a portion of audio data referred to by the current PTS is stored. Means are provided for replacing the PTS value in the PTS pointer with a new current PTS value after data stored at the address set forth in the PTS pointer has been output from the buffer. The address in the PTS pointer is then replaced with a new address corresponding to a portion of audio data referred to by the new current PTS value. Means responsive to the PTS pointer are provided for suspending the output of data from the buffer when the new address is reached. Means are provided for recommencing the output of data from the buffer at a time derived from the new current PTS value. In the event that the new current PTS value is outside a predetermined range, means provided in the apparatus conceal the audio signal and reestablish synchronization.

In an illustrated embodiment, the audio transport packets have a fixed length of M bytes. The transport packets carry a succession of audio frames each contained wholly or partially in said packets. The audio frames each begin with an audio synchronization word. Means are provided for detecting the occurrence of errors in the audio packets. A write pointer for the buffer is advanced by the maximum number of audio frame bytes per audio transport packet (N) and a current audio frame is designated as being in error upon detecting an error in an audio packet of the current audio frame. Means are provided for monitoring the detected audio packets of the current audio frame for the next audio synchronization word after the error has been detected. If the

synchronization word is not received where expected within the audio elementary stream, subsequent audio data is not buffered until the next audio synchronization word is received. This process compensates for too many audio bytes having been buffered when the errored audio packet was detected. Such an event will occur each time the lost packet does not carry the maximum number of possible audio data bytes. Means are provided for resuming the storage of audio data in the buffer if the next audio synchronization word is located within N bytes after the commencement of the search therefor. If the next audio synchronization word is not located within said N bytes after the commencement of the search therefor, the audio timing will be reacquired. In this manner, the size of the sync frames buffered will be maintained including for those frames that are marked as being in error, unless the next sync word is not located where expected in the audio elementary stream to recover from the error before buffering any of the next successive frame. This algorithm allows the decode and presentation processes to rely on buffered audio frames being the correct size in bytes, even when data errors result in the loss of an unknown amount of audio data.

Means can also be provided for concealing error in an audio signal reproduced from data output from the buffer when the data output from the buffer is in error. Means are further provided for altering the audio synchronization word associated with a current audio frame, to signal the decode and presentation process that a particular frame is in error. The concealing means are responsive to altered synchronization words for concealing audio associated with the corresponding audio frame.

Decoder apparatus in accordance with the invention acquires audio information carried by a packetized data stream and handles errors therein. Means are provided for identifying audio packets in the data stream. The successive audio frames are extracted from the audio transport packets. Each audio frame is carried by one or more of the packets, and the start of each audio frame is identified by an audio synchronization word. Means responsive to the synchronization words obtain a synchronization condition enabling the recovery of audio data from the detected audio packets for storage in a buffer. Means are provided for detecting the presence of errors in the audio data. Means responsive to the error detecting means control the flow of data through the buffer when an error is present, to attempt to maintain the synchronization condition while masking the error. Means are provided for reestablishing the audio timing if the controlling means cannot maintain the synchronization condition.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic illustration showing how audio transport packets are formed from an elementary stream of audio data;

FIG. 2 is a block diagram of decoder apparatus that can be used in accordance with the present invention;

FIG. 3 is a more detailed block diagram of the decoder system time clock (STC) illustrated in FIG. 2;

FIG. 4 is a more detailed block diagram of the demultiplexing and data parsing circuit of FIG. 2; and

FIG. 5 is a state diagram illustrating the processing of audio data in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a diagrammatic illustration showing how one or more digital programs can be multiplexed into a stream of transport packets. Multiplexing is accomplished by segmenting elementary streams such as coded video and audio into PES packets and then segmenting these into transport packets. The figure is illustrative only, since a PES packet, such as PES packet 16 illustrated, will commonly translate into other than the six transport packets 24 illustrated.

In the example of FIG. 1, an elementary stream generally designated 10 contains audio data provided in audio frames 14 delineated by synchronization words 12. Similar elementary streams will be provided for video data and other data to be transported.

The first step in forming a transport packet stream is to reconfigure the elementary stream for each type of data into a corresponding packetized elementary stream (PES) formed from successive PES packets, such as packet 16 illustrated. Each PES packet contains a PES header 18 followed by a PES payload 20. The payload comprises the data to be communicated. The PES header 18 will contain information useful in processing the payload data, such as the presentation time stamp (PTS).

The header and payload data from each PES packet are encapsulated into transport packets 24, each containing a transport header 30 and payload data 32. The payload data of the transport packet 24 will contain a portion of the payload data 20 and/or PES header 18 from PES packet 16. In an MPEG implementation, the transport header 30 will contain the packet identifier (PID) which identifies the transport packet, such as an audio transport packet 24, a video transport packet 26, or other data packet 28. In FIG. 1, only the derivation of the audio transport packets 24 is shown. In order to derive video packets 26 and other packets 28, corresponding elementary streams (not shown) are provided which are processed into PES packets and transport packets in essentially the same manner illustrated in FIG. 1 with respect to the formation of the audio transport packets

Each MPEG transport packet contains 188 bytes of data, formed from the four-byte transport header 30 and payload data 32, which can be up to 184 bytes. In the MPEG implementation, an adaptation field of, e.g., eight bytes may be provided between the transport header 30 and payload 32. The variable length adaptation field can contain, for example, the program clock reference (PCR) used for synchronization of the decoder system time clock (STC).

The plurality of audio transport packets 24, video transport packets 26 and other packets 28 is multiplexed as illustrated in FIG. 1 to form a transport stream 22 that is communicated over the communication channel from the encoder to the decoder. The purpose of the decoder is to demultiplex the different types of transport packets from the transport stream, based on the PID's of the individual packets, and to then process each of the audio, video and other components for use in reconstructing a television signal.

FIG. 2 is a block diagram of a decoder for recovering the video and audio data. The transport stream 22 is input to a demultiplexer and data parsing subsystem 44 via terminal 40. The demultiplexing and data parsing subsystem communicates with a decoder microprocessor 42 via a data bus 88. Subsystem 44 recovers the video and audio transport packets from the transport packet stream and parses the PCR, PTS and other necessary data therefrom for use by other decoder components. For example, PCR's are recovered from adaptation fields of transport packets for use in synchronizing a decoder system time clock (STC) 46 to the system time clock of the encoder. Presentation time stamps for the video and audio data streams are recovered from the

respective PES packet headers and communicated as video or audio control data to the video decoder **52** and audio decoder **54**, respectively.

The decoder time clock **46** is illustrated in greater detail in FIG. **3**. An important function of the decoder is the reconstruction of the clock associated with a particular program. This clock is used to reconstruct, for example, the proper horizontal scan rate for the video. The proper presentation rate of audio and video presentation units must also be assured. These are the audio sample rate and the video frame rate. Synchronization of the audio to the video, referred to as "lip sync", is also required.

In order to generate a synchronized program clock, the decoder system time clock (STC) **46** receives the PCR's via terminal **60**. Before the commencement of the transport stream decoding, a PCR value is used to preset a counter **68** for the decoder system time clock. As the clock runs, the value of this counter is fed back to a subtracter **62**. The local feedback value is then compared with subsequent PCR's in the transport stream as they arrive at terminal **60**. When a PCR arrives, it represents the correct STC value for the program. The difference between the PCR value and the STC value, as output from subtracter **62**, is filtered by a loop filter **64** and used to drive the instantaneous frequency of a voltage controlled oscillator **66** to either decrease or increase the STC frequency as necessary. The STC has both a 90 kHz and 27 MHz component, and the loop filter **64** converts this to units in the 27 Mhz domain. The output of the VCO **66** is a 27 MHz oscillator signal which is used as the program clock frequency output from the decoder system time clock. Those skilled in the art will recognize that the decoder time clock **46** illustrated in FIG. **3** is implemented using well known phase locked loop (PLL) techniques.

Before beginning audio synchronization, the decoder of FIG. **2**, and particularly subsystem **44**, will remain idle until it is configured by decoder microprocessor **42**. The configuration consists of identifying the type of audio data stream to be processed (e.g., Dolby AC-3 or Musicam audio), identifying the PID of packets from which the audio PCR values are to be extracted, and identifying the PID for audio packets.

During the idle state, subsystem **44** will instruct audio decoder **54** to conceal the audio output. Concealment can be accomplished by zeroing all of the audio samples. Subsequent digital signal processing will result in a smooth aural transition from no sound to sound, and back to no sound. The concealment of the audio output will be terminated when the synchronization process reaches a tracking state. Decoder microprocessor **42** configures the audio format as AC-3 or Musicam, depending on whether audio decoder **54** is an AC-3 or Musicam decoder. Microprocessor **42** determines the audio PID and audio PCR PID from program map information provided in the transport stream. The program map information is essentially a directory of PID's, and is identified via its own PID.

Once the demultiplexer and data parsing subsystem **44** is commanded to enter a Frame Sync state via an acquire command, it will begin searching for two consecutive audio sync words and will supply the decoder microprocessor **42** with the audio sampling rate and audio bit rate indicated within the audio elementary stream. To locate the sync words, subsystem **44** will receive transport packets on the audio PID and extract the PES data, searching for the occurrence of the audio sync word, which is a predetermined, fixed word. For example, the AC-3 audio sync word is 0000 1011 0111 0111 (16 bits) while the Musicam sync word is 1111 1111 1111 (12 bits).

The number of bits between the first bit of two consecutive audio sync words is referred to as the frame size. The frame size depends on whether the audio stream is AC-3 or Musicam and has a different value for each combination of audio sample and bit rate. In a preferred embodiment, subsystem **44** is required to synchronize to AC-3 and Musicam sample rates of 44.1 ksps and 48 ksps. The AC-3 audio syntax conveys the audio sample rate and audio frame size while the Musicam audio syntax conveys the audio sample rate and audio bit rate. Both AC-3 and Musicam specify one sync frame size for each bit rate when the sample rate is 48 ksps. However, AC-3 and Musicam specify two sync frame sizes for each bit rate when the sample rate is 44.1 ksps, a fact which complicates synchronization, especially through packet loss. When the sample rate is 44.1 ksps, the correct sync frame size between the two possibilities is indicated by the least significant bit of the AC-3 frame size code or by a Musicam padding bit.

Once two consecutive audio sync words have been received with the correct number of bytes in between, as specified by the sync frame size, subsystem **44** will store the audio sample rate and audio bit rate implied by the audio syntax for access by the decoder microprocessor **42**, interrupting the microprocessor to indicate that subsystem **44** is waiting for the microprocessor to supply it with an audio PTS correction factor. The correction factor is necessary in order to know when to output audio data to the audio decoder **54** during initial acquisition and during tracking for proper lip synchronization. The value is denoted as dPTS. The lip sync value used for tracking is slightly less than that used for initial acquisition to allow for time errors which will exist between any two PTS values, namely that which is used for acquisition and those which are used for tracking.

Decoder microprocessor **42** sets the correction factors such that audio and video will exit the decoder with the same time relationship as it entered the encoder, thus achieving lip synchronization. These correction factors are determined based on audio sample rate and video frame rate (e.g., 60 Hz or 50 Hz). These dependencies exist because the audio decompression processing time required by audio decoder **54** potentially depends on audio sample and bit rate while the video decompression implemented by video decoder **52** potentially depends on video frame rate and delay mode. In a preferred implementation, the PTS correction factors consist of 11 bits, representing the number of 90 kHz clock periods by which audio data is to be delayed before output to the audio decoder **54**. With 11 bit values, the delay can be as high as 22.7 milliseconds.

Once the demultiplexing and data parsing subsystem **44** requests the decoder microprocessor **42** to supply the correction factors, it will monitor reception of consecutive sync words at the expected positions within the audio elementary stream. If an error condition occurs during this time, subsystem **44** will transition to searching for two consecutive audio sync words with the correct number of data bytes in between. Otherwise, subsystem **44** remains in State dPTS-wait until the decoder microprocessor services the interrupt from subsystem **44** by writing $dPTS_{acq}$ to subsystem **44**.

Once subsystem **44** is provided with the PTS correction factors, it checks whether a transport packet has been received on the audio PCR PID containing a PCR value, carried in the adaptation field of the packet. Until this has occurred, reception of consecutive sync words will continue [State=PCR Acquire]. If an error condition occurs during this time, subsystem **44** will transition to searching for two consecutive audio sync words [State=Frame Sync]. Otherwise, it will remain in State=PCR Acquire until it receives a PCR value on the audio PCR PID.

After a PCR has been acquired, subsystem **44** will begin searching for a PTS [State=PTS Acquire], which is carried in the PES header of the audio transport packets. Until this has occurred, subsystem **44** will monitor the reception of consecutive sync words. If an error condition occurs during this time, it will transition to an error handling algorithm [State=Error Handling]. Otherwise, it will remain in the PTS acquire state until it receives a PTS value on the audio PID.

When subsystem **44** receives an audio PTS value, it will begin searching for reception of the next audio sync word. This is important since the PTS defines the time at which to output the data which begins with the next audio frame. Since audio frames are not aligned with the audio PES, the number of bytes which will be received between the PTS and the next audio sync word varies with time. If an error condition occurs before reception of the next audio sync word, subsystem **44** returns to searching for audio frame synchronization [State=Frame Sync]. It should be appreciated that since audio sync frames and PES headers are not aligned, it is possible for a PES header, and the PTS which it may contain, to be received between the 12 or 16 bits which form an audio sync word. In this case, the sync word to which the PTS refers is not the sync word which is split by the PES header, but rather the following sync word.

When subsystem **44** receives the next sync word, it has acquired PTS. At this point, it will store the received PTS and the PES data (starting with the sync word which first followed the PTS) into an audio buffer **50**, together with the buffer address at which it writes the sync word. This stored PTS/buffer address pair will allow subsystem **44** to begin outputting audio PES data to the audio decoder **54** at the correct time, starting with the audio sync word. In a preferred embodiment, the buffer **50** is implemented in a portion of dynamic random access memory (DRAM) already provided in the decoder.

Once subsystem **44** begins buffering audio data, a number of parameters must be tracked which will allow it to handle particular error conditions, such as loss of an audio transport packet to transmission errors. These parameters can be tracked using audio pointers including a PTS pointer, a DRAM offset address pointer, and a valid flag pointer discussed in greater detail below.

After PTS is acquired, subsystem **44** begins waiting to synchronize to PTS [State=PTS Sync]. In this state, the demultiplexer and data parsing subsystem **44** continues to receive audio packets via terminal **40**, writes their PES data into buffer **50**, and maintains the error pointers. When this state is entered, subsystem **44** compares its audio STC to the correct output start time, which is the PTS value in the PTS pointer plus the acquisition PTS correction factor ($dPTS_{acq}$). If subsystem **44** discovers that the correct time has passed, i.e., $PCR>PTS+dPTS_{acq}$, one or more of the three values is incorrect and subsystem **44** will flag decoder microprocessor **42**. At this point, the state will revert to State=Frame Sync, and subsystem **44** will return to searching for two consecutive audio sync words. Otherwise, until $PCR=PTS+dPTS_{acq}$, subsystem **44** will continue to receive audio packets, write their PES data into the buffer **50**, maintain the error pointers, and monitor the reception of consecutive sync words.

When $PCR=PTS+dPTS_{acq}$, subsystem **44** has synchronized to PTS and will begin tracking the audio stream [State=Track]. At this time, subsystem **44** will begin transferring the contents of the audio buffer to the audio decoder **54** upon the audio decoder requesting audio data, starting with the sync word located at the buffer address pointed to by the PTS pointer. In the tracking state, subsystem **44** will continue to receive audio packets, write their PES data into the buffer **50**, maintain the error pointers, and monitor reception of consecutive sync words. If an error condition occurs during this time, subsystem **44** will transition to error processing. Otherwise, it will remain in State=Track until an error occurs or microprocessor **42** commands it to return to the idle state.

As subsystem **44** outputs the sync word of each sync frame to the audio decoder **54** as part of the "audio" referred to in FIG. **2**, it will signal the error status of each audio sync frame to the audio decoder using the sync word. The sync word of audio sync frames in which subsystem **44** knows of no errors will be output as specified by the Dolby AC-3 or Musicam specification, as appropriate. The sync word of audio sync frames in which subsystem **44** knows of errors will be altered relative to the correct sync words. As an example, and in the preferred embodiment, every other bit of the sync word of sync frames to which an error pointer points will be inverted, starting with the most significant bit of the sync word. Thus, the altered AC-3 sync word will be 1010 0001 1101 1101 while the altered Musicam sync word will be 0101 0101 0101. Only the bits of the sync word will be altered. The audio decoder **54** will conceal the audio errors in the sync frame which it receives in which the sync word has been altered in this manner. However, the audio decoder will continue to maintain synchronization with the audio bitstream. Synchronization will be maintained assuming the audio bit rate did not change, and knowing that two sync frame sizes are possible when the audio sample rate is 44.1 ksps.

In accordance with the preferred embodiment, audio decoder **54** will maintain synchronization through sample and bit rate changes if this feature is enabled by the decoder microprocessor **42**. If the microprocessor disables sample rate changes, audio decoder **54** will conceal the audio errors in each sync frame received with a sample rate that does not match the sample rate of the sync frame on which the audio decoder last acquired, and will assume that the sample rate did not change in order to maintain synchronization. The audio decoder is required to process through bit rate changes. If an error in the bit rate information is indicated, e.g., through the use of a cyclic redundancy code (CRC) as well known in the art, audio decoder **54** will assume that the bit rate of the corresponding sync frame is the same bit rate as the previous sync frame in order to maintain synchronization. If the decoder microprocessor **42** has enabled rate changes, the audio decoder **54** will assume that the rates indicated in the sync frame are correct, will process the sync frame, and use the appropriate sync frame size in maintaining synchronization with the audio bitstream.

Demultiplexer and data parsing subsystem **44** will also aid microprocessor **42** in checking that audio data continues to be output at the correct time by resynchronizing with the PTS for some PTS values received. To accomplish this, when a PTS value is received it will be stored in the PTS pointer, along with the audio offset address at which the next sync word is written in audio buffer **50**, if the PTS pointer is not already occupied. In doing this, subsystem **44** will ensure that the next sync word is received at the correct location in the audio PES bitstream. Otherwise, the PTS value will not be stored and subsystem **44** will defer resynchronization until the next successful PTS/DRAM offset address pair is obtained. Subsystem **44** will store the PTS/DRAM offset address pair in the PTS pointer until it begins to output the associated audio sync frame. Once it begins outputting audio data to the audio decoder **54**, subsystem **44** will continue to service the audio decoder's requests for

audio data, outputting each audio sync frame in sequence. This will continue until the sync frame pointed to by the PTS pointer is reached. When this occurs, subsystem **44** will stop outputting data to the audio decoder **54** until PCR=PTS+$dPTS_{track}$. This will detect audio timing errors which may have occurred since the last resynchronization by this method.

If PCR>PTS+$dPTS_{acq}$ when subsystem **44** completes output of the previous sync frame, the audio decoder **54** is processing too slow or an undetected error has occurred in a PCR or PTS value. After this error condition, subsystem **44** will flag microprocessor **42**, stop the output to the audio decoder **54**, clear audio buffer **50** and the pointers, and return to searching for two consecutive sync words separated by the correct number of audio data bytes. If the audio decoder **54** is not requesting data when the buffer read pointer equals the address pointed to by the PTS pointer, an audio processing error has occurred and subsystem **44** will maintain synchronization with the audio stream, clear its audio buffer and pointers, and return to searching for two consecutive audio sync words [State=Frame Sync].

In order to handle errors, subsystem **44** sets a unique error flag for each error condition, which is reset when microprocessor **42** reads the flag. Each error condition which interrupts microprocessor **42** will be maskable under control of the microprocessor. Table 1 lists the various error conditions related to audio synchronization and the response by subsystem **44**. In this table, "Name" is a name assigned to each error condition as referenced in the state diagram of FIG. **5**. "Definition" defines the conditions indicating that the corresponding error has occurred. "INT" is an interrupt designation which, if "yes", indicates that subsystem **44** will interrupt microprocessor **42** when this error occurs. "Check State" and "Next State" designate the states in which the error will be detected (checked) and the audio processor will enter, respectively, with the symbol ">" that the designated error will be detected when the audio processing state of subsystem **44** is higher than the designated state. The audio processing state hierarchy, from lowest to highest, is:

1. Idle
2. Frame Sync
3. $dPTS_{wait}$
4. PCR_{acq}
5. PTS_{acq}
6. PTS Sync
7. Track

The symbol "≧" preceding a state indicates that the error will be detected when the audio processing state of subsystem **44** is equal to or higher than the designated state. The designated state(s) indicate(s) that the error will be detected in this state or that the audio processing of subsystem **44** will proceed to this state after the associated actions are carried out. The designation "same" indicates that the audio processing of subsystem **44** will stay in the same state after the associated actions are carried out.

The heading "Buffer Action" indicates whether the audio buffer is to be flushed by setting its read and write pointers to be equal to the base address of the audio buffer. The designation "none" indicates no change from normal audio buffer management.

The heading "Pointer Action" indicates by the term "reset" that the PTS pointer, error pointers or both will be returned to the state specified as if subsystem **44** had been reset. The designation "none" indicates no change from normal pointer management. The designation "see other actions" indicates that other actions under the "Other Actions" heading may indicate a pointer to be set or reset. The "Other Actions" heading states any additional actions required of the subsystem **44** as a result of the error.

TABLE 1

SUMMARY OF ERRORS, EXCEPTIONS, AND ACTIONS.

Name	Definition	Int	Check State	Next State	Buffer Action	Pointer Action	Other Actions
pta_err	PCR > PTS + $dPTS_{acq}$	yes	pta_sync	frame_sync	flush	reset	none
pts_err	PCR > PTS + $dPTS_{acq}$	yes	track	frame_sync	flush	reset	Stop output to Audio Decoder (ADP).
sync_err	Input processor loses sync with input audio frames	yes	>idle	frame_sync	flush	reset	Stop output to ADP.
ov_err	Audio Buffer overflows	yes	≥pta_sync	frame_sync	flush	reset	Input processor maintains synchronization with the audio bitstream. Stop output to ADP.
under_err	Audio Buffer underflows	no	track	same	none	none	Input processor maintains synchronization with the audio bitstream. Stop output to ADP.
fa_err	Input processor reaches Audio PES data which indicates the audio sample rate has changed since the current PID was acquired	yes	>frame_sync	same	none	none	Continue processing as if the audio sample rate had not changed.
fb_err	Input processor receives Audio PES data which indicates the audio bit rate has changed relative to the last audio sync frame reached	yes	>frame_sync	same	none	none	If bit rate changes are enabled, input processor will continue processing, trusting that the bit rate in fact changed and using the appropriate sync frame size to maintain synchronization. If bit rate changes are not enabled, input processor will continue processing using the bit rate indicated by the last audio sync frame received.
pts_miss	Sync word not found due to loss of audio data after a PTS is received	no	≥pts_acquire	same	none	none	None but other error conditions may also apply in this case
pcr_dis1	Input processor reaches a transport packet on the Audio PCR PID with the discontinuity_indicator bit of its adaptation_field set	no	pta_sync	pta acquire	flush	pta:reset error:none	Input processor stops storing PTS values in the PTS pointer until after reception of the next Audio PCR value.
pcr_dis2	Input processor receives a transport packet on the Audio PCR PID with the discontinuity_indicator bit of its adaptation_field set	no	track	same	none	pts:reset error:none	Input processor stops storing PTS values in the PTS pointer until after reception or the next Audio PCR value.
aud_err1a	Audio data of one transport packet of the current input sync frame is lost due to errors	See other actions	>idle	same or frame_sync; see other actions	none	pts:none error:see other actions	Maintain Audio Buffer fullness by advancing the FIFO write pointer by 184 bytes (MPEG), use an error pointer to mark the current sync frame as in error, and continue processing without generating an interrupt. If it is possible that more than one audio sync word was lost with the missing audio transport packet, such as when supporting Musicam Layer II at less than 64 kbps or AC-3 at less than 48 kbps, return to the Frame Sync state and generate an interrupt. If the next audio sync word is not received when expected, begin a byte-by-byte search for the audio sync word during the reception of subsequent audio data. Once the sync byte search is started, stop storing audio data in the buffer until the sync word in found. Do not store the first byte examined during the search. Resume storing audio data when the sync byte is found, starting with the sync word itself. If the sync word is not found during the first 184 bytes searched, return to the Frame Sync state[1] and generate an interrupt

TABLE 1-continued

SUMMARY OF ERRORS, EXCEPTIONS, AND ACTIONS.

Name	Definition	Int	Check State	Next State	Buffer Action	Pointer Action	Other Actions
aud_err1b	Audio data of one transport packet of the current input sync frame is lost due to errors after aud_err1a has occurred during the same input sync frame	yes	>idle	frame_sync	flush	pts:reset error:none	none
aud_err2	Audio data of more than one transport packet of the current input sync frame is lost due to errors	yes	>idle	frame_sync	flush	pts:reset error:see other actions	Use an error pointer to mark the current sync frame as in error.
ptrs_full	Audio data of one transport packet is lost while Error Mode is Unprotected	yes	≥pts_sync	frame_sync	flush	reset	Input processor maintains synchronization with the audio bitstream. Stop output to ADP.

[1]To implement the above error processing for MPEG or DigiCipher II implementations, the Input Processor can maintain an audio frame byte count by:
setting a counter's value so the sync frame size in bytes as each sync word is received,
decrementing the counter as each received audio byte is stored in the Audio Buffer (FIFO),
decrementing the counter by 184 bytes when a single audio transport packet is lost to compensate for the advancement of the FIFO write pointer by 184,
incrementing the counter by the smaller of the two sync frame sizes in bytes corresponding to the current bit rate if the above decrement resulted in a negative counter value (indicating the lost transport packet possibly contained the next audio sync word and accounting for the possibility that the audio sample rate is 44.1 Ksps and the sync frame size has changed from the larger value to the smaller value),
returning to the Frame Sync state if the above increment resulted in a counter value which was still negative (indicating the lost transport packet possibly contained more than one audio sync word), and
beginning the byte-by-byte sync word search when the counter is zero.

As indicated above, the demultiplexing and data parsing subsystem **44** of FIG. **2** maintains several pointers to support audio processing. The PTS pointer is a set of parameters related to a PTS value, specifically a PTS value, a DRAM offset address, and a validity flag. In the illustrated embodiment, the PTS value comprises the 17 least significant bits of the PTS value received from the audio PES header. This value is associated with the audio sync frame pointed to by the pointer's DRAM offset address field. The use of 17 bits allows this field to specify a 1.456 second time window ($(2^{17}-1)$/90 kHz), which exceeds the maximum audio time span which the audio buffer **50** is sized to store.

The DRAM offset address maintained by the PTS pointer is a 13-bit offset address, relative to the audio buffer base address, into the DRAM at which the first byte of the audio sync frame associated with the pointer's PTS value is stored. The 13 bits allows the pointer to address an audio buffer as large as 8192 bytes.

The PTS pointer validity flag is a one-bit flag indicating whether or not this PTS pointer contains a valid PTS value and DRAM offset address. Since MPEG does not require PTS values to be transported more often than every 700 milliseconds, subsystem **44** may find itself not having a valid PTS value for some intervals of time.

After the decoder is reset, the valid flag of the PTS pointer is set to invalid. When a new PTS value is received, if the valid flag is set, the newly received PTS value is ignored. If the valid flag is not set, the newly received PTS value is stored into the PTS pointer but its valid flag is not yet set to valid. After a new PTS value is stored into the PTS pointer, the processing of audio data is continued and each audio data byte is counted. If the next audio sync frame is received and placed into the buffer correctly, the DRAM offset address (which corresponds to the buffer address into which the first byte of the sync word of this sync frame is stored) is stored into the pointer's DRAM offset address field. Then, the pointer's valid flag is set to valid. The next audio sync frame is received and placed into the buffer correctly when no data is lost for any reason between reception of the PTS value and reception of a subsequent sync word before too many audio bytes (i.e., the number of audio bytes per sync frame) are buffered. If the next audio, sync frame is not received or placed into the buffer correctly, the valid flag is not set to valid.

After the PTS pointer is used to detect any audio timing errors which may have occurred since the last resynchronization, the valid flag is set to invalid to allow subsequent PTS pointers to be captured and used. This occurs whether the PTS pointer is in the PTS sync or tracking state.

The error pointers are parameters related to an audio sync frame currently in the buffer and known to contain errors. The error pointers comprise a DRAM offset address and a validity flag. The DRAM offset address is a 13-bit offset address, relative to the audio buffer base address, into the DRAM at which the first byte of the audio sync frame known to contain errors is stored. Thirteen bits allows the pointer to address an audio buffer as large as 8192 bytes. The validity flag is a one-bit flag indicating whether or not this error pointer contains a valid DRAM offset address. When receiving data from a relatively error free medium, subsystem **44** will find itself not having any valid error pointers for some intervals of time.

Subsystem **44** is required to maintain a total of two error pointers and one error mode flag. After reset, the validity flag is set to invalid and the error mode is set to "protected." When a sync word is placed into the audio buffer, if the valid flag of one or more error pointers is not set, the buffer address of the sync word is recorded into the DRAM offset address of one of the invalid error pointers. At the same time, the error mode is set to protected. If the validity flag of both error pointers is set when a sync word is placed into the buffer, the error mode is set to unprotected but the DRAM offset address of the sync word is not recorded.

When audio data is placed into the buffer and any error is discovered in the audio data, such as due to the loss of an audio transport packet or the reception of audio data which has not been properly decrypted, subsystem **44** will revert to the PTS acquire state if the error mode is unprotected. Otherwise, the validity bit of the error pointer which contains the DRAM offset address of the sync word which starts the sync frame currently being received is set. In the rare event that an error is discovered in the data for an audio sync frame during the same clock cycle that the sync word for the sync frame is removed from the buffer, the sync word will be corrupted as indicated above to specify that the sync frame is known to contain an audio error. At the same time, the validity bit is cleared such that it does not remain set after the sync frame has been output. This avoids the need to reset subsystem **44** in order to render the pointer useful again.

When audio data is being removed from the audio buffer, the sync word is corrupted if the DRAM offset address of any error pointer matches that of the data currently being removed from the buffer. At the same time, the validity bit is set to invalid.

The decoder of FIG. **2** also illustrates a video buffer **58** and video decoder **52**. These process the video data at the same time the audio data is being processed as described above. The ultimate goal is to have the video and audio data output together at the proper time so that the television signal can be reconstructed with proper lip synchronization.

FIG. **4** is a block diagram illustrating the demultiplexing and data parsing subsystem **44** of FIG. **2** in greater detail. After the transport packets are input via terminal **40**, the PID of each packet is detected by circuit **70**. The detection of the PIDs enables demultiplexer **72** to output audio packets, video packets and any other types of packets carried in the data stream, such as packets carrying control data, on separate lines.

The audio packets output from demultiplexer **72** are input to the various circuits necessary to implement the audio processing as described above. Circuit **74** modifies the sync word of each audio frame known to contain errors. The modified sync words are obtained using a sync word inverter **78**, which inverts every other bit in the sync words output from a sync word, PCR and PTS detection circuit **80**, in the event that the audio frame to which the sync word corresponds contains an error. Error detection is provided by error detection circuit **76**.

The sync word, PCR and PTS detection circuit **80** also outputs the sync word for each audio frame to an audio sample and bit rate calculator **86**. This circuit determines the audio sample and bit rate of the audio data and passes this information to decoder microprocessor **42** via data bus **88**.

The PCR and PTS are output from circuit **80** to a lip sync and output timing compensator **82**. Circuit **82** also receives the dPTS values from microprocessor **42**, and adds the appropriate values to the PTS in order to provide the necessary delay for proper lip synchronization. Compensator **82** also determines if the delayed presentation time is outside of the acceptable range with respect to the PCR, in which case an error has occurred and resynchronization will be required.

Buffer control **84** provides the control and address information to the audio output buffer **50**. The buffer control **84** is signaled by error detection circuit **76** whenever an error occurs that requires the temporary suspension of the writing of data to the buffer. The buffer control **84** also receives the delay values from lip sync and output timing compensator **82** in order to control the proper timing of data output from the buffer.

FIG. **5** is a state diagram illustrating the processing of audio data and response to errors as set forth in Table 1. The idle state is represented by box **100**. Acquisition of the audio data occurs during the frame sync state **102**. The dPTS-wait state is indicated by box **104**. Boxes **106**, **108** and **110** represent the PCR_{acq}, PTS_{acq}, and PTS sync states, respectively. Once audio synchronization has occurred, the signal is tracked as indicated by the tracking state of box **112**. The outputs of each of boxes **104**, **106**, **108**, **110** and **112** indicate the error conditions that cause a return to the frame synchronization state **102**. The error PCR DIS1 during the PTS sync state **110** will cause a return to the PTS acquire state, as indicated in the state diagram of FIG. **5**.

It should now be appreciated that the present invention provides methods and apparatus for acquiring and processing errors in audio data communicated via a transport packet scheme. Transport packet errors are handled while maintaining audio synchronization. During such error conditions, the associated audio errors are concealed. Corrupted data in an audio frame is signaled by altering the sync pattern associated with the audio frame. PTS's are used to check the timing of processing and to correct audio timing errors.

Although the invention has been described in connection with various specific embodiments, it should be appreciated and understood that numerous adaptations and modifications may be made thereto, without departing from the spirit and scope of the invention as set forth in the claims.

We claim:

1. A method for processing digital audio data from a packetized data stream carrying digital television information in a succession of fixed length transport packets, each of said packets including a packet identifier (PID), some of said packets containing a program clock reference (PCR) value for synchronizing a decoder system time clock (STC), and some of said packets containing a presentation time stamp (PTS) indicative of a time for commencing the output of associated data for use in reconstructing a television signal, said method comprising the steps of:

monitoring the PID's for the packets carried in said data stream to detect audio packets, some of said audio packets carrying an audio PTS;

storing audio data from the detected audio packets in a buffer for subsequent output;

monitoring the detected audio packets to locate audio PTS's;

comparing a time derived from said STC with a time derived from the located audio PTS's to determine whether said audio packets are too early to decode, too late to decode, or ready to be decoded; and

adjusting the time at which said stored audio data is output from said buffer on an ongoing basis in response to said comparing step.

2. A method in accordance with claim **1** wherein a PTS pointer is provided to maintain a current PTS value and an address of said buffer identifying where a portion of audio data referred to by said current PTS is stored, said timing adjustment being provided by the further steps of:

replacing said PTS value in said PTS pointer with a new current PTS value after data stored at said address has been output from said buffer;

replacing said address in said PTS pointer with a new address corresponding to a portion of audio data referred to by said new current PTS value;

suspending the output of data from said buffer when said new address is reached; and

recommencing the output of data from said buffer when said decoder system time clock reaches a presentation time derived from said new current PTS value.

3. A method in accordance with claim **2** wherein said presentation time is determined from the sum of said new current PTS value and an offset value that provides proper lip synchronization by accounting for a video signal processing delay.

4. A method in accordance with claim **1** wherein the time at which the audio data is output from said buffer is dependent on an offset value added to said PTS for providing proper lip synchronization by accounting for a video signal processing delay.

5. A method in accordance with claim **1** comprising the further steps of:

examining the detected audio packets to locate the occurrence of at least one audio synchronization word therein for use in achieving a synchronization condition prior to locating said audio PTS's;

commencing a reacquisition of said synchronization condition if said comparing step determines that said audio packets are too late to decode.

6. A method in accordance with claim **5** wherein two consecutive audio synchronization words with a correct number of audio data bytes in between define an audio frame, said audio frame including only one of said two consecutive audio synchronization words, said method comprising the further steps of:

detecting the occurrence of errors in said audio packets;

upon detecting a first audio packet of a current audio frame containing an error, advancing a write pointer for said buffer by the maximum number of payload bytes (N) contained in one of said fixed length transport packets and designating said current audio frame as being in error;

monitoring the detected audio packets of said current audio frame for the next audio synchronization word after said error has been detected, and if said synchronization word is not received where expected in the audio stream, discarding subsequent audio data while searching for said synchronization word rather than storing the subsequent audio data into said buffer;

resuming the storage of audio data in said buffer upon detection of said next audio synchronization word if said next audio synchronization word is located within N bytes after the commencement of the search therefor; and

if said next audio synchronization word is not located within said N bytes after the commencement of the search therefor, commencing a reacquisition of said synchronization condition.

7. A method in accordance with claim **6** comprising the further step of concealing television audio errors whenever the audio data from which said television audio is being reconstructed is in error.

8. A method in accordance with claim **7** wherein:

a current audio frame is designated as being in error by altering the audio synchronization word for that frame; and

said concealing step is responsive to an altered synchronization word for concealing audio associated with the corresponding audio frame.

9. A method for processing digital audio data from a packetized data stream carrying digital television information in a succession of transport packets having a fixed length of N bytes, each of said packets including a packet identifier (PID), some of said packets containing a program clock reference (PCR) value for synchronizing a decoder system time clock, and some of said packets containing a presentation time stamp (PTS) indicative of a time for commencing the output of associated data for use in reconstructing a television signal, said method comprising the steps of:

monitoring the PID's for the packets carried in said data stream to detect audio packets;

examining the detected audio packets to locate the occurrence of audio synchronization words for use in achieving a synchronization condition, each two consecutive audio synchronization words defining an audio frame therebetween;

monitoring the detected audio packets after said synchronization condition has been achieved to locate an audio PTS;

searching the detected audio packets after locating said audio PTS to locate the next audio synchronization word;

storing audio data following said next audio synchronization word in a buffer;

detecting the occurrence of errors in said audio packets;

upon detecting a first audio packet of a current audio frame containing an error, advancing a write pointer for said buffer by N bytes and designating said current audio frame as being in error;

monitoring the detected audio packets of said current audio frame for the next audio synchronization word after said error has been detected, and if said synchronization word is not received where expected in the audio stream, discarding subsequent audio data while searching for said synchronization word rather than storing the subsequent audio data into said buffer;

resuming the storage of audio data in said buffer upon detection of said next audio synchronization word if said next audio synchronization word is located within N bytes after the commencement of the search therefor; and

if said next audio synchronization word is not located within said N bytes after the commencement of the search therefor, commencing a reacquisition of said synchronization condition.

10. A method in accordance with claim 9 comprising the further step of concealing television audio errors whenever the audio data from which said television audio is being reconstructed is in error.

11. A method in accordance with claim 10 wherein:

a current audio frame is designated as being in error by altering the audio synchronization word for that frame; and

said concealing step is responsive to an altered synchronization word for concealing audio associated with the corresponding audio frame.

12. A method in accordance with claim 9 wherein said audio data includes information indicative of an audio sample rate and audio bit rate, at least one of said audio sample rate and audio bit rate being variable, said method comprising the further step of attempting to maintain synchronization of said audio packets during a rate change indicated by said audio data by:

ignoring a rate change indicated by said audio data on the assumption that the rate has not actually changed;

concealing the audio frame containing the data indicative of an audio sample rate change while attempting to maintain said synchronization condition; and

commencing a reacquisition of said synchronization condition if said condition cannot be maintained.

13. A method in accordance with claim 9 wherein said audio data includes information indicative of an audio sample rate and audio bit rate, at least one of said audio sample rate and audio bit rate being variable, said method comprising the further step of attempting to maintain synchronization of said audio packets during a rate change indicated by said audio data by:

processing said audio data in accordance with a new rate indicated by said audio data in the absence of an error indication pertaining to the audio frame containing the new rate, while attempting to maintain said synchronization condition;

processing said audio data without changing the rate if an error indication pertains to the audio frame containing the new rate, while concealing the audio frame to which said error condition pertains and attempting to maintain said synchronization condition; and

commencing a reacquisition of said synchronization condition if said condition cannot be maintained.

14. Apparatus for acquiring audio information carried by a packetized data stream and processing errors therein, comprising:

means for detecting audio transport packets in said data stream;

means for recovering audio data from said detected audio transport packets for storage in a buffer;

means for locating an audio presentation time stamp (PTS) in said detected audio transport packets;

means responsive to said PTS for commencing the output of audio data from said buffer at a specified time;

means for monitoring the detected audio transport packets after the output of audio data from said buffer has commenced, to locate subsequent audio PTS's;

means for comparing a time derived from a decoder system time clock (STC) to a time derived from the subsequent audio PTS's to determine whether audio data stored in said buffer is too early to decode, too late to decode, or ready to be decoded; and

means responsive to said comparing means for adjusting the time at which said stored audio data is output from said buffer.

15. Apparatus in accordance with claim 14 further comprising:

means for maintaining a PTS pointer with a current PTS value and an address of said buffer identifying where a portion of audio data referred to by said current PTS is stored;

means for replacing said PTS value in said PTS pointer with a new current PTS value after data stored at said address has been output from said buffer, and for replacing said address in said PTS pointer with a new address corresponding to a portion of audio data referred to by said new current PTS value;

means responsive to said PTS pointer for suspending the output of data from said buffer when said new address is reached; and

means for recommencing the output of data from said buffer at a time derived from said new current PTS value.

16. Apparatus in accordance with claim 15 further comprising:

means for concealing error in an audio signal reproduced from data output from said buffer and reestablishing the detection of said audio transport packets if the time derived from said new current PTS value is outside a predetermined range.

17. Apparatus in accordance with claim 14 wherein said audio transport packets each contain a fixed number N of payload bytes, said packets being arranged into successive audio frames commencing with an audio synchronization word, said apparatus further comprising:

means for detecting the occurrence of errors in said audio packets;

means for advancing a write pointer for said buffer by N bytes and designating a current audio frame as being in error upon detecting an error in an audio transport packet of said current audio frame;

means for monitoring the detected audio transport packets of said current audio frame for the next audio synchronization word after said error has been detected, and if said synchronization word is not received where expected in the audio stream, discarding subsequent audio data while searching for said synchronization word rather than storing the subsequent audio data into said buffer;

means for resuming the storage of audio data in said buffer upon detection of said next audio synchronization word if said next audio synchronization word is located within said fixed number N of bytes after the commencement of the search therefor; and

means for reestablishing the detection of said audio transport packets if said next audio synchronization word is not located within said fixed number N of bytes after the commencement of the search therefor.

18. Apparatus in accordance with claim 17 further comprising:

means for concealing error in an audio signal reproduced from data output from said buffer when the data output from said buffer is in error.

19. Apparatus in accordance with claim 18 further comprising:

means for altering the audio synchronization word associated with a current audio frame to designate that frame as being in error;

wherein said concealing means are responsive to altered synchronization words for concealing errors in audio associated with the corresponding audio frame.

20. Apparatus for acquiring audio information carried by a packetized data stream and processing errors therein, comprising:

means for detecting audio transport packets in said data stream, said packets being arranged into successive audio frames commencing with an audio synchronization word;

means responsive to said synchronization words for obtaining a synchronization condition enabling the recovery of audio data from said detected audio transport packets for storage in a buffer;

means for detecting the presence of errors in said audio data;

means responsive to said error detecting means for controlling the flow of data through said buffer when an error is present, to attempt to maintain said synchronization condition while masking said error; and

means for reestablishing the detection of said audio transport packets if said controlling means cannot maintain said synchronization condition.

21. Apparatus in accordance with claim 20 wherein said audio transport packets each contain a fixed number N of payload bytes, and said means responsive to said error detecting means comprise:

means for advancing a write pointer for said buffer by said fixed number N of bytes and designating a current audio frame as being in error upon the detection of an error in an audio transport packet thereof;

means for monitoring the detected audio transport packets of said current audio frame for the next audio synchronization word after said error has been detected, and if said synchronization word is not received where expected in the audio stream, discarding subsequent audio data while searching for said synchronization word rather than storing the subsequent audio data into said buffer; and

means for resuming the storage of audio data in said buffer upon detection of said next audio synchronization word if said next audio synchronization word is located within said fixed number N of bytes after the commencement of the search therefor.

22. Apparatus in accordance with claim 20 further comprising:

means for concealing error in an audio signal reproduced from data output from said buffer when the data output from said buffer is in error.

23. Apparatus in accordance with claim 22 further comprising:

means for altering the audio synchronization word associated with an audio frame containing a data error to designate that frame as being in error;

wherein said concealing means are responsive to altered synchronization words for concealing errors in audio associated with the corresponding audio frame.

24. A method for managing errors in data received in bursts from a packetized data stream carrying digital information in a succession of fixed length transport packets, at least some of said packets containing a presentation time stamp (PTS) indicative of a time for commencing the fixed rate presentation of presentation units from a buffer into which they are temporarily stored upon receipt, said method comprising the steps of:

monitoring received packets to locate associated PTS's, said received packets carrying presentation units to be presented;

synchronizing the presentation of said presentation units from said buffer to a system time clock (STC) associated with the packetized data stream using timing information derived from the PTS's located in said monitoring step; and

identifying discontinuity errors resulting from a loss of one or more transmitted packets between successive ones of the received packets and, if a discontinuity of no more than one packet is identified, advancing a write pointer of said buffer by a suitable number of bits to compensate for the discontinuity, while maintaining the synchronization of said presentation with respect to said STC.

25. A method in accordance with claim 24 wherein said transport packets each contain a fixed number N of payload bytes, said method comprising the further steps of:

advancing said write pointer by said fixed number N of bytes upon the detection of a discontinuity error;

continuing said monitoring step after said discontinuity error has been detected in order to search for a synchronization word, and if said synchronization word is not located where expected, discarding subsequent presentation units while searching for said synchronization word rather than storing said subsequent presentation units in said buffer; and

resuming the storage of presentation units in said buffer upon the detection of said synchronization word if said synchronization word is located within said fixed number N of bytes after the commencement of the search therefor.

* * * * *

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United States Patent [19]

Kompella et al.

[11] Patent Number: 5,892,754

[45] Date of Patent: Apr. 6, 1999

[54] **USER CONTROLLED ADAPTIVE FLOW CONTROL FOR PACKET NETWORKS**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **660,317**

[22] Filed: **Jun. 7, 1996**

[51] **Int. Cl.**[6] **H04L 12/56**

[52] **U.S. Cl.** **370/236**; 370/252; 370/406; 370/410

[58] **Field of Search** 370/231, 232, 370/235, 236, 252, 253, 400, 406, 410

[56] **References Cited**

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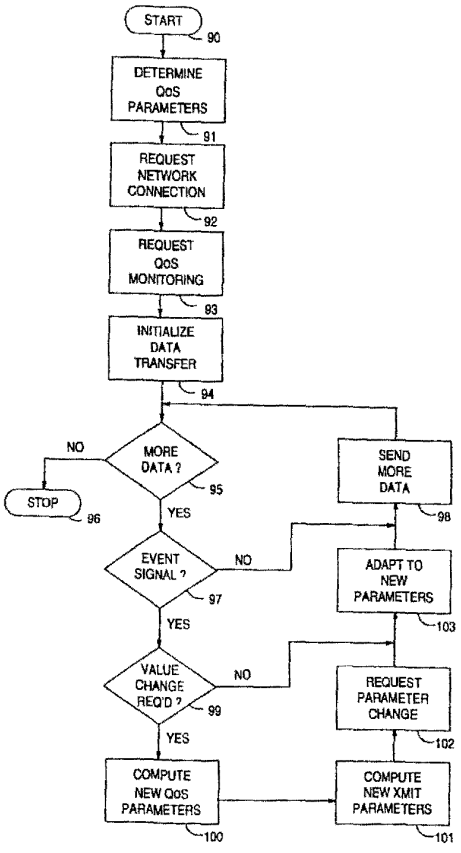
Primary Examiner—Min Jung

Attorney, Agent, or Firm—Gerald R Woods; The University of North Carolina at Chapel Hill

[57] **ABSTRACT**

A flow control system for packet transmission networks is centered in the user applications supplying data to the network. Changes in control are responsive to changes in the transmission parameters of the network, measured in the network and transmitted to the user application. The user application specifies desired ranges of Quality of Service parameters and, when the measured network parameters fall outside of the desired range, the user application modifies the transmission strategy to match the available transmission parameters. Measurements of network parameters are made over a pre-selected observation period to average the values of the transmission parameters.

25 Claims, 5 Drawing Sheets



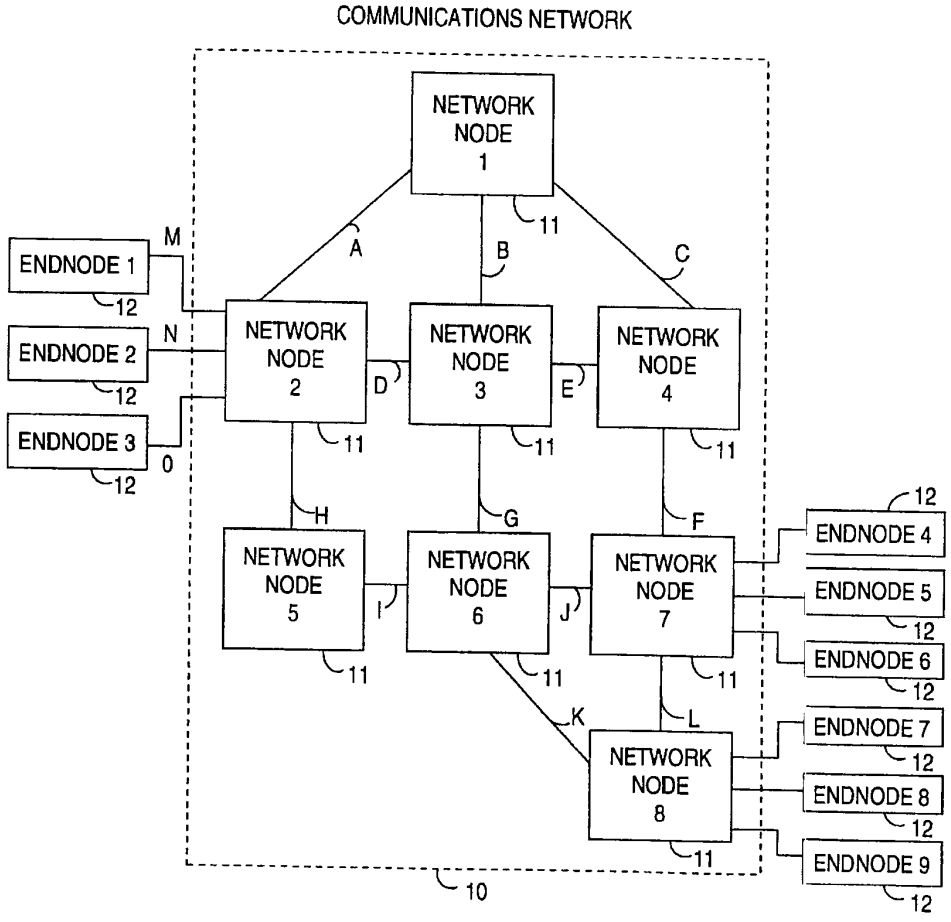


FIG. 1
(PRIOR ART)

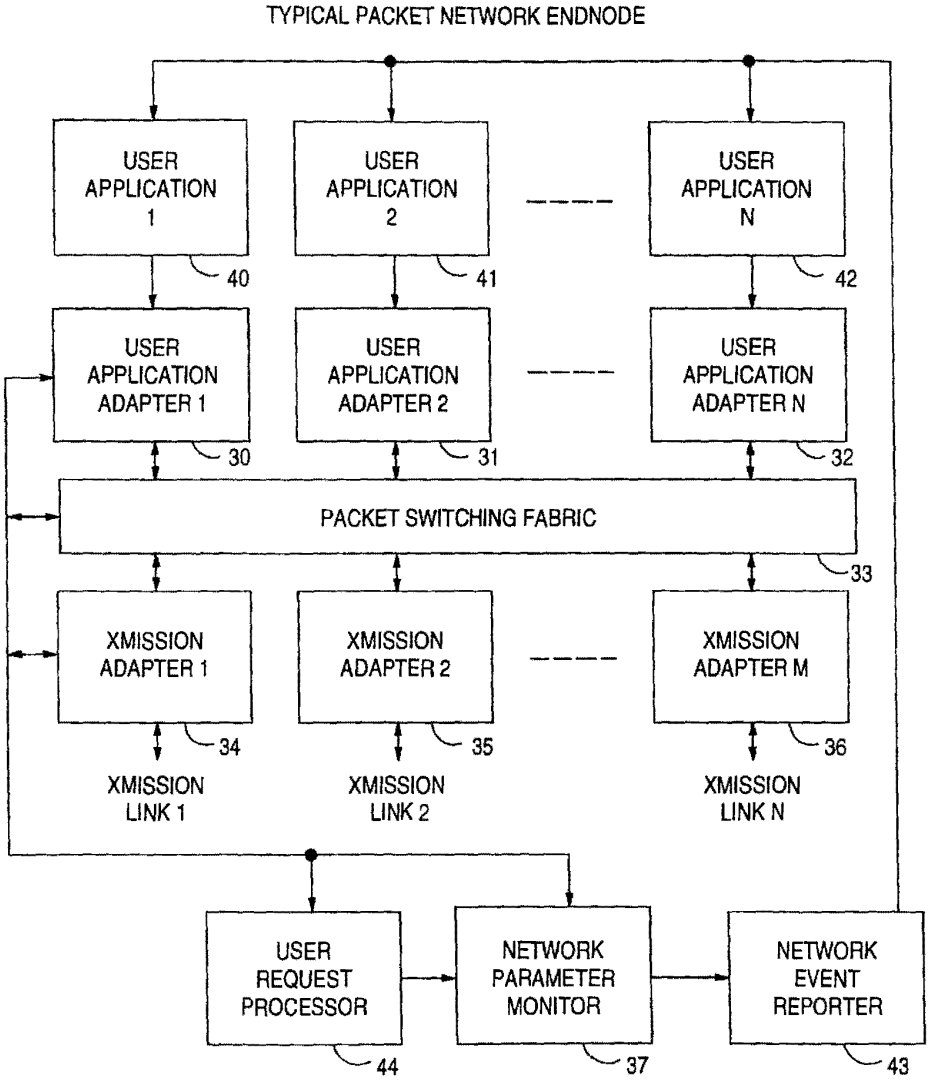

TYPICAL PACKET NETWORK ENDNODE
USER APPLICATION 1
USER APPLICATION 2
USER APPLICATION N
40
41
42
USER APPLICATION ADAPTER 1
USER APPLICATION ADAPTER 2
USER APPLICATION ADAPTER N
30
31
32
PACKET SWITCHING FABRIC
33
XMISSION ADAPTER 1
XMISSION ADAPTER 2
XMISSION ADAPTER M
34
35
36
XMISSION LINK 1
XMISSION LINK 2
XMISSION LINK N
USER REQUEST PROCESSOR
NETWORK PARAMETER MONITOR
NETWORK EVENT REPORTER
44
37
43

FIG. 2

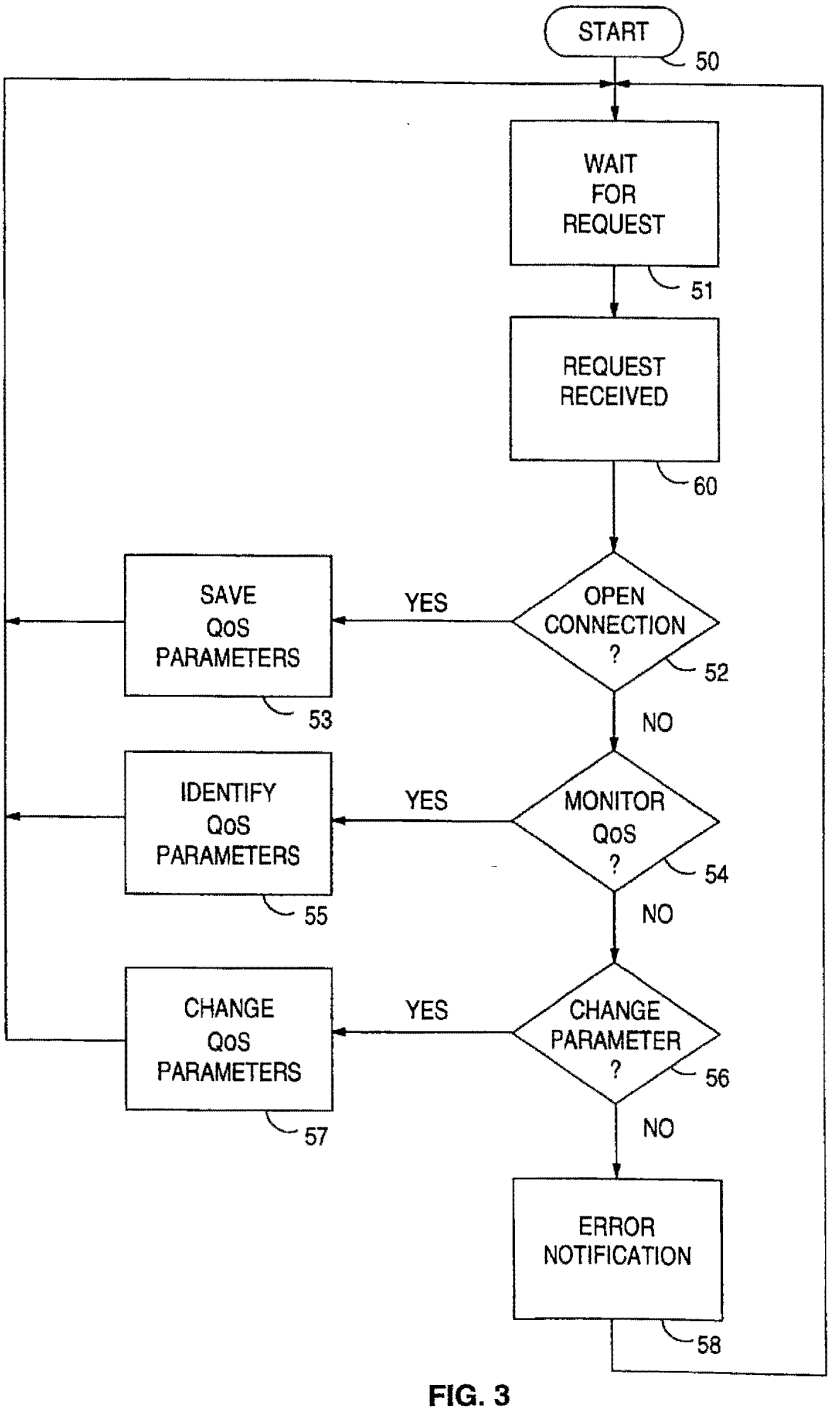

START
50
WAIT FOR REQUEST
51
REQUEST RECEIVED
60
OPEN CONNECTION ?
52
YES
SAVE QoS PARAMETERS
53
NO
MONITOR QoS ?
54
YES
IDENTIFY QoS PARAMETERS
55
NO
CHANGE PARAMETER ?
56
YES
CHANGE QoS PARAMETERS
57
NO
ERROR NOTIFICATION
58

FIG. 3

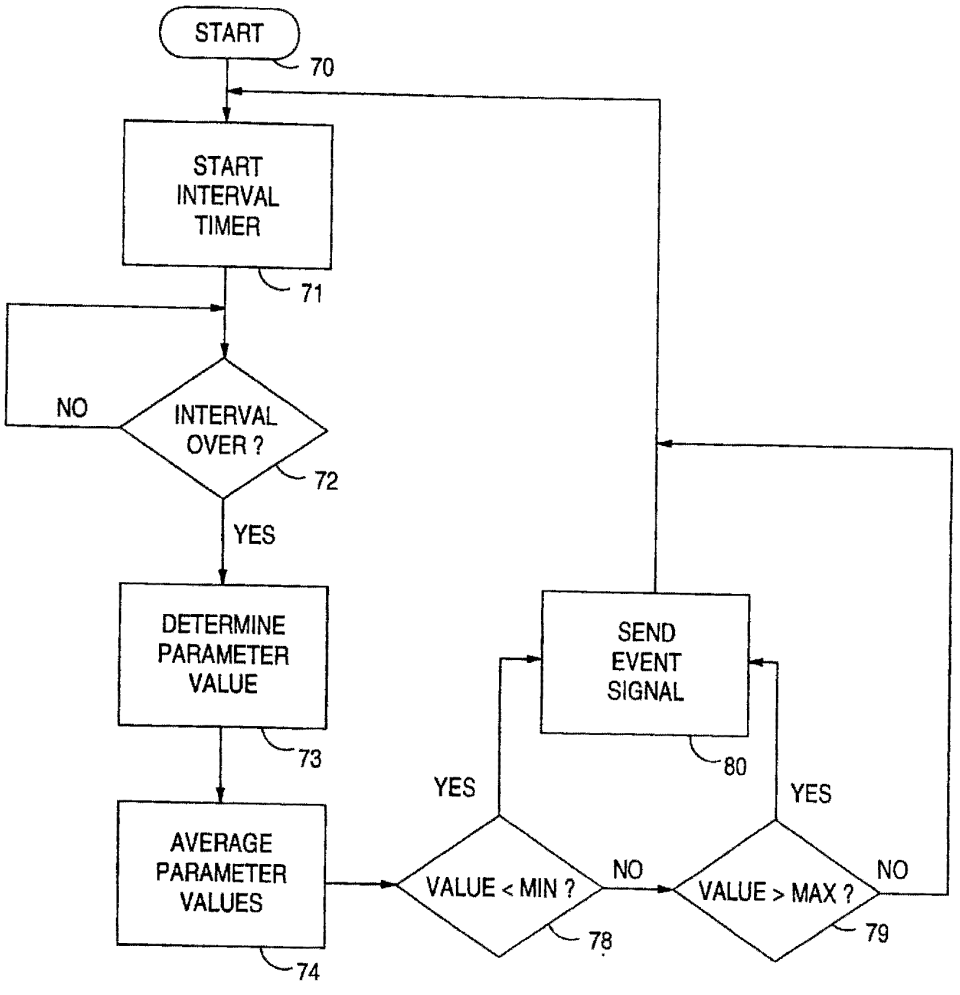

START
70
START INTERVAL TIMER
71
NO
INTERVAL OVER ?
72
YES
DETERMINE PARAMETER VALUE
73
AVERAGE PARAMETER VALUES
74
VALUE < MIN ?
78
YES
NO
SEND EVENT SIGNAL
80
VALUE > MAX ?
79
YES
NO

FIG. 4

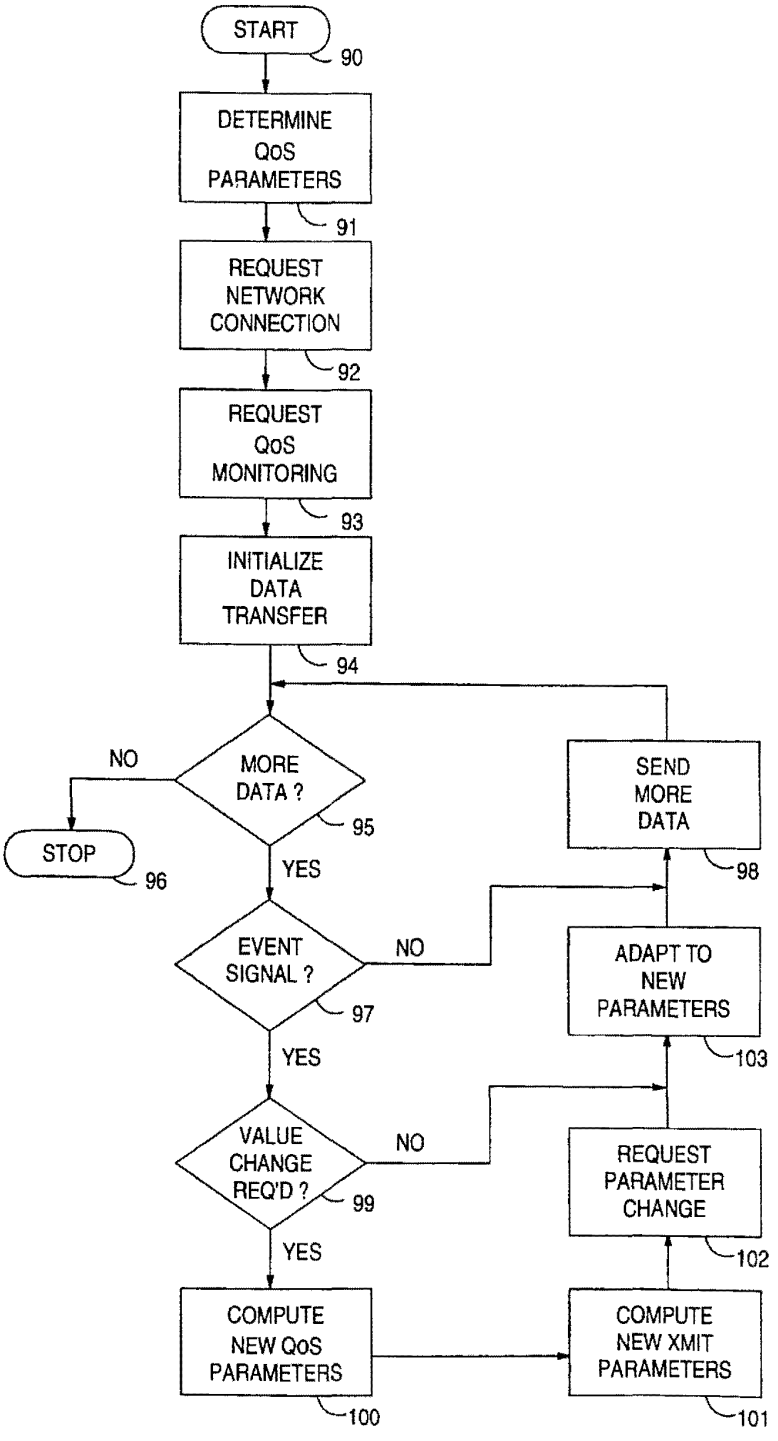

START
90
DETERMINE QoS PARAMETERS
91
REQUEST NETWORK CONNECTION
92
REQUEST QoS MONITORING
93
INITIALIZE DATA TRANSFER
94
MORE DATA ?
95
NO
STOP
96
YES
EVENT SIGNAL ?
97
NO
YES
VALUE CHANGE REQ'D ?
99
NO
YES
COMPUTE NEW QoS PARAMETERS
100
COMPUTE NEW XMIT PARAMETERS
101
REQUEST PARAMETER CHANGE
102
ADAPT TO NEW PARAMETERS
103
SEND MORE DATA
98

FIG. 5

USER CONTROLLED ADAPTIVE FLOW CONTROL FOR PACKET NETWORKS

TECHNICAL FIELD

This invention relates to packet communications systems and, more particularly, to traffic flow control in such systems.

BACKGROUND OF THE INVENTION

Numerous types of flow control have been devised for packet transmission systems. Such control mechanisms regulate a user application's behavior with respect to the transmission of data into the network and are typically implemented in the operating system and in the network protocol software. For example, if a user application attempts to send a large quantity of data to the network, and the network is overloaded, the network software buffers store the data that cannot be transmitted and attempts to deliver the data that can be transmitted. When there are no more buffers available, or if the buffers allocated to this application have been exhausted, the operating system typically suspends the user application, preventing the application from transmitting any more data until buffer space becomes available. The network protocol may also slow down the transmission of data because the receiving application cannot keep up with the data flow. These types of control mechanisms are known as flow control mechanisms. These network-based mechanisms are clearly not optimized for any particular user application, but are simply imposed on all user applications by the network.

Some flow control mechanisms in network protocols, such as the Transmission Control Protocol (TCP), are window oriented. That is, the receiving application will permit the transmitting user application to send only a certain amount of data (a "window") and, until the receiving application opens up the window further, the sending application is not allowed to transmit data. In TCP, the sending station backs off from its transmitting rate exponentially if acknowledgments from the receiving application do not arrive fast enough (before a local timer expires). These types of flow control mechanisms operate independently of the applications and often do not interact well with application requirements.

Another type of flow control mechanism is the so-called rate-based flow control, and includes High Performance Routing (HPR) in the Advanced Peer-to-Peer Network (APPN). These rate-based flow control mechanisms monitor the round-trip time of data flow and adjust the rate at which data is released from the transmitting application in response to the flow rate. That is, the rate-based flow control mechanism only allows data to enter into the network at a rate it (the network) has deemed sustainable over the long term, usually based on measurements of a test message sent to the receiving application. The application is thus constrained to transmit at this predetermined rate over the long term, even though transient rates may be greater due to buffering. Clearly, these constraints on the sending application are never optimal for the particular data being transmitted.

Having the network software act as a moderator of data flow into the network has significant advantages. The network is able to monitor its own behavior and thus determine overload situations. As taught in U.S. Pat. No. 5,326,523, the adaptive rate-based (ARB) flow control mechanism in HPR allows the data outflow to be controlled by the congestion status of the network, in effect allowing the data to flow out of a node at a rate commensurate with the actual congestion

experienced in the network. For time-insensitive applications such as E-mail and file transfer, the rate-based adaptation of the network is excellent, relieving network overload without adding significant complexity to the user applications.

Unfortunately, for time-sensitive applications such as multimedia, audio and video conferencing and video-on-demand, network-implemented flow control mechanisms are totally inadequate. For example, if a video source, transmitting at thirty frames per second, is network flow controlled to deliver only twenty frames per second, the receiving application can either play the twenty frames that it receives (with gaps), and discard the ten frames that arrive late, or it may attempt to play all of the frames, but at the price of introducing substantial latency into the system. Neither of these results is particularly desirable since the quality or real time delivery of the picture is significantly degraded.

Many types of data applications are capable of performing satisfactorily at a number of different operating points in the multidimensional space defined by the network transmission parameters such as throughput, latency, latency variations, i.e., jitter, error rates, and so forth. For simplicity, the terms "transmission parameters" and "Quality of Service parameters" are used interchangeably in this application. In the above example, the video source could transmit fewer frames per second, obviating the need for transmitting the ten frames later, and providing a picture quality better than transmitting twenty of thirty frames and discarding the other ten frames. In general, user applications are capable of adapting to changing network conditions such as congestion in a variety of different ways such as using different coding, using data compression, different image sizes, different color representation, different frame rates, forward error correction, and so forth. None of these adaptations to network conditions can be used when adaptation is controlled solely by the network software. Similarly audio signals can be sensibly adapted to different transmission conditions by re-scaling the audio signals.

SUMMARY OF THE INVENTION

In accordance with the illustrative embodiment of the present invention, the state of congestion in a packet communications system is made available to the user applications utilizing that communications system. That is, the network facilities monitor the network so as to obtain the best possible information concerning the values of all of the network transmission parameters, including throughput, latency, jitter and so forth. However, since the network does not have the best information concerning how best to adapt to changes in these transmission parameters, these transmission parameter values are made available to each user application. More particularly, a programming interface with user applications is provided with extensions which enable the network software to inform the user applications of the values of these transmission parameters. The user application can be provided with a system call to inquire about the network transmission parameters, or the network software can asynchronously supply the user application with signals indicating the occurrence of events affecting transmission parameters. These event signals can be handled like other external event signals such as timer events, semaphore events, user signals, and so forth, which are already part of most operating systems. The latter technique, advising user applications of transmission parameter affecting events, is the preferred alternative since the user application may not know the best times to query the network for transmission parameters.

In accordance with one feature of the present invention, a certain amount of hysteresis in introduced into the event reporting process to prevent the application from responding to transient changes which do not persist over the long term. In particular, each application notifies the network of the Quality of Service (QoS) specifications required for that application. Such QoS specifications consist of a lower bound, an upper bound and an operating level for that parameter. The lower bound is the value of the parameter below which the application would like an input signal, the upper bound is the value of the parameter above which the application would like an input signal, and the operating level is the value at which the application would prefer to operate over the long term. The operating level need not be midway between the upper and lower bounds, but merely between these maximum and minimum values. The user application will then receive transmission parameter input signals only when the value of the parameter falls outside of the upper or lower bound. The provision of both upper and lower bounds is necessary to insure that the application can return to the preferred operating level after congestion has abated.

In accordance with another feature of the present invention, an observation period is specified for each transmission parameter. That is, each transmission parameter is monitored at the end of an observation period. If the monitored value of the parameter lies outside of the specified bounds, its value can be sent to the user application. In the alternative, if the instantaneous value of the parameter is unstable, some computed function of the parameter value may be used, such as an average or an exponential average, both to ensure that the value is actually within or outside of the bounds, and as the better value to be passed to the user application. If the user application realizes that the operating levels or bounds on any parameter are no longer suitable for the current network status, new operating points and bound values can be passed to the network, overriding the previous values.

BRIEF DESCRIPTION OF THE DRAWINGS

A complete understanding of the present invention may be gained by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIG. **1** shows a general block diagram of a packet communications network in which a user-controlled flow control mechanism in accordance with the present invention might find use;

FIG. **2** shows a more detailed block diagram of typical endnode in the network of FIG. **1** at which point packets may enter the network to be forwarded along the route to a destination for each packet, and in which transmission parameter observation and user application notification of parameter variations in accordance with the present invention might find use;

FIG. **3** shows a flow chart of the processing of user requests for opening a connection, and monitoring and controlling transmission parameters in processor **44** of FIG. **2**, all in accordance with the present invention;

FIG. **4** shows a flow chart of the processing of transmission parameter violations in monitor **37** and reporter **43** of FIG. **2** in accordance with the present invention; and

FIG. **5** shows a general flow chart of the process of adapting transmission parameters to changes in the quality of service provided by the network of FIG. **1**, such process taking place in a user application such as applications **40**, **41** and **42** of FIG. **2** in accordance with the present invention.

To facilitate reader understanding, identical reference numerals are used to designate elements common to the figures.

DETAILED DESCRIPTION

Referring more particularly to FIG. **1**, there is shown a general block diagram of a packet transmission system **10** comprising eight network nodes **11** numbered **1** through **8**. Each of network nodes **11** is linked to others of the network nodes **11** by one or more communication links A through L. Each such communication link may be either a permanent connection or a selectively enabled (dial-up) connection. Any or all of network nodes **11** may be attached to end nodes, network node **2** being shown as attached to end nodes **1**, **2** and **3**, network node **7** being shown as attached to end nodes **4**, **5** and **6**, and network node **8** being shown as attached to end nodes **7**, **8** and **9**. Network nodes **11** each comprise a data processing system which provides data communications services to all connected nodes, network nodes and end nodes, as well as providing decision points within the node. The network nodes **11** each comprise one or more decision points within the node, at which point incoming data packets are selectively routed on one or more of the outgoing communication links terminated within that node or at another node. Such routing decisions are made in response to information in the header of the data packet. The network node also provides ancillary services such as the calculation of new routes or paths between terminal nodes, the provision of access control to packets entering the network at that node, and the provision of directory services and topology database maintenance at that node. In accordance with the present invention, one or more of network nodes **11** can also comprise a centralized route management system.

Each of end nodes **12** comprises either a source of digital data to be transmitted to another end node, a utilization device for consuming digital data received from another end node, or both. Users of the packet communications network **10** of FIG. **1** may utilize an end node device **12** connected to the local network node **11** for access to the packet network **10**. The local network node **11** translates the user's data into packets formatted appropriately for transmission on the packet network of FIG. **1** and generates the header which is used to route the packets through the network **10**. In accordance with the present invention, one or more of nodes **11** and **12** of FIG. **1** is equipped to provide user-controlled data flow control for access to the network of FIG. **1**.

In order to transmit packets on the network of FIG. **1**, it is necessary to calculate a feasible path or route through the network from the source node to the destination node for the transmission of such packets. To avoid overload on any of the links on this route, the route is calculated in accordance with an algorithm that insures that adequate bandwidth is available on each leg of the new connection. One such optimal route calculating systems is disclosed in U.S. Pat. No. 5,233,604 granted Aug. 3, 1993. Once such a route is calculated, a connection request message is launched on the network, following the computed route and updating the bandwidth occupancy of each link along the route to reflect the new connection. Data packets may then be transmitted along the calculated route from the originating node to the destination node (and from the destination node to the originating node) by placing this route in the header of the data packet. In prior art systems, if the network of FIG. **1** became congested, the network would detect this condition and limit the access of traffic to the system. While this procedure protected the system against overload, it was not

always the best way to transmit the user's data, particularly multimedia video data requiring real time delivery.

In FIG. 2 there is shown a general block diagram of a network endnode control circuit which might be found in the nodes 12 of FIG. 1. The endnode control circuit of FIG. 2 comprises a high speed packet switching fabric 33 onto which packets arriving at the node are entered. Such packets arrive over transmission links from network nodes of the network, such as links M-O of FIG. 1 via transmission interfaces 34, 35 or 36, or are originated locally via local user interfaces 30, 31 or 32. Switching fabric 33, under the control of route controller 39, connects each of the incoming data packets to the appropriate one of the outgoing transmission link interfaces 34–36 or to the appropriate one of the local user interfaces 30–32, all in accordance with well known packet network operations. Indeed, network management control messages are also launched on, and received from, the packet network in the same fashion as data packets. That is, each network packet, data or control message, transmitted on the network of FIG. 1 can be routed by way of switching fabric 30, as shown in FIG. 2.

Routes or paths through the network of FIG. 1 are calculated to satisfy the Quality of Service (QoS) parameters determined to be necessary to adequately transmit a particular data stream as taught in the afore-mentioned U.S. Pat. No. 5,233,604. These Quality of Service parameters include such things as throughput (bandwidth), latency (path delay) and jitter (latency variations). If, due to changes in traffic loading or outages, the selected path is no longer capable of providing the desired QoS parameters, it is customary to restrict the access to the network in such a way as to reduce the load on the system. Such restricted access was imposed on input data streams regardless of the degradation thereby introduced into the transmitted signals.

In accordance with the present invention, some input signals to a packet communications network can be better accommodated in a network with reduced capability by the user application source of those input signals than by the network management facilities. Video and audio signals, for example, depend on real time delivery of the successive video frames for realistic reproduction of the moving picture. Delayed transmissions enforced by the network can degrade the video signals in such a fashion as to render the signal useless. The user application, on the other hand, can choose to reduce the frame rate of a video signal and thereby produce a useable, albeit degraded, video signal. The present invention provides a mechanism which allows the user application to control the flow control access to a network such as that of FIG. 1 by passing information about the state of the network to the user application, and allowing that user application to use this information to control the rate of data delivery to the network.

In accordance with the present invention, a user request processor 44 is provided in FIG. 2 to receive and process flow control requests from user applications 40–42. Such requests can include requests to access the network, requests to monitor certain Quality of Service parameters, and requests to change a particular Quality of Service parameter in response to changes in the network requiring flow control intervention. In response to a request processed in processor 44, network parameter monitor 37 uses prior art methods to monitor the desired parameter. As will be described hereinafter, this monitoring is particularized for a given network parameter and is averaged over a specified observation interval. Results of such monitoring are reported, using prior art signaling methods, to the user applications 40–42 by network event reporter 43. In response to these network events, user applications 40–42 control the flow of data from their respective applications into the network. The detailed processes which take place in blocks 44, 37, 43 and 40–42 are shown in the flow charts of FIGS. 3 through 5.

The processes of FIGS. 3 through 5 can, of course, be implemented by designing appropriate special purpose circuits. In the preferred embodiment, however, the processes of FIGS. 3–5 are implementing by programming a general purpose computer of the type normally used to control user stations in packet or cell transmission networks. Such programming is obvious to persons skilled in the network node control and operation arts and will not be further described here.

Referring then to FIG. 3, there is shown a flow chart of the processes taking place in the user request processor 44 of FIG. 2. Starting in start box 50, box 51 is entered where the processor waits for the next request from a user application. In box 60, it is detected that a request is received and, in decision box 52, it is determined whether or not the request is to open a new connection. If so, box 53 is entered where the Quality of Service parameters associated with the new connection are saved. These parameters are used to select a route for the new connection capable of satisfying these parameters. Once such a route is determined, the user requesting the new connection can begin transmitting data to the network for transmission along that route. At this time, the application has not specified which QoS parameter violations of which it would like to be notified.

If the new request is not for an open connection, as determined in decision box 52, then decision box 54 is entered to determine whether the request is to monitor a certain QoS parameter. If the request is to monitor a QoS parameter, box 55 is entered where the identification of the QoS parameters are ascertained (from the request) and passed on to network parameter monitor 37 of FIG. 2. At this time, the network is informed which QoS parameter violations are of interest to the application. Box 51 is then re-entered to await the next request from a user application.

If the new request is not to monitor a particular QoS parameter, as determined by decision box 54, decision box 56 is entered to determine if the new request is to change one of the QoS parameters currently being used for a particular connection from a particular user application. If so, box 57 is entered where the new value of that QoS parameter is substituted for the previously stored value from box 53 or from a previous action in box 57. After the QoS parameter is changed in box 57, box 51 is re-entered to await the next request from a user application.

If the new request is not to change the value of a QoS parameter, as determined by decision box 56, box 58 is entered where an error notification is sent to the user application and to the network manager. That is, if the user request is not for a new connection or to monitor a QoS parameter or to change a QoS parameter, then an error has occurred and the user application is so notified. Box 51 is then re-entered to await the next request from a user application.

In FIG. 4 there is shown a flow chart of the processing of QoS parameter violations detected in network parameter monitor 37 of FIG. 2. Before proceeding to a description of FIG. 4, it is first necessary to describe the operation of the flow control system of the present invention. Each user application, at the time of establishing a new connection, notifies the endnode 12 (FIG. 2) of the Quality of Service parameters required to properly transmit the data stream to be launched from that user application. Rather than simply

sending the values of each parameter, the user application supplies the network with a triplet of values for each QoS parameter consisting of (1) the preferred operating value of that parameter, (2) a lower bound on the value of the parameter below which the user application wants to be notified so as to exercise a flow control option, and (3) an upper bound on the value of the parameter above which the user application wants to be notified so as to exercise a flow control option. In addition, for each QoS parameter, the application supplies an observation interval that determines, for the respective parameter, the frequency of monitoring that parameter. The user application is thus able to ignore small transitory changes in a parameter value and react only to larger, persistent changes. Thus, a certain amount of "hysteresis" is built into the flow control process, smoothing the application adaptation changes. With this in mind, FIG. **4** can now be described. As previously noted, Quality of Service parameters can include such metrics as bandwidth, latency and jitter. For the purposes of simplicity, FIG. **4** describes the monitoring of only a single QoS parameter. Those skilled in the art can extend FIG. **4** to accommodate the monitoring of any of the other possible parameters. Furthermore, the method of measuring the QoS parameters can be implemented in ways well known in the prior art and will not be specifically disclosed herein. The implementation of these other measurements is well known to anyone of ordinary skill in the art and can be implemented without any undue experimentation.

In FIG. **4**, starting in start box **70**, box **71** is entered where an observation interval timer is started. For simplicity, it is assumed that a separate interval timer is provided for each QoS parameter that is to be monitored. For efficiency, however, a plurality of different QoS parameters could be monitored simultaneously, using a common interval timer. The interval timer is used to sample the QoS parameter periodically, rather than continuously, in order to reduce the measurement overhead. After starting the interval timer in box **71**, decision box **72** is entered to determine whether or not the observation interval is over, i.e., the interval timer has timed out. If not, decision box is re-entered to await the termination of the interval. When the observation timer does time out, the interval is recognized as being over and box **73** is entered to measure or determine the current value of the QoS parameter in question. This particular QoS parameter may be measured over the particular observation interval, such as accumulating jitter on a per data packet basis, or a measurement may be taken at the end of the observation interval, such as measuring latency by computing the round trip delay of a test message. The implementation of these measurement techniques are well known to those of ordinary skill in the art and will not be further described here.

In box **74**, the measured or computed value of the parameter is smoothed by computing an average or exponential average or by using some other user-specified smoothing function. The resulting smoothed value is then used to test against the user-specified lower bound in decision box **78**. If the smoothed value from box **74** is less than the lower bound set for that parameter, box **80** is entered to send an event signal to the user application of the violation of the lower bound and the actual smoothed value of the parameter. The user application can then use this value to determine the changes it will make in its transmission strategy to accommodate the new value of the QoS parameter. This process will be taken up in connection with FIG. **5**.

If the smoothed value of the parameter is not below the minimum bound, as determined by decision box **78**, decision box **79** is entered to determine if the smoothed value of the parameter is greater than the upper bound set for that parameter. If so, box **80** is entered to send an event signal to the user application notifying the user application of the violation of the upper bound and the actual measured value of the parameter. The user application uses this value to determine the changes it will make in the transmission strategy to accommodate the new parameter value. Box **71** is then reentered to start a new observation interval. If the measured value does not fall outside of the specified range, as determined by decision boxes **78** and **79**, box **71** is re-entered to start the next measurement interval.

In FIG. **5** there is shown a flow chart of the processing of Quality of Service parameters by a user application, such as one of applications **40–42** of FIG. **2**. Starting in start box **90**, box **91** is entered the determine the desired Quality of Service parameters, and their respective allowable range of values, for a data stream to be transmitted over a desired new network connection. In box **92**, a new network connection is requested (see FIG. **3**) and, in box **93**, the desired Quality of Service parameters are requested for the new connection. The network of FIG. **1** utilizes the specified Quality of Service parameters to select a route through the network of FIG. **1** which satisfies all of the specified parameters, all as taught in the above-mentioned U.S. Pat. No. 5,233,604. Next, box **93** is entered where the user application notifies the network which QoS parameters to monitor. Box **94** is then entered to initialize the transfer of data, for example, video or audio frames. Decision box **95** is then entered to determine if there is any more data signals to be transmitted. If not, the transmission is over and stop box **96** is entered to terminate the transmission process and the connection.

If more data is available for transmission, as determined by decision box **95**, decision box **97** is entered to determine whether or not a QoS parameter violation event signal, transmitted in box **80** of FIG. **4**, has been received. If not, box **98** is entered to transmit one data frame through the network of FIG. **1**, along the selected route. Decision box **95** is then re-entered to determine if the transmission of any more data frames is required. If a QoS parameter violation event signal has been received, as determined decision box **97**, then decision box **99** is entered to determine whether or not the transmission parameters of the user application should be changed in response to the parameter violation. If a change is necessary, box **100** is entered where the user application determines the best action to take in response to the parameter violation, depending on the type of data signal being transmitted, e.g. changing the coding method to reduce bandwidth utilization or packing more signal samples into the same packet to reduce the effects of jitter. The QoS parameters required for change in transmission strategy are computed in box **100** and the resulting new transmission parameters are computed in box **101**. Box **102** is then entered to request the necessary changes in the QoS parameters as shown in FIG. **3**. Box **103** is then entered to make the actual changes in the transmission strategy which are necessary to accommodate the violation of the previous parameters. When the transmission adaptations have been effected in box **103**, box **98** is re-entered to transmit the next data frame over the connection, using the new transmission strategy. Decision box **95** is then re-entered to continue transmitting data using the new strategy.

If no transmission parameter changes are necessary, as determined by decision box **99**, but a violation event signal has been received, as determined by decision box **97**, then box **103** is entered to make the necessary adaptation to the violation, but using all of the previously established QoS

parameters. Transmission then continues, using the new adaptive strategy. It can be seen that the process of FIG. 5 permits the user application to adapt the flow of information into the network to maximize the use of the available network path parameters. Since the user application is in a better position to optimize the transmission of the data stream originating at that user application than is the network manager, superior flow control results from giving the user application control over the data flow into the network. This is in distinct contrast to prior art, network-controlled data flow mechanisms applied uniformly for all data streams regardless of the special requirements of the particular data stream.

What is claimed is:

1. A packet transmission network comprising

a plurality of transmission nodes interconnected by transmission links,

a plurality of user applications for transmitting data streams on said network, said data streams having at least two different modes of transmission requiring different transmission parameters,

means for selecting a data path through said network between two of said user applications to satisfy the transmission parameters of one of said two different modes of transmission,

means for detecting changes in the transmission parameters available on said selected data path,

means for notifying said user applications of said changes in the transmission parameters, and

means, responsive to said means for notifying, for changing to the other of said two different modes of transmission at said user application.

2. The packet transmission network according to claim 1 further comprising

means at each of said user applications for specifying a range of values of said transmission parameters within which said one mode of transmission remains unchanged.

3. The packet transmission network according to claim 1 further comprising

means, in each said user application, for requesting changes in said transmission parameters for a particular connection.

4. The packet transmission network according to claim 1 further comprising

means for storing the quality of service transmission parameters requested by each of said user applications for each requested connection to said user application.

5. The packet transmission network according to claim 1 further comprising

means for computing a smoothing function of the transmission parameter values on each connection through said network for a predetermined observation interval.

6. The packet transmission network according to claim 1 further comprising

means for transmitting an event signal to said user applications when said transmission parameters fall outside of said specified range of values.

7. A method for operating a packet transmission network comprising the steps of

interconnecting a plurality of transmission nodes by transmission links,

transmitting a plurality of data streams from user applications connected to said network, said data streams having at least two different modes of transmission requiring different transmission parameters,

selecting a data path through said network between two of said user applications to satisfy the transmission parameters of one of said two different modes of transmission,

detecting changes in the transmission parameters available on said selected data path,

notifying said user applications of said changes in the transmission parameters, and

in response to said step of notifying, changing to the other of said two different modes of transmission at said user application.

8. The method according to claim 7 further comprising the step of

at each of said user applications, specifying a range of values of said transmission parameters within which said one mode of transmission remains unchanged.

9. The method according to claim 7 further comprising the step of

in each said user application, requesting changes in said transmission parameters for a particular connection.

10. The method according to claim 7 further comprising the step of

storing the quality of service transmission parameters requested by each of said user applications for each requested connection to said user application.

11. The method according to claim 7 further comprising the step of

smoothing the values of transmission parameters for each connection through said network.

12. The method according to claim 7 further comprising the step of

transmitting an event signal to said user applications when said transmission parameters fall outside of said specified range of values.

13. A data flow control system for packet communications systems connected to a plurality of user applications comprising

means in said packet communications system for measuring the transmission parameters of at least one route from one of said user applications to another of said user applications,

means in each of said user applications, responsive to said means for measuring, for changing the flow rate of data transmitted over said at least one route,

means in said user applications for specifying a range of permissible values for each of said transmission parameters, and

means in each of said user applications for requesting changes in the requested transmission parameters for said at least one route.

14. The data flow control system according to claim 13 further comprising

means for storing the quality of service parameters for said at least one route in said packet communications system.

15. The data flow control system according to claim 13 further comprising

means in said packet communications system for smoothing the values of said transmission parameters.

16. A method for controlling data flow into a packet communication system connected to a plurality of user applications comprising the steps of

in said packet communications system, measuring the transmission parameters of at least one route from one of said user applications to another of said user applications,

in each of said user applications, in response to said means for measuring, changing the flow rate of data transmitted over said at least one route,

in each of said user applications, specifying a range of permissible values for each of said transmission parameters, and

in each of said user applications, requesting changes in the requested transmission parameters for said at least one route.

17. The method according to claim 16 further comprising the step of

storing the quality of service parameters for said at least one route in said packet communications system.

18. The method according to claim 16 further comprising

in said packet communications system, smoothing the values of said transmission parameters over a predetermined measuring interval.

19. A packet transmission network comprising

a plurality of transmission nodes interconnected by transmission links,

a plurality of user applications for transmitting data streams on said network, said data streams having at least two different modes of transmission requiring different transmission parameters,

means for selecting a data path through said network between two of said user applications to satisfy the transmission parameters of one of said two different modes of transmission,

means for detecting changes in the transmission parameters available on said selected data path,

means for notifying said user applications of said changes in the transmission parameters,

means, responsive to said means for notifying, for changing to the other of said two different modes of transmission at said user application, means in each said user application for requesting a new connection satisfying a specified range of transmission parameters,

means in each said user application for requesting said network to monitor specified network parameters for each said connection, and

means in each said user application for requesting changes in said specified transmission parameters.

20. A method for operating a packet transmission network comprising the steps of

interconnecting a plurality of transmission nodes by transmission links,

transmitting a plurality of data streams from user applications connected to said network, said data streams having at least two different modes of transmission requiring different transmission parameters,

selecting a data path through said network between two of said user applications to satisfy the transmission parameters of one of said two different modes of transmission,

detecting changes in the transmission parameters available on said selected data path,

notifying said user applications of said changes in the transmission parameters,

in response to said step of notifying, changing to the other of said two different modes of transmission at said user application,

in each said user application, requesting a new connection satisfying a specified range of transmission parameters,

in each said user application, requesting said network to monitor specified network parameters for each said connection, and

in each said user application, requesting changes in said specified transmission parameters.

21. A data flow control system for packet communications systems connected to a plurality of user applications comprising

means in said packet communications system for measuring the transmission parameters of at least one route from one of said user applications to another of said user applications, and

in each of said user applications,

means responsive to said means for measuring, for changing the flow rate of data transmitted over said at least one route,

means for requesting a new route through said packet communications system satisfying specified ranges of values of transmission parameters,

means for requesting the measurement of specific transmission parameters over a specified route, and

means for requesting a change in a previously specified transmission parameter.

22. A method for controlling data flow into a packet communications system connected to a plurality of user applications comprising the steps of

in said packet communications system, measuring the transmission parameters of at least one route from one of said user applications to another of said user applications,

in each of said user applications, in response to said means for measuring,

changing the flow rate of data transmitted over said at least one route,

requesting a new route through said packet communications system satisfying specified ranges of values of transmission parameters,

requesting the measurement of specific transmission parameters over a specified route, and

requesting a change in a previously specified transmission parameter.

23. In a user application for use with a packet transmission network having a plurality of transmission nodes interconnected by transmission links, a network route selector for selecting a data path through said network between said user application and a second user application, said user application transmitting a data stream on said network in one of at least two different modes of transmission requiring different transmission parameters, a network parameter monitor for detecting changes in transmission parameters available on a selected data path and a network event reporter for providing notification of detected changes in transmission parameters, a flow control system comprising:

means for receiving a notification of a change in transmission parameters on the selected data path from the network event reporter; and

means responsive to the receipt of said notification to change a different one of the different modes of transmission.

24. A flow control system as defined in claim 23 further including means for requesting changes in transmission parameters for the selected data path.

25. A flow control system as defined in claim 23 further including:

means for requesting a new connection to a second user application satisfying a specified range of transmission parameters,

means for specifying network parameters to be monitored by the network parameter monitor, and

means for requesting changes in the network in transmission parameters established for a connection.

* * * * *

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EXAMINER	
VU, THONG H	
ART UNIT	PAPER NUMBER
2142	5

DATE MAILED: 07/10/2003

Please find below and/or attached an Office communication concerning this application or proceeding.

PTO-90C (Rev. 07-01)

PRG

Office Action Summary	Application No.	Applicant(s)	
	09/608,126	DIETZ ET AL.	
	Examiner	Art Unit	
	Thong H Vu	2142	

-- *The MAILING DATE of this communication appears on the cover sheet with the correspondence address* --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133)
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *30 June 2000* .

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-21* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-21* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on *30 June 2000* is/are: a)☒ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

11)☐ The proposed drawing correction filed on _____ is: a)☐ approved b)☐ disapproved by the Examiner.

If approved, corrected drawings are required in reply to this Office action.

12)☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. §§ 119 and 120

13)☐ 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:

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)).

* See the attached detailed Office action for a list of the certified copies not received.

14)☐ 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.

15)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☒ Information Disclosure Statement(s) (PTO-1449) Paper No(s) *4* .
4) ☐ Interview Summary (PTO-413) Paper No(s). _____ .
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other: .

1. Claims 1-21 are pending .

2. The numbering of claims is not in accordance with 37 CFR 1.126 which requires the original numbering of the claims to be preserved throughout the prosecution. When claims are canceled, the remaining claims must not be renumbered. When new claims are presented, they must be numbered consecutively beginning with the number next following the highest numbered claims previously presented (whether entered or not).

Misnumbered of paragraphs in claims 1 and 10 have been renumbered (a), (b) (c) (d) for claim 1 and (c), (d) for claim 10.

3. Claim 1 is objected to because of the following informalities: a flow-entry database comprises **none** or more flow-entries. Examine consider as **one** or more flow entries. Appropriate correction is required.

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

4. Claims 1-21 are rejected under 35 U.S.C. § 102(e) as being anticipated by Anderson et al [Anderson 5,850,388]

5. As per claim 1, Anderson discloses a method of analyzing a flow of packets (or frames) passing through a connection point (protocol analyzer) on a computer network [col 4 line 49-col 6 line 19], the method comprising:

(a) receiving a packet from a packet acquisition device [protocol analyzer, col 8 line 26-col 9 line 13];

(b) looking up a flow-entry database [database, col 5 lines 24-46, col 9 lines 30-40, col 23 lines 35-45, col 24 lines 6-20,57-col 25 line 50; lookup table, col 18 lines 29-37] comprising one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow [previous session, col 24 lines 6-13; prior entries, col 28 lines 26-43];

(c) if the packet is of an existing flow, updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry [col 17 lines 15-23, col 25 lines 22-47, col 27 lines 24-34, col 28 lines 49-67]; and

(d) if the packet is of a new flow, storing a new flow-entry for the new flow in the flow-entry database [updat new information, col 27 lines 10-53], including storing one or more statistical measures kept in the flow-entry [statistics, col 27 lines 10-34], wherein every packet passing though the connection point is received by the packet acquisition device [protocol analyzer col 8 line 26-col 9 line 13].

6. Claim 17 contains the similar limitations set forth of method claim 1. Therefore, claim 17 is rejected for the similar rationale set forth in claim 1

7. As per claim 2, Anderson discloses extracting identifying portions from the packet, wherein the looking up uses a function of the identifying portions [information is extracted from a frame, col 9 line 42-col 10 line 18].

8. As per claim 3, Anderson discloses the steps are carried out in real time on each packet passing through the connection point [col 4 line 58-col 5 line 46].

9. As per claim 4, Anderson discloses the one or more statistical measure includes selected from the set of consisting of the total packet count for the flow, the time and a differential time from the last entered time to the present time [col 28 lines 58-67].

10. As per claim 5, Anderson discloses including one or more metrics (parameters) related to the flow of a flow entry from one or more of the statistical measure in the flow entry [col 10 lines 20-40, col 19 lines 30-45,col 22 lines 16-65].

11. As per claim 6, Anderson discloses the metrics include one or more quality of service (QOS) metrics (id, tiem, length col 22 lines 16-23].

12. As per claim 7, Anderson discloses the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time.

13. As per claim 8, Anderson discloses calculating one or more quality of service (QOS) metrics from the base metrics [col 14 lines 39-60, col15 lines 32-46,col 17 lines 45-57].

14. As per claim 9, Anderson discloses the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to determine respective metrics for the combined interval [col 28 lines 58-67].

15. As per claim 10, Anderson discloses

(c) includes if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow [between the last update and the present update, col 26 lines 6-40];

(d) includes if the packet is of a new flow, performing any state operations required for the initial state of the new flow [new data and user initial slect how often information on station statistics was to update, col 26 lines 6-15].

16. As per claim 11, Anderson discloses reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry [col 30 line 58-col 31 line 10].

17. As per claim 12, Anderson discloses reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [col 30 line 58-col 31 line 10].

18. As per claim 13, Anderson discloses reporting is part of the state operations for the state of the flow [col 30 line 58-col 31 line 10].

19. As per claim 14, Anderson discloses updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry [col 16 lines 47-54, col19 lines 17-24, col 22 line 66-col 23 line 6] .

20. As per claim 15, Anderson discloses receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow as inherent of new data received [col 28 lines 58-67].

21. As per claim 16, Anderson discloses one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow as inherent feature of parameters [col 22 lines 16-65].

22. As per claim 20, Anderson discloses including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow [software performes statistical calculations ,col 7 lines 33-53].

23. As per claim 21, Anderson discloses the statistical processor determines and reports the one or more metrics from time to time [col 30 line 58-col 31 line 10].

24. Any inquiry concerning this communication or earlier communications from the examiner should be directed to examiner Thong Vu, whose telephone number is (703)-305-4643.
The examiner can normally be reached on Monday-Thursday from 8:00AM- 4:30PM.
If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Mark Powell, can be reached at (703) 305-9703.
Any inquiry of a general nature or relating to the status of this application should be directed to the Group receptionist whose telephone number is (703) 305-9700.
Any response to this action should be mailed to: Commissioner of Patent and Trademarks, Washington, D.C. 20231 or faxed to :

After Final	(703) 746-7238
Official:	(703) 746-7239
Non-Official	(703) 746-7240

Hand-delivered responses should be brought to Crystal Park 11,2121 Crystal Drive, Arlington. VA., Sixth Floor (Receptionist).

Thong Vu
Patent Examiner
Art Unit 2142

Notice of References Cited	Application/Control No. 09/608,126	Applicant(s)/Patent Under Reexamination DIETZ ET AL.	
	Examiner Thong H Vu	Art Unit 2142	Page 1 of 1

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	J	US-			
	K	US-			
	L	US-			
	M	US-			

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*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
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	O					
	P					
	Q					
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	S					
	T					

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	V	Measurement and analysis of the digital DECT propagation channel; IEEE 1998
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	X	

A copy of this reference is not being furnished with this Office action (See MPEP § 707 05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

US005850388A

United States Patent [19]

Anderson et al.

[11] Patent Number: 5,850,388

[45] Date of Patent: Dec. 15, 1998

[54] **PROTOCOL ANALYZER FOR MONITORING DIGITAL TRANSMISSION NETWORKS**

[75] Inventors: **Craig D. Anderson**, Durham; **Mark B. Anderson**, Chapel Hill; **Eugene N. Cookmeyer**, Apex; **Ralph A. Daniels**, Clayton; **Lee E. Wheat**, Durham; **Roger A. Lingle**, Raleigh, all of N.C.

[73] Assignee: **Wandel & Goltermann Technologies, Inc.**

[21] Appl. No.: **742,093**

[22] Filed: **Oct. 31, 1996**

Related U.S. Application Data

[60] Provisional application No. 60/023,459, Aug. 2, 1996.

[51] **Int. Cl.**[6] **H04L 12/26**

[52] **U.S. Cl.** **370/252**; 371/20.1; 395/183.15

[58] **Field of Search** 370/241, 252, 370/253; 371/20.1; 395/183.15, 200.94

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Primary Examiner—Melvin Marcelo

Attorney, Agent, or Firm—Moore & Van Allen, PLLC; William G. Dosse

[57] **ABSTRACT**

A new and improved protocol analyzer for monitoring digital transmission networks is disclosed. The protocol analyzer of the present invention is capable of displaying station level statistics, network statistics, real-time event information, and protocol distribution. The protocol analyzer of the present invention is additionally capable of creating baseline network performance information and displaying the baseline information simultaneously with real-time performance information, pre-programming monitoring sessions, and generating presentation-quality reports in conjunction with analyzing digital transmission networks, all in real time.

1 Claim, 18 Drawing Sheets

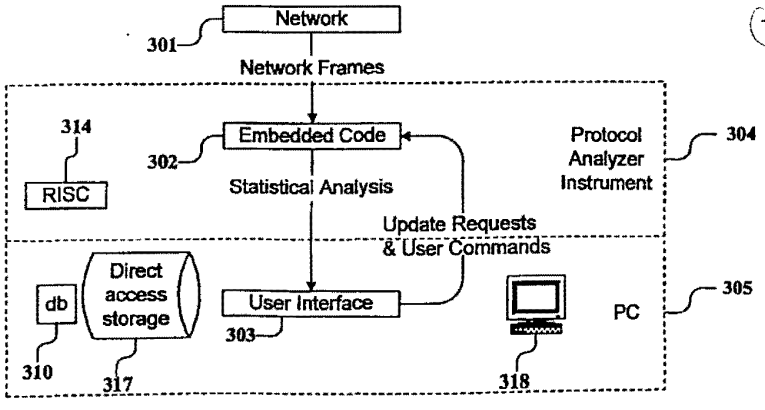

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FIG. 1

LAYER 7 - APPLICATION LAYER
LAYER 6 - PRESENTATION LAYER
LAYER 5 - SESSION LAYER
LAYER 4 - TRANSPORT LAYER
LAYER 3 - NETWORK LAYER
LAYER 2 - DATA LINK LAYER
LAYER 1 - PHYSICAL LAYER

FIG. 2

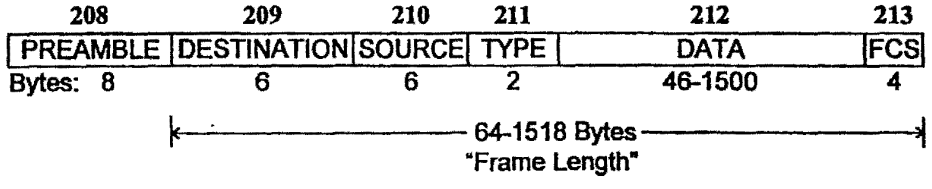


FIG. 3

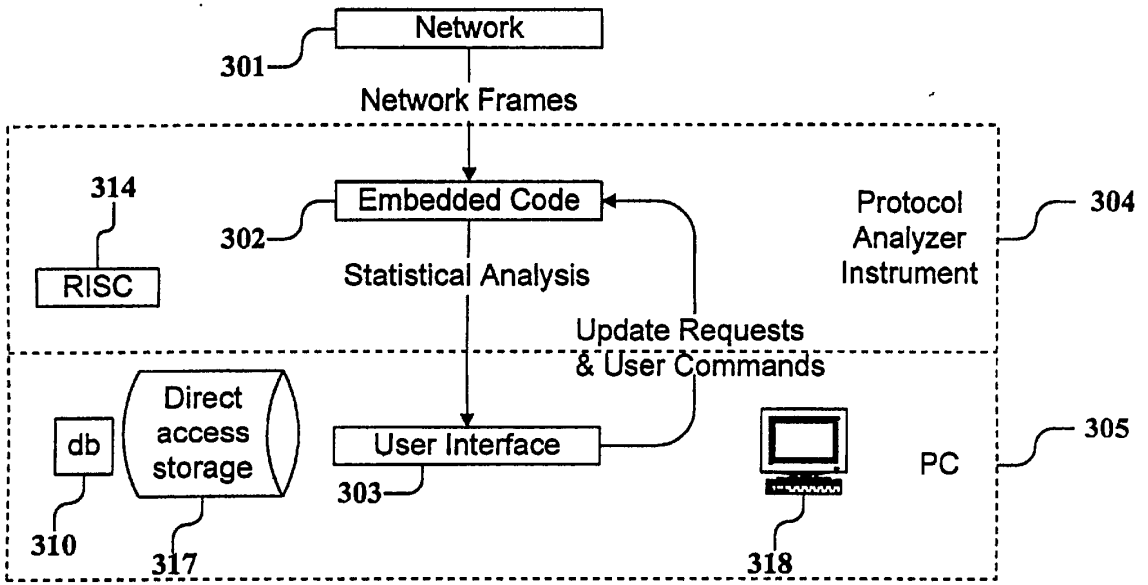

Network
301
Network Frames
314
RISC
Embedded Code
302
Statistical Analysis
Protocol
Analyzer
Instrument
304
Update Requests
& User Commands
db
Direct
access
storage
User Interface
303
PC
305
310
317
318

FIG. 4

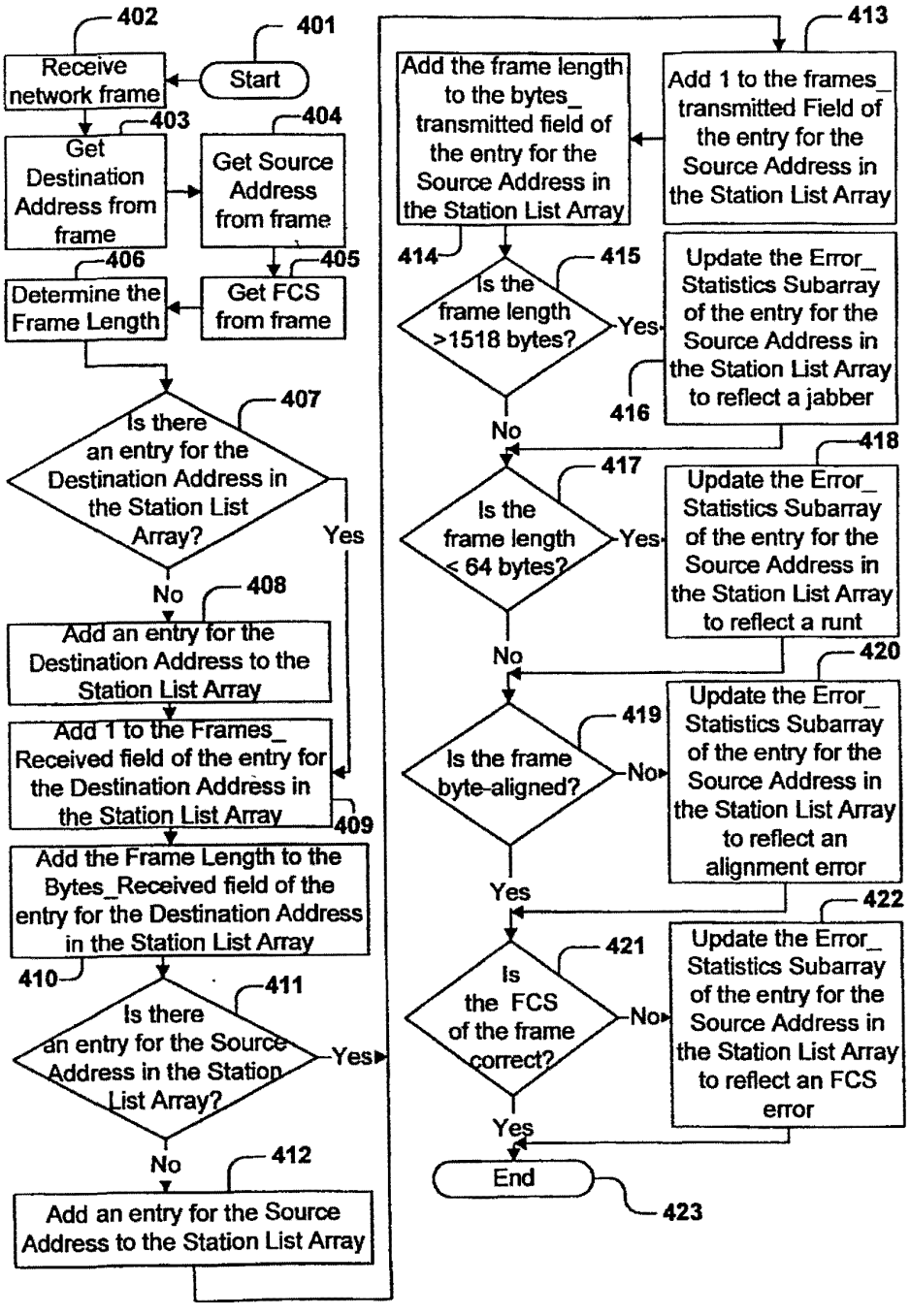

Start
401
Receive network frame
402
Get Destination Address from frame
403
Get Source Address from frame
404
Get FCS from frame
405
Determine the Frame Length
406
Is there an entry for the Destination Address in the Station List Array?
407
Yes
No
Add an entry for the Destination Address to the Station List Array
408
Add 1 to the Frames_ Received field of the entry for the Destination Address in the Station List Array
409
Add the Frame Length to the Bytes_Received field of the entry for the Destination Address in the Station List Array
410
Is there an entry for the Source Address in the Station List Array?
411
Yes
No
Add an entry for the Source Address to the Station List Array
412
Add 1 to the frames_ transmitted Field of the entry for the Source Address in the Station List Array
413
Add the frame length to the bytes_ transmitted field of the entry for the Source Address in the Station List Array
414
Is the frame length >1518 bytes?
415
Yes
No
Update the Error_ Statistics Subarray of the entry for the Source Address in the Station List Array to reflect a jabber
416
Is the frame length < 64 bytes?
417
Yes
No
Update the Error_ Statistics Subarray of the entry for the Source Address in the Station List Array to reflect a runt
418
Is the frame byte-aligned?
419
No
Yes
Update the Error_ Statistics Subarray of the entry for the Source Address in the Station List Array to reflect an alignment error
420
Is the FCS of the frame correct?
421
No
Yes
Update the Error_ Statistics Subarray of the entry for the Source Address in the Station List Array to reflect an FCS error
422
End
423

FIG. 5

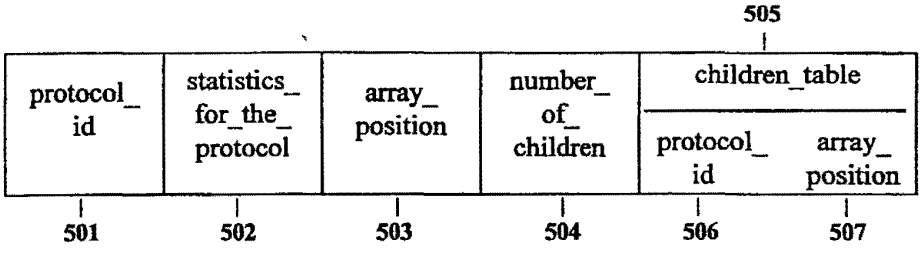

505
protocol_ id
statistics_ for_the_ protocol
array_ position
number_ of_ children
children_table
protocol_ id
array_ position
501
502
503
504
506
507

FIG. 6

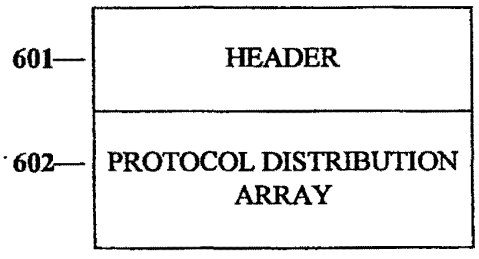

601
HEADER
602
PROTOCOL DISTRIBUTION ARRAY

FIG. 7

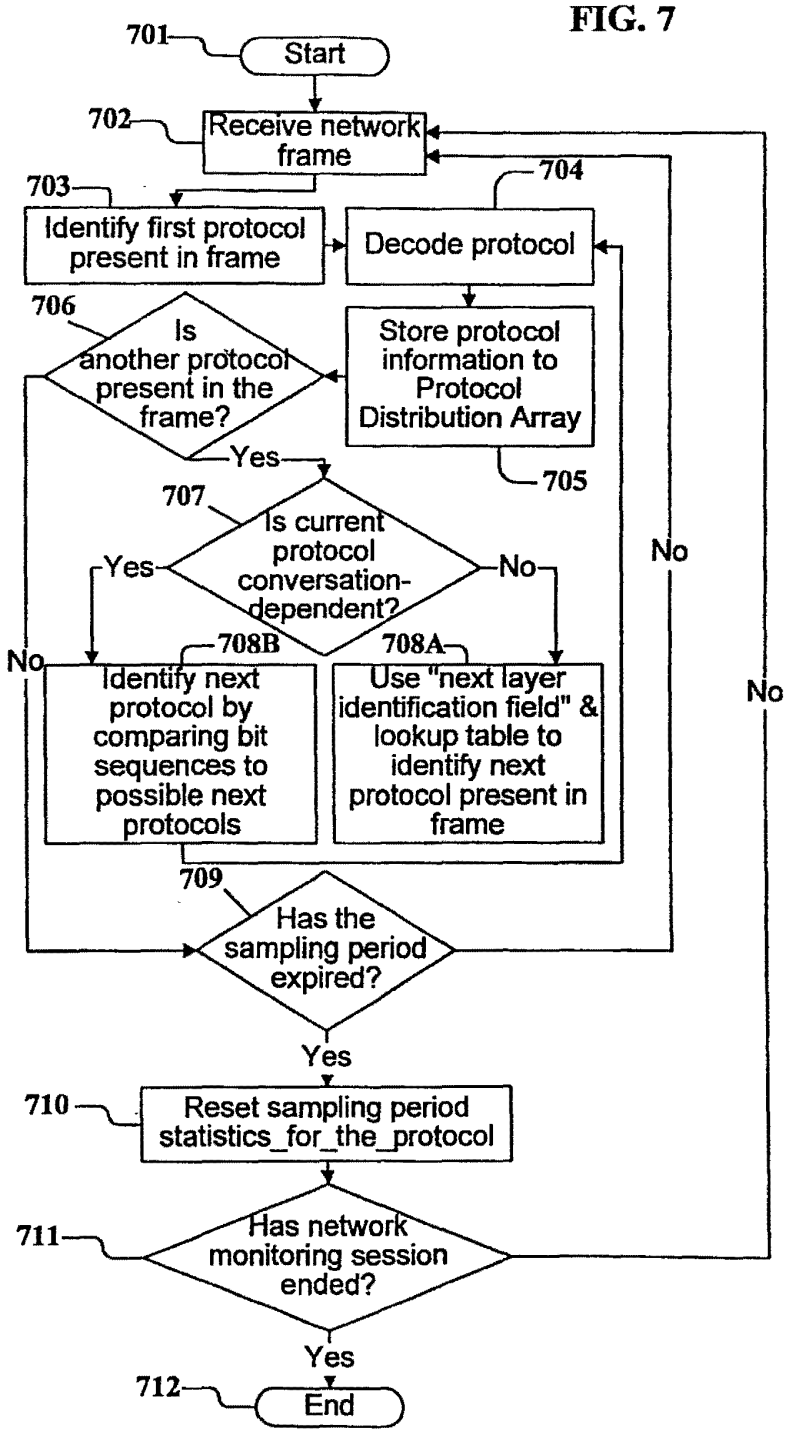

701
Start
702
Receive network frame
703
Identify first protocol present in frame
704
Decode protocol
705
Store protocol information to Protocol Distribution Array
706
Is another protocol present in the frame?
Yes
No
707
Is current protocol conversation-dependent?
Yes
No
708A
Use "next layer identification field" & lookup table to identify next protocol present in frame
708B
Identify next protocol by comparing bit sequences to possible next protocols
709
Has the sampling period expired?
Yes
No
710
Reset sampling period statistics_for_the_protocol
711
Has network monitoring session ended?
Yes
No
712
End

FIG. 8

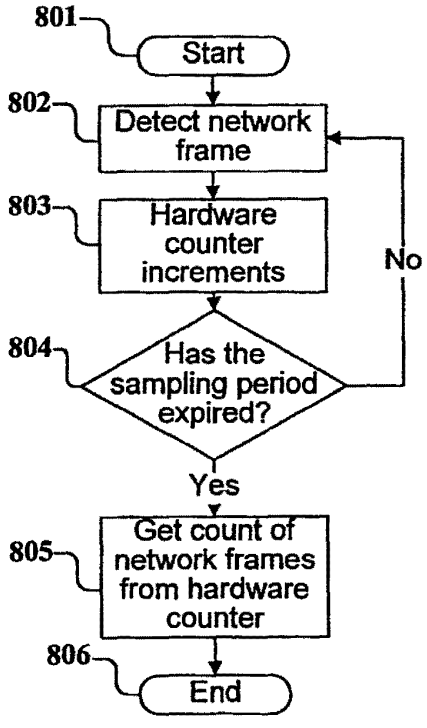

801
Start
802
Detect network frame
803
Hardware counter increments
804
Has the sampling period expired?
No
Yes
805
Get count of network frames from hardware counter
806
End

FIG. 9

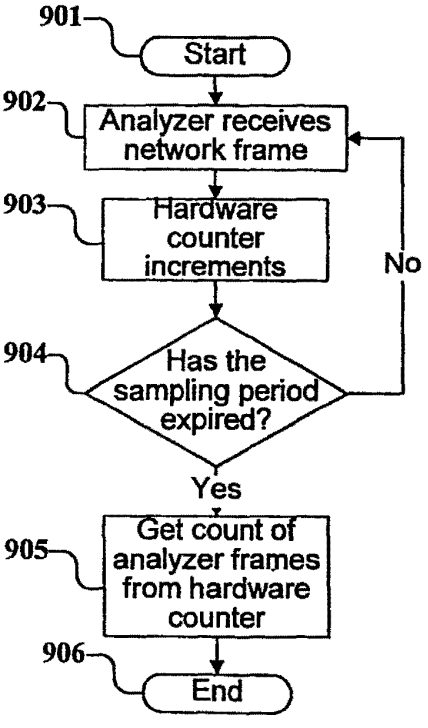

901
Start
902
Analyzer receives network frame
903
Hardware counter increments
904
Has the sampling period expired?
No
Yes
905
Get count of analyzer frames from hardware counter
906
End

FIG. 10

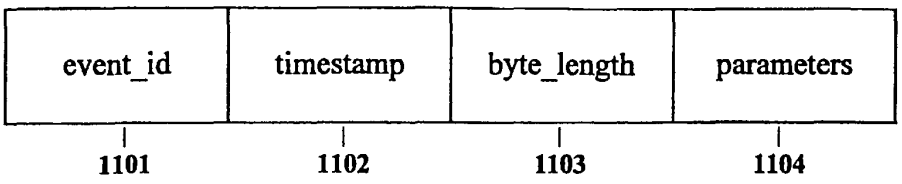


FIG. 11

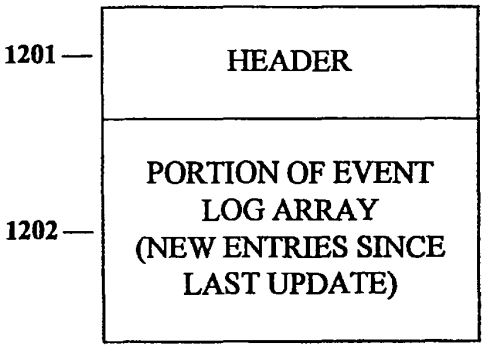


FIG. 12

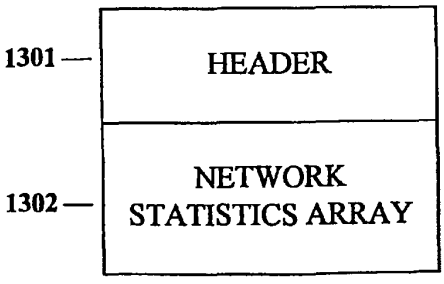


FIG. 13

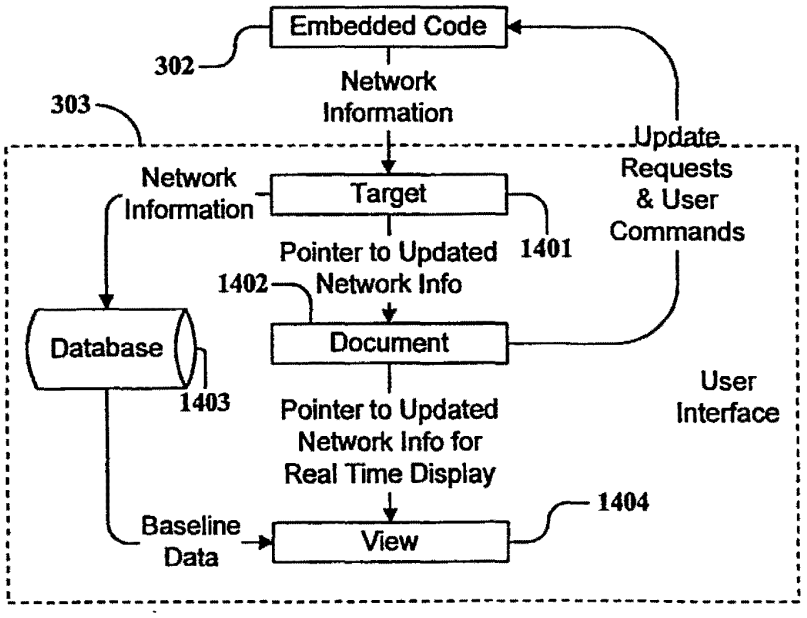

Embedded Code
302
Network Information
303
Update Requests & User Commands
Network Information
Target
1401
Pointer to Updated Network Info
1402
Database
Document
1403
User Interface
Pointer to Updated Network Info for Real Time Display
1404
Baseline Data
View

FIG. 14

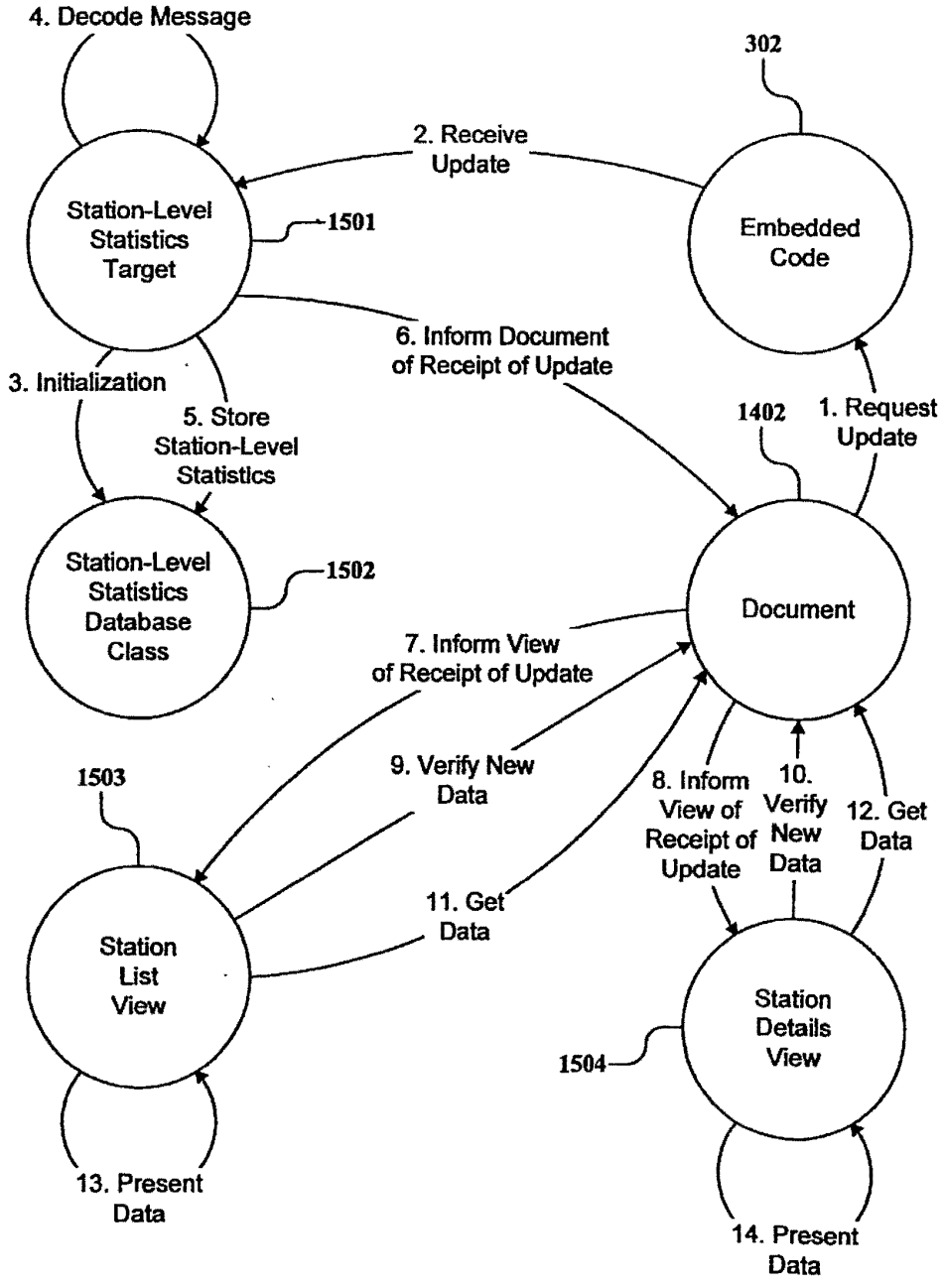

4. Decode Message
302
2. Receive Update
Station-Level Statistics Target
1501
Embedded Code
6. Inform Document of Receipt of Update
3. Initialization
5. Store Station-Level Statistics
1402
1. Request Update
Station-Level Statistics Database Class
1502
Document
7. Inform View of Receipt of Update
1503
9. Verify New Data
8. Inform View of Receipt of Update
10. Verify New Data
12. Get Data
11. Get Data
Station List View
Station Details View
1504
13. Present Data
14. Present Data

FIG. 15

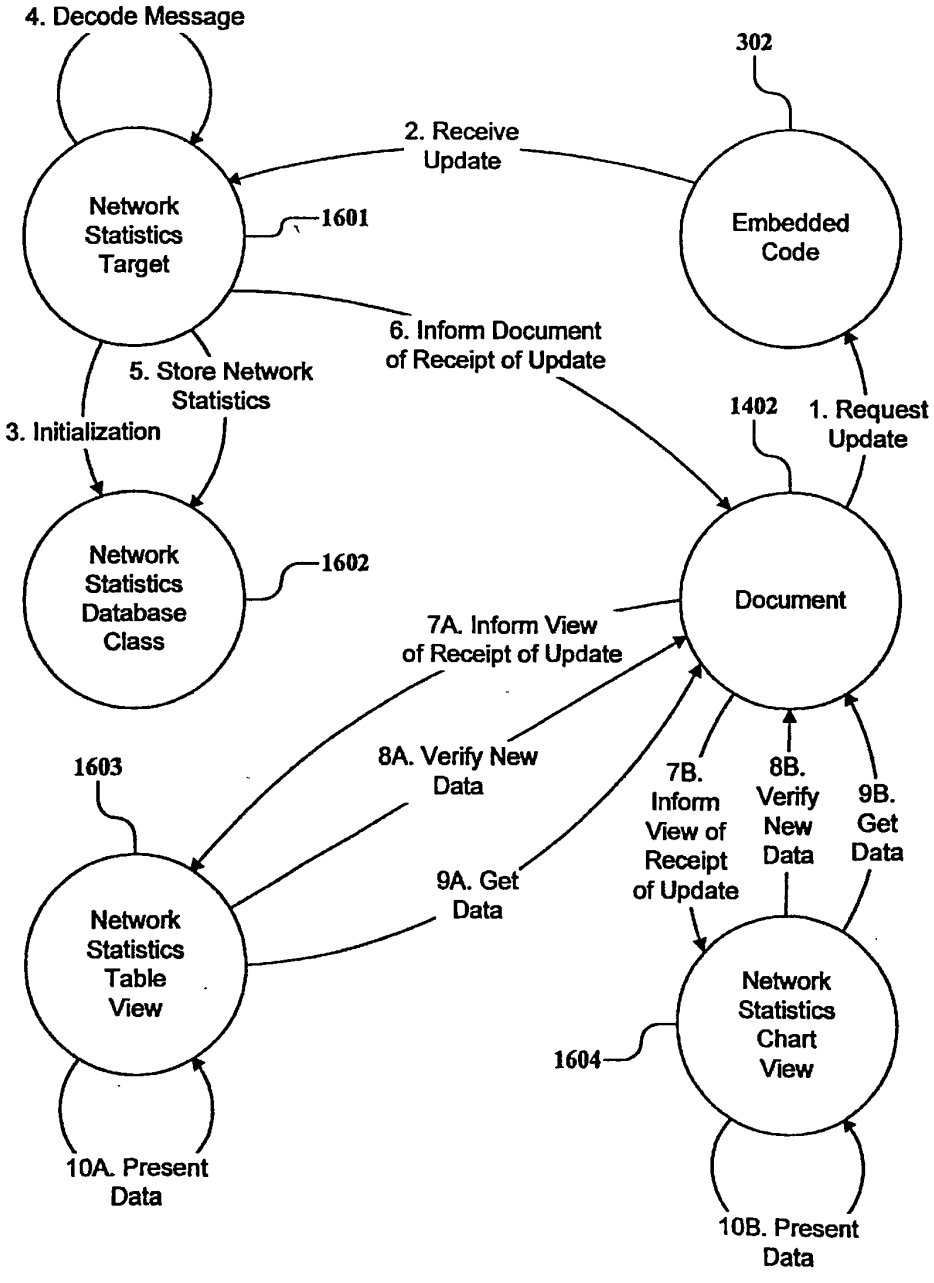

4. Decode Message
302
2. Receive Update
Network Statistics Target
1601
Embedded Code
6. Inform Document of Receipt of Update
5. Store Network Statistics
3. Initialization
1402
1. Request Update
Network Statistics Database Class
1602
Document
7A. Inform View of Receipt of Update
1603
8A. Verify New Data
7B. Inform View of Receipt of Update
8B. Verify New Data
9B. Get Data
9A. Get Data
Network Statistics Table View
Network Statistics Chart View
1604
10A. Present Data
10B. Present Data

FIG. 16

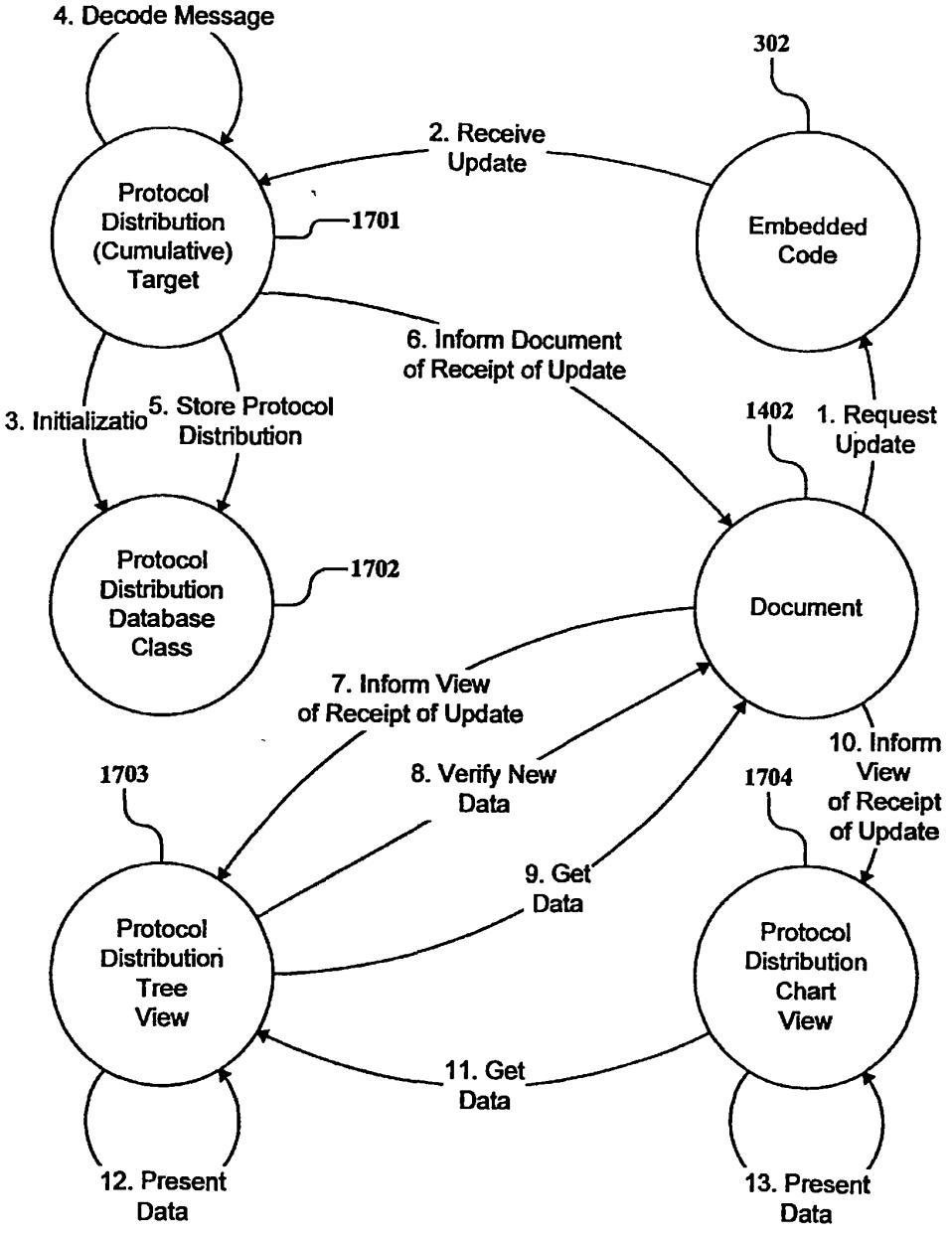
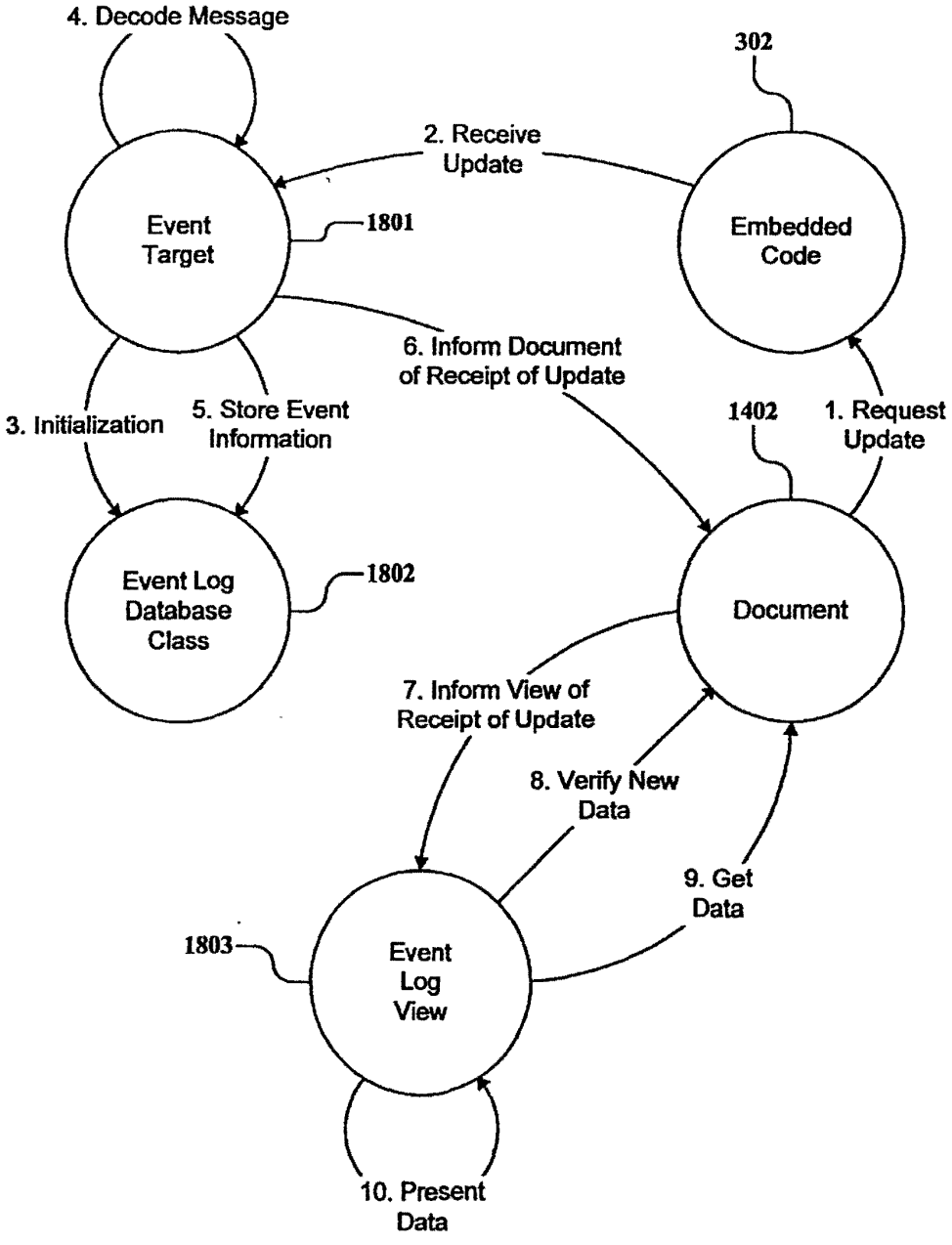

4. Decode Message
302
2. Receive Update
Protocol Distribution (Cumulative) Target
1701
Embedded Code
6. Inform Document of Receipt of Update
3. Initializatio
5. Store Protocol Distribution
1402
1. Request Update
Protocol Distribution Database Class
1702
Document
7. Inform View of Receipt of Update
10. Inform View of Receipt of Update
1703
8. Verify New Data
1704
9. Get Data
Protocol Distribution Tree View
Protocol Distribution Chart View
11. Get Data
12. Present Data
13. Present Data

FIG. 17


4. Decode Message
302
2. Receive Update
Event Target
1801
Embedded Code
6. Inform Document of Receipt of Update
3. Initialization
5. Store Event Information
1402
1. Request Update
Event Log Database Class
1802
Document
7. Inform View of Receipt of Update
8. Verify New Data
9. Get Data
1803
Event Log View
10. Present Data

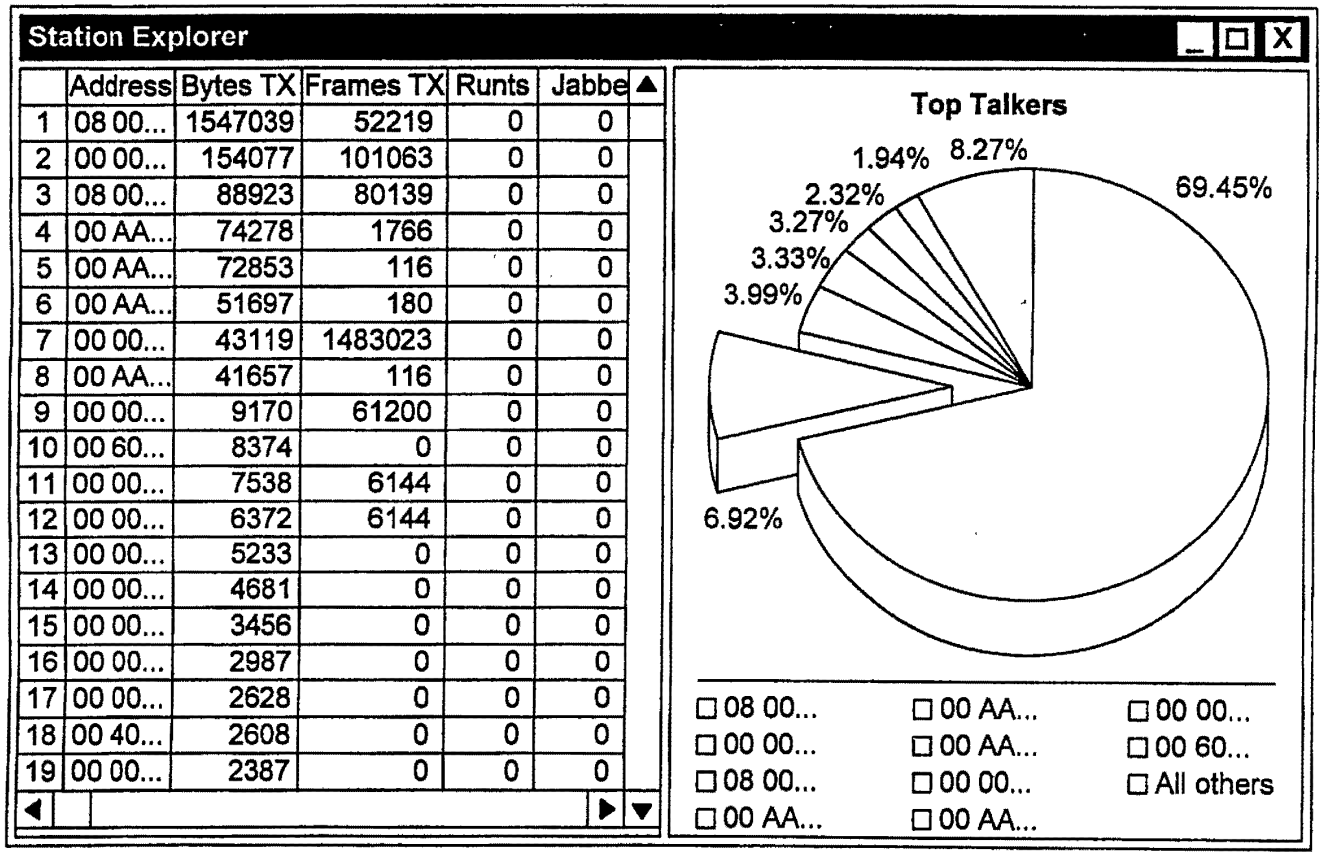

Station Explorer
Address Bytes TX Frames TX Runts Jabbe
1 08 00... 1547039 52219 0 0
2 00 00... 154077 101063 0 0
3 08 00... 88923 80139 0 0
4 00 AA... 74278 1766 0 0
5 00 AA... 72853 116 0 0
6 00 AA... 51697 180 0 0
7 00 00... 43119 1483023 0 0
8 00 AA... 41657 116 0 0
9 00 00... 9170 61200 0 0
10 00 60... 8374 0 0 0
11 00 00... 7538 6144 0 0
12 00 00... 6372 6144 0 0
13 00 00... 5233 0 0 0
14 00 00... 4681 0 0 0
15 00 00... 3456 0 0 0
16 00 00... 2987 0 0 0
17 00 00... 2628 0 0 0
18 00 40... 2608 0 0 0
19 00 00... 2387 0 0 0
Top Talkers
69.45%
8.27%
1.94%
2.32%
3.27%
3.33%
3.99%
6.92%
08 00...
00 AA...
00 00...
00 00...
00 AA...
00 60...
08 00...
00 00...
All others
00 AA...
00 AA...

FIG. 18

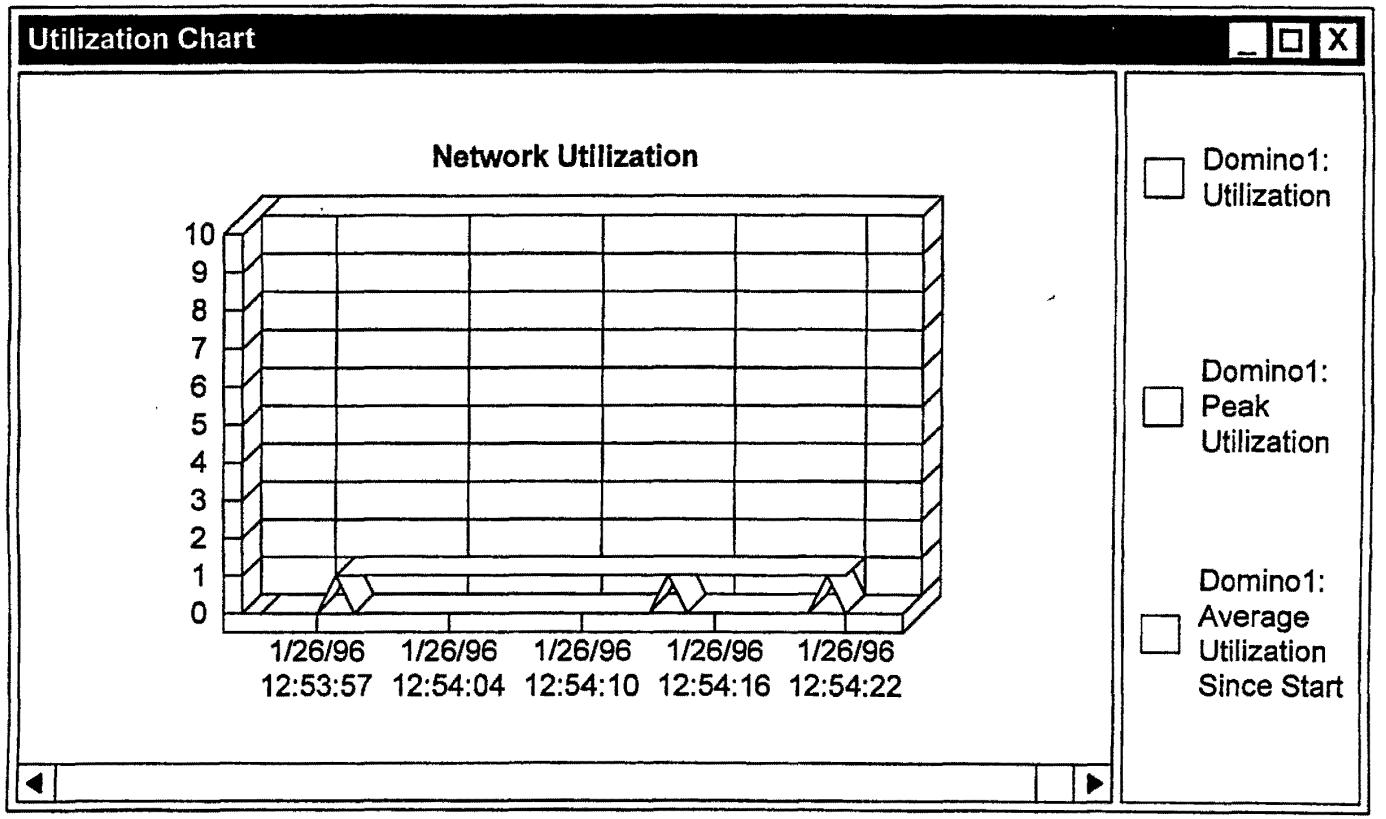

Utilization Chart
Network Utilization
10
9
8
7
6
5
4
3
2
1
0
1/26/96 12:53:57
1/26/96 12:54:04
1/26/96 12:54:10
1/26/96 12:54:16
1/26/96 12:54:22
Domino1: Utilization
Domino1: Peak Utilization
Domino1: Average Utilization Since Start

FIG. 19A

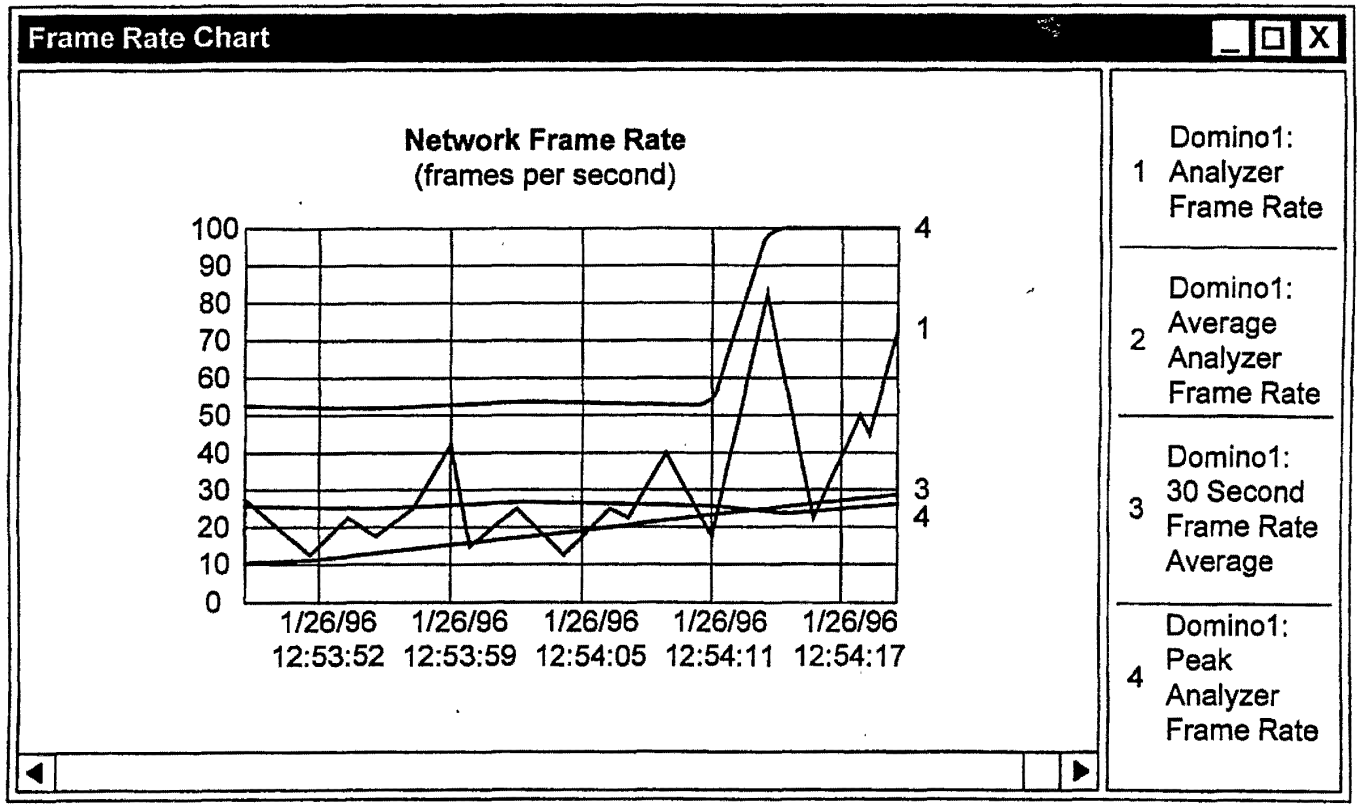

Frame Rate Chart
Network Frame Rate
(frames per second)
100
90
80
70
60
50
40
30
20
10
0
1/26/96 12:53:52
1/26/96 12:53:59
1/26/96 12:54:05
1/26/96 12:54:11
1/26/96 12:54:17
4
1
3
4
1 Domino1: Analyzer Frame Rate
2 Domino1: Average Analyzer Frame Rate
3 Domino1: 30 Second Frame Rate Average
4 Domino1: Peak Analyzer Frame Rate

FIG. 19B

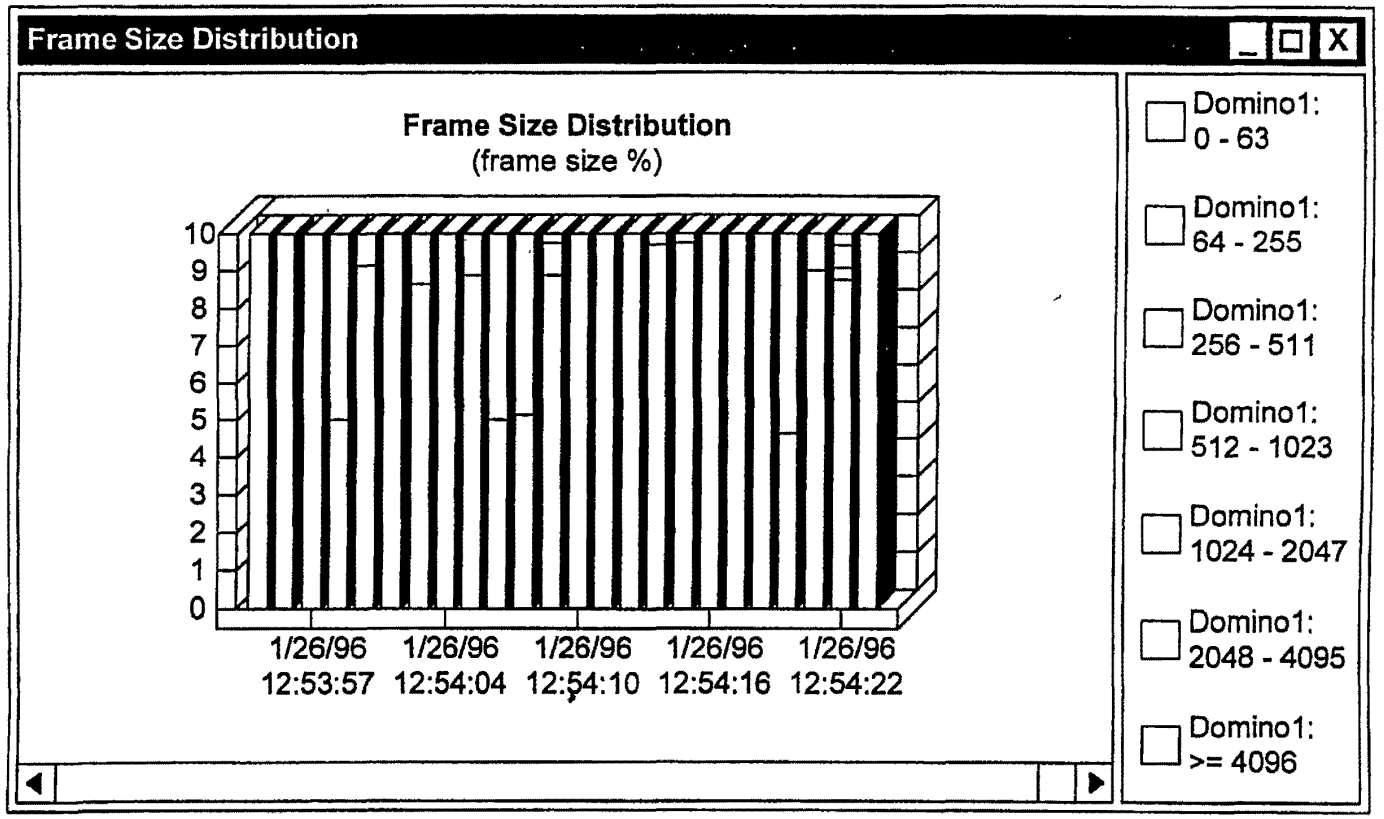

Frame Size Distribution
Frame Size Distribution
(frame size %)
10
9
8
7
6
5
4
3
2
1
0
1/26/96 12:53:57
1/26/96 12:54:04
1/26/96 12:54:10
1/26/96 12:54:16
1/26/96 12:54:22
Domino1: 0 - 63
Domino1: 64 - 255
Domino1: 256 - 511
Domino1: 512 - 1023
Domino1: 1024 - 2047
Domino1: 2048 - 4095
Domino1: >= 4096

FIG. 19C

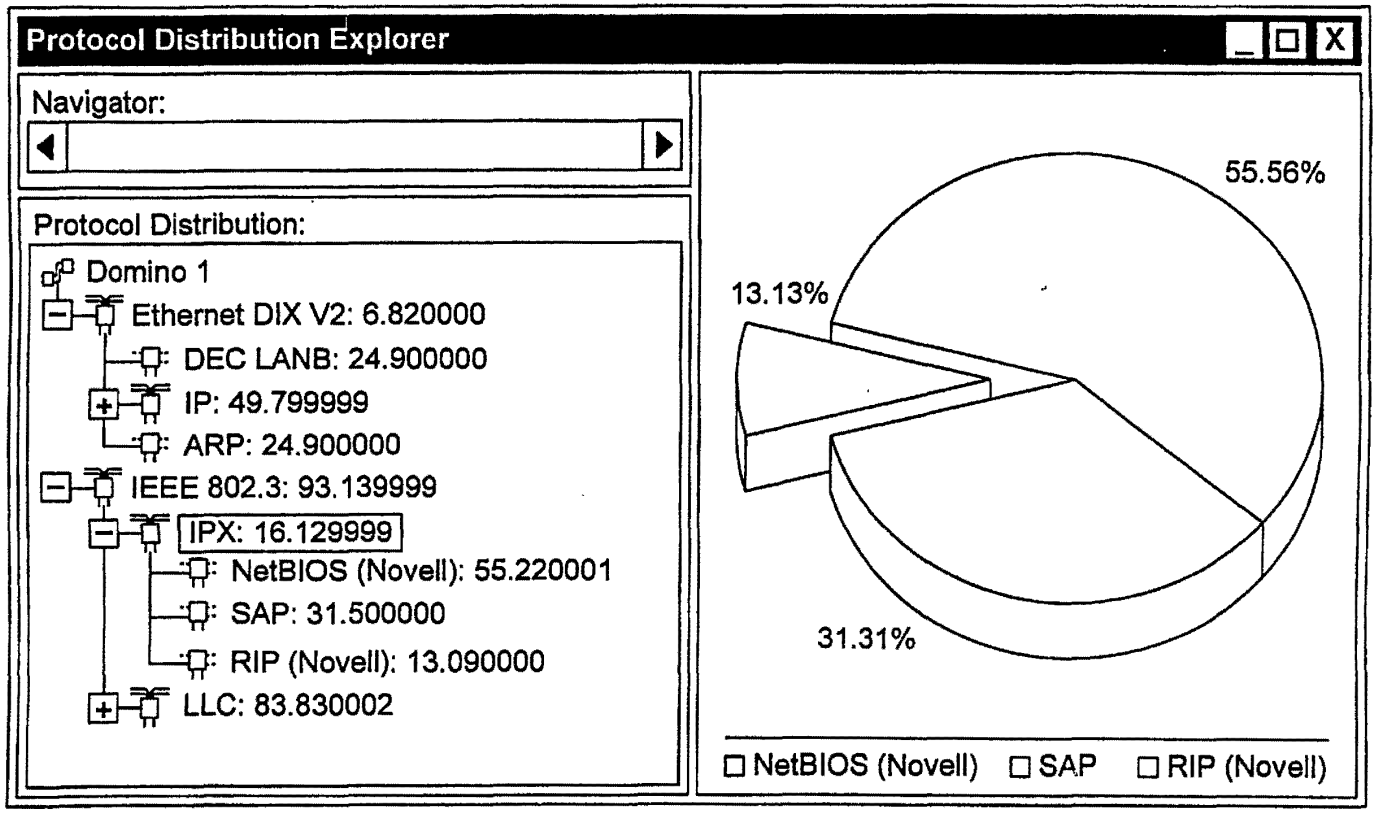

Protocol Distribution Explorer
Navigator:
Protocol Distribution:
Domino 1
Ethernet DIX V2: 6.820000
DEC LANB: 24.900000
IP: 49.799999
ARP: 24.900000
IEEE 802.3: 93.139999
IPX: 16.129999
NetBIOS (Novell): 55.220001
SAP: 31.500000
RIP (Novell): 13.090000
LLC: 83.830002
55.56%
13.13%
31.31%
NetBIOS (Novell)
SAP
RIP (Novell)

FIG. 20

Event Explorer

	Analyzer	Date / Time	Event
5	Domino 1	04/22/96 13:27:29	IP address 0.0.0.0 is being used by both MAC station 00 00 00 00 and MAC station 00 00 81 11 77.
6	Domino 1	04/22/96 13:27:29	An IP broadcast address of 0.0.0.0 is being used as a source address.
7	Domino 1	04/22/96 13:27:28	126 multicast frames have been detected. This exceeds the configured threshold.
8	Domino 1	04/22/96 13:27:29	121 broadcast frames have been detected. This exceeds the configured threshold.
9	Domino 1	04/22/96 13:27:27	Event Logging Started
10	Domino 1	04/22/96 07:21:52	Station 198.85.38.1 has sent one or more ICMP "port unreachable messages. The last notification of this was sent to station 198.85.34.113 and indicated that port 138 was unreachable.
11	Domino 1	04/22/96 07:21:36	IP address 0.0.0.0 is being used by both MAC station 00 00 00 00 and MAC station 00 00 81 11 77.
12	Domino 1	04/22/96 07:21:36	An IP broadcast address of 0.0.0.0 is being used as a source address.

FIG. 21

PROTOCOL ANALYZER FOR MONITORING DIGITAL TRANSMISSION NETWORKS

This application claims priority to provisional application number 60/023,459, filed Aug. 2, 1996.

FIELD OF THE INVENTION

The present invention relates generally to the field of computer and data communications networks and systems and more particularly to protocol analyzers for monitoring and analyzing digital transmission networks.

BACKGROUND OF THE INVENTION

Wide area computer networks ("WANs") first emerged in the 1970's to enable computers to communicate across broad geographic areas. Distributed computing resources, such as personal computers, workstations, servers and printers, have proliferated in recent years due to the declining cost and increasing performance of computer hardware. This has been a key factor in the growth of local area network technology. Local area networks ("LANs") allow increased productivity and utilization of distributed computers or stations through the sharing of resources, the transfer of information and the processing of data at the most efficient locations. As organizations have recognized the economic benefits of using LANs, network applications such as electronic mail, file transfer, host access and shared databases have been developed as means to increase user productivity. This increased sophistication, together with the growing number of distributed computing resources, has resulted in a rapid expansion in the number of installed LANs.

As the demand for LANs has grown, LAN technology has expanded and now includes many different physical connection configurations ("network topologies" or "networks"), such as Ethernet, a LAN that employs a bus topology where the computing resources are connected to a single cable; Token Ring, a LAN that employs a ring topology where the computing resources are connected to a single closed loop cable; and Fiber Distributed Data Interface ("FDDI"), a LAN that supports fiber optic cables where the computing resources are connected in a series of dual rings. These and the many other types of networks that have appeared typically have several different cabling systems, utilize different bandwidths and transmit data at different speeds. In addition, hardware and software systems for LANs usually have different sets of rules and standards ("protocols") which define the method of access to the network and communication among the resources on the network, such as Novell NetWare, IBM NetBIOS, DECNet, AppleTalk and Banyan Vines. More recently, large users of LANs have increasingly sought to integrate local area networks with WANs, and this trend is expected to intensify as inter-network technology advances so as to permit more rapid delivery of advanced multimedia communications utilizing Asynchronous Transfer Mode ("ATM"), an advanced high-speed switching protocol, and other broadband transmission technologies.

Digital data are usually transmitted over a network in frames (also referred to as "data frames" or "packets") which can be of fixed or variable length depending upon the number of bits in the data portion of the frame. Frames usually have headers (e.g., addresses) and footers on the two ends of the frame, with the conveyed data bits being in the middle. These headers and footers are also sometimes referred to as "protocols." The structure of a frame is discussed in more detail below in the section entitled Frame Analysis. The nature and content of the headers and footers are usually dictated by the type of network.

Transmissions from one network computer to another must be passed through a hierarchy of protocol layers. Each layer in one network computer carries on a conversation with the corresponding layer in another computer with which communication is taking place, in accordance with a protocol defining the rules of communication. In reality, information is transferred down from layer to layer in one computer, then through the communication channel medium and back up the successive layers in the other computer. To facilitate understanding, however, it is easier to consider each of the layers as communicating with its counterpart at the same level, in a horizontal direction.

The hierarchy of network layers is illustrated in FIG. 1. The highest network layer is the Application Layer 7. It is the level through which user applications access network services. The Presentation Layer 6 translates data from the Application Layer 7 into an intermediate format and provides data encryption and compression services. The Session Layer 5 allows two applications on different computers to communicate by establishing a dialog control between the two computers that regulates which side transmits, when each side transmits, and for how long. The Transport Layer 4 is responsible for error recognition and recovery, repackaging of long messages into small packages of information, and providing an acknowledgment of receipt. The Network Layer 3 addresses messages, determines the route along the network from the source to the destination computer, and manages traffic problems, such as switching, routing, and controlling the congestion of data transmissions. The Data Link Layer 2 packages raw bits into logical structured packets or frames. It then sends the frame from one computer to another. If the destination computer does not send an acknowledgment of receipt, the Data Link Layer 2 will resend the frame. The Physical Layer 1 is responsible for transmitting bits from one computer to another by regulating the transmission of a stream of bits over a physical medium. This layer defines how the cable is attached to the network interface card within the station computer and what transmission technique is used to send data over the cable. As a message is passed down through the layers, each layer may or may not add protocol information to the message.

As LANs and WANs have increased in number and complexity, networks have become more likely to develop problems which, in turn, have become more difficult to diagnose and solve. Network performance can suffer due to a variety of causes, such as the transmission of unnecessarily small frames of information, inefficient or incorrect routing of information, improper network configurations and superfluous network traffic. Specific network hardware and software systems may also contain design flaws which affect network performance or limit access by users to certain of the resources on the network. These problems are compounded by the fact that most local and wide area networks are continually changing and evolving due to growth, reconfiguration and the introduction of new network topologies, protocols, interconnection devices and software applications.

Increasing numbers of organizations use local and wide area networks, and the accurate and timely transmission and processing of information on LANs and WANs have become vital to the performance of many businesses. Mission-critical applications, such as telemarketing, order-entry, airline reservation systems and bank electronic funds transfer systems, now reside on LANs and WANs. The financial

consequences of network problems that adversely affect these applications can be enormous. Without network analysis products which identify how and where data are moving on local and wide area networks, users of these networks have no means to effectively analyze and monitor performance or to isolate problems for prompt resolution.

Network analyzers monitor the digital traffic or bit stream so as to identify and examine principally the headers and footers of each frame in order to analyze the health of the digital network. Hence, they are often called network protocol analyzers. The period of time during which a network is being analyzed is referred to as a "network monitoring session." Typically, protocol analyzers are designed to identify, analyze and resolve interoperability and performance problems across the principal configurations of LAN and WAN topologies and protocols.

The protocol analyzers enable computer network users to perform a wide variety of network analysis tasks, such as counting errors, filtering frames, generating traffic and triggering alarms. There are many examples of digital network transmission protocol analyzer instruments. One such example is shown in U.S. Pat. No. 4,792,753, granted to Iwai on Dec. 20, 1988. Another digital network transmission protocol analyzer, directed particularly to Token Ring networks, collects several types of information about a network, including statistics, events, and network attributes by analyzing sequences of control frame transmissions and is shown in U.S. Pat. No. 5,097,469, granted to Douglas on Mar. 17, 1992. Many of the protocol analyzer instruments are combined with user interfaces having display and keyboard and/or other input capability. The generation and display of certain message traffic characteristics are addressed in U.S. Pat. No. 3,826,908, granted in July 1974 to Weathers et al. U.S. Pat. No. 4,775,973, granted to Toberlin, et al., on Oct. 4, 1988, discloses a method and apparatus for monitoring protocol portions of digital network transmissions and displaying a matrix of traffic from transmitting stations and to destination stations. U.S. Pat. No. 5,375,126 granted to Wallace on Dec. 20, 1994, discloses a system for testing digital data telecommunication networks, with display of fault analysis, comparative viewing of fault-free benchmark data and with provision to offer suggestions as to probable causes of faults. In the network communications monitor of U.S. Pat. No. 5,442,639, granted on Aug. 15, 1995, to Crowder et al., selected frames may be captured in a capture buffer, stored electronically, and/or displayed in real time. U.S. Pat. No. 5,487,073, granted to Urien on Jan. 23, 1996, discloses commanding a communications coupler to perform a set of network function tests. The network status results of the tests are sent to a data-processing unit for display.

Protocol analyzers are produced in two general types. One is larger, less portable and more comprehensive in the scope of tests which it can perform. This type is used primarily by developers and manufacturers of network systems. The other type is smaller, more portable, and often easier to operate and lower-priced, albeit often with some limitations as to the scope of its testing capability. This latter type of protocol analyzer is produced primarily for field service technicians who maintain computer network systems.

A protocol analyzer's monitoring, diagnostic and problem resolution activities are usually under software control. Such software control is exercised by a main central processing unit (CPU), which is usually one or more microprocessors contained within the protocol analyzer itself. The protocol analyzer may also utilize a separate computer controller, such as a "laptop," to facilitate human interface.

To some degree, the software which protocol analyzers use may be characterized as expert system software which facilitates isolation of problems on a network being analyzed. This expert system software may be contained in the protocol analyzer's internal memory or in the separate computer controller. The utility, efficiency, comprehensiveness, and ease of use of a protocol analyzer, particularly one designed for use by a field technician, is in large part directly proportional to the corresponding capabilities of the software in the protocol analyzer and even in its computer controller.

Current protocol analyzers for use by field technicians have numerous limitations. One such limitation is the inability to analyze and display comprehensive network transmission information in real-time (as the transmissions occur). When analysis of network transmissions must be done off-line, the likelihood that an important network occurrence or "event" will be missed is significantly increased.

In addition, current protocol analyzers do not present network transmission information in sufficiently meaningful or detailed ways, nor do they allow for on-line comparison of current network performance to prior network performance. For example, it would be useful if more meaningful displays of the numerous types of statistics related to the network as a whole or just a given station on the network were available to the user in juxtaposition with other information. Also, many users would like to see complicated information and detailed protocol distribution statistics displayed in a manner that is easier to use and easier visually to understand. Display to the user of more detailed information about anomalies or "events" that occur on the system would be useful to a user, especially if displayed in a more usable form and in "real time" and accumulated over a network monitoring session. Certainly, conveniently-displayed troubleshooting assistance would be helpful, as would visual reporting in "real time" and accumulated over an analysis session. Off-line analysis of selected frames captured during a network monitoring session could be more conveniently displayed to the user.

Finally, while protocol analyzers of the prior art provide reasonable diagnostic capability, they do not guide the field technician through event analysis and the appropriate solutions. In general, these limitations combine to prevent effective guidance to the field technician in actually analyzing and solving the network problem.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a new and improved protocol analyzer capable of displaying station level statistics, displaying real time event detection, creating baseline network performance information and comparing said baseline information with real-time performance information and displaying to a user the results of that comparison, pre-programming monitoring sessions, generating reports in conjunction with analyzing digital transmission networks, all in real time.

In accordance with one embodiment of the present invention, the operation of a protocol analyzer includes one or more of the following: monitoring, in real time, the transmission of data packets having protocol portions and data portions; identifying the protocol portions of said packets in real time; analyzing, in real time, the protocol portions of said packets to ascertain relevant information; storing said information to a database in real time; sorting said information in real time, according to station level parameters; statistically analyzing said sorted information in

real time to obtain statistical information; displaying said statistical information in real-time reports, displaying said statistical information in report formats selected by an operator; displaying real time performance of the network simultaneously with baseline network performance; simultaneously displaying statistical information gathered from a plurality of protocol analyzer instruments; pre-programming the monitoring of the transmission of data packets wherein the operator may select the duration of the network monitoring session; monitoring in real time one or more selected and assorted network parameters and comparing the results of said analysis with arbitrary threshold values for said parameters to determine if the transmission on the network is exceeding said threshold so as to constitute an event; analyzing in real time said sorted information to calculate the probabilities of the possible causes of said ascertained events; and displaying in real time the one or more possible causes of said event.

It is another object of the present invention to analyze and meaningfully display the statistics of the occurrence and distribution of protocols encapsulated within the several levels of the several data frames analyzed by a protocol analyzer instrument.

In accordance with another embodiment of the present invention, the operation of a protocol analyzer includes one or more of the following: monitoring, in real time, the transmission of data packets having protocol portions and data portions; identifying the protocol portions of said packets in real time; analyzing, in real time, the protocol portions of said packets to ascertain relevant information; storing said information to a database in real time; sorting said information according to protocol distribution criteria; statistically analyzing said sorted information; and displaying said statistical information.

In accordance with yet another embodiment of the present invention, the operation of a protocol analyzer includes one or more of the following: monitoring, in real time, the transmission of data packets having protocol portions and data portions; identifying the protocol portions of said packets in real time; analyzing, in real time, the protocol portions of said packets to ascertain relevant information; storing said information to a database in real time; sorting said information according to ISO layer; sorting said information according to protocol sub-families; statistically analyzing said sorted information; and displaying said statistical information in a protocol-tree format.

It is yet another object of the present invention to analyze, store the analysis results and display the analysis results, in real time, of digital data transmission comprising data frames having protocol portions and data portions, without the need to wait for the later analysis of protocol portions of frames, which protocol portions were stored in real time. This and other objects of the present invention are achieved by use of a RISC (Reduced Instruction Set Computer) processor to analyze the protocol portion of each frame, in real time, followed by contemporaneous statistical analysis of the RISC (Reduced Instruction Set Computer) processor analysis of the protocols of several successive frames, followed by substantially simultaneous storage and display of the statistical analysis results.

It is still another object of the present invention to store the results of the analysis of digital data transmission in a database capable of storing and retrieving the analysis results to permit display in real time. This and other objects of the present invention are achieved by use of an object oriented database and object oriented application programming to access said object oriented database.

It is still yet another object of the present invention to log, store, and display digital data transmission events in real time. This and other objects of the present invention are achieved by recognizing, in a protocol analyzer instrument, the occurrence of an event, periodically polling the protocol analyzer instrument for, among other information, a record of events that occurred since the last polling, transmitting, to a user interface, a message containing information about the events that occurred since the last polling, receiving the new event information in an event target ("target" is a term used to identify a software device to which data can be sent for storage, forwarding, or processing), storing the new event information in an event log object in an event log database class, informing a document of receipt of new event information, the document informing an event log view of receipt of new information, obtaining confirmation of new event log information and a pointer thereto in the database, and incorporating the new event information into a display of event log information.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood by reference to the following detailed description when considered in conjunction with the following drawings wherein like reference numbers denote the same or similar portions or processes shown throughout the several Figures in which:

FIG. **1** is an illustration of the hierarchy of network protocol layers;

FIG. **2** is a diagram describing the structure of an Ethernet data frame;

FIG. **3** is a diagram which illustrates the flow of data, analysis, and control in accordance with the present invention;

FIG. **4** is a flowchart illustrating the process by which statistics for individual stations on a network (station-level statistics) are calculated;

FIG. **5** is a diagram illustrating the structure of an entry in the protocol distribution array within a digital memory;

FIG. **6** is a diagram illustrating the structure of the message for a protocol distribution update;

FIG. **7** is a flowchart illustrating the method by which protocol distribution is calculated;

FIG. **8** is a flowchart illustrating the method by which the Network Statistic "Network Frames Received" is calculated;

FIG. **9** is a flowchart illustrating the method by which Network Statistic "Analyzer Frames Received" is calculated;

FIG. **10** illustrates the structure of an entry in the Event Log Array;

FIG. **11** illustrates the structure of an Event Update Message;

FIG. **12** illustrates the structure of a Network Statistics Update Message;

FIG. **13** illustrates the structure of the user interface;

FIG. **14** is a scenario diagram for a station-level statistics update;

FIG. **15** is a scenario diagram for a network statistics update;

FIG. **16** is a scenario diagram for a protocol distribution update;

FIG. **17** is a scenario diagram for an event update;

FIG. **18** illustrates the visual appearance of an example of a split-screen display of station-level statistics;

FIGS. 19A, 19B, and 19C illustrate three examples of the appearance of chart display formats for network statistics;

FIG. 20 illustrates an example of the appearance of a split-screen display of protocol distribution; and

FIG. 21 illustrates the appearance of a display screen listing of events.

DETAILED DESCRIPTION OF THE INVENTION

I. Introduction

The following detailed description is divided into sections which have section titles to indicate the general nature of the information that follows. The sections and their titles are intended solely to assist in organization of the description and to aid the reader. They are not intended to indicate that information suggested by any one section title is not contained in any other section.

Where the description of the design and operation of the present invention is illustrated by use of an example which is specific to a particular network topology, it may be presumed unless stated otherwise that the network topology is Ethernet. Limiting examples to Ethernet networks is intended only to provide consistency in order to facilitate understanding and is not meant to indicate a limitation of the suitability of the present invention for analyzing other network topologies such as token ring, FDDI, frame relay, etc.

II. Overview of the Implementation of the Invention

The preferred embodiment of the present invention comprises a hardware implementation and a software implementation.

A. Software Implementation

The software implementation of the present invention performs two functions. The first is to perform meaningful statistical calculations on the protocol information retrieved from the network. The portion of the software implementation responsible for performing these calculations will be referred to hereinafter as the "embedded code."

The second function performed by the software implementation of the invention is to provide the software with means for interaction between the protocol analyzer and the operator. Such interaction includes the displaying of the data calculated by the embedded code as well as responding to operator commands. The portion of the software implementation which performs this function will hereinafter be referred to as the "user interface" or "UI." The user interface is preferably coded in the Microsoft Visual C++ programming language produced by Microsoft Corporation at One Microsoft Way, Redmond, Wash. 98052-9953, and operates in the Microsoft Windows 3.1 and Microsoft Windows 95 operating systems, also produced by Microsoft Corporation.

B. Hardware Implementation

The hardware implementation of the present invention likewise performs two functions. First, it provides a physical platform for execution of the embedded code and for interfacing with the network being monitored. This portion of the hardware implementation of the invention will hereinafter be referred to as the "protocol analyzer instrument." The present invention may comprise a plurality of protocol analyzer instruments (see FIG. 3), each having at least one RISC processor and each monitoring a different network or segment of a network or monitoring the same network or segment but at a different port or station on the network.

The second function performed by the hardware implementation is to provide the physical means for the operation of the user interface. Such means include input devices (such as a keyboard, a mouse, a trackball, etc.) and a display device (such as a cathode ray tube monitor or a liquid crystal display). In the preferred embodiment of the invention, this second function is performed by a laptop personal computer (PC) containing an Intel 80486 or Pentium processor operating at 25 MHz or faster, preferably eight megabytes or more of random access memory, a hard disk drive with at least about forty-five megabytes of free disk space, a 3.5 inch floppy disk drive, a bi-directional parallel communication port, a keyboard, and a pointing device such as a trackball, joystick, or mouse. This second portion of the hardware implementation of the invention will be referred to hereinafter as the "PC."

In the preferred embodiment, the PC is connected to one or more protocol analyzer instruments through the PC's parallel communication port. The software implementation (both the embedded code and the user interface) of the invention is stored in a storage device (such as a hard disk drive, a magnetic tape drive, or other similar medium) on the PC. When the operator activates the protocol analyzer instrument, an initialization process takes place in which the embedded code is downloaded from the PC's storage device through the parallel communication port to the protocol analyzer instrument(s).

C. Protocol Analyzer Instrument

Except for the features described herein, the protocol analyzer instrument can be similar to the hardware implementations of conventional protocol analyzers. See U.S. Pat. No. 4,792,753 (mentioned above). In the preferred embodiment of the present invention, the protocol analyzer instrument is a DominoLAN DA-320 Internetwork Analyzer manufactured by Wandel & Goltermann Technologies, Inc. at 1030 Swabia Court, Research Triangle Park, N.C. 27709-3585. (DominoLAN is a trademark of Wandel & Goltermann Technologies, Inc.) The Domino Getting Started Guide, the Domino Operating Guide, the DominoLAN Toolbox Applications, and the Release Notes for the relevant release, all of which are included with the DA-320 analyzer, are hereby incorporated by reference as if fully set forth herein.

The protocol analyzer instrument preferably comprises two hardware modules, a network interface (NI) module and a protocol analysis (PA) module which preferably occupy the same convenient physical cabinet. Each module is controlled by its own INMOS T425 transputer processor operating at 25 MHz and using a 32-bit word RISC (Reduced Instruction Set Computer) architecture ("RISC processor"), manufactured by SGS Thompson Corporation, INMOS, Ltd., 1000 Aztec West, Almondsbury, Bristol, BS12 4SQ, UK.

These RISC processors are responsible for execution of the embedded code when the protocol analyzer instrument is in use. The use of a processor with a limited instruction set, such as a RISC processor, results in increased processing speed. This increased processing speed allows both the NI and PA modules of the protocol analyzer instrument to perform real time analysis of the network transmissions. While the preferred embodiment utilizes RISC processors to achieve the desired processing speed, alternatives such as the Intel 960 processor manufactured by Intel Corporation, 2200 Mission College Blvd., Santa Clara, Calif. 95052; and the PowerPC processor manufactured by Motorola, Inc., P.O. Box 20912, Phoenix Ariz. 85036, will be readily apparent to a person having ordinary skill in the art. (PowerPC is a registered trademark of International Busi-

ness Machines Corporation.) The scope of the invention, therefore, should not be limited to the description of the preferred hardware implementation contained herein.

The NI module is preferably equipped with 512 kilobytes of static random access memory (SRAM), while the PA module preferably has four megabytes of dynamic random access memory (DRAM) and is expandable to sixteen megabytes. The preferred protocol analyzer instrument also contains a LAN card printed circuit pack (art number 82C581), which comprises two LAN chips (part number 82C585), purchased from 3Com Corp., and a plurality of hardware counters used to count the number of frames and bytes detected on the network.

D. Data Flow Overview

FIG. **3** illustrates an overview of the flow of information about the operation of a network **301**. Data-bearing frames (see FIG. **2**) are transmitted over the Network **301** and are received and analyzed by Embedded Code **302** executed by a Protocol Analyzer Instrument **304** using its one or more RISC processors **314** and hard-wired analyzer circuits within the Protocol Analyzer Instrument. The results of that protocol analysis are then available to be sent, as commanded by the user, to a software-based User Interface **303** running on the PC **305** for storage and presentation to the user. The User Interface then presents the analysis results to the user via the PC's display device **318**. The User Interface **303** also passes the user's commands (e.g., network parameters to be monitored, sampling rate, etc.) to the Embedded Code **302**.

FIG. **3** also illustrates that the PC **305** contains a mass memory device **317**, sometimes referred to as a direct access storage device. This is the hard disc drive of the preferred embodiment of the PC **305** that is used, inter alia, to implement the preferred embodiment of the present invention. The User Interface **303** works with a POET object-oriented database program **310** selectively to store, on the mass memory or hard drive **317**, the results of the analyses that are performed by the Protocol Analyzer Instrument **304** and which are then periodically uploaded to the PC **305**.

III. Frame Analysis

The format of a data frame varies slightly depending on the network type (i.e. token ring network, ethernet, etc.) but the analysis of the frame is basically the same. For example, the format of an ethernet network data frame is illustrated in FIG. **2**. The frame begins with an eight-byte Preamble field **208** which is used for synchronization. This is followed by the Destination address **209** (the address of the station which is to receive the data frame). Next is the Source address field **210** (the address of the station which sent the data frame). The address fields contain the Medium Access Control ("MAC") addresses of the source and destination stations. The MAC address is a unique address hard wired into the station's network interface card (NIC). Each address field is six bytes in length. The Type field **211**, which follows the address information, is a two-byte field that specifies the higher layer protocol used in the Data field. The Data field **212**, which is the only variable-length field, is next and ranges from 46 to 1500 bytes. It contains the higher level protocols currently in use as well as the data being transmitted. Last is a four-byte Frame Check Sequence ("FCS") field **213**, which is used for error detection. The term "frame length" refers to the total number of bytes contained in the frame less the number of bytes in the Preamble **208**. The contents of each field are identified by the embedded code executed on the protocol analyzer instrument. The exact method by which relevant information is extracted from a frame would be readily apparent to a person having ordinary skill in the art of programming software for protocol analyzers.

In the present invention, frame analysis is performed by the embedded code executed by the protocol analyzer instrument. By performing frame analysis on the protocol analyzer instrument, which preferably contains two RISC processors, the analysis of the frames can be accomplished in real-time. The contents of each frame received during a network monitoring session are temporarily stored in the memory located on the protocol analyzer instrument. The portion of this memory which stores the contents of received frames will be referred to hereinafter as the "capture buffer." The frames stored in the capture buffer will be referred to hereinafter as "captured frames." The contents of the capture buffer are continuously updated. When the buffer is filled, the oldest captured frames are discarded and replaced with newly captured frames.

IV. Filtering

Filtering is the process by which the user can select certain types of frames to be analyzed. The user can specify certain parameters that frames must meet before the frames are sent to the NI module. Filtering is preferably accomplished using a hardware filter, contained within the NI module, such as the filter disclosed in a copending U.S. patent application Ser. No. 08/384,855, filed on Feb. 7, 1995, in the name of Bradley Anderson, which is incorporated by reference to the same extent as if fully reproduced herein now issued as U.S. Pat. No. 5,590,159.

The hardware filter compares incoming bit sequences to the bit sequence which corresponds to the user-defined parameters and only frames containing bit sequences which match the bit sequence corresponding to the user defined parameters are sent to the NI module of the protocol analyzer instrument. These frames are the only frames which are analyzed. As an arbitrary example of the filtering operation, only frames addresses to station A are to be analyzed and/or only frames transmitted by station B are to be analyzed.

V. Embedded Code

A. Station-Level Statistics

Statistics for each station on a network will be referred to hereinafter as "station-level statistics." Station-level statistics such as, but not limited to, number of bytes transmitted, number of frames transmitted, number of bytes received, number of frames received, and total number of errors generated by that station are all calculated by the embedded code running on the protocol analyzer instrument.

As station-level statistics for each station operating on the network are calculated, they are stored in an array called the "station list array" in the memory of the protocol analyzer instrument. An array is a data structure used to store data. Many other data structures, which can also be used to store data, are well known to persons having ordinary skill in the art of programming. The use of the term "array" throughout this specification is not meant to be limited strictly to arrays; because, many of these other data structures would also suffice.

The station list array contains: the station address, traffic statistics (bytes received, bytes transmitted, frames received, and frames transmitted, etc.), and error statistics for each station which is or has been active on the network during the network monitoring session. The type of error statistics calculated will vary depending on the type of network.

FIG. **4** illustrates the process by which station-level statistics are calculated for an ethernet network. Station-

level statistics which are unique to other network topologies, such as FDDI, Token Ring, frame relay, etc., are calculated in a manner which is analogous to the process described below.

After the start **401** of the station-level statistics calculation, receipt of a frame is recognized at programming step **402** by the protocol analyzer instrument. Next, the address information of each frame is used preferably to identify the destination address at programming step **403** and to identify the source address at programming step **404** for each data frame sent over the network. The destination address portion **209** (see FIG. **2**) of the frame is identified, and the bytes contained in that portion of the frame are examined in order to ascertain the destination station to which the frame has been addressed. The source address portion **210** of the frame is identified, and the bytes contained in that portion of the frame are examined in order to ascertain the source station from which the frame was sent.

Preferably, the next step in the calculation of station-level statistics is programming step **405** in which the value of the Frame Check Sequence ("FCS") field **213** is identified in programming step **405**. In an ethernet frame, the FCS is contained in the last four bytes of the frame. The FCS is a four-byte cyclic redundancy check ("CRC") or checksum which is calculated by the source station. The source station calculates the FCS by performing a well-known mathematical function on the bits in the Destination **209**, Source **210**, Type **211**, and Data **212** fields of the frame. The FCS is used for purposes of error detection.

The length of the frame is preferably determined in programming step **406** by summing the total number of bytes in the Destination **209**, Source **210**, Type **211**, Data **212** and FCS **213** fields.

The next step **407** is to determine whether there is an entry corresponding to the destination address of the frame in the station list array in the memory of the protocol analyzer instrument. If that particular destination station has previously received or sent any frames during the network monitoring session, there will be an entry corresponding to that destination station's address in the station list array. If that destination station has not yet received or sent any frames during the network monitoring session, there is no entry for that destination address in the station list array. If there is no entry corresponding to that particular destination address in the station list array, an entry corresponding to that destination address is created by programming step **408**.

The frames_received array variable of the station list array entry corresponding to the destination address is incremented by one at the programming step **409**.

Where used, an underscore within a term denotes a variable name as opposed to a-value or definition. Also, an array is a memory structure.

Similarly, the bytes_received array variable of the station list array entry corresponding to the destination address is incremented in step **410** by the frame length of the current frame.

The step **411** determines whether there is an entry corresponding to the source address of the frame in the station list array. If the source station has previously received or sent any frames during the network monitoring session, there will be an entry corresponding to the source station's address in the station list array. If the source station has not yet received or sent any frames, there is no entry for the source address in the station list array. If there is no entry corresponding to the source address in the station list array, an entry corresponding to the source address is created by step **412**.

The frames_transmitted array variable of the station list array entry corresponding to the source address is incremented by one at programming step **413**. Similarly, the bytes_transmitted array variable of the station list array entry corresponding to the source address is incremented by the frame length of the current frame in step **414**.

The next steps involve updating the error_statistics array variable of the entry in the station list array corresponding to the source address. The error_statistics array variable is actually a subarray whose length depends upon the number of types of errors detected for the particular network topology. It contains the error_id and the number_of errors for each type of error detected for the corresponding station. The error_id is an arbitrary, predefined code which represents one of several types of errors that the protocol analyzer instrument is equipped to recognize. For an ethernet network, these errors include but are not limited to "jabbers," "runts," "alignment errors," and "FCS errors." Each of these errors is discussed in detail below. Number_of_errors represents the number of occurrences of the particular error type attributable to the corresponding station.

The first step **415** in updating the error_statistics subarray of the entry in the station list array corresponding to the source address of the current frame is to determine whether the length of the current frame is greater than the maximum 1518 bytes permitted in an Ethernet frame. Such overly-long frames are commonly referred to as jabbers. Jabbers originate from a source station that will not stop transmitting. If a frame's length is greater than 1518 bytes, it is likely that the source station is defective. If the current frame is a jabber, the error_statistics subarray of the entry in the station list array corresponding to the source address is updated accordingly at programming step **416**.

Step **417** determines whether the frame length of the current frame is less than 64 bytes. Such frames are commonly referred to as runts. Runts are short frames which may also indicate that the source station is defective. If the current frame is a runt, the error_statistics subarray of the entry in the station list array corresponding to the source address is updated accordingly in step **418**.

Programming step **419** determines whether the current frame is byte-aligned. A frame is said to be byte aligned if the frame size in bits is evenly divisible by eight. For this purpose, the frame size is said to be equal to frame length (expressed in bits) plus the length of the preamble (also expressed in bits). That is, the existance of an arithmatic remainder from the division by eight of the number of bits in the frame plus preamble indicates that the frame does not contain a whole number of bytes.

The determination of whether a frame is byte-aligned is done by the LAN chip on the protocol analyzer instrument (mentioned above under Protocol Analyzer Instrument). If the current frame is not byte aligned, an alignment error has occurred. The error_statistics subarray, of the entry in the station list array corresponding to the source address, is updated accordingly by programming step **420**.

As discussed above, the source station calculates the FCS by performing a mathematical function on the bits in the Destination, Source, Type, and Data fields of the data frame. The LAN chip, also discussed above, performs the same mathematical function and compares the results to the contents of the FCS. If the two do not match, an FCS error has occurred, indicating that the frame is corrupt. Step **421** examines the results of that calculation and comparison by the LAN chip in order to determine whether one or more bits of the current frame may have been corrupted in transmission.

If the current frame contains an FCS error and is thus corrupt, the error_statistics subarray of the entry in the station list array corresponding to the source address is updated accordingly in step **422**.

After all of the above station-level statistics and any other desired station-level statistics have been calculated, the final step involves transmitting the information stored in the station list array to the PC for use by the user interface. This transmission is facilitated through the use of a "message," which is the preferred method of communication among the various hardware and software components of the preferred embodiment of the present invention.

The message for station-level statistics consists of a header and the contents of the station list array. The header identifies the destination for the message and the type of message, in much the same format as the messages illustrated in FIGS. **6**, **11**, and **12**. In this case, the message would be a station-level statistics update message. The contents of the station list array are placed in the message in the order in which they were initially placed in the station list array.

When the User Interface (UI) software in the PC requests information on station-level statistics, the message is sent from the protocol analyzer instrument to the PC for use by the user interface. A person having ordinary skill in the art of digital transmission protocol analyzers will know that station-level statistics peculiar to other network topologies can be calculated in a similar manner.

B. Network Statistics

Statistics based upon network performance as a whole will be referred to hereinafter as "network statistics." Network statistics are calculated by the embedded code running on the protocol analyzer instrument. Network statistics may be cumulative (calculated over the entire network monitoring session, which might typically be a twenty-four-hour period) or per sampling period (calculated over a sampling period specified by the user, which might typically be a one-second period).

Network statistics may also vary somewhat between the various network topologies. For example, network statistics calculated for an ethernet network include number of Network Frames Received, Network Frame Rate, number of Analyzer Frames Received, Analyzer Frame Rate, Peak Analyzer Frame Rate, Peak Frame Rate Timestamp, Average Frame Rate, Average 32-Second Frame Rate, Utilization, Average Utilization, Peak Utilization, Peak Utilization Timestamp, number of Broadcast Frames Received, number of Multicast Frames Received, Frame Size Distribution-Cumulative, Frame Size Distribution-Sample, number of Network Collisions, number of Alignment Errors and the numbers of Jabber, Runt, and FCS Errors. Each of these statistics is discussed below.

Referring now to FIG. **8**, the number of Network Frames Received is calculated by a hardware counter on the protocol analyzer instrument. From the Start step **801**, the protocol analyzer instrument detects receipt of a network frame in programming step **802**. The hardware counter is connected directly to the network line and is able to count every frame traveling over the network, i.e. Network Frames Received. For each frame detected, the hardware counter is incremented in step **803**. This process is repeated until the sampling period has expired, step **804**. When the network monitoring session has ended, it ends at some point after or to coincide with the expiration of a sampling period. The number of Network Frames Received is then obtained from the hardware counter by the Embedded Code software in the protocol analyzer instrument, step **805**, for later uploading to the PC.

Similarly, the Network Frame Rate is the number of Network Frames Received, preferably over a one second interval, as monitored by a hardware counter, and is calculated every second.

As the NI module of the protocol analyzer instrument receives frames, these frames are transmitted to the PA module of the protocol analyzer instrument, where the frames are processed. However, if the Network Frame Rate is extremely high, some of the frames may not be sent to the PA module for processing. In this situation, some of the frames will still be counted as having been received by the NI module but may never be processed or analyzed by the PA module, see discussion above regarding Frame Analysis for a discussion of some of the types of frame analyses that may be performed by the PA module.

In addition, the user has the option of choosing to monitor only certain types of frames, see discussion above under Filtering. In this case, all of the frames that are received by the NI module will still be counted as having been received, in order to arrive at the number of Network Frames Received. However, only frames which meet the user-defined parameters are passed to the PA module. Therefore, in these situations when only selected types of frames are passed to the PA module for analysis, the number of frames actually sent to the PA module is different from the value of Network Frames Received.

The number of frames actually sent to the PA module is referred to as the Analyzer Frames Received. The Analyzer Frames Received are calculated by the program shown in FIG. **9**. From the Start step **901**, the PA module of the protocol analyzer instrument receives a frame from the NI module in step **902**. Another hardware counter is incremented accordingly in step **903**. The process is repeated until the sampling period has expired, step **904**. The final count is then obtained by the Embedded Code from the counter in step **905** for later uploading by the PA module to the PC.

Similarly, Analyzer Frame Rate is the number of Analyzer Frames Received, preferably over a one second interval and is calculated every second. The highest frame rate (in frames per second) detected during the network monitoring session by the analyzer for any single sampling period and the time at which it occurred represents Peak Analyzer Frame Rate and Peak Frame Rate Timestamp. For each sampling period, the current Analyzer Frame Rate is compared to the Peak Analyzer Frame Rate. If the current Analyzer Frame Rate is greater than the Peak Analyzer Frame Rate, the Peak Analyzer Frame Rate is replaced with the current Analyzer Frame Rate. The Peak Frame Rate Timestamp is then replaced with the current time.

The Average Frame Rate is calculated in a manner similar to the Analyzer Frame Rate except that the Average Frame Rate is averaged over the time elapsed during the Network Monitoring Session rather than over one second. Similarly, the Average 32-Second Frame Rate represents the Average Frame Rate over the past 32 seconds as opposed to the entire Network Monitoring Session. Therefore, for the first thirty-one seconds of a monitoring session, there will be no value for Average 32-Second Frame Rate.

After the first thirty-two seconds, the Average 32-Second Frame Rate is recalculated every second on a rolling basis (the frame rate is averaged over the most recent thirty-two second time span).

The embedded code on the protocol analyzer instrument is responsible for calculating the Network Utilization statistic. Network Utilization represents the percentage of the

theoretical network bandwidth that is currently being used. For an ethernet network, the theoretical network bandwidth is ten million bits per second (ten megabaud). This is equivalent to 1,250,000 bytes per second (one byte=eight bits).

The embedded code calculates Network Utilization every second in the following manner. First, the total number of bytes represented by the Preamble **208**, Destination **209**, Source **210**, Type **211**, Data **212** and FCS **213** fields of each frame (see FIG. 2) received during the second are summed. To this is added an additional twelve bytes for each frame received during a sampling period to represent quiet time. Quiet time is a 9.6 microsecond interval that follows each frame, during which no data are sent over the line. At a ten megabaud transmission rate, that 9.6 microseconds is equivalent to ninety-six bits or twelve, eight-bit bytes. Therefore, quiet time is the equivalent of twelve byte times.

The embedded code then divides this value by 12,500 (1,250,000 bytes/sec×100%). The resulting percentage statistic is referred to as Network Utilization. Average Utilization is an average of all Utilization values over the duration of the network monitoring session.

Peak Utilization represents the highest percentage of network capacity used during the current session and Peak Utilization Timestamp represents the time at which the peak utilization was detected. For each sampling period, the current Utilization is compared to the Peak Utilization. If the current Utilization is greater than the Peak Utilization, the Peak Utilization is replaced with the current Utilization. The Peak Utilization Timestamp is then replaced with the current time.

Frame Size Distribution is the network statistic that represents the number of frames, classified by size range, that were received by the protocol analyzer instrument since the analyzer was started for the monitoring session (Frame Size Distribution-Cumulative) or during a specified sampling period (Frame Size Distribution-Sample). Frame Size Distribution is calculated through the use of two memory arrays which store information on frame size distribution. One array stores frame size distribution on a cumulative basis and the other array stores frame size distribution on a sampling period basis. There are positions in both arrays corresponding to arbitrary size ranges (e.g. the value for the number of frames detected with lengths between 167 and 255 bytes is stored in position 2 of each array).

The above process is summarized as follows: The frame length of each frame (see Frame Analysis above) is examined. Next, the appropriate memory-array position of the cumulative array is incremented by one to reflect the occurrence of a frame in that particular size range. If the frame was detected during the sampling period, the appropriate array position of the sampling period array is also incremented by one.

As discussed above, under Protocol Analyzer Instrument, the protocol analyzer instrument includes a commercially-obtained LAN chip. The LAN chip is responsible for calculating Broadcast Frames Received, Multicast Frames Received and Network Collisions.

A broadcast frame is a frame sent from one station to all other stations on the network. A broadcast frame's destination address contains an address (referred to as a "broadcast address") that all other stations recognize as being addressed to them. Similarly, a multicast frame is a frame sent to a selected group of stations on a LAN. A multicast frame contains an address (referred to as a "multicast address") that the selected group of stations recognize as being addressed to them. By examining the Destination address field **209** (FIG. 2) of an incoming network frame, the LAN chip can recognize a broadcast address or a multicast address. If the Destination address field **209** contains an address which represents a broadcast or multicast address, the respective counter corresponding to either broadcast frames or multicast frames on the NI module is incremented by one. These counts represent the Broadcast Frames Received and Multicast Frames Received statistics.

Collisions occur when two stations on an Ethernet network stations attempt to transmit frames at the same time, resulting in their transmissions "colliding." Access to an Ethernet network is regulated by a Carrier Sense Multiple Access/Collision Detection (CSMA/CD) contention-based algorithm which is well known to a person having ordinary skill in the art. An Ethernet station listens to the network to determine whether any traffic is present. When the network is clear, it transmits and then listens again to see if the data collides with traffic from any other station. If all is clear, the transmission is complete. If a collision occurs, the station waits a short, random amount of time and retransmits. The LAN chip detects collisions by performing the standard CSMA/CD algorithm when a frame is received. If a collision is detected, a collision counter is incremented by one. This counter is part of the LAN chip.

The present invention also calculates network-wide statistics for errors such as Alignment Errors, Jabbers, Runts, and FCS Errors (see Station Level Statistics above for detailed definitions of these errors). These errors are detected by the LAN chip on the protocol analyzer instrument in a manner similar to that described above.

The network statistics which are unique to other network topologies, such as token ring, FDDI, frame relay, etc., are calculated in a manner which is analogous to the above process.

Information on all network statistics are stored into an array ("network statistics array"). The information stored for each statistic varies depending on the type of statistic, but basically, the value of each statistic is stored into an array along with a timestamp.

When the UI requests information on network statistics, the information stored in the network statistics array is sent to the PC for use by the user interface. This transmission is facilitated through the use of a message. The structure of a network statistics update message is shown in FIG. **12**.

The message for network statistics consists of a header **1301** and the contents of the network statistics array **1302**. The header identifies the destination for the message and the type of message (network statistics update message in this case). The contents of the network statistics array are placed in the message in the order in which they were initially placed in the network statistics array.

It will be evident to a person having ordinary skill in the art that network statistics for other network topologies can readily be calculated in a similar manner.

C. Protocol Distribution

The distribution and percentage distribution of the various protocols present in data frames are hereinafter referred to as "protocol distribution". The calculation of protocol distribution is performed by the embedded code executed by the protocol analyzer instrument.

Referring now to FIG. **7**, after the start step **701**, the protocol distribution calculation begins with programming step **702** in which the network frame is received. Step **703** next determines the first protocol present in the frame

received by the protocol analyzer instrument. For an ethernet frame, this is done by looking at the Type field **211** (see FIG. 2) of the frame. The Type field **211** of an ethernet frame designates the first protocol present in the Data field **212** of the frame. If the Type field **211** contains a value greater than hexadecimal 500, the first protocol present is the Ethernet Version 2 (EthernetV2) protocol, otherwise the first protocol present is the IEEE 802.3 protocol. This first protocol (either the EthernetV2 protocol or IEEE 802.3 protocol) is found in the data portion **212** of the frame.

Next, that protocol (and subsequently all other protocols contained in the frame) is decoded in step **704**. The protocol being decoded at any particular time is referred to as the current protocol.

The next step **705** involves storing information for the current protocol. Information on the current protocol is stored in a memory array. An entry in this array is shown in FIG. 5 ("protocol distribution array entry") and contains: the protocol_id **501**, statistics_for_the_protocol **502**, array_position **503**, number_of_children **504**, and a children_table **505**. Each of these array variables is discussed below. Array information for a protocol is updated whenever that particular protocol is detected in a received frame.

If the current protocol has not previously been detected, a new array entry is created for that protocol. Additionally, if the current protocol is encapsulated within the frame differently than prior occurrences of that protocol, a new array entry is created. The protocol distribution array is stored in the memory of the protocol analyzer instrument and is maintained for the duration of the network monitoring session.

The protocol_id **501** array variable is a programmer defined, arbitrary number used by the embedded code to identify the current protocol. The protocol_id **501** is used to help identify the protocol in the protocol distribution array and has no relationship to the "next layer protocol identification field" defined above. The "next layer protocol identification field" contains a value which is used to identify the protocol directly encapsulated within the current protocol. When this encapsulated protocol is placed into the array, it will be assigned a protocol_id **501** distinct from the value which was in the "next layer protocol identification field" (the value used to initially identify the encapsulated protocol).

The statistics_for_the_protocol **502** includes four entries: (1) the number of frames received (on a cumulative basis for the network monitoring session) which contained the current protocol; (2) the total number of bytes (cumulative basis for the network monitoring session) within those frames (cumulative number of frames) containing the current protocol; (3) the number of frames received (per sampling period, i.e. the sampling time period specified by the user) which contained the current protocol; (4) the total number of bytes (per sampling period) within those frames (sampling period frames). Statistics which are calculated per sampling period are reset at the expiration of the sampling period.

The array_position **503** indicates the position, in the protocol distribution array, where the information on the current protocol is stored.

The number_of children **504** for a particular protocol (the "parent") represents the total number of unique children detected for the parent protocol since the network monitoring session began. A "child" of a parent protocol is any protocol which is encapsulated directly (immediately follows) within the parent.

The children_table **505** is a subarray containing information for all of the children of the parent. This information includes the protocol_id **506** of the child and the array_position **507** of the child.

The next step (step **706**) in calculating protocol distribution is to determine if there is another protocol (the "next protocol") encapsulated within the current protocol. If there is a next protocol encapsulated within the data portion **212** of the current protocol or frame, there are two methods used to identify it.

Most protocols contain a "next layer protocol identification field" which is much like the Type field **211** of the Ethernet frame and contains a numerical identification code corresponding to the next protocol present in the frame (i.e., the protocol encapsulated directly within the first protocol). The exact location and contents of the "next layer protocol identification field" within a protocol can vary depending on the standards for that type of protocol. For example, the IEEE 802.3 protocol is defined by the Institute of Electronics and Electrical Engineers' standard 802.3.

Some protocols, however, either do not contain a "next layer protocol identification field" or their "next layer protocol identification field" contains insufficient information for any station other than the ones that are communicating to identify the next protocol. These protocols, including Transport Control Protocol ("TCP") and User Datagram Protocol ("UDP"), are referred to as "conversation-dependent" protocols. Step **707** determines whether the current protocol is conversation-dependent.

If the current protocol is not conversation dependent, it's "next layer protocol identification field" is preferably used in conjunction with a lookup table in step **708A** to identify the next protocol present in the frame. This lookup table is stored in the memory of the protocol analyzer instrument. The lookup table maps the value found in the "next layer protocol identification field" to the corresponding protocol which now identifies the protocol encapsulated directly within the data portion **212** of the current protocol.

If, however, it is determined in Step **707** that the current protocol is a conversation-dependent protocol, the unknown next protocol encapsulated within the current protocol is detected in step **708B** by comparing bit sequences of the unknown next protocol to known bit patterns from the protocols which can be encapsulated within the current protocol. These known bit patterns can be obtained by referencing the standard defining the protocol. For instance, the UDP protocol is defined by Request for Comments (RFC) number 768, promulgated by the Institute of Electronics and Electrical Engineers. Similarly, the TCP protocol is defined by Request for Comments (RFC) number 793, promulgated by the Institute of Electronics and Electrical Engineers. The known patterns are preferably contained in a lookup table which is used to map known bit patterns to corresponding protocols.

As an example, if the current protocol is UDP, the bits in the unknown next protocol would be compared to bit patterns known to exist in the DHCP (Dynamic Host Configuration Protocol), BootP (Bootstrap Protocol), NetBIOS DGM (Datagram Protocol), RIP (Routing Information Protocol), RWHO (Remote Unix WHO Protocol), TACACS , SNMP (Simple Network Management Protocol) Version 2, and NTP (Network Time Protocol) protocols, all of which can be encapsulated within the UDP protocol.

If a bit sequence in the unknown next protocol sufficiently resembles a bit pattern known to exist in any of these protocols, the protocol corresponding to the known pattern is deemed to be the unknown next protocol and is detected as such.

The above processes are performed iteratively (due to Step 706) for each protocol present in the frame until all protocols present in the frame have been decoded. The entire process is repeated for all frames detected during the sampling period (step 709) or detected during the network monitoring session (step 711), as specified by the user. Upon the expiration of a sampling period, the statistics_for_the_ protocol which are calculated per sampling period are reset in step 710.

After the protocol distribution has been determined by the protocol analyzer instrument and before the step 710 reset operation, the information stored in the protocol distribution array is transmitted to the PC for use by the user interface. This transmission is facilitated through the use of a message. The structure of a protocol distribution update message is shown in FIG. 6.

The message for protocol distribution consists of a header 601 and the contents of the protocol distribution array 602. The header identifies the destination for the message and the type of message (protocol distribution update message in this case). The contents of the protocol distribution array are placed in the message in the order in which they were initially placed in the protocol distribution array.

When the UI requests information on protocol distribution, the message is sent from the PA module of the protocol analyzer instrument to the PC for use by the user interface.

D. Event Information

The embedded code is also capable of detecting and logging "events" in real-time during network monitoring sessions. An "event" occurs when a parameter being monitored on the network exceeds a predefined or user-defined threshold. That user-defined threshold can even be a number of occurrences on the network of some specific phenomenon, during a sampling period. The threshold specifies a value (e.g. number of occurrences, in the case of parameters such as runts, jabbers, etc., or percentage, in the case of a parameter such as Network Utilization) per specified time period and the number of consecutive time periods for which the value must be exceeded to constitute an event. For example, a user can set a threshold, for the parameter runts, of five runts per ten minute sampling period for two consecutive sampling periods. If more than five runts are detected in each of two consecutive sampling periods, the occurrence would be logged as an event.

Ethernet events detected include: High Utilization, High Frame Rate, High Broadcast Rate, High Multicast Rate, Network Collisions, Alignment Errors, FCS Errors, Runts, Jabbers, and Illegal Source Address. Events which are unique to other network topologies, such as FDDI, Token Ring, frame relay, etc., are detected in a manner which is analogous to the process for detecting ethernet events described below.

Utilization, Frame Rate, Broadcast Rate, Multicast Rate, Network Collisions, Alignment Errors, FCS Errors, Runts, and Jabbers are all calculated by the LAN chip on the protocol analyzer instrument. For a discussion of how these rates and errors are calculated or detected, see Station-Level Statistics and Network Statistics above. These rates and errors are flagged as events when they exceed defined thresholds.

An Illegal Source Address error occurs when a frame containing an illegal MAC source address is received. An illegal MAC source address field might contain all binary ones. Such illegal MAC addresses can be caused by a malfunctioning network interface card ("NIC") or NIC driver, they can be artificially produced by some type of traffic generator, or they might be the result of a collision. An Illegal Source Address event occurs when any Illegal Source Address error is detected by the protocol analyzer instrument (i.e., the threshold for this event is usually zero).

Internet Protocol ("IP") events include: Duplicate IP Address, Illegal Source IP Address, and Zeros Broadcast Address. The errors which are the bases of these events only occur if the IP "protocol" is currently in use. The presence, if any, of the IP "protocol" in a frame is detected during the protocol decode process described in detail above in Protocol Distribution. The IP "protocol" contains a field identifying the IP Source Address. This field will be referred to as the "IP Source Address field." The IP "protocol" also contains a field identifying the IP Destination Address. This field will be referred to as the "IP Destination Address field."

A Duplicate IP Address error occurs when two stations try to use the same network IP address. This error is detected by analyzing the IP Source Address field of the IP "protocol." A memory array or other data structure ("IP station list") is used to store information on all detected IP addresses. An array or other data structure ("MAC station list") is used to store information on MAC addresses. These two station lists are cross referenced with each other through the use of linkages and pointers to determine the relationship between every MAC address and every IP address. In other words, every IP address is associated with a MAC address. One MAC address can have several IP addresses but each IP address can correspond to only one MAC address. If two MAC stations in the MAC station list are using the same IP address, a Duplicate IP Address error has occurred. A Duplicate IP Address event occurs when any Duplicate IP Address error is detected by the protocol analyzer instrument (i.e., the threshold for this event is also usually zero).

An Illegal Source IP Address error occurs when the IP Source Address field of the IP "protocol" contains invalid data such as all zeros, a broadcast address, or a multicast address. This error is detected by analyzing the IP Source Address field of the IP "protocol." An Illegal Source IP Address event occurs whenever an Illegal Source IP Address error has been detected by the protocol analyzer instrument (i.e., the threshold for this event is also zero).

A Zeros Broadcast Address error occurs when a sending station has used all zeroes to represent a broadcast address in the portion (IP Destination Address) of the IP "protocol" containing the IP destination address. This error is detected by analyzing IP Destination Address field of the IP "protocol." The IP Destination Address should be all ones when used to designate a broadcast address. A Zeros Broadcast Address event occurs whenever the number of Zeros Broadcast Address errors detected by the protocol analyzer instrument exceeds the defined threshold defined for this event.

ICMP (Internet Control Message Protocol) events include: Host Unreachable, ICMP Redirect, ICMP Parameter Error, Network Unreachable, Port Unreachable, Source Quench, and Time-to-Live Exceeded. The messages which are the bases of these events only occur if the ICMP "protocol" is currently in use. The presence, if any, of the ICMP "protocol" in a frame is detected during the protocol decode process described in detail above in Protocol Distribution.

A Host Unreachable message (a network message not related to a "message" sent by the PA to the UI) is sent by a router to notify the sender of a frame that the router cannot forward that frame to the appropriate destination. A router is a software or hardware connection between two or more

networks that enables traffic to be routed from one network to another based upon the intended destinations of the traffic. The appropriate field of the ICMP "protocol" is analyzed to determine whether a Host Unreachable message has been received. A Host Unreachable event occurs when the number of Host Unreachable messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

An ICMP Parameter Error is a message (another network message) indicating that a frame has been discarded due to a problem in its header portion. The appropriate field of the ICMP "protocol" is analyzed to determine whether an ICMP Parameter Error message has been received. An ICMP Parameter Error event occurs when the number of ICMP Parameter Error messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

An ICMP Redirect message (also another network message) occurs when a sending station addresses a frame to a default router because it does not know any other route for that particular destination. If the default router sees that it must transmit the frame out of the same port on which it was received, the router sends the host an ICMP Redirect message advising the sending station of a better router for that destination. The appropriate field of the ICMP "protocol" is analyzed to determine whether an ICMP Redirect message has been received. An ICMP Redirect event occurs when the number of ICMP Redirect messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

A Network Unreachable message (another network message) is sent from a router to the sender of a frame when the router does not have a route or a default route to which to forward the data frame. The appropriate field of the ICMP "protocol" is analyzed to determine whether a Network Unreachable message has been received. A Network Unreachable event occurs when the number of Network Unreachable messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

A Port Unreachable message (another network message) is sent by a destination station to inform the source station that the port indicated by the source station is not currently in use by any process. The appropriate field of the ICMP "protocol" is analyzed to determine whether a Port Unreachable message has been received. A Port Unreachable event occurs when the number of Port Unreachable messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

A Source Quench message (another network message) is sent, by a router or a host, stating that it is receiving so many data frames that its buffers are overflowing. The message is sent back to the source of the excess data frames instructing that source station to slow the flow of data. The appropriate field of the ICMP "protocol" is analyzed to determine whether a Source Quench message has been received. A Source Quench event occurs when the number of Source Quench messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

A Time-to-Live Exceeded message is generated by a router which has received and discarded a transmission which has exceeded its allowable lifetime. Sometimes routing loops form between routers that cause a frame to be forwarded endlessly through the same set of routers over and over. In the IP "protocol," there is a field, called the time-to-live (TTL) field, that limits the lifetime of a frame containing the IP "protocol." The TTL field prevents such an occurrence. When a host generates an IP message (another network message), it gives the TTL field a number value between one and 255. The value is basically equal to the number of routers that can forward the IP message. Each time a router forwards the IP message it reduces the TTL number by one. If a router receives an IP message with a TTL value of one, it decrements the TTL number to zero and discards the message.

The router transmits a Time-to-Live Expired message back to the source to notify the source about the discard. The appropriate field of the ICMP "protocol" is analyzed to determine whether a Time-to-Live Expired message has been received. A Time-to-Live Expired event occurs when the number of Time-to-Live Expired messages received by the protocol analyzer instrument exceeds the defined threshold for this event.

As events are detected, information on the events including event_id, timestamp, byte_length, and parameters are stored in a circular array (event log array). The use of two pointers (one to denote the memory location of the recordation of the last event detected and the other to denote the memory location of the last event sent to the UI) and a circular array allows event updates to be sent to the PC when requested by the UI.

The structure of an entry in this circular array is shown in FIG. **10**. "Event_id" **1101** is the variable name used to refer to the programmer-defined id code of the event. Timestamp **1102** is the date and time at which the specific event occurred. Byte_length **1103** is the total number of bytes in the parameter **1104** portion of the array entry. Parameter **1104** contains information on each event. This parameter information is used by the UI portion to construct a detailed event message for display or reporting of the event to the user. For example, if the error was Duplicate IP Address Detected, there would be three parameters, namely the MAC addresses of the two stations using the same IP address as well as the IP address itself.

After events have been detected, information about the events is transmitted to the PC for use by the user interface portion. This transmission is facilitated through the use of a message. The structure of an event update message is shown in FIG. **11**. The event update message contains a header **1201** and a portion of the event log array **1202**. The information sent from the event log array is the event_id **1101**, timestamp **1102**, byte_length **1103** and parameters **1104** for the entries in the event log array **1202** since the last update sent to the UI.

VI. User Interface

A. Overview

As discussed above, the user interface is the portion of the software implementation of the present invention that is executed by the PC. At the beginning of a network monitoring session, the user selects which network parameters are to be monitored. Each of these parameters, including station-level statistics, network statistics, event information and protocol distribution is discussed in detail above. The User Interface (UI) is capable of displaying any station-level statistic, network statistic, event information, and protocol distribution (discussed above) which the user requests to see and which the protocol analyzer instrument can capture and report to the UI.

FIG. **13** illustrates the general structure of the user interface (UI). The UI sends request messages to the Embedded Code **302** seeking update information about the various network parameters ("network information").

A message is a preferred method of communication among the various hardware and software components of the

present invention. The message contains a header portion which identifies the destination for the message and the type of message (e.g., Network Statistics Request Message, Network Statistics Update Message, etc.). The message also contains the data being transmitted (e.g., the updated network statistics themselves).

The user can select how often network information is updated, i.e. how often the UI requests updates from the embedded code on these parameters. The operation of the UI is largely software controlled using custom software (the design of which is disclosed herein) and also uses off-the-shelf software tools. The custom software is preferably designed using a technique known as "object-oriented programming" which is described in a text entitled *Object Oriented Design with Applications*, by Grady Booch, copyright 1991, from Benjamin Cummings Publishing Co., Inc., Redwood City, Calif., which is incorporated by reference as though fully reproduced herein. Many of the terms used herein, e.g., object, class, scenario diagram, etc., are taken from the Booch text and are well known to programmers familiar with object oriented programming. Another text by Grady Booch, entitled *Object-Oriented Analysis and Design with Applications*, second edition, copyright 1994, is similarly incorporated herein by reference.

The portion of the UI software that is responsible for sending update request messages is referred to as the "Document" **1402** (FIG. 13). The Document **1402** is the portion of the software that is responsible for managing the flow of data for the UI. After a Request Message is sent to the Embedded Code **302**, the Embedded Code **302** sends the updated network information to an appropriate software "Target" **1401** via an Update Message. The word "target" refers to a software device that is used to accept data for storage, forwarding, or processing.

There is a software Target **1401** for every network parameter that is monitored. In other words, Network Statistics Update Messages are routed to the Network Statistics Target and Station-level Statistics Update Messages are routed to the Station-Level Statistics Target and so on. The Target **1401** is responsible for receiving updated network information, storing the information in a Database **1403** (discussed in detail below) located on the PC's storage device, and providing the Document **1402** with a pointer to the memory location containing the updated network information.

Views **1404** are the portions of the UI software that are responsible for presenting network information, in the form of charts, tables, tree formats, etc., to the user via the PC's display device, e.g., a color cathode ray tube. There is a View **1404** for each network parameter (i.e. network statistics, protocol distribution, etc.) and each type of presentation method (i.e., charts, tables, tree formats etc.). For example, there is a view entitled Network Statistics Chart View, which presents network statistics in a graphical or chart format. A plurality of views can be used at the same time to present network information to the user in several formats simultaneously.

If the user is viewing network information in real-time (i.e., as the information is being uploaded from the protocol analyzer instrument), the Document **1402** informs the appropriate View **1404** of the receipt of some update from the embedded code **302**. The View **1404** then gets from the Document **1402** the pointer to the memory location (in the PC's RAM or random access memory) that contains the updated network information. The View **1404** then presents this information in the appropriate format to the user via the PC's display device.

When the term "real-time" is used in relation to the presentation of network information, the presentation of such information is actually done as updates are received from the embedded code rather than simultaneously with the calculations.

If the user is not viewing "real time" network information but is viewing network information from a database containing network information gathered during a previous network monitoring session (i.e., "baseline data"), the View **1404** gathers relevant information from the Database **1403** and presents the information in the appropriate format to the user via the PC's display device.

Simultaneous display of a plurality of network parameters, either all real time, or all from the database, or mixed is accomplished through the use of well-known features and capability inherent in the Microsoft Windows operating system. Therefore, information on a plurality of network parameters can be displayed simultaneously. Also, nothing has been incorporated into the present invention that limits or disables these well known features and capabilities.

The various Views are programmed to present the network information to the user in the forms of charts, graphs, tables and trees as mentioned above. Off-the-shelf products are used to present the network information to the user.

The product ChartFx (Version 3.0), marketed by Software FX, Inc. at 7100 West Camino Real, Boca Raton, Fla. 33060, is used to display network information in the form of charts and graphs. Network information on station-level statistics, network statistics and protocol distribution in preferably displayed in the form of charts and/or graphs. The User's Manual for ChartFx is hereby incorporated by reference as if fully reproduced herein.

The product SpreadVBX++ (Ver. 2.0), marketed by FarPoint Technologies, Inc. at 133 South Center Court, Suite 1000, Morrisville, N.C. 27560, is used to display network information in the form of tables and spreadsheets. Network information relating to station-level statistics, network statistics and event information is preferably displayed in the form of tables and/or spreadsheets. The User's Manual for SpreadVBX++ is hereby incorporated by reference as if fully reproduced herein.

The product TreeControl (Version 1), marketed by Premia Creative Controls Corp. at 1075 N.W. Murray Blvd., Suite 268, Portland, Oreg. 97229, is used to display protocol distribution in a tree format. The User's Manual for TreeControl is hereby incorporated by reference as if fully reproduced herein.

In creating the User Interface of the present invention, use was made of the Microsoft Foundation Class (MFC) Library, made by Microsoft Corp., i.e., many terms, including "document" and "view," were taken from the literature relating to that library. The User's Manual for the MFC Library is hereby incorporated by reference as if fully reproduced herein.

B. Database

The preferred embodiment of the present invention utilizes an object-oriented (OO) database application. In the preferred embodiment of the invention, the database application used is the POET database product (Ver. 3.0), marketed by Poet Software Corp. at 999 Baker Way, Suite 100, San Mateo, Calif. 94404. The Reference Manual for POET 3.0 is hereby incorporated by reference as if fully reproduced herein.

POET 3.0 is an OO database application which uses a C++ programming language Application Program Interface

(API). Other database applications which use a C++ API would also be appropriate for use in the present invention. The present invention could also utilize ODBC (Open Database Connectivity) database applications if they are used in conjunction with an SQL (Structured Query Language) API.

The primary reason why an object-oriented database as opposed to a standard relational database was selected to implement the present invention is the increased access speed attainable by using an object-oriented database. An object-oriented database such as POET stores C++ objects in a database and allows the programmer to retrieve them using the database operations. The objects read from the database look and act just like the objects stored because an object-oriented database knows how to read C++ class declarations and therefore, manage C++ objects.

In the preferred embodiment of the invention, the database may be saved to a storage device for use as a "baseline" against which future network monitoring sessions may be compared.

C. Station-Level Statistics User Interface

FIG. **14** is a "scenario diagram" depicting the process by which station-level statistics are displayed to the user in real time. First, the Document **1402** requests an update of station-level statistics from the Embedded Code **302**. Second, the Station-Level Statistics Target **1501** receives the updated station-level statistics (i.e. the station-level statistics update message discussed above under Station-Level Statistics).

In step three, the Station-Level Statistics class **1502** is initialized. By "initialized" is meant that a new instance is created of that POET object of the station-level-statistic type, for storing the new data. The Station-Level Statistics class is a class in the POET database which contains information on station-level statistics.

In step four, the Station-Level Statistics Target **1501** decodes the Station-Level Statistics Update Message. The Station-Level Statistics Target **1501** begins this decoding process by reading the message header and the station list array from the update message. Next, it determines which type of station-level statistics are contained in the update message (i.e., ethernet statistics, token ring statistics, FDDI statistics, frame relay statistics, etc.). Finally, the Station-Level Statistics Target **1501** places each of the station-level statistics obtained from the decoded update message in a POET data object for storage and later access.

If the user has selected to store information on station-level statistics to a database on the PC's storage device for later use as a baseline, this information is stored in the appropriate location in the POET database in step five.

In step six, the Station-Level Statistics Target **1501** informs the Document **1402** that the Target **1501** has received some kind of an update. A pointer to the POET data objects containing the updated station-level statistics is sent from the Target **1501** to the Document **1402**. A pointer is an address which identifies or "points to" the memory location in RAM that contains the data.

In steps seven and eight, the Document **1402** informs the Station List View **1503** and the Station Details View **1504** that the views may have to be updated. That is, the Document **1402** informs the Views **1503** and **1504** that some new data has been received but not the exact type and content of the new data. The Station List View **1503** controls the display of a listing of MAC addresses and other information about activity at those MAC address stations. The Station Details View **1504** controls the display of sortings and other detailing of the stations to highlight such factors as which stations are transmitting the most frames, which are receiving the most frames, which are involved with the most error messages, etc. The scope and nature of the details displayed is arbitrary to the user.

In steps nine and ten, the Station List View **1503** and the Station Details View **1504** request verification from the Document **1402** that there is new data which should, in fact, be added to the Station List View **1503** and Details View **1504**. This step is useful because the user has initially selected how often information on station-level statistics was to updated, and it is possible that there was no new station-level statistic information between the last update and the present update. In this case, there are no new data to be added to the views.

If the Document **1402** responds that there are indeed new data, i.e. there is new information in the station-level statistics array, then these new data are obtained by the views in steps eleven and twelve. The Station List View **1503** and the Station Details View **1504** receive a pointer or address to the location in the random-access memory (RAM) of the PC that contains the new data from the Document **1402**. The views then obtain the object containing the new data or information.

Steps thirteen and fourteen involve presenting all of the updated station-level statistics to the user in the form of tables and charts. At this point, the views use the pointers passed to them to gather the new data from its memory location for presentation in the appropriate format. The Station List View **1503** is responsible for displaying the data in the form of a table. This is accomplished through the off-the-shelf product SpreadVBX++, discussed above under User Interface—Overview. The Station List View **1503** is capable of presenting station-level statistics to the user in a sorted order based upon the value of any of the individual statistics. The Station Details View **1504** is responsible for displaying station-level statistics in the form of piecharts indicating top transmitting, receiving, and error producing stations. This is accomplished through use of the off-the-shelf product ChartFx, discussed above under User Interface—Overview.

FIG. **18** illustrates an example of a display screen arrangement for displaying station statistics to the user. The list can show "top talkers" and "top listeners" as well as a host of other catagories of information, the desirability and usefulness of which will be readily evident to a person having ordinary skill in the art of digital network transmission analyzers. A split-screen display is also available with Microsoft Windows to show that the desired statistics can be shown in any number of formats, including the pie chart illustrated in FIG. **18**.

D. Network Statistics User Interface

FIG. **15** is a scenario diagram depicting the process by which information on network statistics is displayed to the user in real time. First the Document **1402** requests an update of network statistics from the Embedded Code **302**. Second, the Network Statistics Target **1601** receives the updated network statistics (i.e. the Network Statistics Update Message discussed above under Network Statistics).

In step three, the Network Statistics class **1602** is initialized. The Network Statistics class is a class in the POET database which contains information on network statistics. One instance of the Network Statistics class is Ethernet Network Statistics which contains network statistic information particular to an Ethernet network.

In step four, the Network Statistics Target **1601** decodes the Network Statistic Update Message. The Network Sta-

tistics Target **1601** begins this decoding process by reading the Header **1301** and the Network Statistics Array **1302** from the update message. Next, the Network Statistics Target **1601** determines which type of network statistics are contained in the update message (i.e., ethernet statistics, token ring statistics, FDDI statistics, frame relay statistics, etc.). Finally, the Network Statistics Target **1601** places each of the network statistics obtained from the decoded update message in a POET data object for storage and later access.

If the user has selected to store information on network statistics to a database on the PC's storage device for later use as a baseline, this information is stored in the appropriate location in the POET database in step five. The appropriate storage location in the POET database is based upon the relevant class (i.e., Ethernet Network Statistics, Token Ring Network Statistics, etc.).

In step six, the Network Statistics Target **1601** informs the Document **1402** that the Target **1601** has received an update. A pointer to the data objects containing the updated network statistics is sent from the Target **1601** to the Document **1402**.

In step seven, the Document **1402** informs the Network Statistics Table View **1603** and/or the Network Statistics Chart View **1604** (depending on which view(s) the user is using) that the views may have to be updated.

In step eight, the Network Statistics Table View **1603** and/or Network Statistics Chart View **1604** request verification from the Document **1402** that there is, in fact, new data which should be added to the chart and/or table views. This step is useful because the user has selected how often information on network statistics was to be updated, and it is possible that there was no new network statistic information between the last update and the present update. In this case, there are no new data to be added to the charts and/or tables.

If the Document **1402** responds that there are indeed new data, i.e. there is new information in the network statistics array, then these new data are obtained in step nine. The Network Statistics Table View **1603** and/or the Network Statistics Chart View **1604** receive a pointer to the new data from the Document **1402**.

Step ten involves presenting all of the updated network statistics to the user in the form of tables and charts. At this point, the views use the pointers passed to them to gather the new data from their RAM memory location for presentation in the appropriate format. The Network Statistics Table View **1603** is responsible for displaying the data in the form of tables, and this is accomplished through the off-the-shelf product SpreadVBX++, discussed above under User Interface—Overview. The Network Statistics Chart View **1604** is responsible for displaying network statistics in the form of charts and graphs, and this is accomplished through use of the off-the-shelf product ChartFx, discussed above under User Interface—Overview.

FIGS. **19**A, **19**B and **19**C illustrate three examples of display screen display formats useful for showing network statistics to the user. FIG. **19**A illustrates how a network utilization chart might look. FIG. **19**B illustrates how a network frame rate chart might look, and FIG. **19**C illustrates how a frame size distribution chart might look. While charts are shown, a person having ordinary skill in the programming art, and a person having ordinary skill in the digital network transmission art will be the aware that may other other formats of display can readily be substituted for charts.

E. Protocol Distribution User Interface

FIG. **16** is a scenario diagram depicting the process by which cumulative protocol distribution information is displayed to the user in real time. The process by which protocol distribution that is calculated per sampling period is displayed to the user is analogous to this process.

First the Document **1402** requests an update of protocol distribution from the Embedded Code **302**. Second, the Protocol Distribution (Cumulative) Target **1701** receives the updated protocol distribution information (i.e. the Protocol Distribution Update Message discussed above under Protocol Distribution).

In step three, the Protocol Distribution class is initialized. The Protocol Distribution class **1702** is a class in the POET database which contains information on protocol distribution. Instances of the Protocol Distribution class include Protocol Distribution (Cumulative), which contains protocol distribution information on a cumulative basis, i.e. since the network monitoring session began, and Protocol Distribution (Sample), which contains information on protocol distribution for the user-defined sampling period.

In step four, the Protocol Distribution (Cumulative) Target **1701** decodes the Protocol Distribution Update Message. The Protocol Distribution (Cumulative) Target **1701** begins this decoding process by reading the Header **601** (FIG. **6**) of the "message" and Protocol Distribution Array information or data array or portion **602** of the message, that was taken from the Protocol Distribution Array of the memory of the protocol analyzer instrument.

As discussed above under Protocol Distribution, each entry in the Protocol Distribution Array data **602** portion of the message contains the protocol_id, statistics_for_the_protocol, number_of_children, and a children_table. By iteratively examining the contents of each entry in the Protocol Distribution Array **602** portion of the message and cross-referencing the entry with prior entries, the Protocol Distribution (Cumulative) Target **1701** builds a hierarchical protocol distribution structure (tree structure). If the user has chosen to view protocol distribution in a percentage format, the appropriate statistics_for_the_protocol are converted to a percentage (i.e., the total number of bytes received for the protocol is divided by the total number of bytes received and then multiplied by one hundred). Finally, the Protocol Distribution (Cumulative) Target **1701** places each element of the newly created hierarchical protocol distribution structure in a POET data object for later storage and access.

If the user has selected to store protocol distribution information in a database on the PC's storage device for later use as a baseline, this information is stored in the appropriate location in the POET database (i.e., Protocol Distribution (Cumulative)) in step five.

In step six, the Protocol Distribution (Cumulative) Target **1701** informs the Document **1402** that the Target **1701** has received an update. A pointer to the location, in the PC's RAM memory, of the POET data objects that contain the updated hierarchical protocol distribution structure is sent from the Target **1701** to the Document **1402**.

In step seven, the Document **1402** informs the Protocol Distribution Tree View **1703** that the view should perhaps be updated.

In step eight, the Protocol Distribution Tree View **1703** requests verification from the Document **1402** that there is new data which should be added to the tree-type display of protocol distribution. This step is used because the user selected how often information on protocol distribution was updated. It is possible that, while there were some new data received, there may have been no new protocol distribution information contained in the new data received from the time of the last update and the present update. In this case, there are no new data to be added to the tree.

If the Document **1402** responds that there are indeed new protocol distribution data, i.e. there is new information in the protocol distribution array, then these new data are obtained in step nine. The Protocol Distribution Tree View **1703** receives a pointer to the new data (in RAM) from the Document **1402**.

In step ten, the Document **1402** informs the Protocol Distribution Chart View **1704** that the view should be updated. In step eleven, the Protocol Distribution Chart View **1704** receives a pointer to the new data from the Protocol Distribution Tree View **1703**.

Steps twelve and thirteen involve presenting the data to the user in a tree format and a chart format. At this point, the views use the pointers passed to them to gather the new data from its memory location in the RAM of the PC for presentation in the appropriate format. The Protocol Distribution Tree View **1703** is responsible for displaying the data in a tree format. It builds a tree structure based upon the hierarchical protocol distribution structure. An off-the-shelf product entitled TreeControl (discussed above under User Interface—Overview) is used to display the tree structure. The Protocol Distribution Chart View **1704** is responsible for displaying protocol distribution in a pie-chart format. This is accomplished through use of the off-the-shelf product ChartFx, discussed above under User Interface—Overview.

FIG. **20** illustrates how a split-screen display can be used to highlight one ISO protocol layer, instantly revealing usage by the protocols detected on the network.

F. Event Information User Interface

FIG. **17** is a scenario diagram depicting the process by which event information is displayed to the user in real time. First the Document **1402** requests an update of event information from the Embedded Code **302**. Second, the Event Target **1801** receives the updated event information (i.e. the event update message discussed above under Event Information).

In step three, the Event Log database class **1802** is initialized. The Event Log class is a class in the POET database which contains event information.

In step four, the Event Target **1801** decodes the Event Update Message. The Event Target **1801** begins this decoding process by reading the message header and the portion of the event log array. It then places information relating to each event, as contained in the portion of the event log array of the memory of the protocol analyzer instrument into a POET data object in RAM storage of the PC for later storage and access.

If the user has selected to store event information in a database on the PC's storage device for later use as a baseline, the information is stored in the appropriate location in the POET database in step five.

In step six, the Event Target **1801** informs the Document **1402** that the Target **1801** has received an update. A pointer to the POET data objects containing the updated event information is sent from the Target **1801** to the Document **1402**.

In step seven, the Document **1402** informs the Event Log View **1803** that the view should perhaps be updated. In step eight, the Event Log View **1803** requests verification from the Document **1402** that there is, in fact, new data which should be added to the Event Log View. This step is useful because the user had selected how often event information was updated, and it is possible that there was no new event information from the time of the last update to the time of the present update. In this case, there are no new data to be added to the view.

If the Document **1402** responds that there is indeed new data, i.e. there is new information in the event log array in the memory of the PC, then these new data are obtained by the Event Log View **1803** in step nine. The Event Log View **1803** receives from the Document **1402**, a pointer to the new data now stored in the PC's RAM.

Step ten involves presenting all of the updated event information to the user in a table format. At this point, the event log view uses the pointer passed to it to gather the new event information from its memory location in the PC's RAM for presentation in the appropriate format. For each event, the Event Log View **1803** presents the name of the event (derived from the event_id), the time of the event, and a brief description of the event (derived from the event parameters) in the form of a table. Presentation of event information in a table format is accomplished through the off-the-shelf product SpreadVBX++, discussed above under User Interface—Overview.

FIG. **21** illustrates a preferred example of how detected events can be sorted and displayed with timestamps, on the PC's display device so as to enhance the user's ability to find information quickly.

G. Hypertext Troubleshooting Information

The user interface is also capable of displaying detailed information about a particular event and the possible causes of the event in a hypertext format. Hypertext in conjunction with the present invention allows a user to access detailed explanations through use of the PC's pointing device. The user can obtain detailed definitions of statistics and events as well as possible causes of each type of event by double-clicking the PC's pointing device on the event or statistic displayed by the user interface. A "window" is opened on a display containing a detailed definition of the event or statistic as well as a brief discussion of the possible causes and ramifications of the event. This information is contained in a standard Microsoft Windows context-sensitive help file format.

In addition to specific information relating to events and statistics, the user interface is also capable of displaying step-by-step troubleshooting information in a hypertext format which assists the user in solving problems on a network by posing increasingly specific queries until a solution is reached. This information is likewise contained in a standard Microsoft Windows help file format. The exact method by which the above data are displayed would be readily apparent to a person having ordinary skill in the art of software programming and in the art of network analyzing. The text of the troubleshooting information can be created and written specifically for the UI by a person having ordinary skill in the digital data transmission art; or troubleshooting information for Ethernet and Token Ring networks can be examined in a textbook entitled *Ethernet and Token Ring Optimization*, by Daniel J. Nassar, Copyright 1996, Henry Holt & Co., Inc., New York, N.Y., which is hereby incorporated by reference as though fully reproduced herein.

H. Reports

As discussed above, transmission information concerning Protocol Distribution, Station-Level Statistics, Network Statistics and Events are displayed for the user in the form of graphs and charts. The transmission information can also be used to create customized presentation-quality reports. These customized reports provide the transmission information in a presentation quality format. The invention also allows the user to specify the time span which the report will cover.

Reports may be printed on a standard printer connected to the PC or displayed on the PC's display device. Reports also may be previewed and modified on-line prior to printing. The reporting feature is implemented using an off-the-shelf reporting application entitled ReportFX (Ver. 1.0), marketed by Software FX, Inc. at 7100 West Camino Real, Boca Raton, Fla. 33060. The User's Manual for ReportFx is hereby incorporated by reference as if fully reproduced herein.

I. Analysis of Captured Frames

The present invention is also capable of saving the contents of the capture buffer to a capture file on a storage device (see Frame Analysis above for discussion of capture buffer). The present invention can then display information about specific frames stored in the capture file. The user interface allows the user to examine a captured frame, search the capture file for filter criteria, view the protocols present in a frame, specific frames, view only those frames which meet specific and print the contents of the frame on a printer attached to the PC. Analysis of captured frames is accomplished by use of a software application entitled Examine which is marketed by Wandel & Goltermann Technologies, Inc. at 1030 Swabia Court, Research Triangle Park, N.C. 27709-3585.

J. Use of Analysis

If an event is noted, depending upon the nature of the event noted, the data portion of the message conveying that event information to the PC will include any MAC addresses that were involved in that event. The user can request reporting or displaying of any combination of further information about that MAC address that might be pertinent to that event.

For example, if a high level of network utilization is noted, the transmitting stations and receiving stations can be displayed as sorted according to the number of messages transmitted or received. This will immediately disclose which stations are transmitting the most (top talkers)and which stations are receiving the most (top listeners).

The station statistics for the top talker or top listener can then be queried by protocol used. If a large number of the frames for a station carry the IP (internet protocol), it could mean that the employee using that station is either gathering a lot of needed project information from the internet or that the employee is "surfing" the internet on company time. Therefore, some supervisory involvement may be in order to ascertain if that employee should be switched to a more lightly-loaded network or should be admonished about wasting company time.

VII. Conclusion

While the protocol analyzer herein described constitutes the preferred embodiment of the present invention, it is to be understood that the invention is not limited to this precise form of apparatus and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

We claim:

1. A protocol analyzer for calculating and displaying protocol distribution in real-time in connection with monitoring data frames carried on a digital transmission network, comprising:

means for monitoring the transmission, over the digital transmission network, of frames containing data and protocols;

means for identifying the protocols within the frames and for identifying the encapsulation of the protocols within the frames:

means for storing the identity and encapsulation of the protocols within the frames:

means for calculating the protocol distribution of the frames; and

means for displaying in real-time the protocol distribution of the frames in a hierarchical tree format based upon the encapsulation of the protocols within the frames, said means comprising:

a first processing instrumentality, comprising means for periodically requesting a protocol distribution update message containing encoded updated protocol distribution information from said means for calculating the protocol distribution of the frames;

a second processing instrumentality, having:

a. means for receiving and decoding the protocol distribution update message to obtain the updated protocol distribution information, and

b. means for providing said first processing instrumentality with a pointer to the updated protocol distribution information;

a display device for displaying the updated protocol distribution information; and

a third processing instrumentality, having:

a. means for obtaining a pointer to the updated protocol distribution information from said first processing instrumentality, and

b. means for sending the updated protocol distribution information to said display device in a hierarchical tree format based upon the encapsulation of the protocols within the frames.

* * * * *

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Our Ref./Docket No: APPT-001-3

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.*	Group Art Unit: 2142
Application No.: 09/608126	Examiner: Vu, Thong H.
Filed: June 30, 2000	
Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	

TRANSMITTAL: RESPONSE TO OFFICE ACTION

OFFICIAL

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:

____ drawing(s);

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.

Certificate of Facsimile Transmission under 37 CFR 1.8

I hereby certify that this correspondence is being facsimile transmitted to the U.S. Patent and Trademark Office at 703-872-9306 addressed to Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on.

Date: 3 Nov 03

Signed: _____

Name: Dov Rosenfeld, Reg. No. 38687

____ 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.

_X_ Applicant(s) hereby petition(s) for an Extension of Time under 37 CFR 1.136(a) of:

_X_ one months ($110) ____ two months ($410)

____ three months ($930) ____ four months ($1450)

If an additional extension of time is required, please consider this as a petition therefor.

_X_ A credit card payment form for the required fee(s) is attached.

_X_ 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):

_X_ Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.

_X_ Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

3 Nov 03
Date

Dov Rosenfeld, Reg. No. 38687

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Our Ref./Docket No: APPT-001-3 Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.* Application No.: 09/608126 Filed: June 30, 2000 Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	Group Art Unit: 2142 Examiner: Vu, Thong H.

TRANSMITTAL: RESPONSE TO OFFICE ACTION

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:

____ drawing(s);

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.

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_X_ Any missing filing fees required under 37 CFR 1.16 for presentation of additional claims.

_X_ Any missing extension or petition fees required under 37 CFR 1.17.

Respectfully Submitted,

3 Nov 2003
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Patent Application Ser. No.: 09/608126	Ref./Docket No: APPT-001-3
Applicant(s): Dietz, *et al.*	*Examiner*.: Vu, Thong H.
Filing Date: June 30, 2000	*Art Unit*: 2142

FAX COVER PAGE

TO: Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

United States Patent and Trademark Office
(Examiner Vu, Thong H., Art Unit 2142)

Fax No.: 703-872-9306

DATE: November 03, 2003

FROM: Dov Rosenfeld, Reg. No. 38687

RE: Response to Office Action

Number of pages including cover: 20

OFFICIAL COMMUNICATION

PLEASE URGENTLY DELIVER A COPY OF THIS RESPONSE TO EXAMINER VU, THONG H., ART UNIT 2142

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Date: Nov 3, 2003 Signed: _____

Name: Dov Rosenfeld, Reg. No. 38687

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application Number	09/608126
Filing Date	30 Jun 2000
First Named Inventor	Dietz, Russell S.
Group Art Unit	2142
Examiner Name	Vu, Thong H.
Attorney Docket Number	APPT-001-3

ENCLOSURES *(check all that apply)*

- ☐ Fee Transmittal Form
- ☒ Fee Attached (extension of time)
- ☒ Amendment / Response
- ☐ ☐ After Final
- ☐ ☐ 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
- ☐ ☐ Response to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Assignment Papers *(for an Application)*
- ☐ Drawing(s)
- ☐ Licensing-related Papers
- ☐ Petition Routing Slip (PTO/SB/69) and Accompanying Petition
- ☐ To Convert a Provisional Application
- ☐ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
- ☐ Small Entity Statement
- ☐ Request of Refund
- ☐ After Allowance Communication to Group
- ☐ Appeal Communication to Board of Appeals and Interferences
- ☐ Appeal Communication to Group *(Appeal Notice, Brief, Reply Brief)*
- ☐ Proprietary Information
- ☐ Status Letter
- ☐ Additional Enclosure(s) *(please identify below):*
- ☐ Return Postcard
- ☐
- ☐

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT/ CORRESPONDENCE ADDRESS

Firm *or* Individual name	Dov Rosenfeld, Reg. No. 38687
Signature	
Date	November 3, 2003

ADDRESS FOR CORRESPONDENCE

Firm *or* 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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Type or printed name	Dov Rosenfeld, Reg. No. 38687		
Signature		Date	November 3, 2003

#7
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11/5/03.

Our Ref./Docket No: APPT-001-3

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Dietz, *et al.*	Group Art Unit: 2142
Application No.: 09/608126	Examiner: Vu, Thong H.
Filed: June 30, 2000	
Title: RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING	

RESPONSE TO OFFICE ACTION UNDER 37 CFR 1.111

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Commissioner:

This is a response to the Office Action of July 10, 2003.

Any ***amendments to the specification*** begin on a new page immediately after these introductory remarks.

Any ***amendments to the claims*** begin on a new page immediately after such ***amendments to the specification***, if any.

Any ***amendments to the drawings*** begin on a new page immediately after such ***amendments to the claims***, if any.

The ***Remarks/arguments*** begin on a new page immediately after such ***amendments to the drawings***, if any.

If there are drawing amendments, an ***Appendix*** including amended drawings is attached following the ***Remarks/arguments***.

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Date: 3 Nov 2003 Signed:

Name: Dov Rosenfeld, Reg. No. 38687

AMENDMENT(S) TO THE CLAIMS:

The following listing of claims will replace all prior versions, and listings, of claims on the application. All claims are set forth below with one of the following annotations.

- (Original): Claim filed with the application.
- (Currently amended): Claim being amended in the current amendment paper.
- (Canceled): Claim cancelled or deleted from the application. No claim text is shown.
- (Withdrawn): Claim still in the application, but in a non-elected status.
- (New): Claim being added in the current amendment paper.
- (Previously presented): Claim added or amended in an earlier amendment paper.
- (Not entered): Claim presented in a previous amendment, but not entered or whose entry status unknown. No claim text is shown.

---

1. (Currently amended) A method of analyzing a flow of packets passing through a connection point on a computer network, the method comprising:

(a) receiving a packet from a packet acquisition device coupled to the connection point;

(b) for each received packet, looking up a flow-entry database ~~comprising none~~ that may contain one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow;

~~(d)~~(c) if the packet is of an existing flow, identifying the last encountered state of the flow, performing any state operations specified for the state of the flow, and updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry,; and

~~(e)~~(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow and storing a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry,

wherein every packet passing though the connection point is received by the packet acquisition device.

2. (Original) A method according to claim 1, further including:

extracting identifying portions from the packet,

wherein the looking up uses a function of the identifying portions.

3. (Original) A method according to claim 1, wherein the steps are carried out in real time on each packet passing through the connection point.

4. (Original) A method according to claim 1, wherein the one or more statistical measures include measures selected from the set consisting of the total packet count for the flow, the time, and a differential time from the last entered time to the present time.

5. (Original) A method according to claim 1, further including reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry.

6. (Original) A method according to claim 7, wherein the metrics include one or more quality of service (QOS) metrics.

7. (Original) A method according to claim 5, wherein the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time.

8. (Original) A method according to claim 7, further comprising calculating one or more quality of service (QOS) metrics from the base metrics.

9. (Original) A method according to claim 7, wherein the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to determine respective metrics for the combined interval.

10. (Currently amended) A method according to claim 1, wherein ~~step (d)~~ step (c) includes if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow; and wherein ~~step (e)~~ step (d) includes if the packet is of a new flow, performing any state operations required for the initial state of the new flow.

11. (Original) A method according to claim 10, further including reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry.

12. (Original) A method according to claim 11, wherein the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time.

13. (Original) A method according to claim 12, wherein the reporting is part of the state operations for the state of the flow.

14. (Original) A method according to claim 10, wherein the state operations include updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry.

15. (Original) A method according to claim 14, further including receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow.

16. (Original) A method according to claim 15, wherein one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow.

17. (Currently amended) A packet monitor for examining packets passing through a connection point on a computer network, each packets conforming to one or more protocols, the monitor comprising:

(a) a packet acquisition device coupled to the connection point and configured to receive packets passing through the connection point;

(b) a memory for storing a database ~~comprising none~~ that may contain one or more flow-entries for previously encountered conversational flows to which a received packet may belong; and

(c) an analyzer subsystem coupled to the packet acquisition device configured to lookup for each packet for each received packet whether a received packet belongs to a flow-entry in the flow-entry database, to update the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry in the case that the packet is of an existing flow, and to store a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry if the packet is of a new flow.

18. (Original) A packet monitor according to claim 17, further comprising:

a parser subsystem coupled to the packet acquisition device and to the analyzer subsystem configured to extract identifying information from a received packet,

wherein each flow-entry is identified by identifying information stored in the flow-entry, and wherein the cache lookup uses a function of the extracted identifying information.

19. (Original) A packet monitor according to claim 17, wherein the one or more statistical measures include measures selected from the set consisting of the total packet count for the flow, the time, and a differential time from the last entered time to the present time.

20. (Original) A packet monitor according to claim 17, further including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow.

21. (Original) A packet monitor according to claim 20, wherein the statistical processor determine and reports the one or more metrics from time to time.

REMARKS

Status of the Application:

Claims 1–21 are the claims of record of the application. Claims 1–21 have been rejected.

Amendment to the Claims:

Applicants have amended the claims to overcome misnumbering and other informality pointed out by the examiner, and to further bring out the inventive aspects over the cited prior art.

Claim Objections

In paragraph 2 of the office action, paragraphs in claims 1 and 10 were objected to as being misnumbered.

This amendment corrects the misnumbering. Applicants thank the examiner for pointing this typographical error out. Examiner was correct in the interpretation.

In paragraph 3 of the office action, the expression "none or more" was objected to.

This amendment changed "none or more" to "one or more" and added that the database may contain one or more entries. The use of "none or more" is common in the art, and regularly appears in specifications, e.g., those put out by the IEEE and W3 consortium. In this case, the use of "none or more" covers the case, for example, that there are not yet any entries in the database. However, because the examiner objected, alternate language was found.

Claim Rejections -35 USC § 102

In paragraph 4 of the office action, claims 1–21 have been rejected under 35 USC 102(e) as being anticipated by U.S. patent 5,850,388 to Anderson et al., hereinafter "Anderson."

Why Anderson does not anticipate Applicant's invention

While aspects of the present invention, like Anderson, provides statistics, the present invention differs from Anderson in several ways. Applicant will argue that Anderson does not anticipate the present invention as follows:

1) The present invention analyzes and compiles statistics about conversational flows; Anderson does not distinguish flows, but rather gathers station-level statistics, and network protocol statistics.

2) The present invention includes looking up each and every packet to see if it belongs to a previously encountered flow; Anderson only provides for looking up a database after analysis as a separate process that looks at statistics gathered: the station-level statistics, or the protocol statistics.

3) An aspect of the present invention includes, for any packet ascertained to belong to an existing flow by looking up the database, identifying the state of the flow, and carrying out any state operations defined that that state; Anderson has no concept of state of the flow, or even of a conversational flow, so that no such state operations are therefore carried out.

4) Anderson provides for filtering the packets prior to analysis; the present invention analyzes each and every packet.

There are many other aspects of the present claims that are not anticipated by Anderson.

Description of Anderson

Anderson describes a protocol analyzer that is capable of displaying station level statistics, network statistics, real-time event information, and protocol distribution.

The operation of Anderson is summarized By FIGS. 3, 4, and 7. FIG. 3 is a diagram illustrating the flow of data, analysis, and control in Anderson, FIG. 4 is a flowchart illustrating the process by which statistics for individual stations on a network (station-level statistics) are calculated, and FIG. 7 is a flowchart illustrating the method by which protocol distribution is calculated.

FIG. 3 is a diagram illustrating the flow of data, analysis, and control. As shown in FIG. 3, Anderson includes a protocol analyzer instrument 304 that carries out station level analysis (see FIG. 4) and protocol analysis (see FIGS. 5, 6, and 7). FIG. 4 is a flowchart illustrating the process by which statistics for individual stations on a network (station-level statistics) are calculated, while FIG. 7 is a flowchart illustrating the method by which protocol distribution is calculated and stored in the data structure shown in FIG. 5 for each protocol recognized. The station level analysis of FIG. 4 is described starting col. 10, line 43, while protocol distribution analysis of FIG. 7 is described starting col. 16, line 64.

The analysis is carried out for a sampling time, e.g., the network monitoring session.

The results of the statistical analysis are sent to a user interface in a PC operated by the user. FIG. 6 illustrates the data structure used to send the protocol distribution to the user interface in the PC.

The user interface includes looking up a database 310. It is the results of the statistical analysis that are looked up to produce various reports for the user.

Description of the present invention

FIG. 3 shows the operation of the analyzer of the present invention. This is also described in more detail in related and incorporated by reference U.S. Patent application 09/608237 for *METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK*, to inventors Dietz, et al, Attorney/Agent Docket APPT-001-1. The present invention adds statistical analysis to U.S. Patent application 09/608237.

FIG. 3 describes a network monitor that includes carrying out protocol specific operations on *every* individual packet that passes through a connection point on a network. The operations include extracting information from header fields in the packet to use for building a signature for identifying the ***conversational flow*** of the packet and for recognizing future packets as belonging to a ***previously encountered flow***. A parser subsystem includes a parser for recognizing different patterns in the packet that identify the protocols used. For each protocol recognized, an extractor extracts important packet elements from the packet. These form a ***signature (i.e., key)*** for the packet. The extractor also preferably generates a hash for rapidly identifying a flow that may have this signature from a database of known flows.

For ***each packet,*** the flow signature of each packet, the hash and at least some of the payload are passed to an analyzer subsystem.

The analyzer subsystem receives parts of each packet from the parser subsystem, and, ***for each packet,*** looks up a database of flow records for previously encountered conversational flows to determine whether a signature is from an existing flow. The analyzer further ***identifies the state of the existing flow,*** and performs any ***state processing operations*** specified for the state. In the case of a newly encountered flow, the analyzer includes a flow insertion and deletion engine for inserting new flows into the database of flows. Any state operations that are specified for the new flow are also carried out.

Statistics are maintained for each conversational flow.

The present invention analyzes and compiles statistics about conversational flows; Anderson does not distinguish flows, but rather gathers station-level statistics, and network protocol statistics.

The present invention includes a process that recognizes ***a conversational flow*** and then generates statistics for the conversational flow. Anderson does not recognize a conversational flow, but instead compiles statistics for particular stations, and/or for particular network protocols used. A conversational flow is not identified simply by the stations that are involved in a communication, but rather by the nature of the communication, e.g., the application program being invoked. Thus, even for the same two stations, the present invention identifies different conversational flows between two stations and compiles statistics on ***each*** conversational flow.

It is important to be able to distinguish between the term "***connection flow***" commonly used to describe all the packets involved with a single connection, and a ***conersational flow*** as used in the present invention. A conversational flow 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. Unlike Anderson, ***the present invention is able to identify and classify conversational flows rather than only connection flows,*** including gathering statistics on the 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. Thus, there may be different *states* to a flow. 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. 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, Washington); and CORBA (Common Object Request Broker Architecture). RPC is a programming interface from Sun Microsystems (Palo Alto, California) 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.

The present invention includes looking up each and every packet to see if it belongs to a previously encountered flow; Anderson only provides for looking up a database after analysis as a separate process that looks at statistics gathered: the station-level statistics, or the protocol statistics.

Each and every packet has its signature extracted. A database that includes any previously encountered flow is looked up to ascertain if the present packet belongs to an existing flow. Anderson does have a database, but it is a database in the PC (304) for use by the user interface. The only information passed to the PC by Anderson's analysis program is station level statistics or protocol distributions obtained during sampling periods. Individual packets or parts thereof are not passed on to the user interface, so each and every packet is not looked up.

An aspect of the present invention includes, for any packet ascertained to belong to an existing flow by looking up the database, identifying the state of the flow, and carrying out any state operations defined that that state;

Anderson has no concept of state of the flow, or even of a conversational flow, so that no such state operations are therefore carried out.

As described above, each conversational flow may have several states before reaching a "steady" state. At any state in the flow, according to an aspect of the invention, there may be some state-specific operations that need to be carried out to continue the identification process. Anderson does not include carrying out state-specific processing, or even the concept of conversational flows.

There is no way the method described by Anderson can carry out the "virtually concatenation" described above. Anderson does not include the concept of the state of a flow.

Anderson provides for filtering the packets prior to analysis; the present invention analyzes each and every packet.

Anderson includes a filter that provides for optionally selects only certain type of frames for analysis. See the paragraph starting col. 10, line 20. Therefore, not only does Anderson not look up its database (Anderson's 310) for each and every packet because only statistics rather than individual packets are passed on to the database, but also not even every packet is subject to the analysis of analyzer 304.

Note that the analysis carried out by Applicant's analyzer (Applicant's FIG. 3) identifies flows, and compiles statistics on the recognized flows. Therefore no would be required. Filters have disadvantages as described in incorporated by reference U.S. Patent application 09/608237.

Examiner's 102(e) rejection of claim 1 over Anderson.

The amendments

In order to further bring out the difference between Anderson and Johnson, the Applicants have amended claim 1 to explicitly state that the packet acquisition device is coupled to the connection point, and that the lookup is carried out for every packet received from the packet acquisition device.

Anderson's database 1403 vs. the flow entry database. Anderson does not look up that database 1403 for each packet

In paragraph 5 of the office action, the Examiner asserts that, in respect to claim 1, Applicant's flow entry database is Anderson's database 1403. This database is part of Anderson's user interface described in Section IV of Anderson starting col. 22, line 48 through to the end of the description (col. 31). As stated in col. 9, lines 36-40, the database is used ***selectively*** to store the results of the analysis that are performed by the protocol analyzer instrument.

Step (b) of claim 1, as amended, include for each received packet, looking up a flow-entry database that may contain one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow. Anderson does not do any looking up of database 1403 for each received packet. In

fact, as shown in FIG. 3, Anderson's database is part of the under interface 303 which is quite removed from Anderson's protocol analyzer 304. Anderson's database received statistical reports, either station level reports or protocol distribution reports, so cannot look up information for each received packet.

Anderson's "previous session" is not a previously encountered conversational flow.

Furthermore, Applicant's lookup is to determine if a packet is part of an existing conversational flow. In paragraph 5, the examiner erroneously asserts that the conversational flow is Anderson's "previous network monitoring session" as in col. 24, lines 6-13. This part of Anderson states:

> *If the user is not viewing "real time" network information but is viewing network information from a database containing network information gathered during a previous network monitoring session (i.e., "baseline data"), the View 1404 gathers relevant information from the Database 1403 and presents the information in the appropriate format to the user via the PC's display device.*

Anderson's session as used here is a ***network monitoring session*** during which data is collected, and not a conversational flow. Anderson clearly defines the network monitoring session as "the period of time during which a network is being analyzed."

Anderson's "prior entries" are not the same as previously encountered conversational flows.

The examiner also asserts that the "prior entries" mentioned in Anderson col. 28, lines 26–43 are the same as Applicants previously encountered conversational flows in the flow-entry database.

It has already been stated that the flow entry database is not the same as Anderson's database 1403.

The prior entries are in the protocol distribution array 602 part of the message shown in FIG. 6 that is used to send the results of protocol analysis from Anderson's analyzer to the PC by use by the user interface.

FIGS. 5, 6, and 7 described the protocol analysis part of Anderson's analyzer. See, for example, Section C. starting col. 16, line 59 for a description of how the protocol analyzer works. Anderson's protocol analysis method tries to recognize every protocol in a frame, one frame at a time. A memory array is set of up for each protocol that is encountered during a sampling period, e.g., during the network monitoring session. Such an array is shown in FIG. 5. Array information is updated each time a protocol is encountered in a received frame. The array keeps track of statistics for protocol during the session.

As states in col. 19, starting line 1, the steps of the analysis are performed iteratively for each protocol present in a received frame until all protocols in the frame have been decoded. The entire process is repeated for all frames detected during the network monitoring session, after which the statistics are reset.

The results of the analysis of all protocols encountered is then sent to the PC for use by the user interface using a protocol distribution update message, as shown in FIG. 6.

Thus, the "prior entries" mentioned in Anderson col. 28, lines 26–43 are prior entries of previously previous distribution update messages that have been collected. Again, this is very different from Applicant's looking up the flow database for previously encountered conversational flows.

There is in fact no concept of a conversational flow in Anderson.

The examiner further asserts that "every packet passing through the connection point is received by the packet acquisition device" is described by Anderson in col. 8, line 26–col. 9, line 13. As already discussed, Anderson provides a filter, so teaches away from even dealing with each packet.

In summary, the examiner has failed to show that claim 1 (as amended) is anticipated by Anderson. Claim 1, as amended, is allowable and action to that end is respectfully requested.

Rejection of dependent claims 2–16 over Anderson.

Claim 1 is now allowable. Therefore, while Applicants do not admit that any of Examiner's arguments on the dependent claims are correct, such arguments are now moot. All dependent claims, including claims 2–16, are allowable.

Rejection of independent claim 10 over Anderson.

In paragraph 15 of the office action, the Examiner asserts that Anderson described identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow. For this assertion, the examiner cites "between the last update and the present update" in col. 26, lines 6-40. Col. 26 describes actions that occur in the user interface, not in the analyzer, and described how previous collected data is analyzed. This is not carried out for each packet. There is now concept of conversational flow or state of the flow in Anderson, and Anderson cannot carry out state operations on the packet.

Thus, even if the examiner remains unconvinced by the arguments with respect to the independent claim 1, the examiner has failed to show that claim 10 is anticipated by Anderson, and claim 10 would still be allowable.

Rejection of dependent claims 11–16 over Anderson.

These claims are all dependent on claim 10. Thus, even if the examiner remains unconvinced by the arguments with respect to the independent claim 1, because claim 10 is allowable, the examiner's arguments with respect to claims 11–16 are moot. The Applicants are not making any admission to such arguments being correct, only that they are moot.

Rejection of independent claim 17 over Anderson.

In paragraph 6 of the office action, the Examiner asserts in that claim 17 contains the similar limitations set forth of method claim 1, and that therefore claim 17 is rejected for the similar rationale set forth in claim 1.

As argued above, the examiner has failed to show that the features of claim 1 (as amended) are anticipated by Anderson.

Claim 17 has been amended to include that the looking up is for every received packet. As argued above, claim 17 would be allowable because Anderson does not include several of its features.

Claim 17 is therefore allowable, and action to that end is respectfully requested.

Rejection of the dependent claims 18–21 over Anderson.

Claim 17 is now allowable. Therefore, while Applicants do not admit that any of Examiner's arguments on the dependent claims are correct, such arguments are now moot. All dependent claims, including claims 18–21, are allowable.

For these reasons, and in view of the above amendment, this application is now considered to be in condition for allowance and such action is earnestly solicited.

Conclusion

The Applicants believe all of Examiner's rejections have been overcome with respect to all remaining claims (as amended), and that the remaining claims are allowable. Action to that end 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, or a telephone call to the undersigned at +1-510-547-3378 is requested.

Respectfully Submitted,

3 Nov 2003
Date

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EXAMINER	
VU, THONG H	

ART UNIT	PAPER NUMBER
2142	8

DATE MAILED: 12/23/2003

Please find below and/or attached an Office communication concerning this application or proceeding.

Office Action Summary	Application No.	Applicant(s)	
	09/608,126	DIETZ ET AL.	
	Examiner	Art Unit	
	Thong H Vu	2142	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *03 November 2003*.

2a)☒ This action is **FINAL**. 2b)☐ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-21* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-21* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. §§ 119 and 120

12)☐ 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:

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)).

* See the attached detailed Office action for a list of the certified copies not received.

13)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application) since a specific reference was included in the first sentence of the specification or in an Application Data Sheet. 37 CFR 1.78.

a) ☐ The translation of the foreign language provisional application has been received.

14)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121 since a specific reference was included in the first sentence of the specification or in an Application Data Sheet. 37 CFR 1.78.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☐ Information Disclosure Statement(s) (PTO-1449) Paper No(s) _____ .
4) ☐ Interview Summary (PTO-413) Paper No(s). _____ .
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other: .

1. Claims 1-21 are pending.

2. Applicant is required to update the copending applications on pages 1-2.

3. Claims 1 and 17 are amended. Therefore, the Final rejection is appropriate.

Response to Arguments

4. In response to applicant's argument that the references fail to show certain features of applicant's invention, it is noted that the features upon which applicant relies (i.e., re-use information from data transaction) are not recited in the rejected claim(s). Although the claims are interpreted in light of the specification, limitations from the specification are not read into the claims. See *In re Van Geuns*, 988 F.2d 1181, 26 USPQ2d 1057 (Fed. Cir. 1993).

5. Applicant's arguments fail to comply with 37 CFR 1.111(b) because they amount to a general allegation that the claims define a patentable invention without specifically pointing out how the language of the claims patentably distinguishes them from the references.

6. Applicant's arguments do not comply with 37 CFR 1.111(c) because they do not clearly point out the patentable novelty which he or she thinks the claims present in view of the state of the art disclosed by the references cited or the objections made. Further, they do not show how the amendments avoid such references or objections.

7. Applicant's arguments, see pages 6-12, filed 11/03/03, with respect to the rejection(s)of claim(s) 1 and 17 under Anderson reference have been fully considered but they are not persuasive. Applicant argues the prior art does not teach:

1. analyzing a conversional flows;

2. looking up each and every packet to see if it belongs to a previously flow;

3. identifying the flow, carrying an operation which defines the state;

4. analyzing each and every packet.

Examiner notes the prior art taught :

(1) analyzing a conversional flows [Anderson, a protocol analyzer monitoring real time event information over the Ethernet which was well-known in the art as full duplex (i.e.: two way communication network), col 16 lines 10-25];

(2) looking up each and every packet [Anderson, each frame, col 11 lines 5-17,col 13 lines 52-67] to see if it belongs to a previously flow [Anderson, determines whether the entry corresponding to the source address of the frame in the station list array, col 11 lines 57-67];

(3) identifying the flow (i.e.: event ID), carrying a operation which defines the state [Anderson, construct a detailed event message for reporting of the event to the user, col 22 lines 25-36];

(4) analyzing each and every packet [Anderson, determines whether the entry corresponding to the source address of the frame in the station list array, col 11 lines 57-67].

Thus, the rejection is sustained.

Claim Rejections - 35 USC § 112

8. Claims 1 and 17 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention (i.e.: a flow entry database that may contain one or more flow entries).

Double Patenting

9. The nonstatutory double patenting rejection is based on a judicially created doctrine grounded in public policy (a policy reflected in the statute) so as to prevent the unjustified or improper timewise extension of the "right to exclude" granted by a patent and to prevent possible harassment by multiple assignees. See *In re Goodman*, 11 F.3d 1046, 29 USPQ2d 2010 (Fed. Cir. 1993); *In re Longi*, 759 F.2d 887, 225 USPQ 645 (Fed. Cir. 1985); *In re Van Ornum*, 686 F.2d 937, 214 USPQ 761 (CCPA 1982); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970);and, *In re Thorington*, 418 F.2d 528, 163 USPQ 644 (CCPA 1969).

A timely filed terminal disclaimer in compliance with 37 CFR 1.321(c) may be used to overcome an actual or provisional rejection based on a nonstatutory double patenting ground provided the conflicting application or patent is shown to be commonly owned with this application. See 37 CFR 1.130(b).

Effective January 1, 1994, a registered attorney or agent of record may sign a terminal disclaimer. A terminal disclaimer signed by the assignee must fully comply with 37 CFR 3.73(b).

Claims 1-21 are rejected under the judicially created doctrine of double patenting over claims 1-10 of U. S. Patent No. 6,651,099 B1 since the claims, if allowed, would improperly extend the "right to exclude" already granted in the patent.

The subject matter claimed in the instant application is fully disclosed in the patent and is covered by the patent since the patent and the application are claiming common subject matter, as follows:

(Application): A method of analyzing a flow of packets passing through a connection point (protocol analyzer) on a computer network,

(Patent '099):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:

(a) receiving a packet from a packet acquisition device coupled to the connection point;

(a) a packet-buffer memory configured to accept a packet from the packet acquisition device;

(b) for each received packet, looking up a flow-entry database that may contain one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow;

(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;

(c) if the packet is of an existing flow, identifying the last encountered state of the flow, performing any state operation specified for the state of the flow, and updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry; 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 announce the protocol and state of the conversational flow of the packet;

(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow and storing a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry, wherein every packet passing though the connection point is received by the packet acquisition device.

(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 (i.e.: new flow entry) 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;

Furthermore, there is no apparent reason why applicant was prevented from presenting claims corresponding to those of the instant application during prosecution of the application which matured into a patent. See *In re Schneller*, 397 F.2d 350, 158 USPQ 210 (CCPA 1968). See also MPEP § 804.

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

10. Claims 1-21 are rejected under 35 U.S.C. § 102(e) as being anticipated by Anderson et al [Anderson 5,850,388].

11. As per claim 1, Anderson discloses a method of analyzing a flow of packets (or frames) passing through a connection point (protocol analyzer) on a computer network [col 4 line 49-col 6 line 19], the method comprising:

(a) receiving a packet from a packet acquisition device [protocol analyzer, col 8 line 26-col 9 line 13];

(b) looking up a flow-entry database [database, col 5 lines 24-46, col 9 lines 30-40, col 23 lines 35-45, col 24 lines 6-20,57-col 25 line 50; lookup table, col 18 lines 29-37] comprising one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow [previous session, col 24 lines 6-13; prior entries, col 28 lines 26-43];

(c) if the packet is of an existing flow, updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry [col 17 lines 15-23, col 25 lines 22-47, col 27 lines 24-34, col 28 lines 49-67]; and

(d) if the packet is of a new flow, storing a new flow-entry for the new flow in the flow-entry database [update new information, col 27 lines 10-53], including storing one or more statistical measures kept in the flow-entry [statistics, col 27 lines 10-34], wherein every packet passing though the connection point is received by the packet acquisition device [protocol analyzer col 8 line 26-col 9 line 13].

12. Claim 17 contains the similar limitations set forth of method claim 1. Therefore, claim 17 is rejected for the similar rationale set forth in claim 1.

13. As per claim 2, Anderson discloses extracting identifying portions from the packet, wherein the looking up uses a function of the identifying portions [information is extracted from a frame, col 9 line 42-col 10 line 18].

14. As per claim 3, Anderson discloses the steps are carried out in real time on each packet passing through the connection point [col 4 line 58-col 5 line 46].

15. As per claim 4, Anderson discloses the one or more statistical measure includes selected from the set of consisting of the total packet count for the flow, the time and a differential time from the last entered time to the present time [col 28 lines 58-67].

16. As per claim 5, Anderson discloses including one or more metrics (parameters) related to the flow of a flow entry from one or more of the statistical measure in the flow entry [col 10 lines 20-40, col 19 lines 30-45,col 22 lines 16-65].

17. As per claim 6, Anderson discloses the metrics include one or more quality of service (QOS) metrics (id, time, length, col 22 lines 16-23].

18. As per claim 7, Anderson discloses the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [Anderson, the last updated, col 29 lines 60-67].

19. As per claim 8, Anderson discloses calculating one or more quality of service (QOS) metrics from the base metrics [col 14 lines 39-60, col15 lines 32-46,col 17 lines 45-57].

20. As per claim 9, Anderson discloses the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to determine respective metrics for the combined interval [col 28 lines 58-67].

21. As per claim 10, Anderson discloses

(c) includes if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow

starting from the last encountered state of the flow [between the last update and the present update, col 26 lines 6-40];

(d) includes if the packet is of a new flow, performing any state operations required for the initial state of the new flow [new data and user initial select how often information on station statistics was to update, col 26 lines 6-15].

22. As per claim 11, Anderson discloses reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry [col 30 line 58-col 31 line 10].

23. As per claim 12, Anderson discloses reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [col 30 line 58-col 31 line 10].

24. As per claim 13, Anderson discloses reporting is part of the state operations for the state of the flow [col 30 line 58-col 31 line 10].

25. As per claim 14, Anderson discloses updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry [col 16 lines 47-54, col19 lines 17-24, col 22 line 66-col 23 line 6] .

26. As per claim 15, Anderson discloses receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow as inherent of new data received [col 28 lines 58-67].

27. As per claim 16, Anderson discloses one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow as inherent feature of parameters [col 22 lines 16-65].

28. As per claim 20, Anderson discloses including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow [software performs statistical calculations ,col 7 lines 33-53].

29. As per claim 21, Anderson discloses the statistical processor determines and reports the one or more metrics from time to time [col 30 line 58-col 31 line 10].

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

30. Claims 1-21 are rejected under 35 U.S.C. § 102(e) as being anticipated by Chapman et al [Chapman 6,330,226 B1].

40. As per claim 1, Chapman discloses a method of analyzing a flow of packets passing through a connection point on a computer network [Chapman, a method of monitoring traffic flows through a traffic admission control apparatus, see abstract, col 3 lines 5-27, Fig 1]

(a) receiving a packet from a packet acquisition device coupled to the connection point [Chapman, the admission control detects the packets, col 3 lines 28-44];

(b) for each received packet, looking up a flow-entry database (i.e.: history table) that may contain one or more flow-entries for previously encountered conversational flows (i.e.: two-way traffic or interactive environment), the looking up to determine if the received packet is of an existing flow [Chapman, matching to a predefined pattern, col 3 lines 28-44];

(c) if the packet is of an existing flow, identifying the last encountered state of the flow (i.e.: most recent update flow), performing any state operation specified for the

state of the flow, and updating the flow-entry of the existing flow including storing one or more statistical measures kept in the flow-entry [Chapman, flow ID is compared and updated, col 3 lines 50-60, col 5 lines 1-7]; and

(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow and storing a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry, wherein every packet passing though the connection point is received by the packet acquisition device [Chapman, new entry is made or stored into database, col 3 lines 50-60, col 4 lines 40-55].

41. Claim 17 contains the similar limitations set forth of method claim 1. Therefore, claim 17 is rejected for the similar rationale set forth in claim 1.

42. As per claim 2, Chapman discloses extracting identifying portions from the packet, wherein the looking up uses a function of the identifying portions [Chapman, detecting the packets, col 3 lines 28-44].

43. As per claim 3, Chapman discloses the steps are carried out in real time on each packet passing through the connection point [Chapman, interactive user, col col 5 lines 20-30].

44. As per claim 4, Chapman discloses the one or more statistical measure includes selected from the set of consisting of the total packet count for the flow, the time and a differential time from the last entered time to the present time as inherent feature of history table record or database [Chapman, col 6 lines 35-45].

45. As per claim 5, Chapman discloses including one or more metrics related to the flow of a flow entry from one or more of the statistical measure in the flow entry [Chapman, flow characteristic, col 4 lines 40-55].

46. As per claim 6, Chapman discloses the metrics include one or more quality of service (QOS) metrics [Chapman, flow characteristic, col 4 lines 40-55].

47. As per claim 7, Chapman discloses the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [Chapman, regular time intervals, col 4 lines 27-37].

48. As per claim 8, Chapman discloses calculating one or more quality of service (QOS) metrics from the base metrics [Chapman, computing the packet loss characteristic, col 5 lines 33-57].

49. As per claim 9, Chapman discloses the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to

determine respective metrics for the combined interval [Chapman, adjust its windows to fit the bandwidth, col 4 lines 15-25].

50. As per claim 10, Chapman discloses (c) if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow [Chapman, detect problem condition, col 4 lines 25-37];

(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow [Chapman, a new entry, col 3 lines 50-60].

51. As per claim 11, Chapman discloses reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry [Chapman, database, col 4 lines 40-55].

52. As per claim 12, Chapman discloses reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [Chapman, the most recent update, col 5 lines 1-7].

53. As per claim 13, Chapman discloses reporting is part of the state operations for the state of the flow [Chapman, a sample history, col 4 lines 25-30].

54. As per claim 14, Chapman discloses updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry [Chapman, the history is updated, col 3 lines 50-60].

55. As per claim 15, Chapman discloses receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow as inherent of new entry received.

56. As per claim 16, Chapman discloses one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow [Chapman, detect problem condition, col 4 lines 25-37].

57. As per claim 20, Chapman discloses including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow [Chapman, database, col 4 lines 40-55].

58. As per claim 21, Chapman discloses the statistical processor determines and reports the one or more metrics from time to time [Chapman, database, col 4 lines 40-55].

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

59. Claims 1-21 are rejected under 35 U.S.C. § 102(e) as being anticipated by Bullard [6,625,657 B1].

60. As per claim 1, Bullard discloses a method of analyzing a flow of packets passing through a connection point on a computer network [Bullard, a method for tracking network record, abstract]

(a) receiving a packet from a packet acquisition device coupled to the connection point [Bullard, monitoring each packet of a network flow, col 28 line 45-col 29 line 5];

(b) for each received packet, looking up a flow-entry database [Bullard, database col 10 lines 7-17; flow description, col 12 lines 52-62; flow descriptors, col 14 lines 17-58] that may contain one or more flow-entries for previously encountered conversational flows (i.e.: bi-directional flow) [col 7 lines 18-25] the looking up to determine if the received packet is of an existing flow [Bullard, matching to older record, col 16 lines 16-36];

(c) if the packet is of an existing flow, identifying the last encountered state of the flow, performing any state operation specified for the state of the flow [Bullard, flow status descriptors, col 14 lines 17-58], and updating the flow-entry of the existing flow [Bullard, updating the record, col 8 lines 20-67] including storing one or more statistical measures kept in the flow-entry [Bullard, statistical phenomenon, col 31 lines 7-40]; and

(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow and storing a new flow-entry for the new flow in the flow-entry database, including storing one or more statistical measures kept in the flow-entry, wherein every packet passing though the connection point is received by the packet acquisition device [Bullard, new NAR, col 16 lines 16-36; new IP packet, col 26 lines 28-46].

61. Claim 17 contains the similar limitations set forth of method claim 1. Therefore, claim 17 is rejected for the similar rationale set forth in claim 1.

62. As per claim 2, Bullard discloses extracting identifying portions from the packet, wherein the looking up uses a function of the identifying portions [Bullard, retrieving identified data, col 34 lines 45-63].

63. As per claim 3, Bullard discloses the steps are carried out in real time on each packet passing through the connection point as inherent feature of Internet provider.

64. As per claim 4, Bullard discloses the one or more statistical measure includes selected from the set of consisting of the total packet count for the flow, the time and a differential time from the last entered time to the present time [Bullard, time periods T1,T2, col 19 line 42-col 20 line 24].

65. As per claim 5, Bullard discloses including one or more metrics related to the flow of a flow entry from one or more of the statistical measure in the flow entry [Bullard, quality of service identifiers, col 14 lines 45-50].

66. As per claim 6, Bullard discloses the metrics include one or more quality of service (QOS) metrics [Bullard, quality of service identifiers, col 14 lines 45-50].

67. As per claim 7, Bullard discloses the reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [Bullard, accounting time interval, col 14 lines 45-50].

68. As per claim 8, Bullard discloses calculating one or more quality of service (QOS) metrics from the base metrics [Bullard, audit the classes in quality of service, col 33 lines 17-27].

69. As per claim 9, Bullard discloses the one or more metrics are selected to be scalable such that metrics from contiguous time intervals may be combined to

determine respective metrics for the combined interval [Bullard, combined value over a time period, col 11 lines 32-38].

70. As per claim 10, Bullard discloses (c) if the packet is of an existing flow, identifying the last encountered state of the flow and performing any state operations specified for the state of the flow starting from the last encountered state of the flow [Bullard, col 16 lines 16-61];

(d) if the packet is of a new flow, performing any state operations required for the initial state of the new flow [Bullard, col 16 lines 16-61].

71. As per claim 11, Bullard discloses reporting one or more metrics related to the flow of a flow-entry from one or more of the statistical measures in the flow-entry [Bullard, statistical probability, col 31 lines 7-40].

72. As per claim 12 Bullard discloses reporting is carried out from time to time, and wherein the one or more metrics are base metrics related to the time interval from the last reporting time [Bullard, report has been generated by a time condition, col 27 lines 55-67].

73. As per claim 13, Bullard discloses reporting is part of the state operations for the state of the flow [Bullard event reporting, col 28 lines 12-25].

74. As per claim 14, Bullard discloses updating the flow-entry, including storing identifying information for future packets to be identified with the flow-entry [Bullard, stored ID, col 23 lines 10-25].

75. As per claim 15, Bullard discloses receiving further packets, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow as inherent of new data.

76. As per claim 16, Bullard discloses one or more metrics related to the state of the flow are determined as part of the state operations specified for the state of the flow [Bullard flow probe correlates the state information, col 24 lines 55-67].

77. As per claim 20, Bullard discloses including a statistical processor configured to determine one or more metrics related to a flow from one or more of the statistical measures in the flow-entry of the flow [Bullard, statistical probability, col 31 lines 7-40].

78. As per claim 21, Bullard discloses the statistical processor determines and reports the one or more metrics from time to time [Bullard, statistical probability, col 31 lines 7-40].

Applicant's amendment necessitated the new ground(s) of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL.** See MPEP § 706.07(a). Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the date of this final action.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to examiner Thong Vu, whose telephone number is (703)-305-4643.

The examiner can normally be reached on Monday-Thursday from 8:00AM- 4:30PM.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, *Jack Harvey*, can be reached at *(703) 305-9705*.

Any inquiry of a general nature or relating to the status of this application should be directed to the Group receptionist whose telephone number is (703) 305-9700.

Any response to this action should be mailed to: Commissioner of Patent and Trademarks, Washington, D.C. 20231 or faxed to :

After Final	(703) 746-7238
Official:	(703) 746-7239
Non-Official	(703) 746-7240

Hand-delivered responses should be brought to Crystal Park 11,2121 Crystal Drive, Arlington. VA., Sixth Floor (Receptionist).

Thong Vu
Patent Examiner
Art Unit 2142

JACK B. HARVEY
SUPERVISORY PATENT EXAMINER

Notice of References Cited	Application/Control No. 09/608,126	Applicant(s)/Patent Under Reexamination DIETZ ET AL.	
	Examiner Thong H Vu	Art Unit 2142	Page 1 of 1

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*A copy of this reference is not being furnished with this Office action (See MPEP § 707 05(a))
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign

US006625657B1

(12) **United States Patent**
Bullard

(10) **Patent No.: US 6,625,657 B1**
(45) **Date of Patent: Sep. 23, 2003**

(54) **SYSTEM FOR REQUESTING MISSING NETWORK ACCOUNTING RECORDS IF THERE IS A BREAK IN SEQUENCE NUMBERS WHILE THE RECORDS ARE TRANSMITTING FROM A SOURCE DEVICE**

(75) Inventor: **William Carter Carroll Bullard**, New York, NY (US)

(73) Assignee: **Nortel Networks Limited**, St. Laurent (CA)

(*) Notice: 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.: **09/276,423**

(22) Filed: **Mar. 25, 1999**

(51) **Int. Cl.**[7] **G06F 15/16**

(52) **U.S. Cl.** **709/237**; 709/248; 709/224

(58) **Field of Search** 709/216, 217, 709/218, 219, 237, 248, 224; 705/40, 35; 707/201; 379/130

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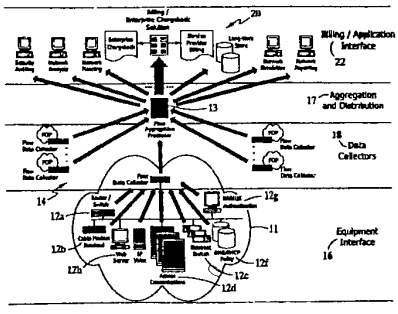
Primary Examiner—Le Hien Luu
(74) *Attorney, Agent, or Firm*—Withrow & Terranova, PLLC

(57) **ABSTRACT**

A system for collecting and aggregating data from network entities for a data consuming application is described. The system includes a data collector layer to receive network flow information from the network entities and to produce records based on the information. The system also includes a flow aggregation layer fed from the data collection layer and coupled to a storage device. The flow aggregation layer receiving records produced by the data collector layer and aggregates received records. The system can also include an equipment interface layer coupled to the data collector layer and a distribution layer to obtain selected information stored in the storage device and to distribute the select information to a requesting, data consuming application.

6 Claims, 36 Drawing Sheets



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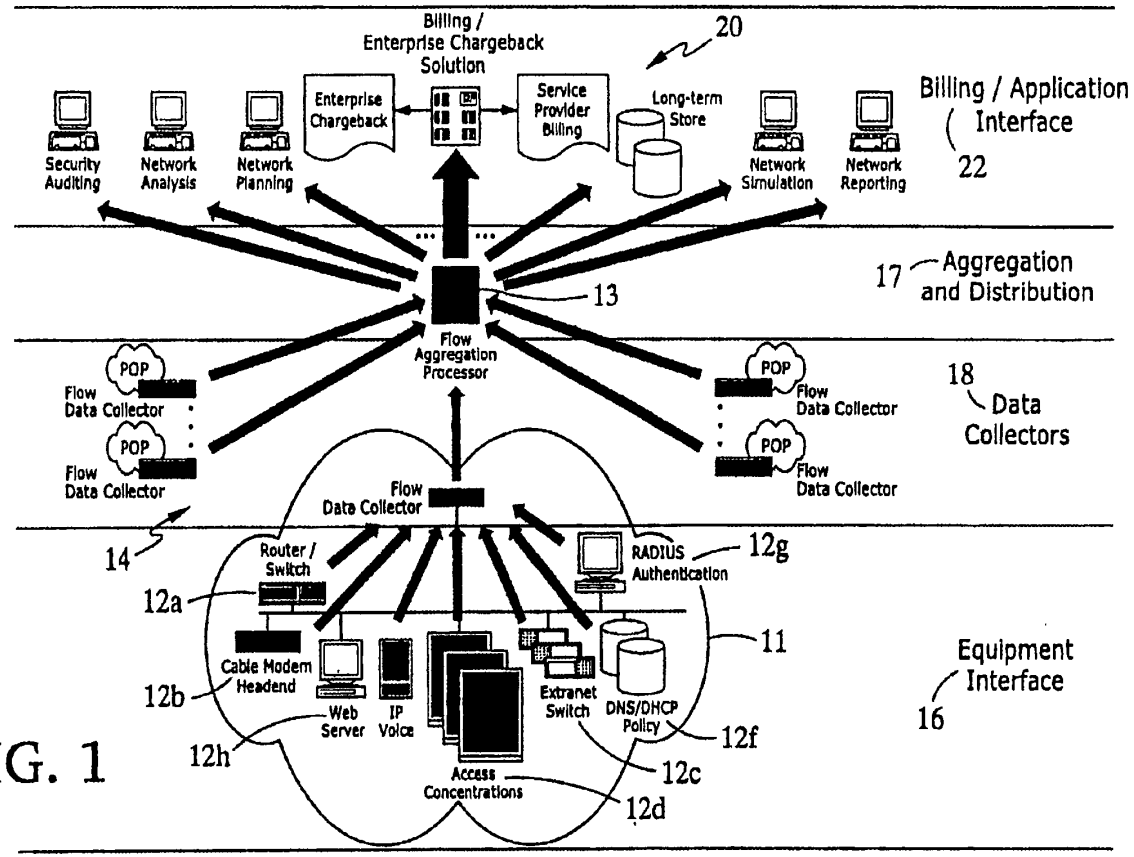
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Enterprise Chargeback
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Long-term Store
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Network Analysis
Network Planning
Network Simulation
Network Reporting
Billing / Application Interface
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17 Aggregation and Distribution
13
Flow Aggregation Processor
POP
Flow Data Collector
18 Data Collectors
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Router / Switch
12a
RADIUS Authentication
12g
11
Cable Modem Headend
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DNS/DHCP Policy
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Equipment Interface
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FIG. 1

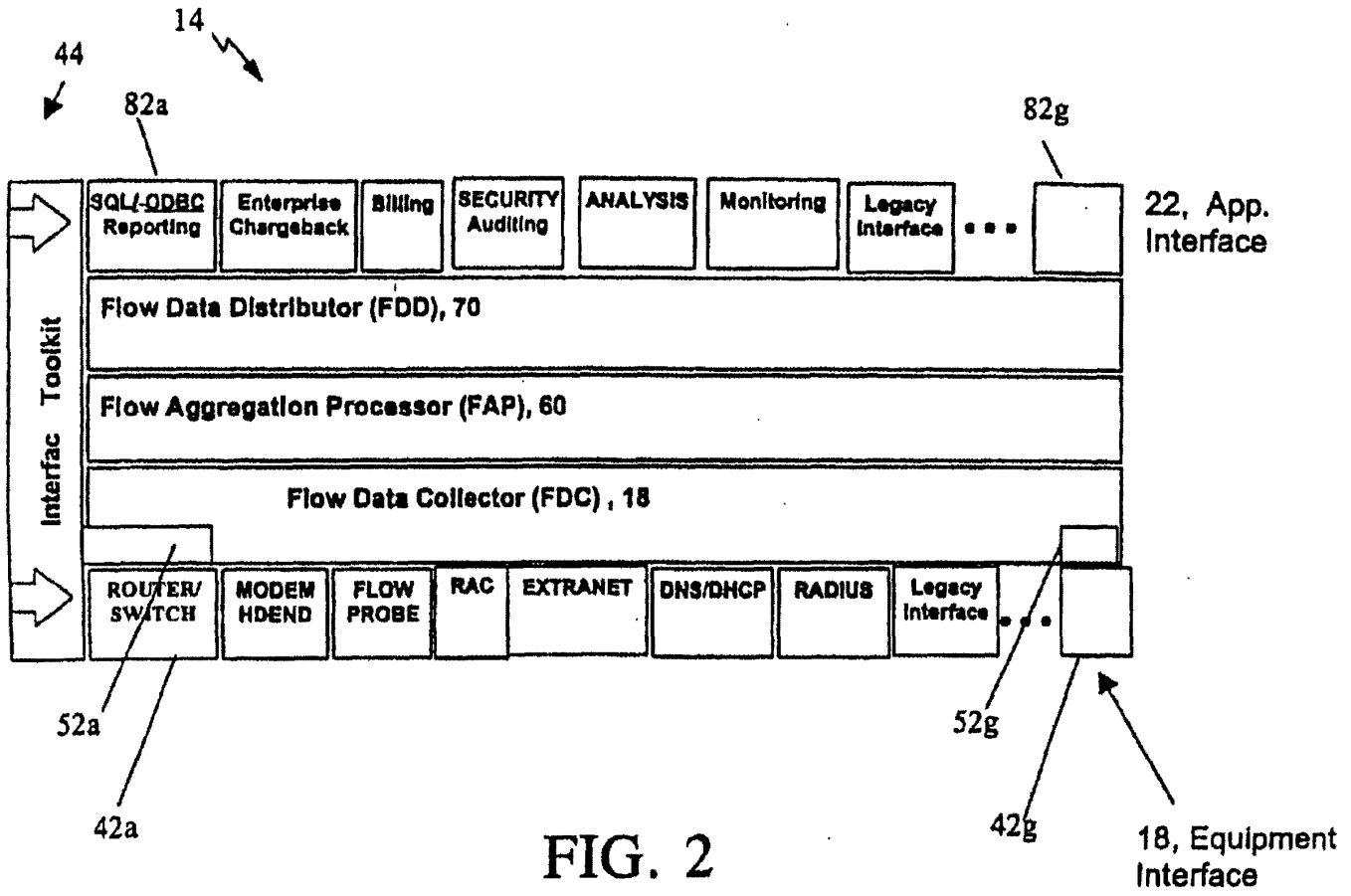
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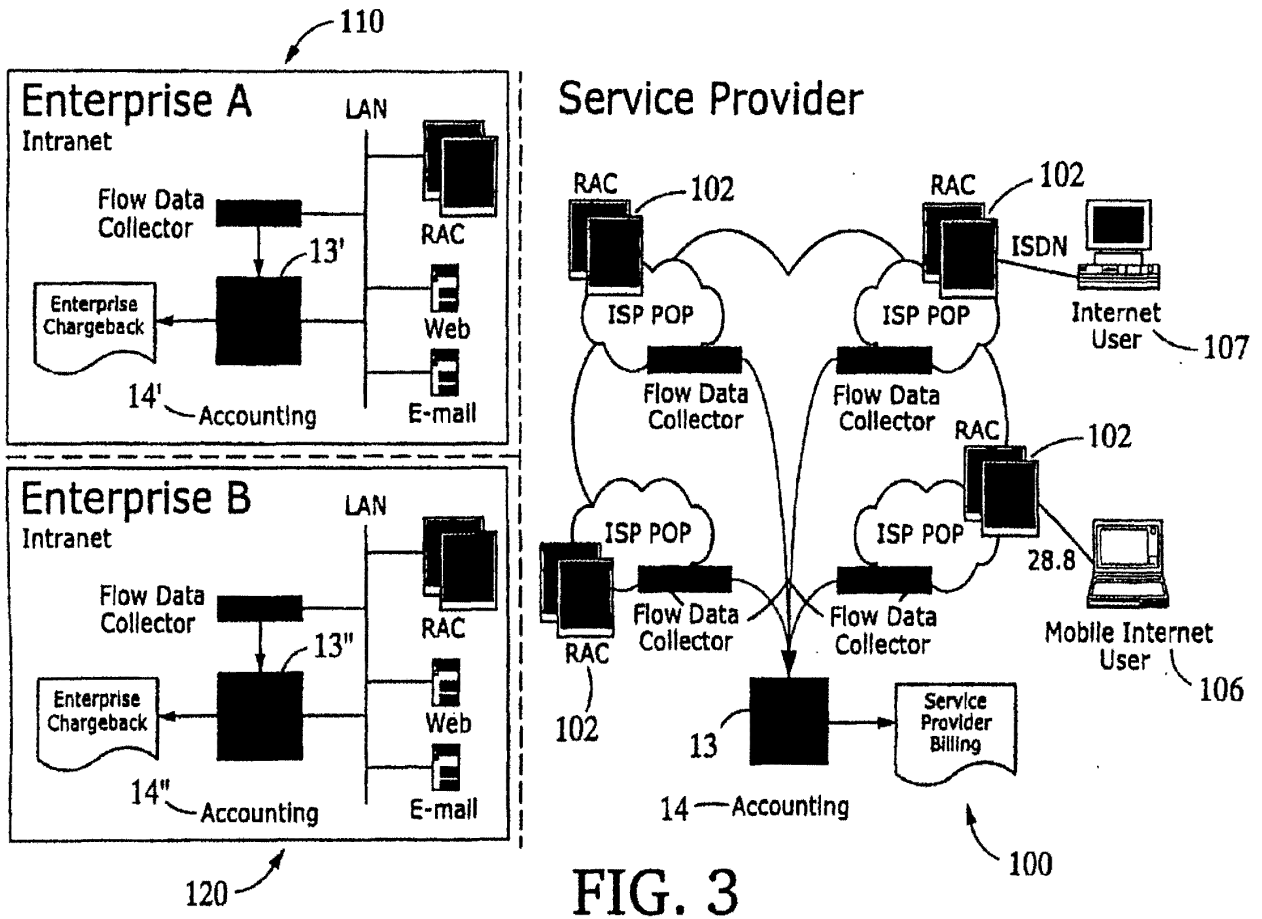
FIG. 2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Service Provider
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RAC
102
ISDN
ISP POP
ISP POP
Internet User
107
Flow Data Collector
Flow Data Collector
RAC
102
ISP POP
ISP POP
28.8
RAC
Flow Data Collector
Flow Data Collector
Mobile Internet User
106
102
13
Service Provider Billing
14
Accounting
100

FIG. 3

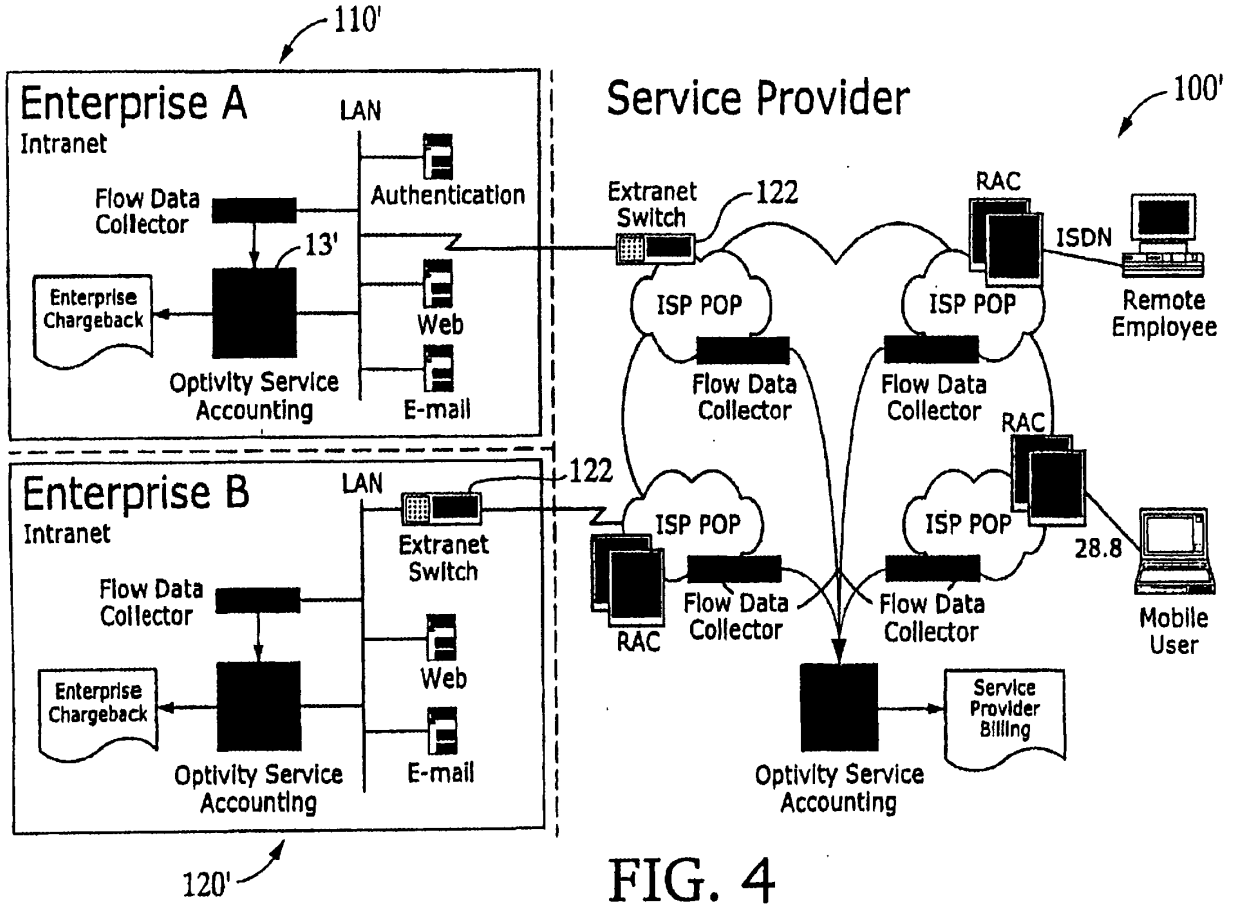

110'
Enterprise A
Intranet
LAN
Authentication
Flow Data Collector
13'
Enterprise Chargeback
Web
Optivity Service Accounting
E-mail
Enterprise B
Intranet
LAN
Extranet Switch
Flow Data Collector
Enterprise Chargeback
Web
Optivity Service Accounting
E-mail
120'
Service Provider
100'
Extranet Switch
122
RAC
ISDN
Remote Employee
ISP POP
ISP POP
Flow Data Collector
Flow Data Collector
RAC
122
ISP POP
ISP POP
28.8
RAC
Flow Data Collector
Flow Data Collector
Mobile User
Service Provider Billing
Optivity Service Accounting

FIG. 4

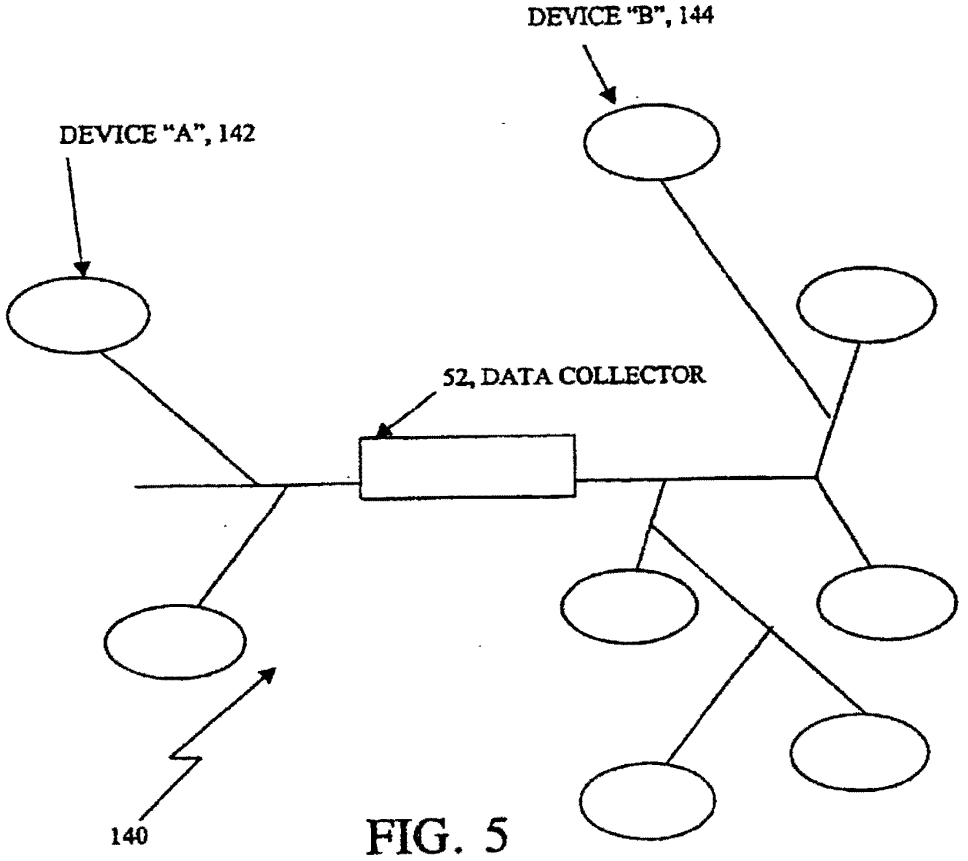


FIG. 5

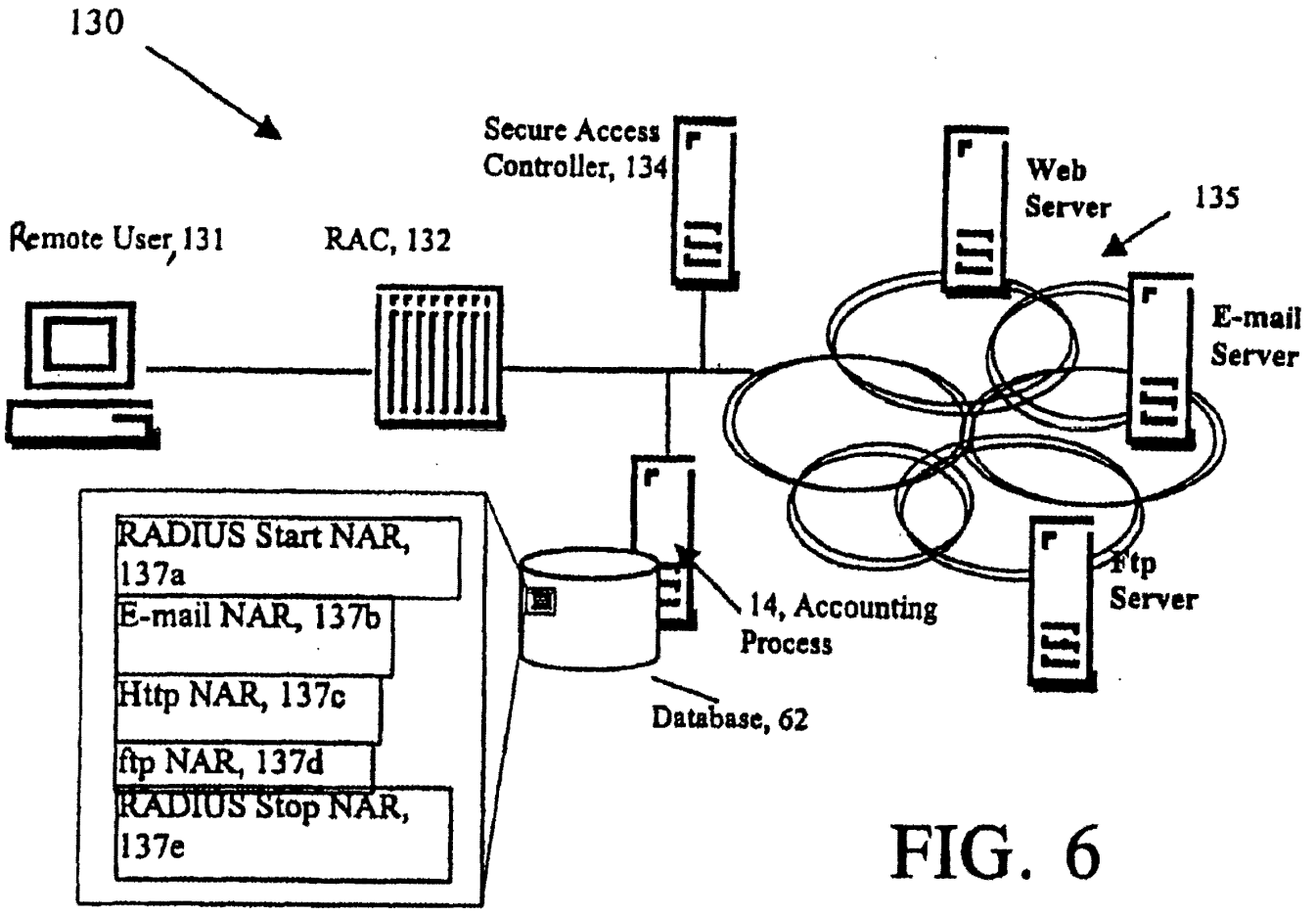

130
Secure Access Controller, 134
Web Server
135
Remote User, 131
RAC, 132
E-mail Server
RADIUS Start NAR, 137a
E-mail NAR, 137b
Http NAR, 137c
ftp NAR, 137d
RADIUS Stop NAR, 137e
14, Accounting Process
Ftp Server
Database, 62

FIG. 6

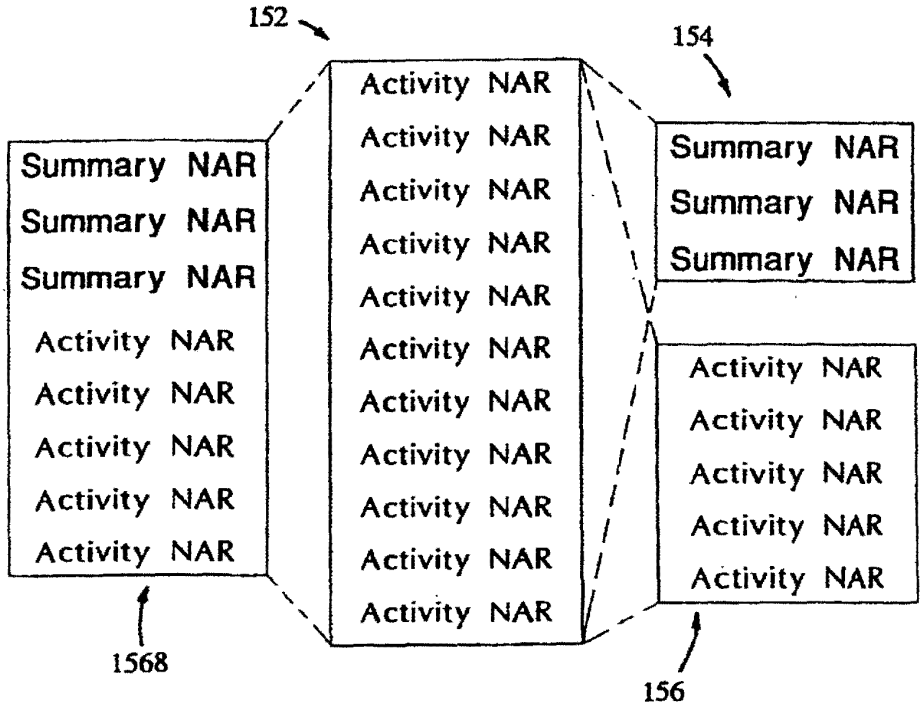

152
154
Summary NAR
Summary NAR
Summary NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Summary NAR
Summary NAR
Summary NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
Activity NAR
1568
156

FIG. 7

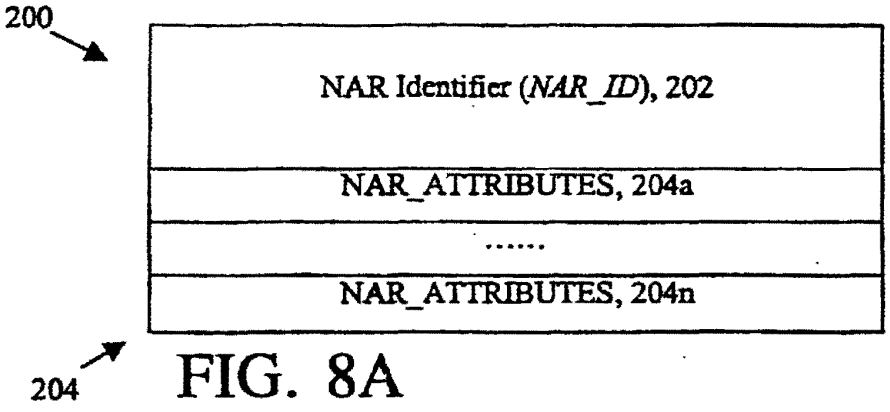

200
NAR Identifier (NAR_ID), 202
NAR_ATTRIBUTES, 204a
.....
NAR_ATTRIBUTES, 204n
204

FIG. 8A

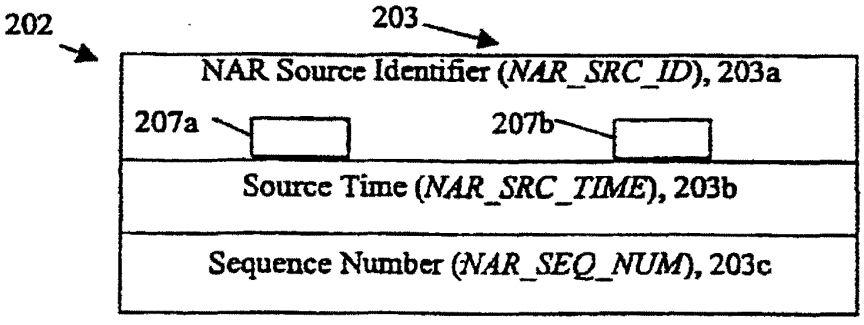

202
203
NAR Source Identifier (NAR_SRC_ID), 203a
207a
207b
Source Time (NAR_SRC_TIME), 203b
Sequence Number (NAR_SEQ_NUM), 203c

FIG. 8B

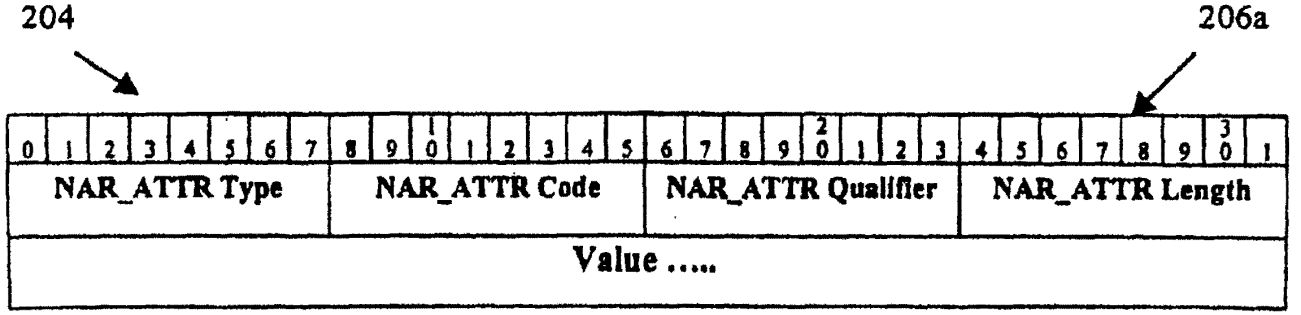

204
206a
0 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1
NAR_ATTR Type
NAR_ATTR Code
NAR_ATTR Qualifier
NAR_ATTR Length
Value .....

FIG. 9A

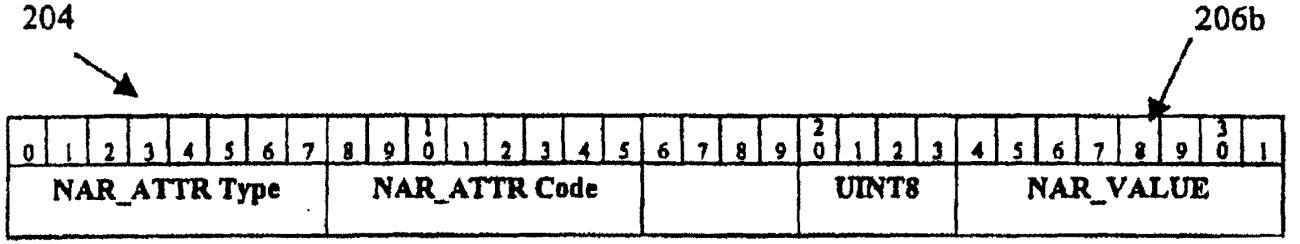

204
206b
0 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1
NAR_ATTR Type
NAR_ATTR Code
UINT8
NAR_VALUE

FIG. 9B

210

0 1 2 3 4 5 6 7	8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31
NAR_ATTR Type	NAR_ATTR Code	NAR_ATTR Qualifier Type	NAR_ATTR Length
0x10	0x00	TIME	3
Seconds			
Seconds			

FIG. 10

220

0 1 2 3 4 5 6 7	8 9 10 1 2 3 4 5	6 7 8 9 20 1 2 3	4 5 6 7 8 9 30 1
NAR_ATTR Type	NAR_ATTR Code	NAR_ATTR Qualifier	NAR_ATTR Length
		Type	
0x20	0x02	Src Dst	STRING	1+(String_len div 4)
Username, 222			

FIG. 11A

230

0 1 2 3 4 5 6 7	8 9 10 1 2 3 4 5	6 7 8 9 20 1 2 3	4 5 6 7 8 9 30 1
NAR_ATTR Type	NAR_ATTR Code	NAR_ATTR Qualifier	NAR_ATTR Length
		Type	
0x20	0x03	Src Dst	STRING	1+(String_len div 4)
			UINT32	2
User Identifier Value, 232			

FIG. 11B

240

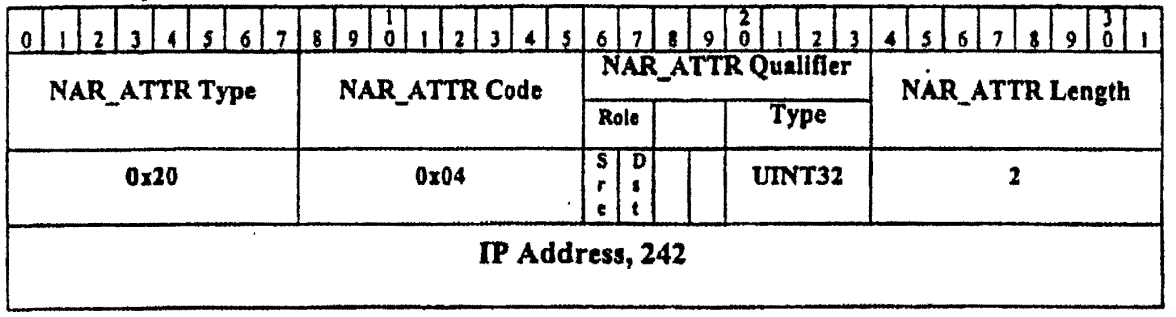


FIG. 11C

250

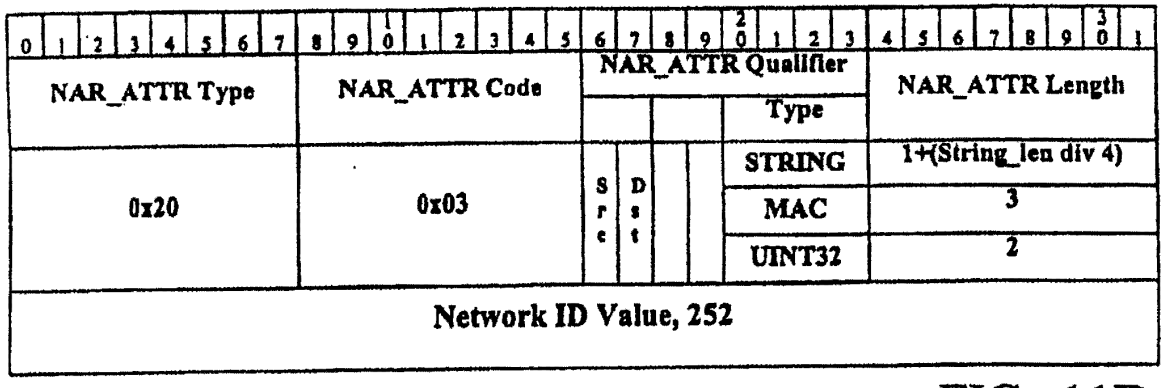
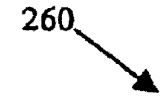


FIG. 11D



0 1 2 3 4 5 6 7	8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31
NAR_ATTR Type	NAR_ATTR Code	NAR_ATTR Qualifier	NAR_ATTR Length
		Type	
0x20	0x06	FLOW	5
IP Source Address, 262			
IP Destination Address, 263			
Transport Protocol, 264		Type of Service, 265	
Source Port, 266		Destination Port, 267	

FIG. 11E

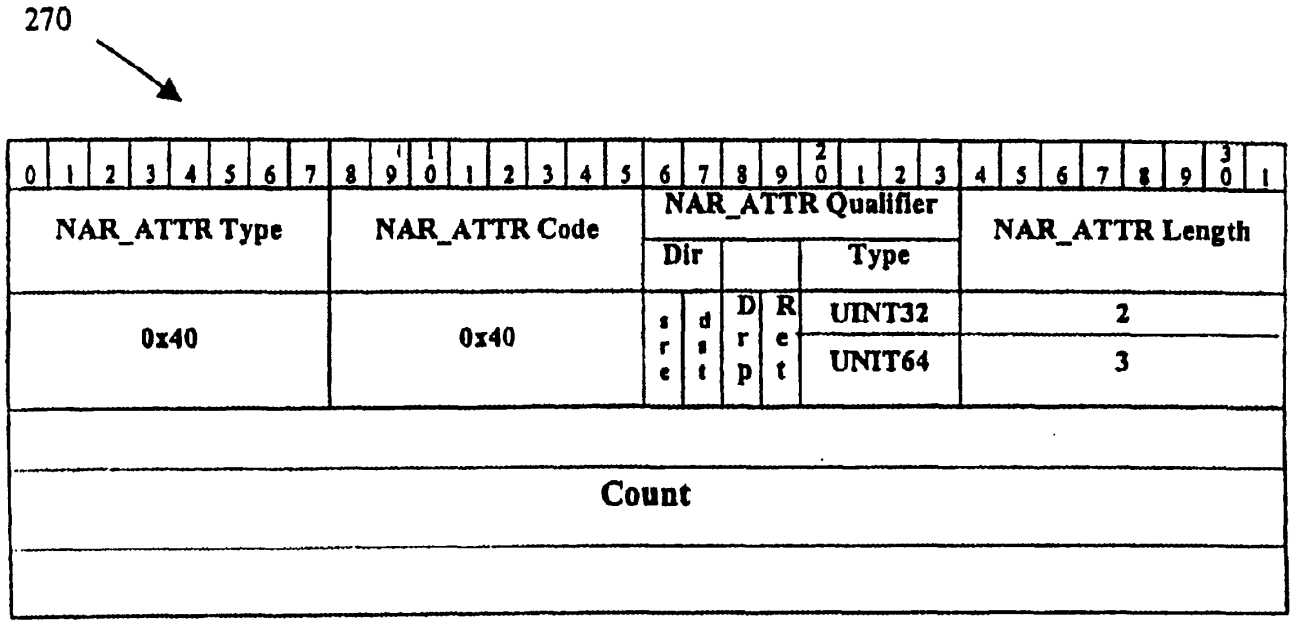

270
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
NAR_ATTR Type
NAR_ATTR Code
NAR_ATTR Qualifier
Dir
Type
NAR_ATTR Length
0x40
0x40
src
dst
Drp
Ret
UINT32
2
UNIT64
3
Count

FIG. 12

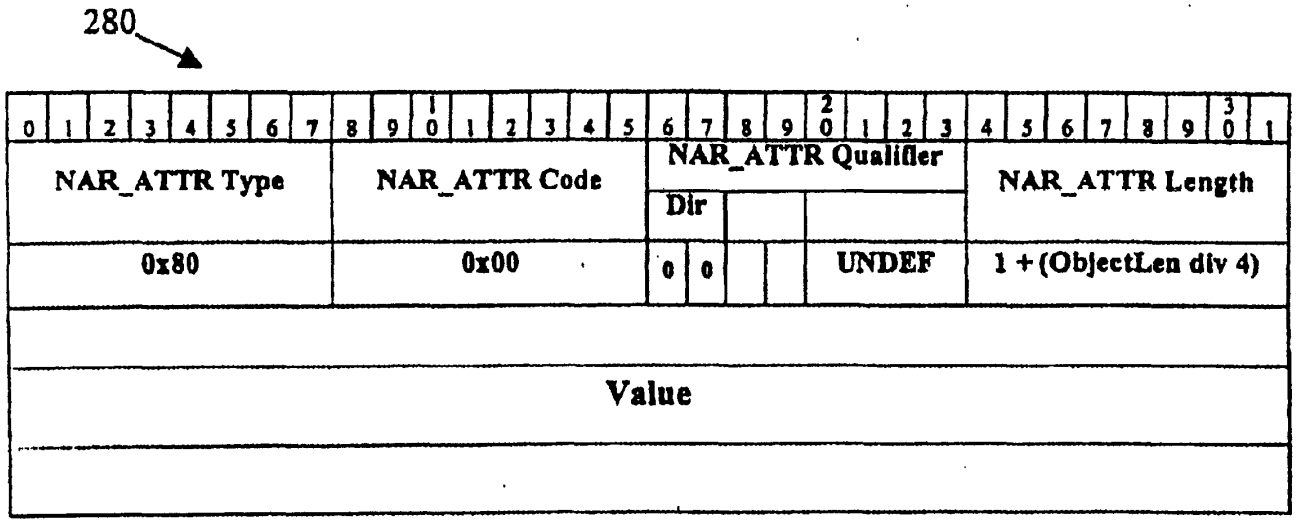

280
0 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1
NAR_ATTR Type
NAR_ATTR Code
NAR_ATTR Qualifier
Dir
NAR_ATTR Length
0x80
0x00
0 0
UNDEF
1 + (ObjectLen div 4)
Value

FIG. 13A

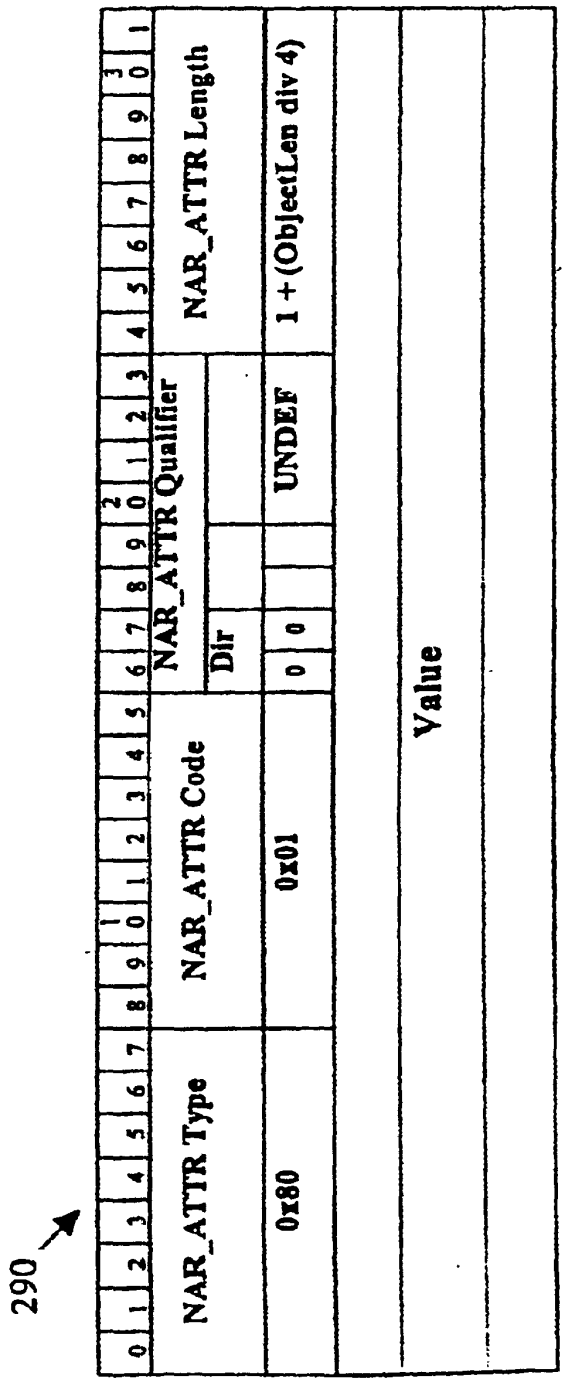

290
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
NAR_ATTR Type
0x80
NAR_ATTR Code
0x01
Dir
0 0
NAR_ATTR Qualifier
UNDEF
NAR_ATTR Length
1 + (ObjectLen div 4)
Value

FIG. 13B

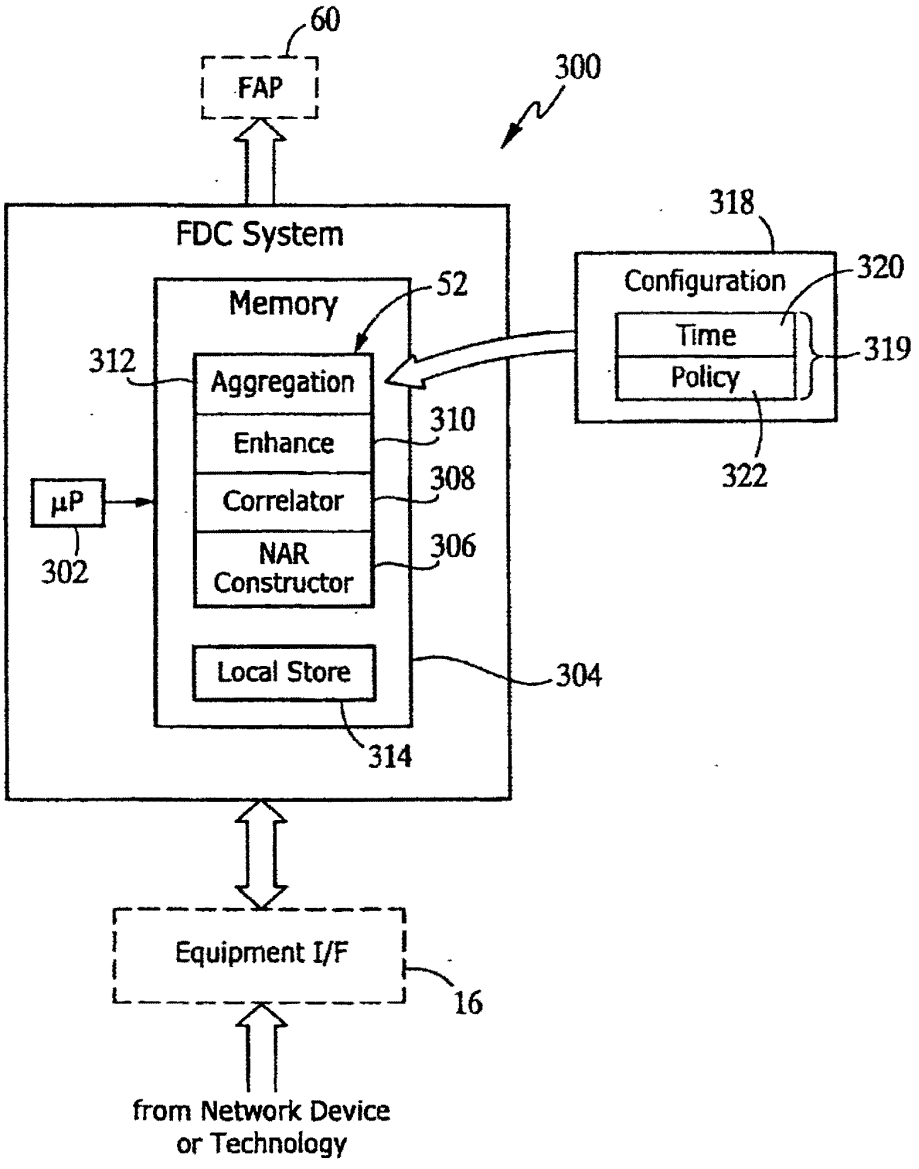

60
FAP
300
FDC System
318
Configuration
320
Time
319
Policy
322
Memory
52
312
Aggregation
310
Enhance
308
Correlator
306
NAR Constructor
μP
302
Local Store
304
314
Equipment I/F
16
from Network Device or Technology

FIG.14

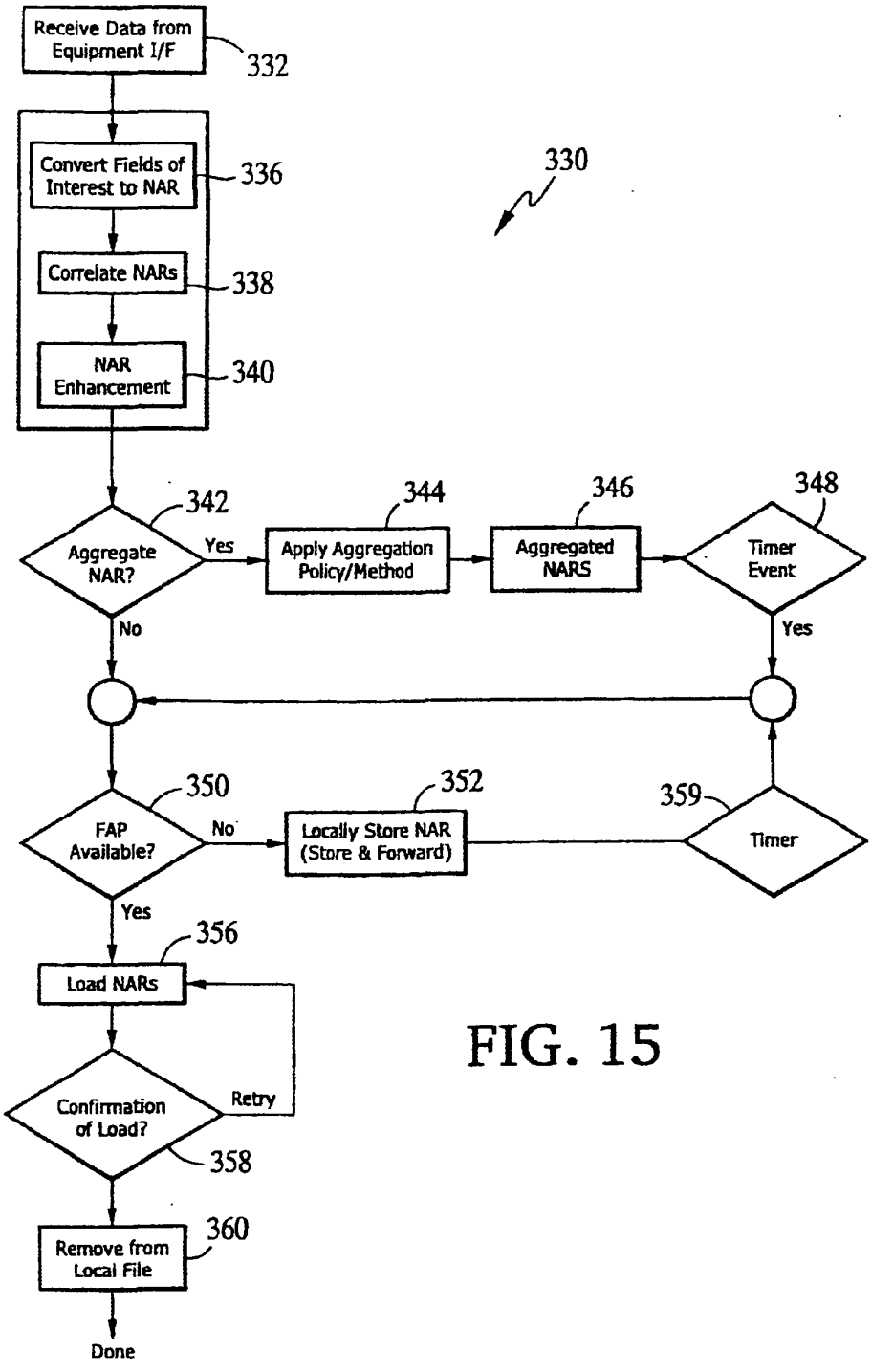

Receive Data from Equipment I/F
332
330
Convert Fields of Interest to NAR
336
Correlate NARs
338
NAR Enhancement
340
342
Aggregate NAR?
Yes
344
Apply Aggregation Policy/Method
346
Aggregated NARS
348
Timer Event
Yes
No
350
FAP Available?
No
352
Locally Store NAR (Store & Forward)
359
Timer
Yes
356
Load NARs
Confirmation of Load?
Retry
358
360
Remove from Local File
Done

FIG. 15

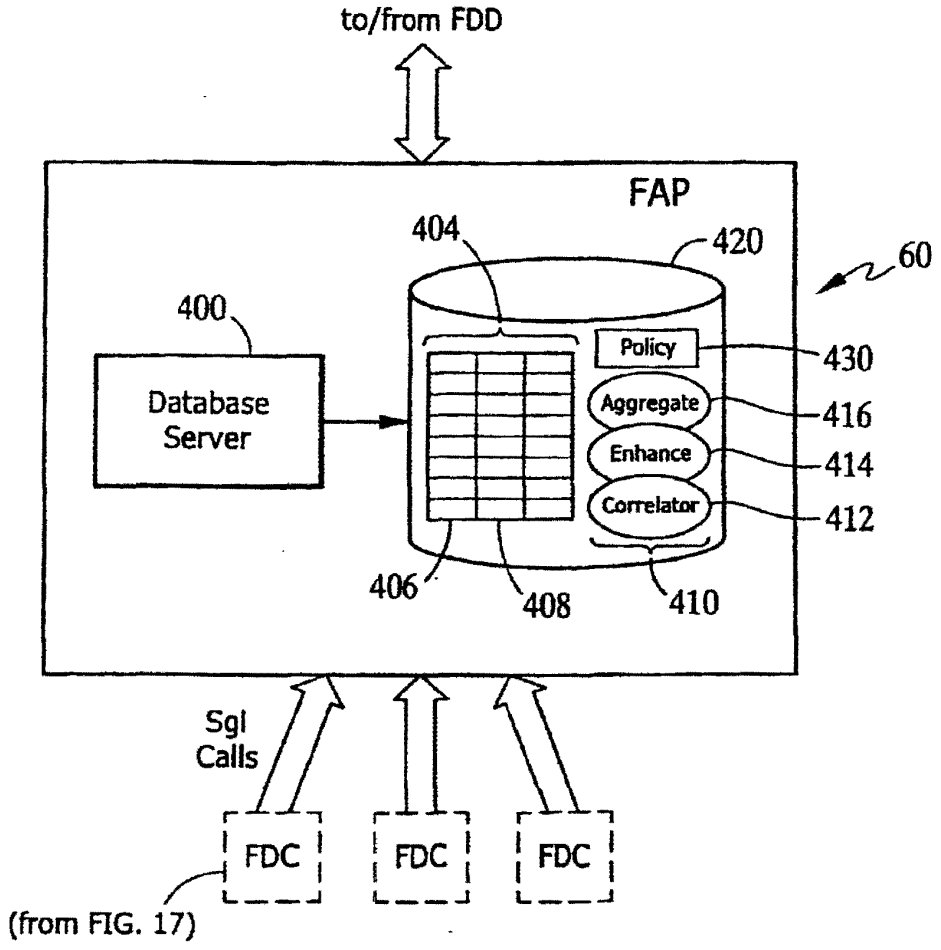

to/from FDD
FAP
404
420
60
400
Database Server
Policy
430
Aggregate
416
Enhance
414
Correlator
412
406
408
410
Sql Calls
FDC
FDC
FDC
(from FIG. 17)

FIG. 16

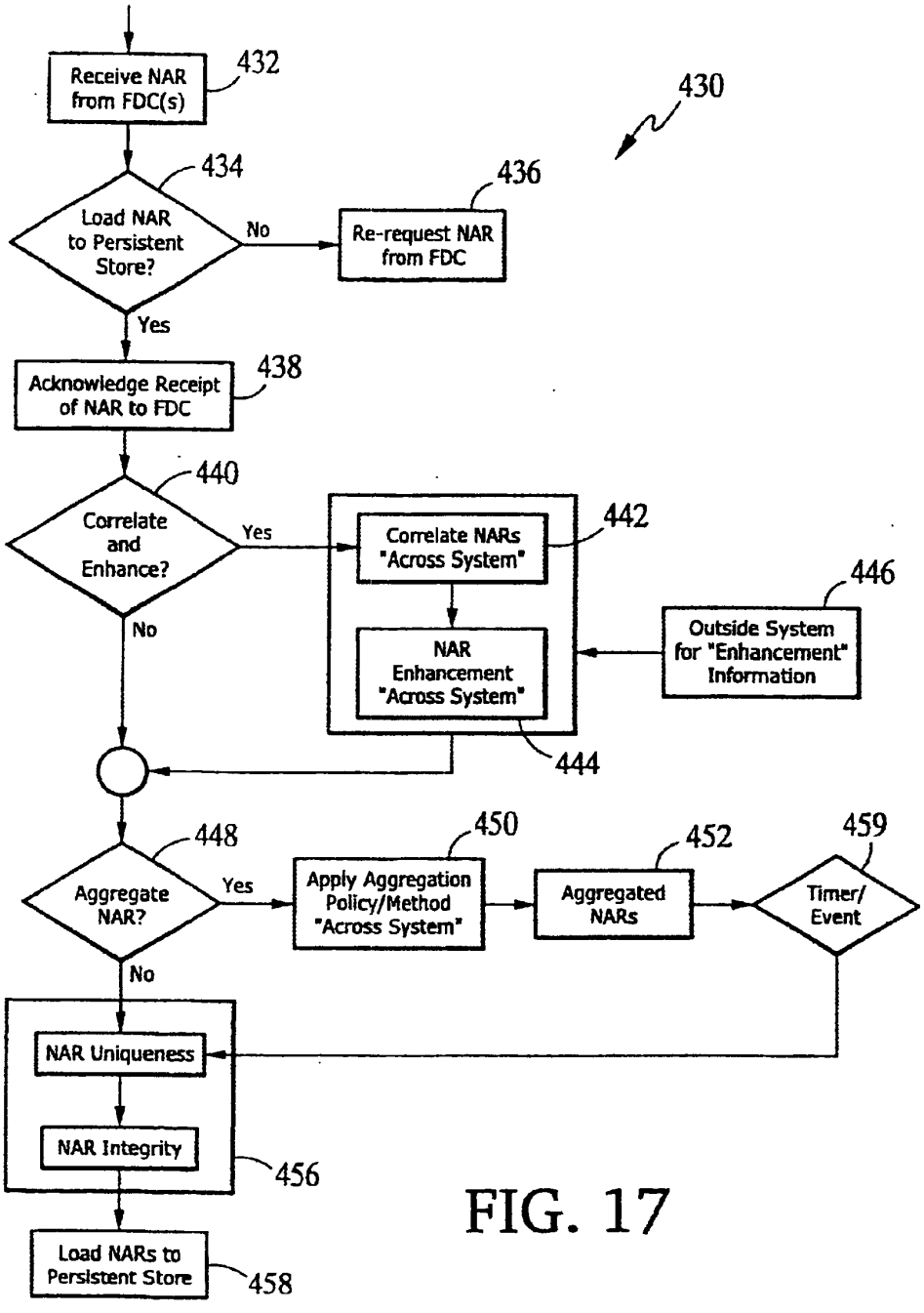

Receive NAR from FDC(s)
432
430
434
Load NAR to Persistent Store?
No
436
Re-request NAR from FDC
Yes
Acknowledge Receipt of NAR to FDC
438
440
Correlate and Enhance?
Yes
Correlate NARs "Across System"
442
446
NAR Enhancement "Across System"
Outside System for "Enhancement" Information
444
No
448
Aggregate NAR?
Yes
450
Apply Aggregation Policy/Method "Across System"
452
Aggregated NARs
459
Timer/ Event
No
NAR Uniqueness
NAR Integrity
456
Load NARs to Persistent Store
458

FIG. 17

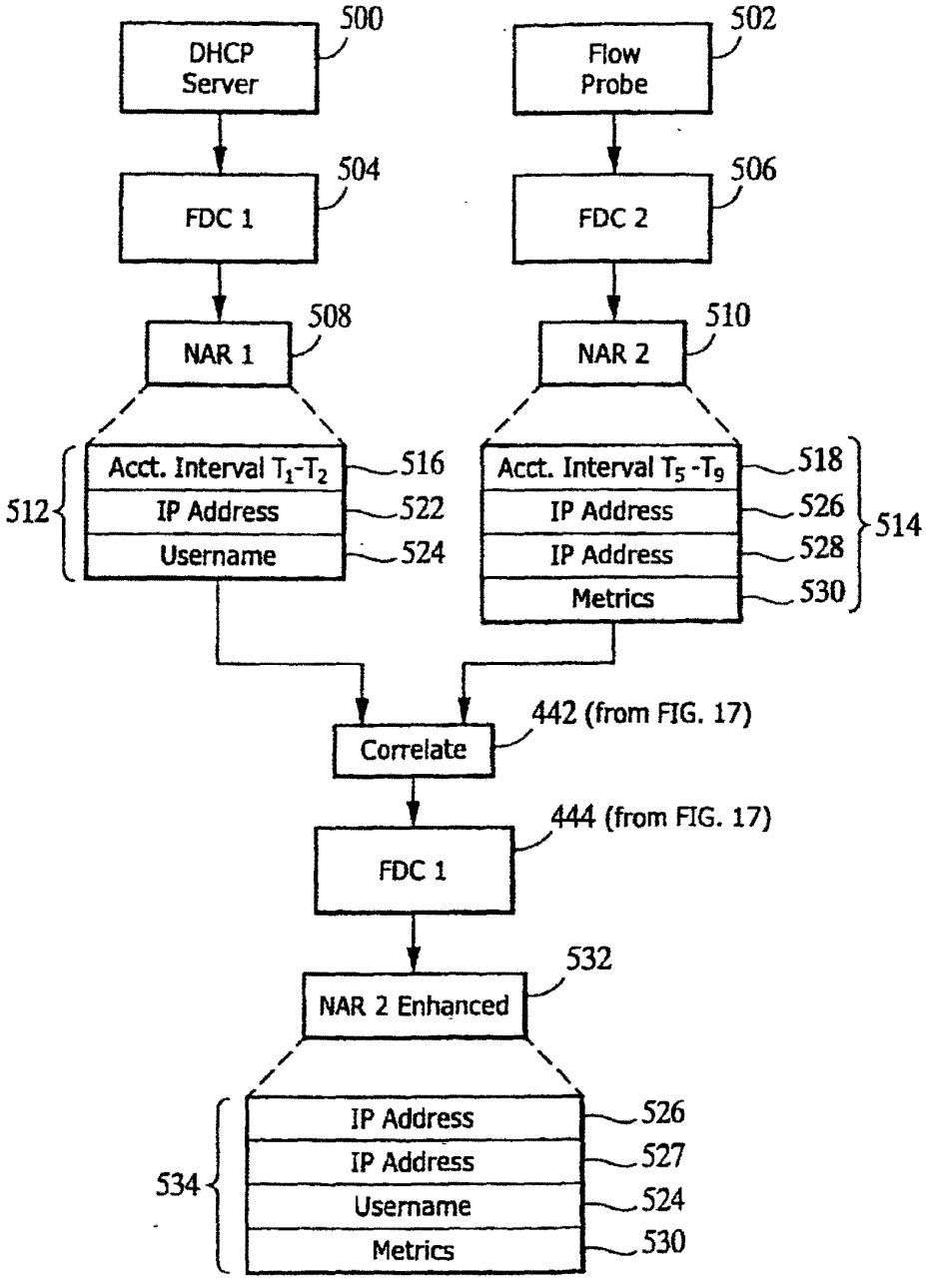

DHCP Server
500
Flow Probe
502
FDC 1
504
FDC 2
506
NAR 1
508
NAR 2
510
Acct. Interval T_1-T_2
516
IP Address
522
Username
524
512
Acct. Interval T_5 -T_9
518
IP Address
526
IP Address
528
Metrics
530
514
Correlate
442 (from FIG. 17)
FDC 1
444 (from FIG. 17)
NAR 2 Enhanced
532
IP Address
526
IP Address
527
Username
524
Metrics
530
534

FIG. 18

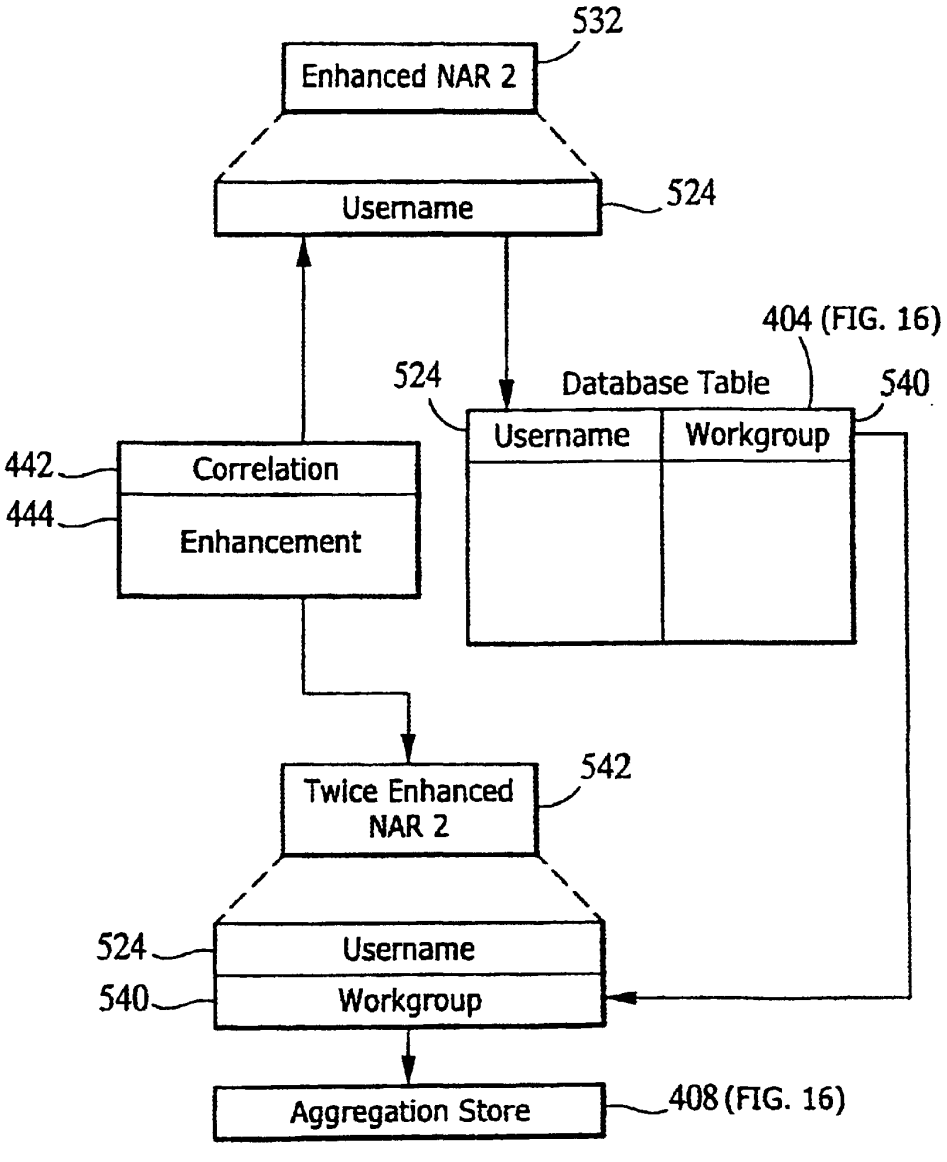

532
Enhanced NAR 2
Username
524
404 (FIG. 16)
524
Database Table
540
Username
Workgroup
442
Correlation
444
Enhancement
542
Twice Enhanced NAR 2
524
Username
540
Workgroup
Aggregation Store
408 (FIG. 16)

FIG. 19

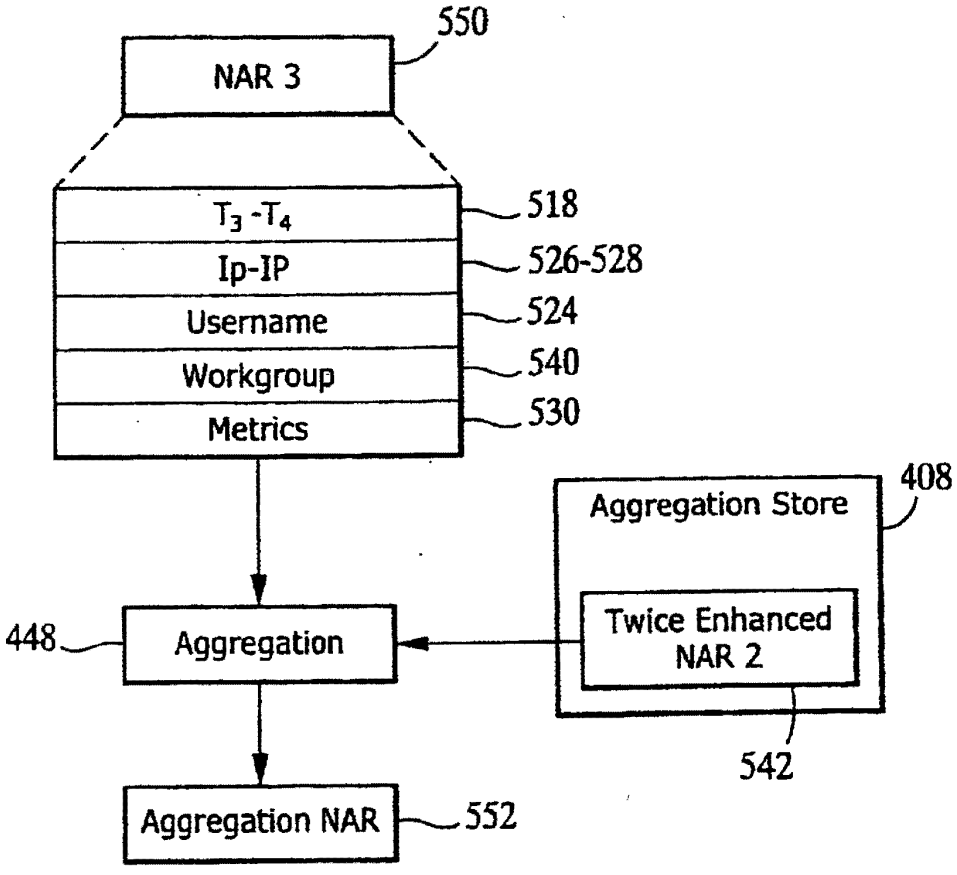

550
NAR 3
T_3 -T_4
518
Ip-IP
526-528
Username
524
Workgroup
540
Metrics
530
Aggregation Store
408
Twice Enhanced NAR 2
542
448
Aggregation
Aggregation NAR
552

FIG. 20

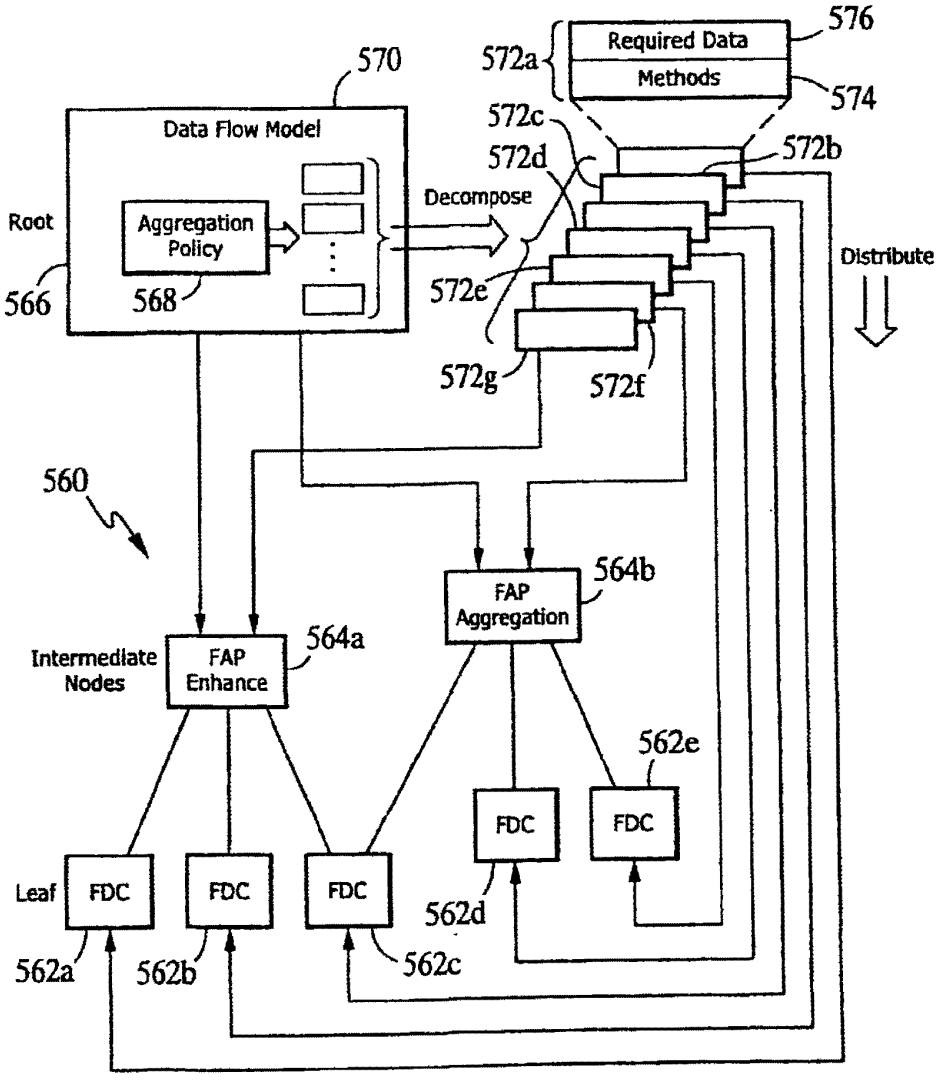

Required Data
Methods
576
572a
574
570
572c
572d
572b
Data Flow Model
Decompose
Root
Aggregation Policy
Distribute
566
568
572e
572g
572f
560
564b
FAP Aggregation
Intermediate Nodes
FAP Enhance
564a
562e
FDC
FDC
Leaf
FDC
FDC
FDC
562d
562a
562b
562c

FIG. 21

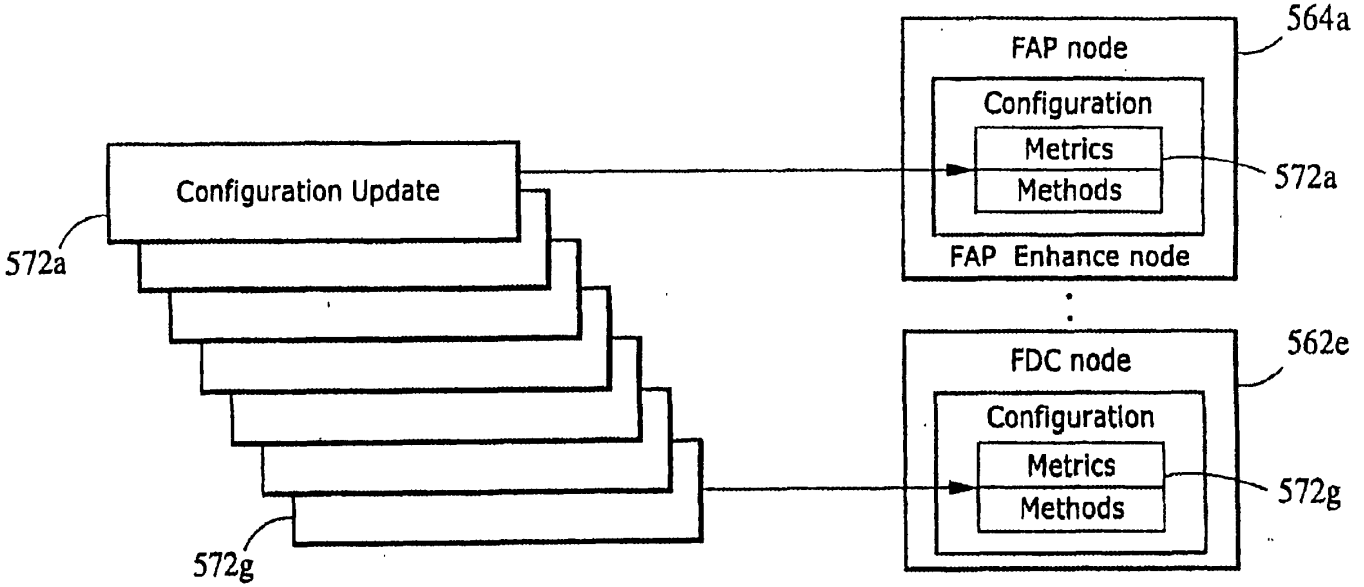

Configuration Update
572a
572g
FAP node
564a
Configuration
Metrics
Methods
572a
FAP Enhance node
FDC node
562e
Configuration
Metrics
Methods
572g

FIG. 22

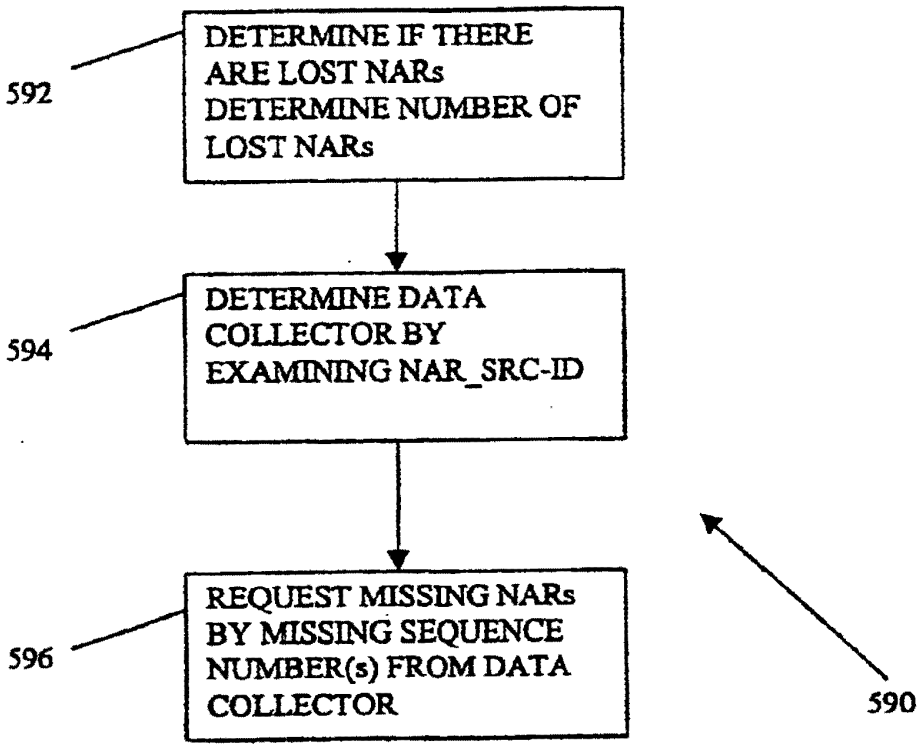

592
DETERMINE IF THERE ARE LOST NARs DETERMINE NUMBER OF LOST NARs
594
DETERMINE DATA COLLECTOR BY EXAMINING NAR_SRC-ID
596
REQUEST MISSING NARs BY MISSING SEQUENCE NUMBER(s) FROM DATA COLLECTOR
590

FIG. 23

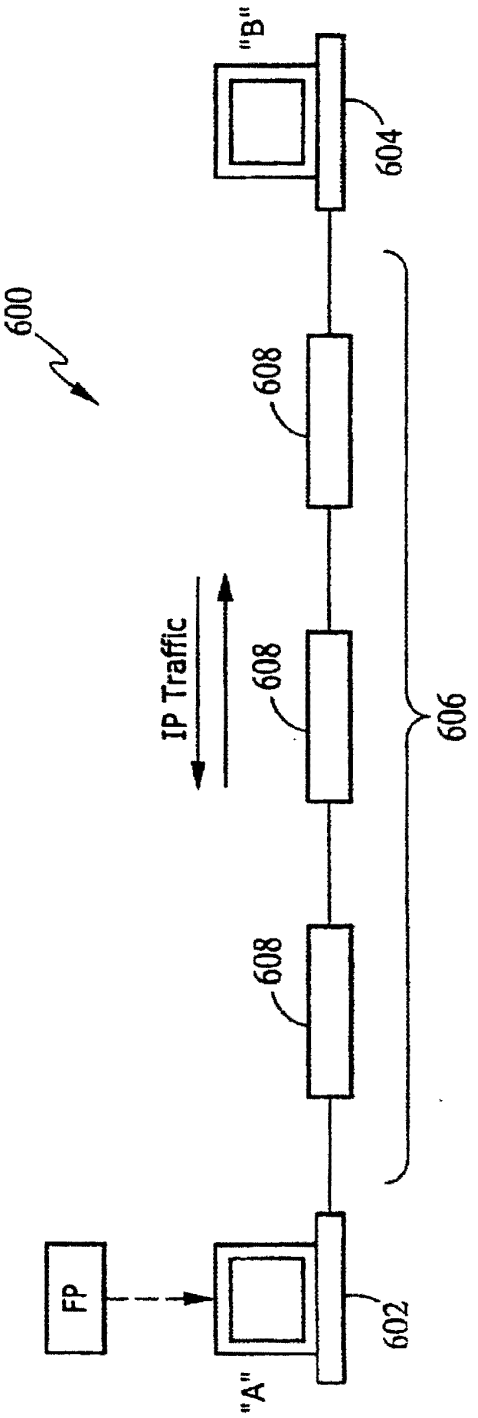


FIG. 24

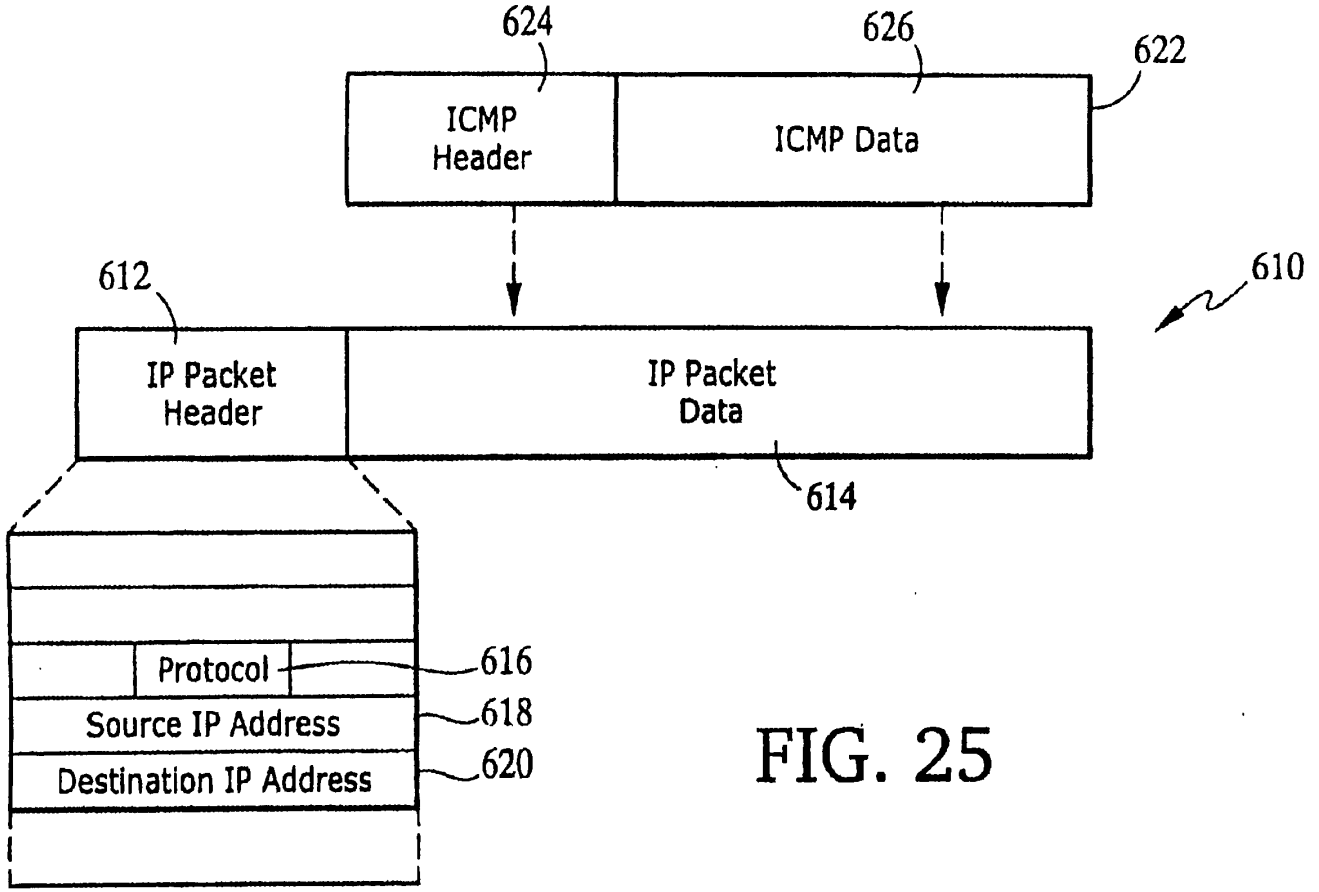

624
626
622
ICMP Header
ICMP Data
612
610
IP Packet Header
IP Packet Data
614
Protocol
616
Source IP Address
618
Destination IP Address
620

FIG. 25

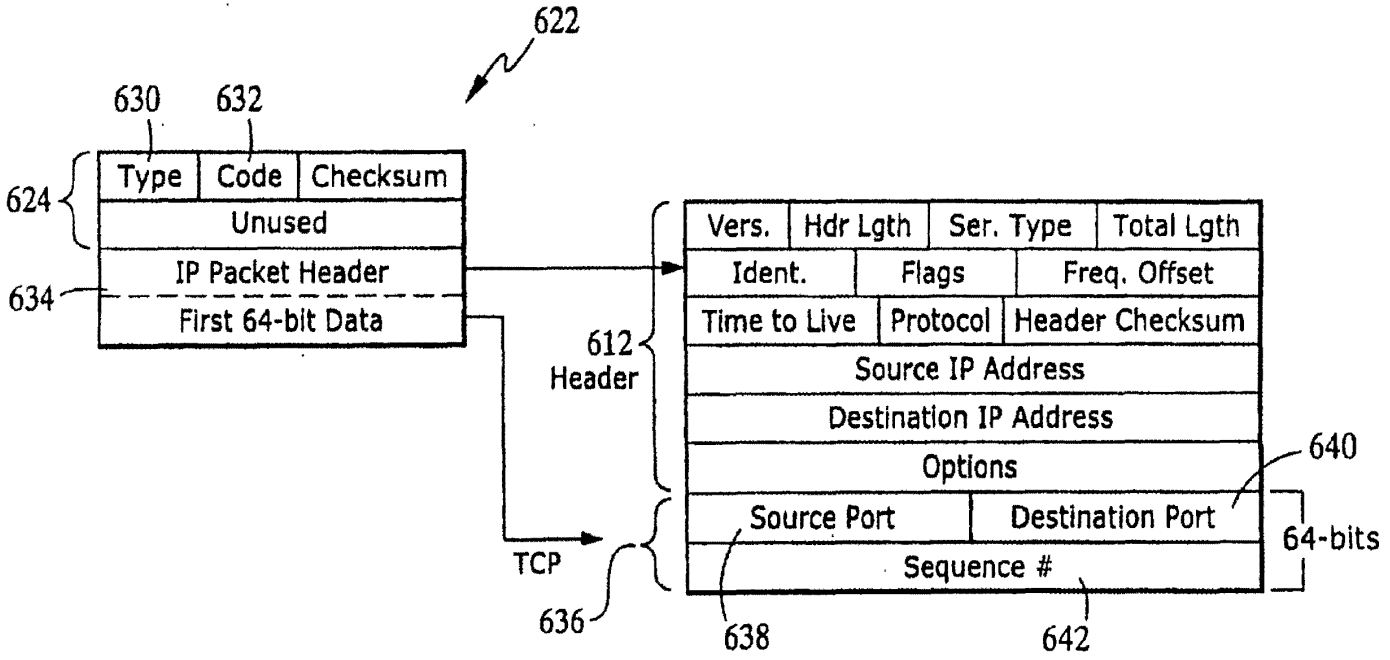

622
630
632
624
Type
Code
Checksum
Unused
IP Packet Header
634
First 64-bit Data
612
Header
Vers.
Hdr Lgth
Ser. Type
Total Lgth
Ident.
Flags
Freq. Offset
Time to Live
Protocol
Header Checksum
Source IP Address
Destination IP Address
Options
640
Source Port
Destination Port
64-bits
TCP
Sequence #
636
638
642

FIG. 26

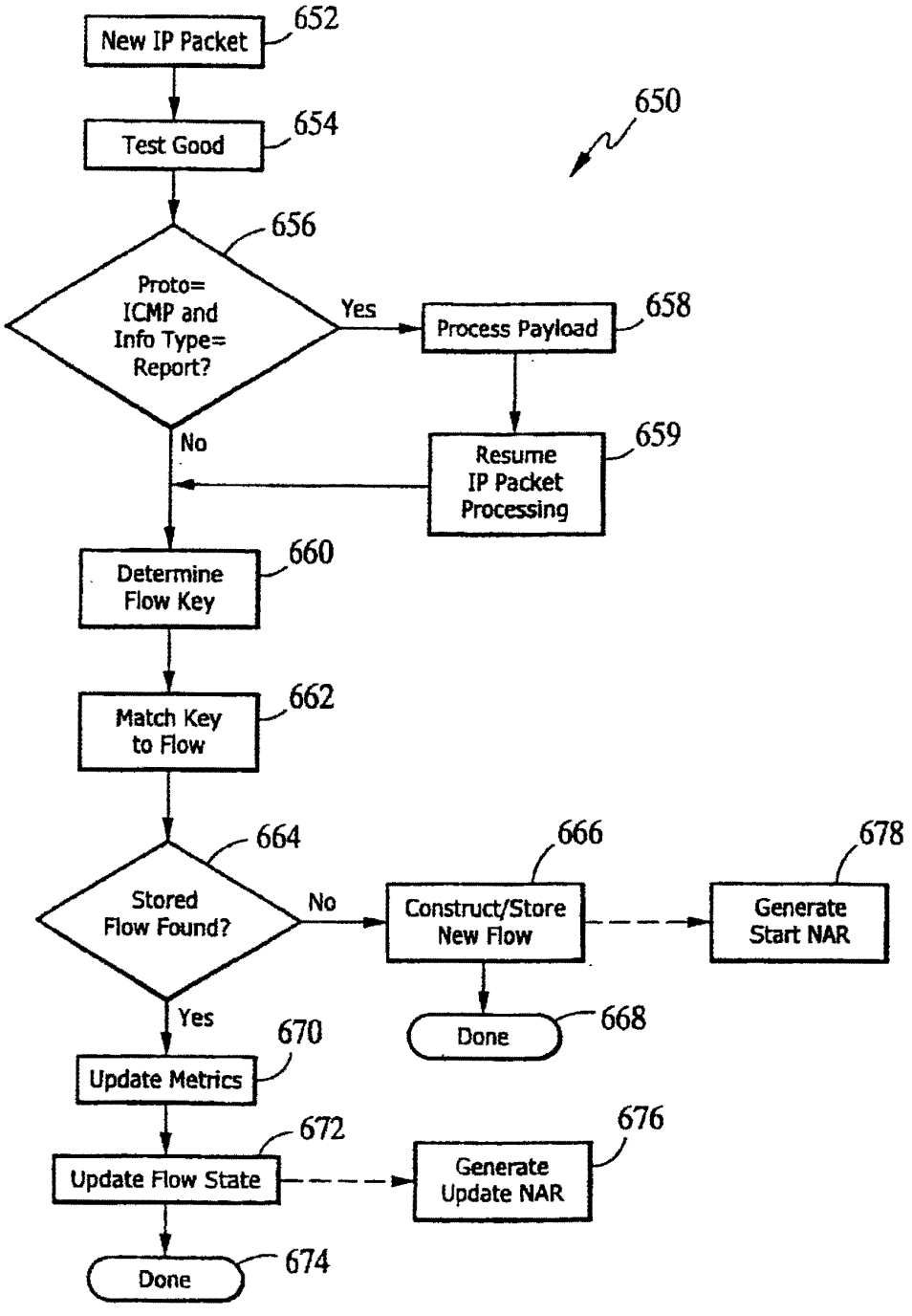

New IP Packet
652
Test Good
654
650
Proto= ICMP and Info Type= Report?
656
Yes
Process Payload
658
No
Resume IP Packet Processing
659
Determine Flow Key
660
Match Key to Flow
662
Stored Flow Found?
664
No
Construct/Store New Flow
666
Generate Start NAR
678
Yes
Done
668
Update Metrics
670
Update Flow State
672
Generate Update NAR
676
Done
674

FIG. 27

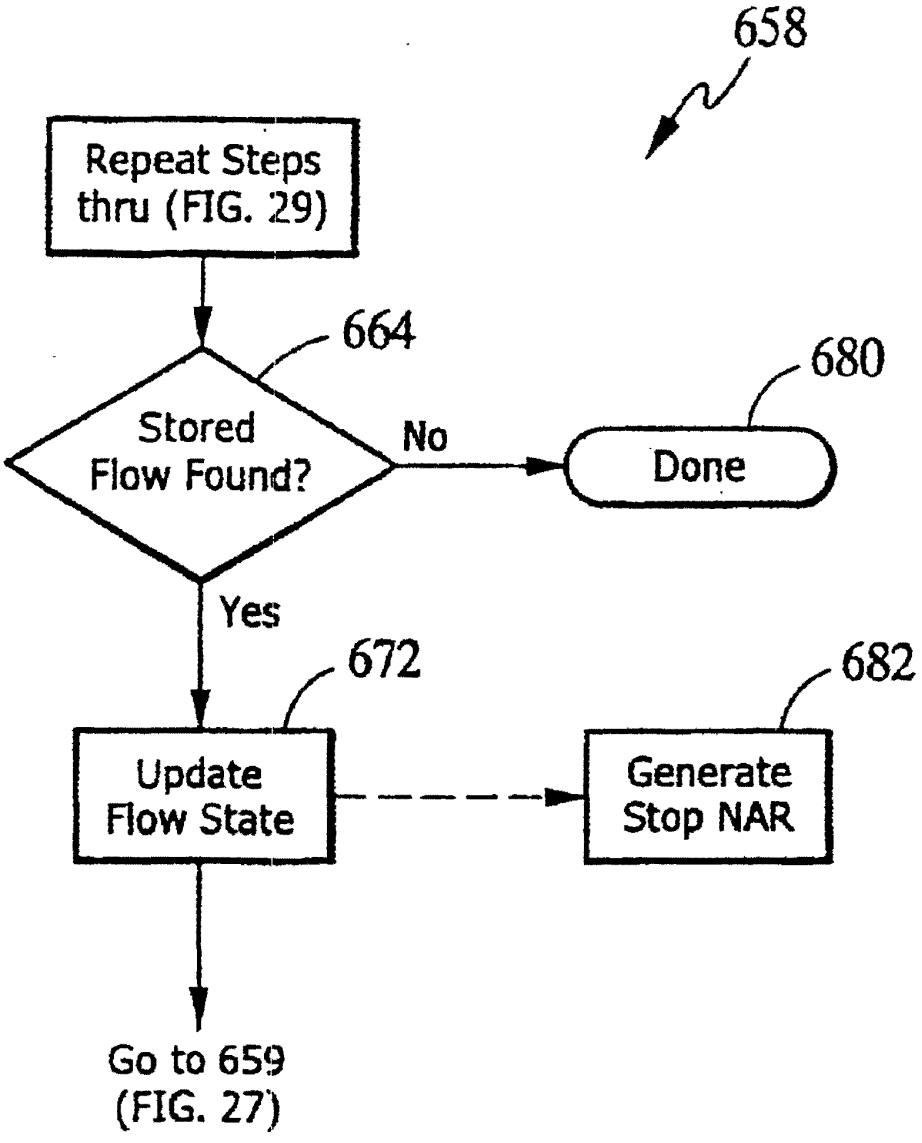

658
Repeat Steps thru (FIG. 29)
664
Stored Flow Found?
No
680
Done
Yes
672
Update Flow State
682
Generate Stop NAR
Go to 659 (FIG. 27)

FIG. 28

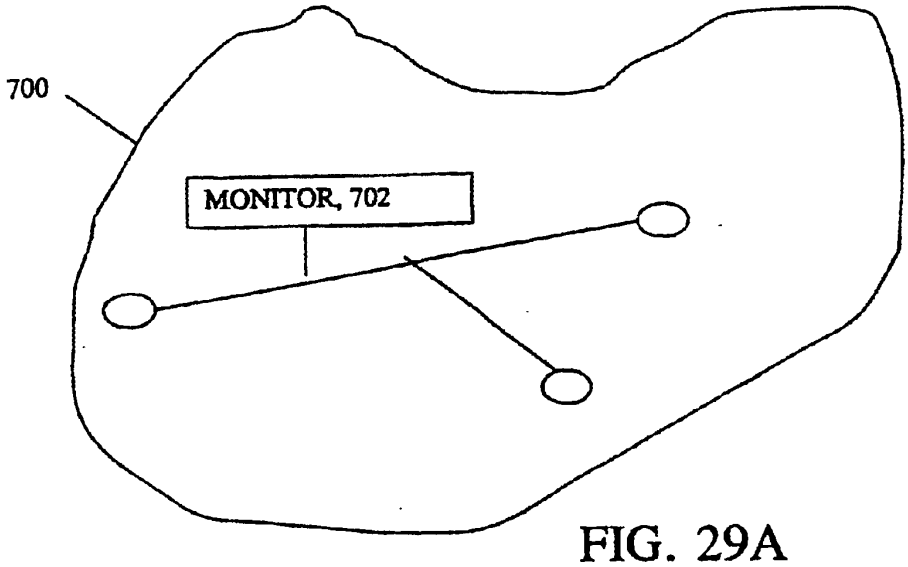


FIG. 29A

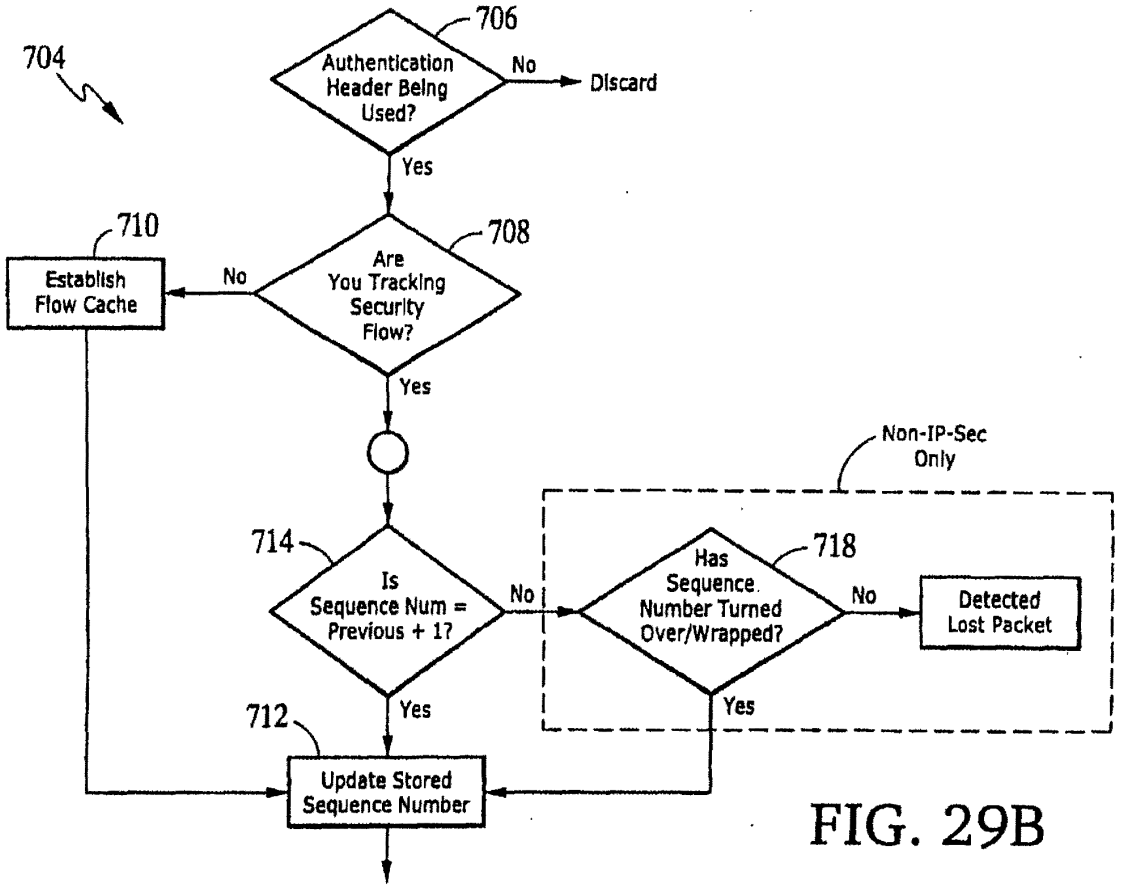

704
706
Authentication Header Being Used?
No
Discard
Yes
708
Are You Tracking Security Flow?
No
710
Establish Flow Cache
Yes
Non-IP-Sec Only
714
Is Sequence Num = Previous + 1?
No
718
Has Sequence Number Turned Over/Wrapped?
No
Detected Lost Packet
Yes
712
Update Stored Sequence Number

FIG. 29B

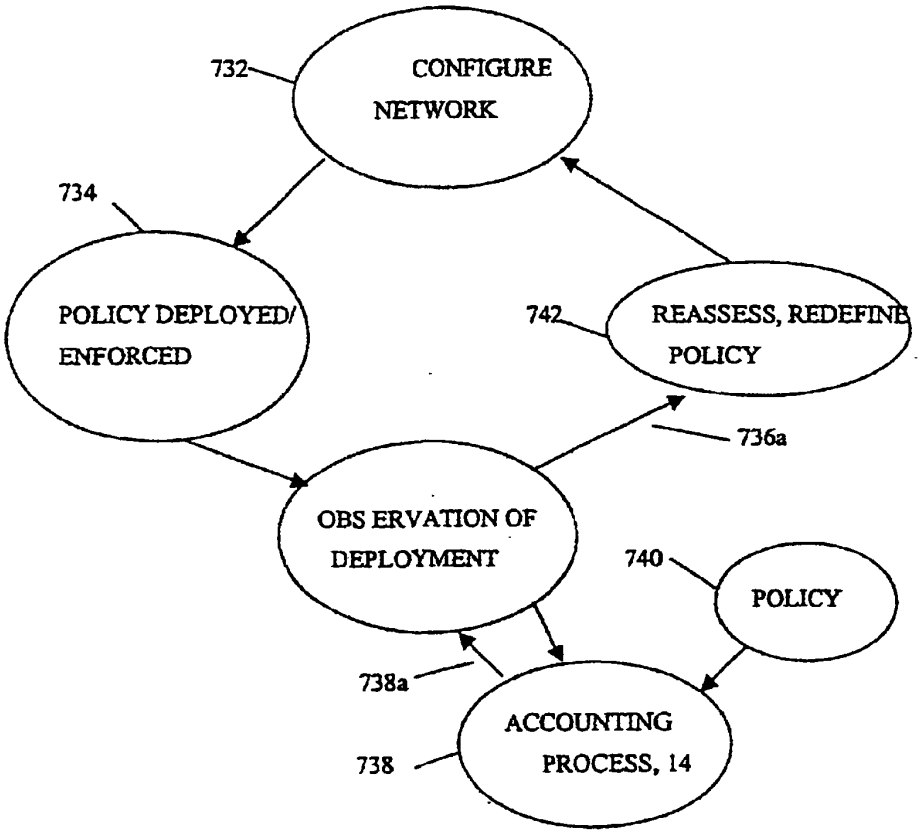

732
CONFIGURE NETWORK
734
POLICY DEPLOYED/ ENFORCED
742
REASSESS, REDEFINE POLICY
736a
OBS ERVATION OF DEPLOYMENT
740
POLICY
738a
ACCOUNTING PROCESS, 14
738

FIG. 30

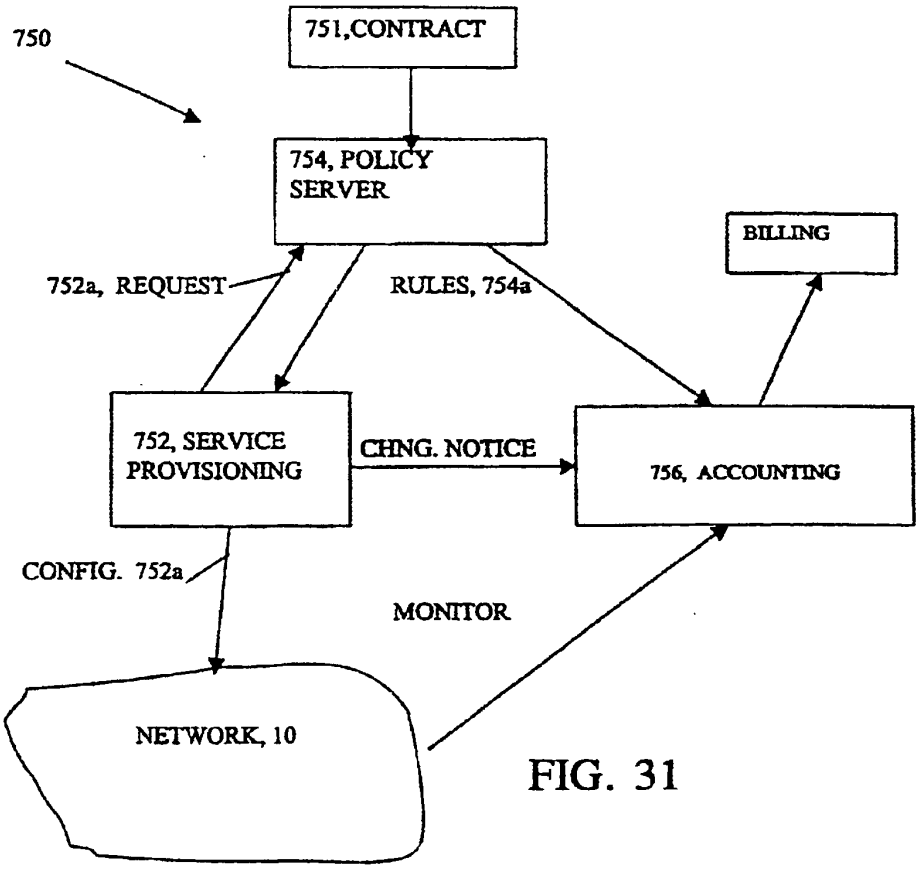

750
751,CONTRACT
754, POLICY SERVER
BILLING
752a, REQUEST
RULES, 754a
752, SERVICE PROVISIONING
CHNG. NOTICE
756, ACCOUNTING
CONFIG. 752a
MONITOR
NETWORK, 10

FIG. 31

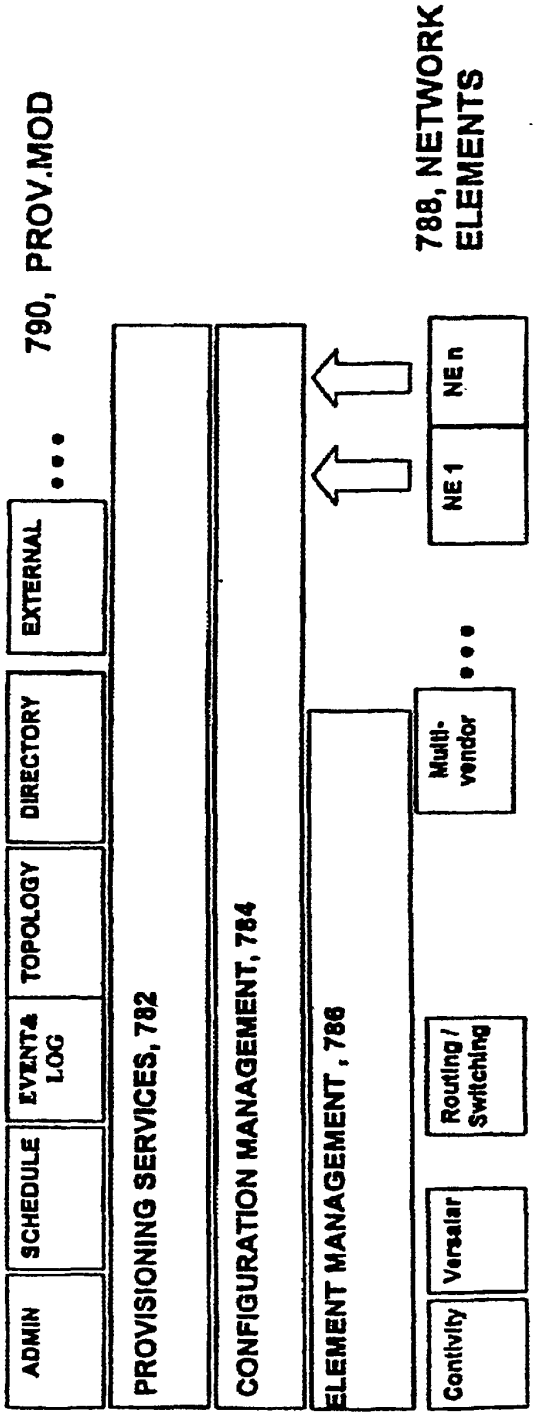

790, PROV.MOD
788, NETWORK ELEMENTS
ADMIN
SCHEDULE
EVENT& LOG
TOPOLOGY
DIRECTORY
EXTERNAL
PROVISIONING SERVICES, 782
CONFIGURATION MANAGEMENT, 784
ELEMENT MANAGEMENT , 786
Cantivity
Versalar
Routing / Switching
Multi-vendor
NE 1
NE n

FIG. 32

SYSTEM FOR REQUESTING MISSING NETWORK ACCOUNTING RECORDS IF THERE IS A BREAK IN SEQUENCE NUMBERS WHILE THE RECORDS ARE TRANSMITTING FROM A SOURCE DEVICE

BACKGROUND

This invention relates to information management for Internet protocol (IP) packet transmission.

Data collection systems are used to collect information from network traffic flow on a network. These data collection systems are designed to capture one type of network traffic from one source type and deliver the data to one application type such as a billing application.

SUMMARY

According to an aspect of the invention, a method for tracking network accounting records in an accounting process that collects and correlates information derived from network data includes producing a network accounting record that has an identifier that uniquely identifies the record within the accounting process with the identifier including a sequence number that specifies a sequence number for network accounting records that originate from the source device and determining when there is a break in the sequence numbers of network accounting records produced from the device. The method also includes requesting missing network accounting records when there is a break in the sequence.

One or more of the following advantage may be provided by one or more aspects of the invention.

The records produced in the accounting system have a sequence number that allows components that are in the next level to detect if there are missing records in a collection of records and can be used to give a sense of how often records are produced in a given time period. With this information being part of every record, an accounting process can determine a sense of the functional capabilities of the intermediate components and detect some aspects of the communication channel between components.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a server running an accounting application monitoring a network.

FIG. **2** is an architectural block diagram of the accounting application used in FIG. **1**.

FIG. **3** is a block diagram of accounting support in an access process used by an Internet/Intranet service provider or a large enterprise.

FIG. **4** is a block diagram of accounting support in an access process used by an Internet/Intranet service provider or a large enterprise using an Extranet switch.

FIG. **5** is graph depiction of a network including data collectors disposed in the network.

FIG. **6** is a flow diagram showing a typical data flow process using an accounting process.

FIG. **7** is a diagram show exemplary network accounting records.

FIGS. **8A–8B**, **9A–9B**, **10**, **11A–11E**, **12** and **13A–13B**, are schematic views of data structures used in network accounting records.

FIG. **14** is a block diagram of a flow data collector system.

FIG. **15** is a flow diagram of the flow data collection process of the flow data collector of FIG. **14**.

FIG. **16** is a block diagram of the flow aggregation processor (FAP).

FIG. **17** is a flow diagram of the flow aggregation process performed by the FAP of FIG. **16**.

FIGS. **18–20** are examples of the FAP enhancement and aggregation portions of the flow aggregation process shown in FIG. **17**.

FIG. **21** is a hierarchical representation of an aggregation adjustment scheme for adjusting the aggregation activity at the levels of the flow aggregation processor and the data collectors.

FIG. **22** is an example of a configuration file update for aggregation (policy) adjustment.

FIG. **23** is a flow chart of an information management process.

FIG. **24** is a representation of a network communications path between two end stations in a network.

FIG. **25** is an illustration of an ICMP message encapsulated in an Internet Protocol (IP) packet and the formats of the ICMP message and the IP packet.

FIG. **26** is an illustration of the format of an ICMP error reporting message header and datagram prefix.

FIG. **27** is a flow probe IP packet processing mechanism.

FIG. **28** is the payload processing/protocol correlation of the IP packet processing mechanism of FIG. **26**.

FIGS. **29A–29B** are diagrams depicting a protocol independent, packet loss detection monitor.

FIG. **30** is a diagram depicting a process to capture quality of service.

FIG. **31** is a diagram of a service management process.

FIG. **32** is a diagram showing an architecture of a service provisioning application.

DETAILED DESCRIPTION

Architecture

Referring now to FIG. **1**, an exemplary arrangement **10** for collecting information from a network is shown. The network includes various network devices **12**. The network devices **12** can be disparate, i.e., different equipment types, operating under different protocols and formats. The network devices **12** are coupled to an accounting process **14** via an equipment interface **16**.

The accounting process **14** includes a flow data collection layer **18** that runs as client processes with the equipment interfaces on or close to the network devices **12**. Individual and multiple data collectors (not referenced) can be disposed at points of presence (POP) in a network **11**. The accounting process **14** includes a flow aggregation and distribution process **17** that runs as a server process on a server **15**. The accounting process **14** assembles the data into a format that can be used by billing or other user defined data consuming applications **20** that interface to the accounting process **14**, through a data consuming application interface **22**. Thus, the accounting process **14** collects via the data collector layer **18** multiple and diverse types of data from the network **11**, normalizes the data into a consistent accounting record, and provides open interfaces to one or more applications, such as billing via the application interface **22**.

The network devices **12**, e.g., switches, routers, remote access concentrators, and so forth can produce data of various types and formats which are all handled in the accounting process **14**. Examples of the network devices **12** include a router or switch **12***a*, cable or telephone modems **12***b*, a flow probe **12***c*, a remote access concentrator **12***d* an Extranet switch **12***e*, a directory naming service (DNS)

server 12*f*, a RADIUS server 12*g* and web server 12*h*. One particular source of data, the flow probe 12*c* will be described below in conjunction with FIGS. 24–28. The network devices 12 can include a "Remote Authentication Dial-In User Service" (RADIUS) server 12*g* that produces RADIUS accounting records using an existing RADIUS accounting process (not shown). The accounting process 14 can interface to the existing RADIUS accounting process and can use existing RADIUS records without modifying the existing RADIUS accounting environment. RADIUS is a well-accepted standard in the industry and is used across a number of different types of technologies (dial-in, cable, DSL, VOIP, etc.), with the most prominent being dial-in access. So, by supporting RADIUS records the accounting process 14 provides the ability to fit into an existing network environment without modification.

The accounting process 14 enables users such as an Enterprise or an Internet Service Provider to maintain an existing accounting configuration. Information sources can include network traffic flow, RADIUS accounting data, RMON/RMON2 data, SNMP-based data, and other sources of network usage data. The accounting process 14 collects data via the data collector layer 16 from multiple disparate sources and produces new type of composite records. These new composite records results is new information which provides a source for network accounting, billing, management, capacity planning, and so forth.

The accounting process 14, as will be described in FIG. 2, has a core process that can handle data records from each of the equipment types above, as well as other equipment types, and can provide data to each of the plurality of user-defined data consuming applications. This accounting process 14 provides flexibility in choosing data consuming applications that use accounting data. Such applications can include billing, enterprise charge-back or cost allocations, capacity planning, trending, application monitoring, user profiling and so forth.

Accounting Architecture

Referring now to FIG. 2, the equipment interface layer 16 of the accounting process 14 includes various equipment interfaces 42*a*–42*i* which are, respectively, an interface 42*a* for the router/switch 12*a*, an interface 42*b* for the cable/modem head end 12*b*, and an interface 42*c* for the flow probe 12*c*. The equipment interface layer 16 also includes additional interfaces such as an interface 12*d* for a remote access concentrator 12*d*, an interface 12*e* for an Extranet switch 12*e*, an interface 42*f* for a DNS server 12*f*, and an interface 42*g* for a RADIUS server 12*g*. The equipment interface can have additional interfaces that can be specified, as new equipment is added. The interfaces 42*a*–42*g* can be developed by an interface toolkit 44. The interface toolkit 44 permits a user to construct a new equipment interface type to couple the accounting process 14 to a new equipment source type.

The accounting process 14 also includes a data collector layer 18. The data collector layer 18 is a distributed layer comprised of individual data collectors, e.g., 52*a*–52*g*. The data collector layer 18 collects data in the form of raw accounting information specific to the device type. The data collector collects data via the aforementioned equipment interfaces 42*a*–42*g*. The data collectors 52*a*–52*g* collect the data and convert data into normalized records herein referred to as Network Accounting Records (NARs). Each of the data collectors 52*a*–52*g*, as appropriate, forwards network accounting records (NARs) to a flow aggregation process 60.

The data collectors 52*a*–52*g* support several different collection models. For example, the data collectors 52*a*–52*g* can support a so-called "push model" in which a connected device initiates a transmission of data to the accounting process 14. The data collectors 52*a*–52*g* also can support a "pull model" in which the accounting process 14 initiates a connection to an equipment interface for the purpose of obtaining data. In addition, the data collectors 52*a*–52*g* can support an "event driven model" in which an event that occurs in either the equipment interface layer 16 or in the accounting process 14 initiates a transfer based on some threshold or criteria being met by the equipment layer 16 or accounting process 14 within which the event occurred.

The data collectors 52*a*–52*g* are distributed throughout the network. The data collectors 52*a*–52*g* are placed close to or within the network device that the collector is assigned to. That is, the data collector can be in-line or out-of-line relative to the device monitored. The data collectors 52*a*–52*g* can be anywhere. The data collectors 52*a*–52*g* can be completely uncoupled from the devices except for communication paths. As new network devices 12 are added to the accounting support arrangement 10, new data collectors are also deployed.

The accounting process 14 also includes a flow aggregation process 60 that is part of the aggregation and distribution process 17 (mentioned above). The flow aggregation process 60 is a central collection point for all network accounting records (NAR's) produced from various data collectors 52*a*–52*g* in the data collection layer 18. The flow aggregation process 60 receives NAR's from various data collectors 52*a*–52*g* and aggregates, i.e., summarizes related information from the received NARs across the accounting support arrangement 10. The aggregation layer 60 produces Summary NAR's i.e., enhanced and unique network accounting records. That is, the flow aggregation process aggregates the records across the network devices; whereas, individual data collectors 52*a*–52*g* can aggregate accounting records from individual data sources. Aggregation will be described below in FIGS. 14–23.

The accounting architecture also includes a data distributor layer 70 (part of the aggregation and distribution process 17). The data distribution layer 70 provides a flexible data distribution mediation between the flow aggregation process 60 and a user-defined application, via an application interface layer 22. Data distributor layer 70 presents information to the application interface layer 22, with a pre-defined format, protocol and schedule that is determined by requirements of a user application. The data distributor layer 70 can support push, pull and event driven data distribution models. The application interface layer 22, is comprised of individual application interfaces 82*a*–82*g* that are provided by the toolkit 44. The toolkit 44 as with the network device interfaces 42*a*–42*g* can be used to produce additional application interfaces 82.

Exemplary Configurations

Referring now to FIG. 3, the accounting process 14 can, in general, support any configuration. Exemplary configurations used by an Internet service provider 100, an Enterprise A that host its own remote access 110, and an Enterprise B that uses the Internet service provider 120, are shown.

As shown in FIG. 3, for the Internet service provider, data collectors 52*a*–52*d* are distributed at specific Points of Presence (POP), such as remote access concentrators 102 managed by the Internet service provider. The remote access concentrators allow, a mobile user 106 or an Internet user 107 with remote access to access an enterprise over the Internet, via the Internet service provider. In this example the Internet service provider arrangement 100 and the large

Enterprise arrangements **110** and **120** include servers **13**, **13'**, and **13"** that run accounting processes **14**, **14'** and **14"**. The accounting processes **14**, **14'** and **14"** each independently manage and collect information regarding network traffic usage.

The Internet service provider arrangement **100** includes the accounting server **13** that runs the accounting process **14**. The accounting process **14** includes a flow data collector layer **18** that gathers data from the service provider network **100**. The flow data collector layer **18** includes distributed, individual flow data collectors **52***a*–**52***d*. The distributed, flow data collectors **52***a*–**52***d* collect transaction specific details about a user's connection type and actual network usage. These data are converted into the NARs in the distributed, flow data collectors **52***a*–**52***d*, as mentioned above. The NARs are aggregated over the entire system by the flow aggregation layer **60** (FIG. 2).

Data is made available to the Internet service provider via the data distribution layer (FIG. 2) so that the Internet service provider can analyze data in order to differentiate service offerings to different users. The Internet service provider can evaluate and use such detailed accounting data collected from various sources to migrate from a single flat rate fee business model to more flexible charging. For example, analysis of the data can enable the Internet service provider to develop new service options that can take into consideration bandwidth usage, time of day, application usage and so forth. In addition, Internet service providers can offer discounts for web hits that may exist in an Internet service provider cache, thereby minimizing the need to look up an address for a requested site on the Internet and can provide free E-mail usage while charging for other types of applications such as file transfer protocol and web traffic.

The data can also be used by other applications such as network planning, security, auditing, simulation, flow profiling capacity planning and network design and so forth. Thus, the Internet service provider can independently monitor and evaluate network traffic caused by remote employees and mobile users, for example.

Similarly, other instances **14'**, **14"** of the accounting process can be used by enterprises, as also shown in FIG. **3**. For example, an enterprise may host its own remote access, as shown for Enterprise A and would include a server **13'** running an accounting process **14'**. An enterprise could use the Internet service provider as shown for Enterprise B, and still have a server **13"** running an accounting process **14"**. The accounting process **14'**, **14"** includes an associated data collector that is coupled to enterprise A and enterprise B local area networks or other network arrangement. In this model, the enterprises use data from the accounting process **14'**, **14"** for enterprise charge-back functions such as billing departments for Internet usage within the enterprise and so forth.

Different instances of the accounting process are used by both the Internet service provider and enterprise A and Enterprise B sites. The instances **14**, **14"**, **14"** of the accounting process are independent they do not need to exchange accounting data. Rather, they exist as separate, independent accounting domains.

Referring now to FIG. **4**, a similar access configuration **100'**, as the configuration **100** (FIG. **3**) can be used with an Extranet switch **122**. Extranet access allows remote users to dial into an Internet service provider (ISP) and reach a corporate or branch office via an ISP. The Extranet switch allows Internet users access to corporate databases, mail servers and file servers, for example. It is an extension of the Internet in combination with a corporate Intranet. In this configuration, the Extranet switch **122** can be owned and operated by an Internet service provider as shown with enterprise A, or it could, alternatively, be owned and operated by an enterprise, as shown with enterprise B. Users would access the corporate network of either enterprise A or enterprise B, via the Internet service provider with various types of tunneling protocols such as L2TP, L2F, PPTP or IPSec, and so forth. The accounting server **13** located at the service provider and also accounting servers **13'**, **13"** within enterprise A and enterprise B allow each the Internet service provider and each of enterprises A and B to run accounting process **14'**, **14"** on the servers **13'**, **13"** to monitor and collect network data.

Transaction Flow Model

Referring now to FIG. **5**, a graph **140** depiction of a very large scale network includes a device "A" **142** communicating with a device "B" **144**. The graph **140** includes nodes (not all numbered) that can represent routers, switches, flow probes, etc. that have interfaces (not shown) which maintain statistics on information passed through the interfaces. For example, a switch may have a number of Ethernet ports and a host could be connected to one of the ports and in communication with one of the interfaces to transfer information over the network. The interface would have counters that are used to track "packet's in, "packet's out", "bytes in, bytes out", and so forth.

In this case of the host connected to the port, or a router or some other device being connected to the port, there is no other connection that the host, router or other device is aware of other than the entire network. This is an example of a "connectless oriented" protocol. A data collector **52** can be disposed in the network in a path between the entities "A" and "B", such that the data collector **52** monitors some of the packets that comprise a flow between "A" and "B." As a single point monitor, the data collector has no concept that there are two ends communicating. The data collector **52** identifies these entities "A" and "B" in various NARs produced by the data collector **52**. At later stage in the processing, either in the data collector **52** or elsewhere in the accounting process **14** the NARs are correlated so that the NARs or some aggregated NAR produced by the data collector **52** or the rest of the accounting process **14** can be associated with the accountable entities "A" and "B" to thus identify a connection between entities "A" and The data collectors **52***a*–**52***g* (FIG. 2) develop a description of the connection. For a router, normally an address of the object that is connected to that interface might serve as an address. A switch has an IP address that can be used as the destination. The actual device that is connected to the switch or router can be used as an accountable object. Although the traffic is not destined for the router, the data collector can use those identifiers as keys to the endpoints "A", "B."

In many cases, the protocol can explicitly determine connections. For example, the TCP/IP protocol is explicitly a "connection oriented" protocol used in the Internet. When the data collector **52** needs to determine a connection, the data collector **52** can exploit the "connection oriented" nature of certain types of protocols such as the TCP/IP protocol. When the data collector **52** tracks a TCP/IP connection, the data collector **52** can determine exactly that A and B are connected, when the connection starts, stops, and updates. With other protocols such as a "connectionless" protocol, and even in some complex environments such as a virtual private network or a proxy server, the data collector **52** does not necessarily know the real endpoints. The data collector **52** only knows that some entity is talking to some other entity.

Thus, the data collector **52** is a single point monitor, that monitors traffic at one point in the network and converts the traffic into a "pipe oriented" or "flow oriented" accounting information. The data collector **52** identifies a source and a destination of the traffic. That is, the data collector develops a "connection oriented tracking." By distributing data collectors **52***a*–**52***g* (FIG. **2**) through out the network the network can be modeled as pipes having two endpoints. A data collector can be disposed in a partial pipe. The data collector **52** determines that one end of the pipe refers to "A" and the end of the pipe refers to "B." The data collector **52** can be disposed anywhere along the network.

The graph **140** represents the network as a directed graph, including partial segments. The endpoints of those partial segments can act as proxy entities to the actual accountable objects. Once independent accounting records that relate to these two entities A and B are aggregated in the accounting process **14**, the accounting process **14** can identify that A and B are connected and have particular metrics.

Some equipment have a half pipe model that generate independent accounting records for each half pipe. The data collectors can assemble full pipe information from half pipe information. The accounting process could be coupled to equipment that gives a half pipe model for A communicating with B and a separate one for B communicating with A. The data collectors **52***a*–**52***g* combine information from these two half pipes into a bidirectional flow.

Referring now to FIG. **6**, an example of data flow **130** through the accounting process **14** is shown. In this example, data flow is initiated by a user **131** making a call to a remote access concentrator (RAC) **132**. Upon receiving the call, the RAC **132** authenticates the user against a secure access controller **134**. After verification, the RAC **132** connects the user to the network **135** and sends a RADIUS Start record (not shown) to the accounting process **14**. The accounting process **14** generates a RADIUS Start NAR **137***a* and stores the RADIUS start NAR in a database **62**. At that point, the remote user may check e-mail, look at a web server and transfer a file. For each transaction, the accounting process **14** captures the IP traffic, generating a e-mail, http, and ftp network accounting records **137***b*–**137***d*, respectively. These are stored in the database **62**. Upon completion of these transactions the user would log out of the network, at which time the RAC would send the accounting process **14** a RADIUS Stop record. The accounting process **14** generates a RADIUS Stop NAR **137***e* and stores the RADIUS stop NAR in the database **62**. All of these records reflecting the user's transactions could be viewed and reported in flexible ways dependent on the needs of an end-user application.

Network Accounting Records (NARs)

The data collector **52** translates collected information into network accounting records (NARs). A NAR includes a header, an accounting entity identifier and metrics. The network accounting record (NAR) is a normalized data record that contains information about a user's network usage activity.

Referring now to FIG. **7** a base level "activity" NAR that includes source, destination, protocol, source port, destination port, byte and packet counts, etc. The base level activity NAR can be combined and aggregated in many different and flexible ways to support various accounting functions. The NAR is an activity record corresponding to some level of detail. Detail can vary based on the level of aggregation being applied, in accordance with the needs of the end-user/application.

FIG. **7** has at one level **152** a plurality of exclusively "Activity NARs" which could correspond to a very low level of detail, or could be the result of a prior aggregation providing a higher level view of the information. Thus, FIG. **7** shows a collection **152** of exclusively activity NARs. From base level data, additional "views" of the NAR could be produced, such as a set of "Summary NARs" **154**, or another set of Activity NARs **156** which could be a result of further aggregation of the base level information, or lastly a combination of a set of Summary NARs and Activity NARs **158**. The summary NAR is produced by the central aggregation layer **60** and can include user identifying information, protocol information, connection time information, and data information, and so forth.

The specifics of what can be combined and aggregated will described below. Thus, the accounting process **14** use of NARs provides the ability to combine and aggregate base level activity information in a flexible way to meet the specific needs of the end-user/application.

TABLE 1 below corresponds to the fields that can be captured in a NAR. This is essentially the activity NAR. The NAR contains these fields, which can then be combined and used to form other activity NARs or summary NARs.

Column Name	Description
OSA_SOURCE_TYPE	List all of the possible data sources from which data can be collected. Reference to OSA_SOURCE_TYPE TABLE.
OSA_SOURCE_SERIAL_NUM	Number which uniquely identifies an OSA FDC.
START_TIME_SEC	Indicates the date and time at which a record was recorded.
START_TIME_USEC	Microseconds component of START_TIME_SEC.
SEQUENCE_NUMBER	Sequence number assigned by the source of the NAR to uniquely identify the record and ensure integrity.
USER_NAME	The user associated with the record.
EVENT	Event type of the record (i.e. Start, Stop, Update).
SESSION_ID	Unique Accounting ID to make it easy to match start and stop records.
SESSION_TIME	Duration of the record in seconds.
SESSION_TIME_USEC	Microseconds component of the SESSION_TIME.
SRC_ADDR	Source address of the record.
DST_ADDR	Destination address of the record
PROTO	Protocol of the record. Reference to OSA_PROTOCOL_TYPE table.
SRC_PORT	Source port number.
DST_PORT	Destination port number.
SRC_OCTETS	Number of bytes transmitted into the network by the source. For RADIUS is equivalent to Acct-Input-Octets.
DST_OCTETS	Number of bytes sent out of the network, to the source. For RADIUS is equivalent to Acct-Output-Octets.
SRC_PKTS	Number of packets transmitted into the network by the source. For RADIUS is equivalent to Acct-Input-Packets.
DST_PKTS	Number of packets transmitted out of the network, to the source. For RADIUS is equivalent to Acct-Output-Packets.
SRC_TOS	The Type of Service coding marked by the source.
DST_TOS	The Type of Service coding marked by the destination.
SRC_TTL	The Time To Live field set by the source and modified by the network until the Nortel flow probe recorded it.
DST_TTL	The Time To Live field set by the destination and modified by the network until the Nortel flow probe recorded it.

-continued

Column Name	Description
OSA_CAUSE	A number that indicates the reason the accounting record was generated.
OSA_STATUS	A value used to indicate the status of an accounting record when it was created.
ACCT_DELAY_TIME	Indicates how many seconds the client has been trying to send this record
ACCT_AUTHENTIC	Indicates how the user was authenticated.
ACCT_TERMINATE_CAUSE	Indicates how the session was terminated
ACCT_MULTI_SESSION_ID	Unique Accounting ID to make it easy to link
ACCT_LINK_COUNT	Indicates the count of links which are known to have been in a given multilink session at the time the accounting record is generated.

The summary NAR and activity NAR have a one-to-many relationship. That is, while there can be a single summary NAR for a particular user over a particular call that will contain information about the sum of usage of network resources over the duration of the call, there can be many activity NARs. The activity NARs capture details about the actual activity and applications being used during the call. The summary NAR, therefore, depicts the total expense of the transaction or a set of transactions on a network, whereas, the activity NARs depict expenses of a transaction at any point in time. The summary NAR is generated in the flow aggregation process **60**, as will be described below. In essence, the summary NAR is generated from individual activity NARs correlated in the data collectors **52***a*–**52***g*, as will be described below.

A NAR is a member of a generic data message set that is used to transport data, such as network accounting data, through the accounting process **14**. These system data messages include "Status Event", "Maintenance Event", "Trace Event", "Network Accounting Record". Accounting process **14** messages share a common MSG_HDR structure that is used to discriminate between the four types of accounting process **14** messages. The Message Header (MSG_HDR) includes Message Type, an Message Event and Cause, and Message Length.

Network Accounting Record Data Structures

As will be described below, the NAR is unique within the accounting process **14**. The NAR has a NAR_ID that specifies an accounting process component ID. The component ID specifies the data collector assigned to a particular network device that produced the NAR. The component ID e.g., NAR_SRC_ID **203***a* (FIG. 8B below) is allocated at the time that the component is produced. The NAR_ID also includes a time stamp at the second and microsecond level so that the accounting process **14** can discriminate between multiple NARs generated by a particular component. A sequence number, e.g., 32 bits is also used to differentiate NARs from the same accounting process component that may have the same time stamp. The sequence number e.g., NAR_SEQ_NUM **203***c* (FIG. 8B) is preferably a monotonically increasing number starting from, e.g., 1. As long as the component is functioning, and producing NARs, the component provides a new sequence number to a new NAR.

Referring now to FIGS. 8A–8C, a Network Accounting Record (NAR) data structure **200** is shown.

As shown in FIG. 8A, the NAR data structure **200** includes two basic accounting objects, a Network Accounting Record Identifier **202**, and optionally one or as shown a plurality of Network Accounting Record Attributes **204***a*–**204***n*, generally denoted as **204**. The Network Accounting Record Identifier **202** has a set of object identifiers that uniquely identifies the network accounting record within the accounting process **14**.

The Network Accounting Record Identifier **202** acts as a database key value that makes the NAR **200** unique within the entire accounting process **14**. The Network Accounting Record Identifier **202** allows the NARs to be handled and managed using database functions such as database integrity analysis and reliability analysis. The Network Accounting Record Identifier **202** also gives the accounting process **14** the ability to track the source of NARs and to build mechanisms such that the accounting process **14** can maintain identity of the origination of NARs throughout the system **10**.

The plurality of Network Accounting Record Attributes **204***a*–**204***n* provide metrics for the NAR **200**. The Network Accounting Record Attributes **204***a*–**204***n* capture specific information contained in data from network devices. Differentiating between the entity identifier **202** and the metric **204** allows the accounting process **14** to perform logical and arithmetical operations on metrics **204** while leaving the accounting identifier intact **202**. The accounting identifier **202** can be enhanced unlike the metrics.

The data collectors **52***a*–**52***g* (FIG. 2) are oriented around the process of filling in the NAR. The metrics are left untouched by the data collector and are passed transparently into the accounting process flow aggregation process **60**. The data collectors **52***a*–**52***g* assign the accounting entity identifiers **202** to the metrics e.g., a source and a destination identifier to the metric. In the example of a router link, the metrics that the router interface provides are in the form of "information in" and "information out" e.g., octets in, octets out, bytes in, bytes out datagrams in, datagrams out, faults in, faults out, and so forth. The data collectors **52***a*–**52***g* determine what "in" and "out" means and assigns the unique identifier that is unambiguous relative to the determined meaning of "in" and "out." Once a data collector **52** has established this convention, the convention is used throughout the system **10**.

Thus, the NAR Identifier **202** provides database constructs to a NAR, whereas, the plurality of Network Accounting Record Attributes **204***a*–**204***n* provide the actual metrics used for network activity reporting and network accounting.

As shown in FIG. 8B, the Network Accounting Record Identifier **202** (NAR_ID) is a set of objects within the NAR that uniquely identifies the NAR throughout the accounting process **14**. The NAR_ID **202** is designed to support a number of properties of a NAR including flexibility, accountability, reliability and uniqueness. In order to provide these properties, the NAR_ID **202** is divided into objects designed to specifically provide these properties. Flexibility is supported through a NAR_HDR **203** section of the NAR_ID. Accountability is attained in the NAR through explicit identification of the source of the NAR by a component identification NAR_SRC_ID **203***a*. The source time is maintained in a NAR_SRC_TIME **203***b*. Reliability is supported, as described above, through the use of a NAR sequence number (NAR_SEQ_NUM) **203***c*, which is designed to enable traditional database integrity mechanisms.

The NAR_ID **202** is used to provide uniqueness for each NAR. The responsibility for guaranteeing the uniqueness of each NAR is handled by every accounting process compo-

nent that has the ability to originate/source network accounting records. This responsibility requires that each accounting process component have the ability to unambiguously identify itself in each NAR that it produces. Thus, NAR type identifier, NAR_TYPE, is comprised of the source component identifier, NAR_SRC_ID, the NAR source time, NAR_SRC_TIME, and the NAR sequence number, NAR_SEQ_NUM. These three data objects act as a database key for a particular network activity record, ensuring the uniqueness of the NAR throughout the entire system.

The NAR_SEQ_NUM can have several purposes. One way that the NAR_SEQ_NUM can be used is as a discriminator when two NARs are produced at the same time. A second way that the NAR_SEQ_NUM is used is as a monotonically increasing index to ensure database integrity. Because the NAR_ID is unique, it should be considered as an allocated value. A NAR_ID is allocated at NAR origination.

If a component creates or modifies the contents of an existing NAR, as for example when aggregating two NARs together, the component originates the NAR_ID. This provides an opportunity for the accounting process **14** to have explicit internal integrity mechanisms that can account for any network accounting record that is processed by the accounting process **14**.

The NAR Source Identifier NAR_SRC_ID **203***a* includes a source type **207***a* and a Source Serial Number **207***b*. The serial number **207***b* is an administratively allocated value e.g., 24-bits that uniquely identifies the NAR source type throughout the accounting process **14**. The source serial number **207***b* should be unique within the specific accounting domain.

The (NAR_SEQ_NUM) **203***c* is a monotonically increasing, e.g., unsigned 32-bit integer that acts as a sequence number for NARs that originate from a particular NAR source. Because the value of the NAR_SEQ_NUM can "wrap around", the combined 64-bit value NAR_SRC_ID and NAR_SEQ_NUM are unique only over a specified time period.

Referring now to FIGS. **9A–9B**, exemplary formats for Network Accounting Record Attributes **204** are shown. There are two variations on a single NAR_ATTRIBUTE format that can be used. As shown in FIG. **9A**, a standard NAR_ATTRIBUTE format **206***a* includes header fields NAR_ATTR type, NAR_ATTR Code, NAR_ATTR Qualifier, and NAR_ATTR Length and a "value field." In order to conserve the size of accounting information, when the size of the value of the NAR_ATTRIBUTE is a byte i.e., 8-bits, as indicated in the NAR-ATTR Qualifier field, the format **206***b* of the NAR_ATTRIBUTE can be as shown in FIG. **9B**, including fields NAR_ATTR type, NAR_ATTR Code and an 8-bit NAR_value field.

Each supported object is assigned an NAR_ATTR Code. Through the NAR_ATTR Code, the accounting process **14** can distinguish the semantics of a particular NAR ATTRIBUTE. Although NAR_ATTR Codes are specific to the NAR_ATTR Type, the NAR_ATTR Code assignments can be unique to aid in implementation. Values can be assigned to provide some explicit hierarchical structure. Each NAR_ATTR has an 8-bit NAR_ATTR Qualifier that provides typing information for the NAR_ATTR. The NAR_ATTR Qualifier is used because some supported objects can be represented using several different types. Counters, for instance can be 32-bit as well as 64-bit, in the case of aggregated objects. Network identifiers may use numeric indexes, or strings as labels. The NAR_ATTR field specifies the length of the NAR attribute including the NAR_ATTR header.

There are five types of Network Accounting Record Attributes that are supported in the NAR. The five attributes are Accounting Time Interval (ACCT_TIME) (FIG. **10**); Accounting Entity Identifier (ACCT_ENTITY_ID), (FIGS. **11A–11E**); Accountable Entity Descriptor (ACCT_ENTITY_Desc); Network Activity Metrics (NET_METRICS)(FIG. **12**); and two Transparent Attributes (TRANS_ATTR)(FIGS. **13A–13B**). As necessary, additional NAR_ATTRIBUTES can be supported. For example, a NAR_ATTRIBUTE type could also include Security Attributes for accounting data to protect against unauthorized introduction or modification of accounting information.

Referring now to FIG. **10**, an Accounting Time Interval record includes a value "seconds" and a value "micro second". The values of "seconds" and "micro seconds" together represent a time stamp of network activity for the NAR, as discussed above. When derived from an absolute time value that represents the end of the accounting time interval, the Accounting Time Interval is the duration, as calculated using the Accounting Time Interval as the starting time value. All Network Accounting Records can have an Accounting Time Interval attribute.

Referring now to FIGS. **11A–11E**, Accountable Entity Identifier data structures are shown. The Accountable Entity Identifiers are a collection of entity description attributes that together identify an accountable entity in the accounting process **14**. The accounting entity identification mechanism facilitates flexible NAR aggregation properties of the accounting process **14**. The ACCT_ENTITY_ID is the description of an accounting object within the accounting process **14**. There can be one or more ACCT_ENTITY_IDs in a given NAR, but there must be at least one ACCT_ENTITY_ID in an Network Accounting Record. The actual accountable object is defined by the entire collection of ACCT_ENTITY_IDs that are included in the NAR.

In transaction based accounting, a network accounting record will contain two ACCT_ENTITY_IDs, representing the source and the destination entities that are involved in the network transaction. For traditional flow based accounting, these would normally be the two network addresses that are involved in the flow. Qualifiers are available in the ACCT_ENTITY_ID objects to indicate which ID is the source and which is the destination of the network transaction.

In direct support of flow based accounting data sources, the accounting process **14** supports a specific IP flow descriptor. This is the traditional IP 5-tuple flow description. The accounting process **14** could also support a 6-tuple flow descriptor that includes a type of service (TOS) indicator in the flow designator. This allows for Class of Service distinction in the accounting model.

For network activity data sources that do not have a transaction accounting model, there may only be a single ACCT_ENTITY_ID present in the accounting record. Qualifiers for the ACCT_ENTITY_ID are available to indicate if the single object is the source, destination, or both, for the accounting metrics that will be included. The types of entities include User Identifiers and Network Entity Identifiers. The network identifiers can include IP Address, Flow Description, and Network Object ID. Other types of accounting entities can be provided.

The actual accountable entities for a specific network accounting record are specified in the complete set of ACCT_ENTITY_ID(s) that are present in the NAR. Operations that can be applied to NARs, specifically aggregation, can influence how ACCT_ENTITY_IDs are used in NARs. Each accountable entity identifier that is

present adds refinement to the definition of what accountable entity the metrics actually apply to, whereas each ACCT_ENTITY_DESC further refines the description of the accountable entity.

Referring now to FIG. 11A, a NAR_USERNAME is a specific type of NAR_USERID data structure. A system string type "Username" **222** can represents a real accountable user within the accounting process **14**. The NAR_USERNAME data structure **220** is used to transmit the string. The semantics can be applied when the string "Username" **222** is supplied by RADIUS or from DCHP management systems. The NAR_USERNAME data structure **220** includes a NAR_USERNAME NAR_ATTR Qualifier that provides for Role designation, indicating whether the object referenced is acting as a source, destination, both or undeterminable within the system. The NAR_ATTR Qualifier bits are set when the Role can be determined without ambiguity.

Referring now to FIG. 11B, a NAR_USER_ID data structure **230** is the general type for identifying an accountable user. The accounting process **14** can use any available object type to represent the NAR_USER_ID value **232**. The NAR_USER_ID value **232** will be a system established STRING type or a user index as generally supplied by a database system. The semantics of the NAR_USER_ID value **232** are consistent within the accounting process **14**, and can be consistent outside of the accounting process **14**.

Referring now to FIG. 1C, a NAR_IP_ADDRESS data structure **240** is shown and which is the general network component identifier for an IP enterprise network. NAR_IP_ADDRESS data structure **240** includes a IP Address **242** that is usually unique within the accountable domain, and thus can be usable as an accounting process **14** identifier. Within the accounting process **14**, the occurrence of this record implies that the address is unique within the accounting realm. NAR_IP_ADDRESS type includes a NAR_IP_ADDRESS NAR_ATTR Qualifier. The NAR_IP_ADDRESS NAR_ATTR Qualifier provides for Role designation, indicating whether the object referenced is acting as a source, destination, both or undeterminable within the system. These bits are set when the Role can be determined without ambiguity.

Referring now to FIG. 11D, a NAR_NETWORK_ID type data structure **250** is shown. The NAR_NETWORK_ID data structure **250** includes a NETWORK_ID value **252** is a general type used for identifying a network component when a network address is inappropriate. The accounting process **14** can use any available object type to represent the NAR_NETWORK_ID, but it is assumed that this value will be an accounting process **14** established STRING type, (e.g., a Media Access Control (MAC) address that is predefined in Network interface cards), object type or a number index that cannot be associated with a network address. The semantics of the NAR_NETWORK_ID is consistent within the accounting process **14**, and can be consistent outside the accounting process **14**. A NAR_NETWORK_ID NAR_ATTR Qualifier provides for Role designation, indicating whether the object referenced is acting as a source, destination, both or undeterminable within the system. These bits are set when the Role can be determined without ambiguity.

Referring now to FIG. IE, a NAR_FLOW_DESC data structure **260** is the general type for reporting on flow based network activity. The NAR_FLOW_DESC is a composite data structure **260** including a IP Source Address **262**, IP Destination Address **263**, Transport Protocol **264**, Type of Service **265**, Source Port **266** and Destination Port **267** that are populated from transport and network layer of IP packets via flow probe. The NAR_FLOW_DESC NAR_ATTR Qualifier provides for Role designation, indicating whether the object referenced is acting as a source, destination, both or undeterminable within the system. These bits are set when the Role can be determined without ambiguity.

Therefore the Network Accounting Activity Records are fundamentally bindings between an accountable entity and a set of metrics that can be associated with that entity over a specified period of time. The NARs provide flexibility in defining, or specifying, the accountable entity. This level of flexibility is required because in network accounting, an accountable entity could potentially refer to objects that are either physical or logical, singular or members of collections, or geographically or topologically constrained, such as network numbers or autonomous system numbers.

A set of accountable entities includes Username and Network Object Identifiers. There can be additional descriptive information available within network activity reports and within networking components that could be used to further describe accountable entities. These entity attribute descriptors can be used in the accounting process **14** to provide additional flexibility in how network activity information is reported and tallied. Support for entity descriptions can include object support for:

- Flow Descriptors
  - Flow Protocol Descriptors
  - Flow Transport Port Descriptors
- Authentication Descriptors
  - NAS Descriptors
- Aggregate Descriptors
  - Class Identifiers
  - Session Identifiers
  - Multi-Session Identifiers
  - VLAN Identifiers
  - ELAN Identifiers
  - Group Identifiers
- Access Identifiers
  - Source and Destination Ethernet Addresses
  - Ingress and Egress Tunnel Ids
  - Ingress and Egress Port Numbers
    - ATM Virtual Circuit VPI/VCI
    - Calling and Called Station Ids
- Flow Status Descriptors
- Class of Service Identifiers
- Quality of Service Identifiers
- Traffic Path Identifiers
- Accounting Time Interval
- Accountable Network Activity Metrics
  - Source and Destination Datagrams
  - Source and Destination Octets
- Extended Network Activity Attributes
  - Network Flow Control Indications
  - Host Flow Control Indications
  - Traffic Burst Descriptors

Referring now to FIG. 12, a NET_METRIC data structure **270** is shown. A NET_METRIC data structure **270** to support a count is shown in FIG. 14. The NET_METRIC data structure **270** is used to hold basic accounting values that can be tallied within the accounting process **14**. The NET_METRIC data structure **270** can support time, octets, datagram, counts and cells, circuits, tunnels and so forth.

Referring now to FIGS. 13A and 13B, two basic transparent objects TRANS_ATTR objects are shown; UNDEFINED **280** and RADIUS **290**. New TRANS_ATTR object

types can be defined as needed. These are objects that a user may want to send through the accounting process **14**, that are customer specific, or proprietary in nature. The accounting process **14** allows for object transparency, i.e., an object that the system does not act on or modify. Thus, the contents of transparent attributes are undefined with respect to the accounting system. They are passed through, unmodified.

Flow Data Collector

Referring to FIG. **14**, a flow data collector system **300** for supporting the flow data collector ("FDC") **52** (from FIG. **2**) is shown. The flow data collector system **300** includes a processor **302** coupled to a memory **304**. In this embodiment, the FDC is a process stored in the memory **304** and executed by the processor **302**. The FDC **52** includes several NAR processing components or processes. These processes include a NAR constructor **306** for converting data gathered by the equipment interface (EI) **16** (shown in dashed lines) from a network device or technology ("network entity")into NAR format. Recall that each equipment interface **42***a*–**42***g* is associated with an flow data collector. Thus, the combination of a equipment interface and a flow data collector support a particular device or technology and collects data from the particular device or technology using a pre-defined format, schedule and protocol specific to that device/technology. The NAR processes further include a correlator **308**, an enhancement process **310** and an aggregator **312** for processing the constructed NARs as appropriate. The details of these processes will be discussed further with reference to FIG. **15** below.

Still referring to FIG. **14**, the memory includes a local store **314** and a flow data collector configuration (file) **318**. The local store **314** stores data received from the equipment interface **16** and processed NARs. The configuration file **318** is provided at startup to configure the flow data collector **52**. The configuration file **318** specifies various configuration parameters **319**, including a time parameter **320** and a policy **322**. The NAR processes **304** populate and process NARs for data received from network devices via the equipment interface **16** in accordance with the policy **322** of the configuration file. NARs being held in the local store **314** are transferred to the flow aggregation process **60** (FIG. **2**, shown here in dashed lines) when the time specified by the time parameter **320** expires.

It can be appreciated from the above description that the flow data collector **52** is a software component of the accounting process and runs on the flow data collector system **300**. The flow data collector system may be any computer system, such as a workstation or host computer, which can communicate with the equipment interface. Alternatively, the FDC may reside in the network device itself. Many known details of the flow data collector system **300** have been omitted from FIG. **17** for the sake of clarity, as the figure is intended to highlight the processes of and memory structures associated with the flow data collector.

Conceptually, as earlier described, each flow data collector of the accounting process architecture is capable of supporting multiple equipment interfaces **16**. At the implementation level, there is a one-to-one correspondence between each flow data collector "process" and a given equipment interface **16**. For example, a single computer system might provide both RADIUS and flow probe support and thus run separate flow data collector processes for the RADIUS EI and the flow probe equipment interface. In such a configuration, where the flow data collector processes are operating independently and loading directly into the flow aggregation processor **60** (FIG. **2**), the computer system itself may be viewed as an flow data collector supporting multiple EIs.

Referring now to FIG. **15**, a data collection process **330** performed by the flow data collector **52** of FIG. **17** is shown. The flow data collector receives **332** data from the equipment interface for an network device. The flow data collector performs an equipment interface specific translation to convert **336** the received data into NAR format as well as populates the NAR header. Once the NAR is populated with the appropriate data, the flow data collector **52** attempts to correlate **338** the newly populated NAR with other NARs. That is, the flow data collector **52** compares the newly populated NAR to NARs currently stored in the local store **314** (from FIG. **14**) to determine if there are multiple instances of the same object. Specifically, correlation is performed by examining the ACCT_ENTITY_ID (from FIGS. **11A–11E**).

The flow data collector uses one clock and one time determinator, so all NARs that the flow data collector is processing or holding are assumed to be in the same time domain. Consequently, the flow data collector need not consider time during correlation. If the flow data collector **52** determines that a NAR ACCT_ENTITY_ID (i.e., the collection of descriptors or objects as described above) in the NAR matches that of another NAR that it is currently holding, the FDC **52** can replace an older (stored) NAR with the new (i.e., most recently populated) NAR and discard the older NAR. For example, the existing or older NAR may be a start record and the new NAR a stop record that includes all the data included in the older NAR, thus superseding the older NAR. Alternatively, if the new NAR is a replica of an existing NAR, the FDC may decide to discard the new NAR. Also, the data collector can determine that the two NARs should be merged or aggregated. Thus, the correlation process may discard the new NAR, replace an older NAR with the new NAR or mark the two matched NARs as candidates for aggregation, a process which is described in detail below.

As part of the correlation process, the flow data collector may enhance **340** the new NAR. That is, the FDC may determine that the NAR cannot be correlated without some amount of enhancement. The FDC **52** enhances the NAR by supplementing the information provided by the original source equipment with information that is not available from that source equipment. The supplemental information is added to the ACCT_ENTITY_ID. Recall that the accounting entity identifier ACCT_ENTITY_ID is a collection of descriptors, so the enhancement process **310** adds to that collection of descriptors. For example, the accounting entity ID ACCT_ENTITY_ID in one NAR might include a source address and a destination address, along with a value indicating how long the flow (for the accounting entity) has been in existence. A subsequently processed NAR record having those same three objects can be correlated. However, if a subsequently processed NAR only has two of the three objects, the flow data collector can enhance the accounting entity ID ACCT_ENTITY_ID for the third (missing) object to permit correlation. Enhancement may involve collecting information from a completely different network device (via a NAR generated by another accounting process component, such as another data collector), or it may be as simple as adding a timestamp to a NAR's accounting entity ID.

As indicated above, the correlation process may determine **342** that two NARs should be "aggregated". Aggregation merges the accounting entity identifiers of the two NARs together. It also merges metrics for NARs that contain metrics, as later described. Aggregation of the accounting entity identifiers is accomplished through an explicit and

implicit matching of those accounting entity identifiers. Correlation relies on the explicitly matched fields, that is, the fields or objects actually used to determine that two NARs should be aggregated. The other descriptors or objects in the accounting entity ID that were not used by the correlation process to make a match may be equal or different. Aggregation of the accountable entity ID portion of the NAR keeps the explicitly matched objects, and determines which of the implicitly matched objects (the matching objects that were not a part of the explicit match) to save or discard. Of course, the nonmatching objects are automatically discarded, as all of the metrics that are the result of this aggregation have to apply to the objects in the aggregated accountable entity ID ACCT_ENTITY_ID. The removal of accounting entity ID descriptors actually serves to lower the semantic complexity of the NAR, whereas enhancement does just the opposite.

When the data collection process **330** involves a decision concerning aggregation, the flow data collector **52** applies **344** the aggregation policy **322** (from FIG. **14**) and uses a method defined therein. The method outlines the decision-making process to be followed by the FDC in the case of implicitly matched objects. The aggregation policy will be discussed in further detail with reference to FIG. **18**. Once the flow data collector aggregates the accounting entity ID ACCT_ENTITY_ID portion of the NAR attributes, it can aggregate the NAR metrics. To aggregate the metrics, the flow data collector performs a summation process on numerical metric values and/or a logical operation (e.g, ANDing, ORing, or XORing) on logical metric values. Aggregation of the metrics is specific to each metric field in the NAR.

Once the NAR aggregation is complete **346**, the FDC changes the NAR header (i.e., the NAR_SRC_ID and NAR_SRC_TIME in the NAR_ID) of the newly aggregated NAR to identify the component (in this case, the FDC) that performed the aggregation as the originator of this particular NAR. The FDC stores aggregated NARs for a period of time determined by the configuration profile's event-based counter or timer **320** (from FIG. **14**). When the timer expires **348**, the FDC is ready to transfer NARs processed by the correlator/(enhancement) and possibly the aggregator as well to the FAP.

Prior to commencing transfer, the flow data collector **52** determines **350** if the flow aggregation processor **60** is available to receive NARs. If the flow aggregation processor **60** is unavailable, the flow data collector stores **352** the NARs to be transferred in its local store **314** (FIG. **16**). The flow data collector **52** continues to check **354** the availability of the flow aggregation processor at periodic intervals until the connection between the flow aggregation processor **60** and the flow data collector is re-established. When the periodic status check indicates **350** that the flow aggregation processor is available, the flow data collector loads **356** NARs into the flow aggregation processor **60**. The loading function can be implemented according to one of many strategies, e.g., a database, file, or data streaming strategy. Other strategies could be used. When the flow data collector receives **358** a confirmation or acknowledgment back from the flow aggregation processor that the NARs were loaded, the transfer is deemed successful and the locally stored copies of the transferred NARs are removed **360** from the local store. Thus, the "store and forward" capabilities of the flow data collector provide a measure of fault tolerance at this accounting process level to ensure reliable data transfer. The flow data collector only transfers NARs when it has determined that the flow aggregation processor is available and it considers the NAR transfer successful only upon receipt of an acknowledgment from the flow aggregation processor.

The flow aggregation processor (FAP) **60** (FIG. **2**) aggregates and/or enhances record data across the system **10**. It receives data from multiple flow data collectors (FDCs) that may be aggregating and enhancing close to the source of the information (as described above with reference to FIG. **17**). As NARs are received from multiple FDCs, the data can be further enhanced and/or reduced (i.e. aggregated) to meet the specific needs of an application or output interface based on the aggregation policy of the flow data processor **60** (FAP). The design and operation of the FAP will be described in more detail below.

Flow Aggregation Processor

Referring now to FIG. **16**, one implementation of the FAP **60** is as a database management system, or more specifically, a Structured Query Language (SQL) database management system, like those commercially available from Oracle or Sybase. Although not shown, it will be appreciated that the FAP is installed on a computer system, such as a host computer. Implemented as a database management system, the FAP includes a database server **400** coupled to a database **402**. The FDCs **52** (from FIG. **14**) can use the "push" model to move NARs up to the FAP via SQL calls. The database **402** stores a plurality of tables **404**, including a NAR table **406** (implemented as a persistent cache) and an aggregation store **408**. Also stored in the database are a plurality of SQL commands and procedures (functions) **410** to be executed by the server **400**. The functions include a FAP correlator **412**, a FAP enhancer (enhancement process) **414** and a FAP aggregator **416**. The database also stores a configuration file **420** for storing configuration parameters such as time and policy information. The operation of the FAP will be described below with reference to FIG. **17**.

Referring to FIG. **17**, an overall flow aggregation process **430** performed by the FAP is shown. The FAP receives **432** a NAR from one or more FDCs and loads **434** the received NAR into a persistent store or cache (of database **492** from FIG. **16**). If the FAP is unable to load the NAR, it requests **436** that the transferring FDC resend the NAR. If the load is successful, the FAP sends **438** an acknowledgment back to the sending FDC. The FAP determines **440** if the NAR can be correlated (with or without enhancement). If the FAP determines that the NAR can be correlated, the FAP correlates **442** the NAR with other NARs received from other FDCs. Once the NAR is correlated, it may be enhanced **444** "across the system", in a manner more fully described with reference to FIG. **18**. The NAR may be enhanced **446** to include enhancement information obtained from an outside source (i.e., collected by a data collector for a different equipment interface). Once any potential correlation and enhancement has been performed, the FAP determines **448** if the NAR is a candidate for aggregation. If so, the FAP applies **450** the aggregation policy **420** (from FIG. **16**) and stores **452** the resulting aggregated NAR in the aggregation store until a predetermined time expires or event occurs **454** (as set in the FAP configuration **420**). The FAP ensures **456** the uniqueness and integrity of any NAR by examining NAR header information prior to re-loading **458** such NAR into the persistent store.

The accounting architecture may be implemented to include a second "shadow" FAP process, also coupled to the data collectors and operating in the manner described above with respect to receiving and processing NARS. In the dual/shadowing FAP implementation, the accounting architecture further includes an error detection module (not shown) coupled to both of the first (primary) and second (shadow) FAP processes. The error detection module operates to detect an error relating to the first flow aggregation

process and cause the aggregate reports from the second flow aggregation process to be transferred to the accounting module (i.e., flow data distributor **70**) in place of the aggregate reports from the first flow aggregation process.

Enhancement

Now referring to FIG. **18**, an example of an application of the FAP enhancement process **444** (from FIG. **20**) is shown. In the illustrated example, enhancement deterministically identifies the source of a captured network accounting record, flow or a transaction across a network. Enhancement accesses other sources of information on the network in order to enhance a record and make it chargeable to a specific user.

In the example shown in the figure, two NARs of different sources are inevitably going to be aggregated together to produce a third unique NAR. A first source equipment (or source) **500** is a DHCP (Dynamic Host Configuration Protocol) server. A second source equipment (or source) **502** is a flow probe (discussed below). The sources **500, 502** have corresponding flow data collectors, a first FDC (FDC1), **504** and a second FDC (FDC2) **506**, respectively, for converting their data into respective NARs NAR1 **508** and NAR2 **510**. As described earlier, each flow data collector assigns an accounting entity identifier **512, 514**, and adds time stamp information **516, 518** on the records of the sources to which they correspond. The NAR1 **508** includes in its assigned accounting entity identifier **512** an "IP address-to-username" assignment, thus including an IP address **522** and a username **524**. The accounting entity identifier **514** for the second source is an IP-to-IP flow and therefore includes a first IP address **526** and a second IP address **528**. The NAR2 of the flow probe includes a metric **530** attribute as well.

These two records NAR1, NAR2 are combined through correlation **442** (from FIG. **17**) and enhancement **444** (FIG. **17**) to generate an enhanced NAR2 **532**. This enhanced NAR has a modified accountable entity identifier **534** and a metric. The modified accountable entity identifier is the existing accounting entity ID **514**, to which the FAP has added the IP-to-user name assignment **512** from the accounting entity ID **512** of the NAR1 **508**.

Still referring to FIG. **18**, the NAR1 **508** has an IP-to-username mapping **512** and an accounting interval **516** comprising a start time and a session time to indicate a time interval bounded by start time "T1" and a start time +session time ("T2"), that is, the accounting interval represents a start time and a stop time. The username **524** in the IP address-to-username mapping is supplied by the DHCP server **500**. In the FAP, this NAR1 information will either go directly to a correlation function or to the local store (which could either be a database, file or memory), where it can be directly accessed by the correlator function. The NAR2 **510** has an accounting entity ID **514**, a T3-to-T4 accounting time interval **518** and a metric **530**. The accounting entity identifier **514** has two IP addresses **526, 528**, one corresponding to a source IP address and the other corresponding to a destination IP address. The NAR2 **502** is passed to the correlator **442**, which determines that the T1-to-T2 time interval **516** from the IP-to-username address map in the NAR1 **508** overlaps or in some way relates to the T3-to-T4 time interval **518** of the NAR2 **510**. The correlator determines that T1, T2, T3 and T4 are related, and that the IP address **522** in the IP-to-username address mapping **512** is associated with one of the two IP addresses **526, 528** in the NAR2 **510**. Thus, the FAP enhances the NAR2 **510** by inserting information from the accounting entity ID **512** (of NAR1 **508**) into the accounting entity ID portion of the NAR2 **510**. The resulting, enhanced NAR2 **532** has an enhanced accounting entity ID **534** that includes the T3-to-T4 timestamp (not shown), the IP-to-IP addresses **526-528** and the username **524**. Thus, the enhanced NAR2 now has a mapping between the username and the one of the IP addresses **526, 528** that is related to the IP address **522**. The metric **530** is unchanged.

It should be noted that the correlator is able to determine that the time intervals are related to each other because the flow data collectors are time synchronized (or closely synchronized, assuming some amount of drift). Thus, if the correlator assumes no drift, then T3-to-T4 must be within the time period of T1-to-T2. The IP-to-username address mapping is an event that has to encompass or cover all of the accounting records that apply to that IP address. Any user assigned to this IP address, started at T1 and ended at T2. Only those records that reference that IP address between T1 and T2 will have this username applied to it. When the two flow data collectors are not strictly synchronized, then the amount by which T3-to-T4 overlaps T1-to-T2 should correspond to the amount of tolerance, i.e., drift, built into the system. The accounting process assumes a drift amount of at least one second for even a strict time synchronization, so T4 can be greater than T2 by one second.

Referring now to FIG. **19**, an aggregation of the enhanced NAR2 **532** (from FIG. **18**) is shown. In this example, the aggregation involves combining NARs with IP-to-username address mappings to workgroups. To accomplish this requires two enhancements, two correlations, and an aggregation phase. As already described above, with reference to FIG. **19**, the IP address-to-username information is received by the FAP and is either passed to the correlation or stored in the local store but available to the correlator. When the IP-to-IP address NAR with metrics is received, the correlator and the enhancer work together to add the username mappings to these IP-to-IP address NAR. The username could be provided for one or both of the source and the destination addresses. More than likely, the username is assigned to the source IP address.

Referring again to FIG. **19**, another correlation and enhancement process **442, 444** maps the username **524** to a workgroup. The FAP builds up search keys using database principles and relational algebra. Thus, for example, the IP address has a one-to-one mapping with a username. (The one-to-one mapping is assured because of the nature of IP addressing and the way that the DHCP server assigns usernames.) Therefore, there can be only one user for an IP address in a given instance. These terms or values are equivalent keys, so the username can easily be replaced with the IP address. The username **524** that was inserted into the enhanced NAR2 **532** can be used as a look-up into a workgroup **540** in one of the database tables **404** (FIG. **16**) because the user is actually a member of a workgroup. Therefore, the enhancement function can be used to insert the workgroup label into the enhanced NAR2 (already enhanced for username) to produce a twice-enhanced NAR2 **542**. If the now twice-enhanced record **542** is to be aggregated, it is held in the aggregation store **408** (FIG. **16**) for some time period T until other NARs are received for potential aggregation.

Suppose now that another NAR is loaded into the FAP. This new NAR passes to correlation, which determines that enhancement is need in order to correlate the new NAR with the twice enhanced NAR2 **542** of FIG. **19**. As a result, the FAP enhances the NAR to include the username **524** and the workgroup **540** to produce a resultant NAR "NAR3" **550**, as shown.

Referring to FIG. **20**, in addition to the username and the workgroup, the other NAR3 attributes include the T3-T4 accounting interval, the IP-IP address mapping and the metrics. With the enhancement, the correlation process **444** determines that the resultant NAR3 now matches the twice enhanced NAR2 **542** held in the aggregation store **408**. Having explicitly matched the two NARs, aggregation **448** is performed. Aggregation preserves the explicitly matched data objects that are in the accounting entity identifier, discards any mismatches in the accounting entity identifier and makes a decision whether to keep the implicitly matched objects (i.e., those that seem to be equal but were not used to make the correlation match). It also then combines the relevant metric values together via summation or logical operations (e.g., ORing, XORing, ANDing). Once the aggregation is complete, the FAP holds the resulting aggregated NAR **552**. As the FAP receives additional NARs, the aggregator continues to sum and perform these logical operations on these metrics values for some aggregation period. The duration of that aggregation period may be in the order of 60 seconds to a week, or however long the FAP is configured to aggregate these records. The termination of that period can be a time-based or event-based. Once an event that terminates the time period occurs or an aggregation timer expires, the aggregated NARs held in the aggregation store are released for output by the FAP.

Aggregation Adjustment

It can be understood from the foregoing description that aggregation exists at different levels of the accounting process. As shown and described above with reference to FIGS. **15** and **17**, both the flow data collector and the FAP are aggregation-capable. Each aggregates in accordance with an overall aggregation policy that defines how aggregation is used to provide the data to meet the needs of a specific application. The aggregation performed by the different levels can also be remotely and independently adjusted, as will now be described.

Aggregation adjustment involves the ability to adjust the level of aggregation to meet specific application data needs. There are two aspects of aggregation adjustment: remote control and variable degree.

Referring to FIG. **21**, a graphical representation of aggregation control and adjustment via a data flow decomposition model is depicted. As shown, the accounting system is depicted as a tree **560**. The flow data collectors are leaf nodes **562***a*–**562***e* and the two illustrated FAP processes are intermediate nodes **564***a*–**564***b*. The root **566** is the collective view of all of the processed accounting information. Given a common view of all the data and the particular accounting information requirements of a given application, the root **566** thus embodies a single accounting/aggregation policy **568**. The accounting policy is defined such that an accounting schema is a direct derivative of the accounting policy **568**.

The accounting policy **568** is viewed as a collection of accounting objects **570**, each defined as an accounting entity identifier **572** and a set of metrics (not shown). The accounting entity identifier is an abstract object resulting from construction functions that use the flow data collector data as its original starting point. If an accounting entity ID is in the accounting policy as a part of a collection of accounting objects, it is there because it can be constructed from the FDC data and the collective set of operations that allow for correlation, enhancement and aggregation. Therefore, if an accounting entity ID can be constructed, it can be decomposed.

To implement a given user/application requirement, therefore, the data flow model **566** decomposes each object's accounting entity ID into policy information **572***a*–g, which includes a collection of data **574** that can be supplied by the available flow data collectors and a set of functions or methods **574** needed to correlate, aggregate or enhance that data in order to construct the accounting entity identifier.

Aggregation adjustment takes an accounting policy that is a collection of accounting objects and decomposes those accounting objects into their accounting entity identifiers and then further decomposes the accounting entity identifiers in a recursive fashion to provide the collection of basic data and functions needed to construct those accounting identifiers. This concept builds on the logical directed graphs as seen in many compilers or data flow systems. Knowing the order of the functions, the data requirements and dependencies, the data flow software can build the logical graph from the decomposition and that specifies data requirements and methods that can be distributed to configuration files in the flow data collectors and FAPs to result in adjusting the configuration of those accounting components.

For example, suppose a user wants to receive accounting on an hourly basis from all of the potential sources of information. The flow data collectors **562***a*–**562***e* are the components that are available for collecting the raw information to generate the accounting data in accordance with a user-specified accounting policy. The internal FAP processes **564***a*–**564***b* further correlate, enhance and aggregate to evolve the data towards the overall accounting data to meet the accounting policy **568** specified by a user. Thus, the user's information requirements are translated into a policy (i.e., collection of _objects), which is received by the accounting system and decomposed into the sets of data requirements and methods for each of the available accounting components **562***a*–**562***e*, **564***a*–**564***b*, that is, policy information **572***a*–**572***g*). Assuming that these components or processes are already configured, these sets represent configuration updates that are distributed to and stored in the configuration files (see FAP configuration file **420** from FIG. **16** and FDC configuration file **318** from FIG. **14**) in their respective processes.

Referring now to FIG. **22**, a depiction of the configuration update is shown. The decomposition/configuration update process is implemented in software and is based on known data flow technology used in conjunction with an available visualization tool to act as a front-end graphical interface. Using such visualization tools, the updated configuration is simply mapped to the appropriate component.

It should be noted that not all accounting processes have a complete collection of data collectors. For instance, if the accounting process is to perform user-based accounting and the accounting process only has a flow probe, then it will be necessary to request that the user supply a static table of IP-to-username mappings or a source of DHCP user IP address mappings. The source of that "outside" information becomes part of the decomposition strategy.

Information Management

The NAR sequence number (NAR_SEQ_NUM FIG. **8B**) allows components that are in the next level to detect if there are missing NARs in a collection of NARs and can be used to give a sense of how often NARs are produced in a given time period. With the time stamps and the sequence numbers, a per second creation rate of NARs throughout the system can be determined. With this information being part of every NAR, the accounting process **14** can determine a sense of the functional capabilities of the intermediate components and detect some aspects of the communication

channel between components. Also included in a NAR identifier is a component type identifier **207***a* which specifies what kind of component produced the NAR and its serial number **207***b* as described above in FIG. **8**B. The component type identifier allows the accounting process **14** to keep component statistics and characteristics based on component type. It also allows specific processing on the NARs. NAR IDs are allocated in a very specific way through a management system in order to insure that the IDs are actually unique within the accounting process **14**.

Referring now to FIG. **23**, the sequence numbers (NAR_SEQ_NUM) are a key reliability feature **590** of the accounting process **14**. By having the sequence numbers as part of the NARS and knowing that the numbers are monotonically increasing enables the accounting process **14** to track and identify **592** lost traffic or records. It also enables the accounting process to determine **592** the amount of lost traffic. By having the NARs with stored accounting process component IDs (e.g. a data collector assigned to a particular network device that is allocated at the time that the collector is assigned) the information management process **590**, can identify **594** the data collector responsible for the flow. The accounting process **14** can call back to the data collector that produced the NARs of a particular flow and request **596** that the missing NARs (i.e., those NARs for which there are missing sequence numbers) be retransmitted.

Flow Probe

As discussed above in reference to FIG. **2**, the accounting process supports a flow probe e.g., **12***c* that captures a user's network activity for purposes of IP accounting. The flow probe **12***c* monitors all traffic over a given network link and captures data associated with the different flows in the traffic on that link. It is capable of monitoring IP data flows over a number of technologies (e.g., Ethernet, ATM, FDDI, etc.).

One important feature of the flow probe is its ability to detect and report on successful and unsuccessful connectivity. This capability is useful to billing and chargeback applications. For example, a user may try to connect to a particular switch or reach a particular network, but is rejected. The flow probe **12***c* can identify that transaction as unsuccessful and provides the billing application with information that the billing application can use in determining whether or not the user should be charged for that transaction. The flow-based connectivity model embodied in the flow probe is described generally with reference to FIGS. **23–25**, and specifically with reference to FIGS. **27–28**.

Referring to FIG. **24**, a representation of a network **600** in which an end system "A" **602** is connected to another end system "B" **604** is shown. The terminal systems A **602** and B **604** communicate with one another over a communication path **606**. Along that path are multiple intermediate devices **608** (e.g., routers, switches) to support the communication services required for communications between A and B. Although the path from A to B is depicted as a single straight line, it may be appreciated that the actual physical topology of this path most likely is extremely complex. For the purpose of understanding the flow probe's connectivity model, however, it is not necessary to know how the actual network would be configured.

The physical deployment of the flow probe in a network, such as the network **600**, is based on two criteria: performance, e.g., a 100 Mb probe must be deployed within a region of the network that operates at 100 Mb, and granularity of the information to be generated. That is, if the performance or the quality of service provide by A is of particular interest, then the flow probe is located as close to A as possible so that the flow probe will see all of the traffic that is seen by A.

The deployment of the flow probe may be in-line or out-of-line of the stream of IP packets of interest. Thus, the flow probe **12** may be deployed in-line, i.e., integrated into either of the components that are actually party to a conversation (like end station A **602**, as shown in the figure), one of the devices **608** that are actually supporting the communication or out-of-line, i.e., packets are copied and delivered to a remote position.

Generally, a flow is defined as any communication between communicating entities identified by an IP address, a protocol and a service port. All IP packets (or datagrams) are categorized using the fields present in the packets themselves: source/destination IP addresses, the protocol indicated in the IP header PROTO field, and, in the case of UDP or TCP, by the packet's source and destination port numbers.

In a given network segment monitored by the flow probe, much of the typical IP traffic includes TCP protocol traffic. Because the flow probe is a flow based monitor that is actually tracking the TCP as a flow, it is completely aware of the TCP protocol and that protocol's three-way handshake algorithm (state machine). The TCP flow has indicators to indicate that a connection is being established or a flow is being disconnected. However, these messages are only relevant to the two communicating parties (e.g., A and B in FIG. **27**). The end system A may request that it be able to communicate with B and sends a "TCP SYN" indication. Any of the networking devices **608** along the path **606** can reject this SYN request, completely independent of the intended destination (in this example, end system B) and without the knowledge that the end system B is a party to this communication request. There are a variety of problems that can cause an internal network component to reject a request. For example, a router between A and B may find that there is no route available for forwarding a packet towards B or that the routing path is inoperable (and no alternate exits), or the router may find that it doesn't have the resources to handle the packet.

The Internet Control Message Protocol (ICMP) is designed to convey this type of error event information back to the originator of the request. For example, suppose device **608** is a router that is in a "failed" state and cannot process the SYN request that it received from A. The support exists in the Internet protocol, specifically, ICMP, to signal this condition back to A. Originator A has the ability to correlate the error event with the request and inform the requesting application that its request is not going to be supported. Because the network uses a completely independent protocol, i.e. ICMP, to convey the information, it is necessary to correlate these independent protocols (TCP and ICMP) to provide the accounting process with the information it needs to know about a given transaction. Specifically, the accounting process needs to know if the transaction was successful or unsuccessful and the cause of failure if unsuccessful.

As an independent monitor operating outside of the context of the originating entity ("A", in this example), the flow probe is able to produce a complete and accurate record of the transaction by mapping the network control information to the user request information. To do so, flow probe correlates the state information in protocols such as TCP with error event or condition messages provided by other protocols, such as ICMP. In this manner, it is possible to determine if a particular request for a service has actually been denied as a result of some network independent event. The flow probe correlates the dissimilar protocols together and finds a way of representing the network event in its normal reporting of the TCP flow.

The flow probe has specific reporting mechanisms for the specific protocols. The TCP protocol, for instance, has many more metrics associated with its protocol states than UDP based flows. However, because ICMP relevant events or network relevant events are not associated with or have any impact on the state of TCP or UDP or any of the normal protocols, the flow probe provides a mechanism for tagging its state tracking with the error event. The NAR is represented as a start flow indication, a continuing or status record and a stop record. All of the flow probe's internal protocol indications map to start, continuous or stop states. When a network rejection event comes in (e.g., in the form of an ICMP message, or other type of internet control information), regardless of what state the probe is tracking as the current state, it reverts to a stop state and has to expand upon the normal time or transition based stop conditions to include an specific ICMP event as the cause of the closed state. The flow probe NAR includes bit indications for the actual protocol states that it is tracking. For ICMP generated events, the flow probe indicates whether the source or the destination was affected by the events. In order to convey this network rejection or network event back to the parent flow, the NAR allows for specific network rejection logic to be reported either by the source or the destination, and has specific bit indicators in either the source or the destination fields.

There are two key aspects to the connectivity scheme of the flow probe as described thus far. First, the probe determines that an ICMP event has occurred. Second, the probe correlates that event to the "parent" flow, i.e., the same flow as that associated with the failed request, and stores the exact ICMP event into some state associated with that flow so the event can be reported to the accounting system in a NAR. At this point it may be useful to examine the IP packet and ICMP message formats in general, as well as examine certain fields of interest.

Referring to FIG. **25**, an exemplary IP packet format **610** is shown. The IP packet format **610** includes an IP packet header **612** and an IP packet data field **614**. The IP packet header **612** includes a PROTOCOL field **616** for indicating the protocol of the message encapsulated therein. The header also includes a source IP address field **618**, a destination IP address field **620** and other known fields (not shown). In the example of FIG. **25**, the message contained in the IP packet data field (or payload) is an ICMP message or packet **622**. The ICMP packet is formatted to include an ICMP header **624** and an ICMP data field **626**. In the example, the protocol field **616** would be set to indicate a protocol value corresponding to ICMP.

Referring to FIG. **26**, an exemplary ICMP message format **622** for reporting errors is shown. The format includes an ICMP message header **624**. The header **624** includes a type field **630**, which defines the meaning of the message as well as its format, and a code field **632** that further defines the message (error event). The error reporting message types (type values) include: destination unreachable (**3**); source quench (**4**); source route failed (**5**); network unreachable for type of service (**11**); and parameters problem (**12**). Each of the types has a number of code values. For a destination unreachable message (TYPE field value is **3**), the possible codes (code values) include: network unreachable (**0**); host unreachable (**1**); protocol unreachable (**2**); port unreachable (**3**); fragmentation needed and DF set (**4**); source route failed (**5**); destination network unknown (**6**); destination host unknown (**7**); source host isolated (**8**); communication with destination network administratively prohibited (**9**); communication with destination host administratively prohibited (**10**); network unreachable for type of service (**11**); and host unreachable for type of service (**12**).

Also included in the ICMP message format is a datagram prefix field **634**, which contains a prefix—header and first 64 bits of data—of the IP datagram that was dropped, that is, the datagram that triggered the error event message. The datagram prefix field **634** corresponds to the ICMP message (packet) payload. The IP datagram or packet header **612**, partially illustrate in FIG. **24**, is shown here in its entirety. Assuming that the IP datagram carries a TCP message, the protocol value would correspond to TCP and the portion of the IP datagram's data **636** (first 64-bits) would in fact correspond to a TCP message header **636**, which includes a source port field **638**, destination port field **640** and a sequence number field **642**. The source port is the port number assigned to the process in originating (source) system. The destination port is the port number assigned to the process in the destination system.

It will be understood that TCP is an example protocol. The field **636** could correspond to a portion of packet header from a packet of another protocol type. Also, the error reporting protocol could be a protocol other than ICMP, and the amount of header in field **636** could be more or less than **64** bits, that is, this amount may be adjusted so that the appropriate flow information can be obtained from the header of the message contained in the discarded IP packet, as described below.

Referring to FIG. **27**, a packet processing method ("the process") **650** performed by the flow probe is shown. The process captures **652** a new IP packet (datagram) and tests **654** the received packet to determine if it is good (i.e., well-formed). The process **650** examines **656** the protocol field in the IP packet header to determine if the protocol is the ICMP protocol. If the protocol is ICMP and the information type field is set to one of the five error reporting messages described above, the process bypasses the IP packet and ICMP message headers and processes **658** the ICMP message or packet payload (FIG. **26**), which corresponds to a portion of IP packet which that was discarded and to which the event message relates. The payload process will be described with reference to FIG. **28** below. Once the payload processing is complete, the processing of the IP packet resumes **659** the processing that would be performed if the IP packet had not been detected as containing an ICMP message of the error reporting variety as discussed above, as will now be described.

Still referring to FIG. **27**, if the protocol is not ICMP and/or the information type is not an error report, the IP packet is processed as follows. The probe scans **660** the header to determine the values of the fields which correspond to the "flow key", the fields which define "the flow" for the probe. Each flow probe can be configured for a particular flow key definition. For example, the flow key might be the source/destination IP addresses, the source/destination ports and the protocol. The probe determines **662** if the flow key of the processed packet header matches a flow already stored in the flow probe. A local store in the flow probe is used to hold flow representations including flow key parameters, metrics, state information. The state information will include, in addition to the protocol control-related states (i.e., TCP "FIN"), error event/state change cause and source/destination to which the message is addressed. These flow representations are converted into NARs for accounting process reporting purposes.

Still referring to FIG. **27**, if the flow probe cannot match **664** the flow key information to a stored flow, the probe constructs (and stores) **666** a new flow and completes **668**

the process. If the probe finds a match, it updates **670** metrics for the matching stored flow (or "parent" flow). It also updates **672** the flow state of the parent and then completes **674** the process. It should be noted that the construction of a new flow triggers **676** the generation of a start NAR and the update of the flow state triggers **678** the generation of an update NAR. The generation of NARs by the flow probe will be discussed later.

Referring to FIG. **28**, processing of the ICMP message payload, i.e., the embedded IP packet, **658** (from FIG. **27**) is shown. The processing of the ICMP message payload processing is recursive in nature. The essential method is the same as used above for an IP packet (FIG. **27**), with a few differences. If the flow probe determines **664** that there is no stored flow corresponding to the flow of the dropped IP packet or datagram (indicated by the ICMP message in the data prefix field or payload **634** of FIG. **26**), the processing is complete **680**. If a stored flow matching the flow key of the dropped datagram is found, the probe updates **672** the flow state to indicate a "rejected" state for the stored flow. It also updates the flow state information to indicate whether it was the stored flow's source or destination that was associated with the ICMP message and the event cause. The state change (to rejected state) triggers **682** the generation of a stop NAR, as is later described. Once the probe has completed the payload processing **658**, it resumes **659** the processing of the original IP packet (as indicated in FIG. **27**).

Thus, the payload processing can be viewed as a packet processing exception, an exception that is invoked when it is determined that an ICMP error reporting message has been received. The ICMP messsage reports a error event and the IP packet associated with that error event. The exception process serves to correlate the flow of the discarded IP packet in the ICMP message with the parent (matching stored) flow, thus mapping the ICMP error (state) information to the parent IP flow.

The flow probe reports on network traffic activity through a flow probe NAR, which reports IP flow traffic activity. The flow probe categorizes network traffic into one of four classes of traffic flow: I) connection oriented (e.g., TCP); ii) new connectionless; iii) request/response connectionless (e.g., UDP, DNS); and iii) connectionless persistent (e.g., NFS, Multicast BackBONE or "MBONE" multicast traffic). To each of these class it applies connection oriented semantics for a uniform approach to status reporting. That is, flow probe treats these dissimilar transaction models as if they were the same. There is one uniform structure for the status reports generated for each of the 4 different transactions. Each status report includes transaction start and stop information, MAC and IP source and destination addresses, the IP options that were seen, the upper layer protocol used, the transaction source and destination byte and packet counts and upper layer protocol specific information. The protocol specific information and the criteria for when the status reports are created, is different for each of the four transaction types.

The connection oriented protocol understood by the flow probe is TCP. Flow probe has complete knowledge of the TCP state machine and thus can generate status reports with each state transition seen within any individual TCP. There is also a provision for generating time interval based status reporting in the TCP connections that the flow probe is tracking. The status report indicates which states were seen, if any packets were retransmitted, if the source or destination had closed, and if the report had been generated by a time condition. In a default mode, the flow probe generates a cumulative status at the time a TCP closes, or times out. This strategy offers the greatest amount of data reduction on transactions.

Any non-TCP traffic is categorized as a connection-less transaction. When configured to generate the most detailed level of reporting for connectionless traffic, the flow probe can report the discovery of a new connection-less transaction; the existence of a request/response pair within the transaction (as exists when the probe has seen a single packet from both the source and the destination for the transaction); the continuation or transaction persistence, and so forth. The transaction persistence status is generated with a timer function. If it has been seen within a configured timer window, a report is generated.

The status report for non-TCP traffic indicates if the report is an initial report, a request/status report or a continuation (or a current transaction) report.

In the default mode, the flow probe generates a status report when it has seen a request/response "volley" within a transaction and every 15 minutes thereafter, if the transaction persists. This offer immediate notification of request/response traffic and a fair amount of data reduction on connection-less transactions.

Thus, the flow probe state tracking includes protocol-specific state information. It provides detailed information on transport specific flow initiation, such as TCP connection establishment, as well as flow continuation and termination event reporting.

Protocol Independent Packet Monitor

Referring to FIG. **29A**, a network **700** includes a monitor **702** that runs a process for detecting packet loss. The monitor **702** will be particularly described using IP SEC authentication headers. The monitor **702** uses sequence numbers that exist in IP SEC authentication headers. The monitor **702** can be used to detect lost packets in any type of protocol that uses sequence numbers in headers of the packets, etc. The monitor **702** is an independent monitor that can be disposed anywhere in the network **700**. The monitor **702** is protocol independent.

The network **700** would include a plurality of such independent monitors **702** each disposed at corresponding single points in the network **70**. Typically, the monitor **702** can be disposed in-line such as in a network device such as a switch, router, access concentrator, and so forth. Alternatively, the monitor can be disposed in an out of line arrangement in which network packets are copied from the device and coupled to the out-of line monitor.

The monitor **702** examines each packet of a network flow that passes through the device associated with the monitor **702**. The monitor **702** receives serialized IP packets. The packets can have the format specified by the Network Working Group, by S. Kent, Request for Comments: 2402, November 1998 "IP Authentication Header" as part of the "Internet Official Protocol Standards", The Internet Society (1998). The IP Authentication header includes a Next Header field that identifies the type of the next payload after the Authentication Header, Payload Length an 8-bit field specifies the length of AH, and a reserved 16-bit field. The IP Authentication header also includes a Security Parameters Index an arbitrary 32-bit value that, in combination with a destination IP address and security protocol, uniquely identifies the Security Association for a datagram and a Sequence Number. The sequence number is an unsigned 32-bit field containing a monotonically increasing counter value (sequence number). It is always present in such datagrams and is provided form the purpose to enable an anti-replay service for a specific security authentication. According to the standard if anti-replay is enabled the transmitted Sequence Number is not allowed to cycle. Thus, the sender's counter and the receiver's counter are reset by

establishing a new security authentication and thus a new key prior to the transmission of the 2^{32nd} packet. The datagram also includes Authentication Data, i.e., a variable-length field that contains the Integrity Check Value (ICV) for the datagram.

Referring now to FIG. **29**B, a packet loss detector process **704** that runs in the monitor **702** is shown. The packet loss detector process **704** examines **706** header information in the packet, to determine if the packet includes an authentication header. If the packet does not include an authentication header, then the packet loss detector process **704** ignores **24** the packet and exits to wait for the next packet. If the packet includes an authentication header, the packet loss detector process **20** tests **708** to determine if the packet loss detector process **20** had been tracking the flow that is represented by the source and destination IP addresses and the SPID value that is in the authentication header. The packet loss detector will perform a cache look up to determine if the flow is stored in a cache of currently tracked flows. The packet loss detector process **20** tests **708** those values to see if the packet loss detector process **704** is currently tracking that security flow.

If the packet loss detector process **704** is not tracking that security flow, the packet loss detector process **20** will establish **710** a flow cache entry for that flow in a cache that can be maintained in memory (not shown). The packet loss detector process **704** will store the source and destination IP address and the SPID value from of the authentication header. The flow cache also includes all other authentication headers from other security flows that have previously been tracked. The flow cache enables the packet loss detector process **20** to monitor and track many hundreds, thousands, and so forth of different security flows. A cache entry is established for every different flow. Once the cache entry is established, the packet loss detector process **704** updates **712** the sequence number entry in the cache for that security flow. That is, the initial sequence number in the authentication header for the encountered flow is stored. The sequence number can start at any arbitrary value.

If, however, the packet loss detector process **704** determined **708** that it is tracking the flow, then the packet loss detector process **704** tests **714** if the sequence number in the current packet is equal to the previous sequence number noted for this flow plus 1. If the sequence number in the current packet is equal to the previous sequence number plus 1, then the packet loss detector process **704** can stop the current evaluation because the packet loss detector process **704** did not detect and the system did not experience any packet loss on that particular association. The packet loss detector process **704** will update **712** the stored sequence number for that flow in the cache.

If the sequence number in the current packet does not equal the previous sequence number noted for this flow plus 1, the packet loss detector process **704** for the IP SEC Authenication packets detected a potentially missed packet.

For some protocols that permit wrap around, the packet loss detector process **704** tests **718** if the sequence number has wrapped around e.g., gone from 32 bits of all ones to 32 bits of all zeros. The IP SEC Authentication packets currently do not permit wrap around, so test **718** would not be necessary for IP SEC Authentication Headers. If for other protocols (or latter versions of the IP SEC Authenication protocol), the packet loss detector process **704** detects a wrap around condition then there has not been any packet loss and the packet is dropped. The packet loss detector process **704** will update **712** the stored sequence number for that flow in the cache. If the sequence number is any other number, i.e., it did not turn over to all zeros, then there may have been packet loss. If there may have been packet loss, the packet loss detector process **704** can determine how many packets have been lost by determining how many sequence numbers are missing.

When packets may traverse more than one packet monitor **10**, the packet loss detector process **704** may produce a packet loss detected indication that does not indicate that the packets were actually dropped. A packet loss drop indication in a multi-monitor embodiment indicates that the lost packets did not come through the particular packet loss detector process **704**. However, the indicated lost packets could be on other segments of the network. That is, it is possible that other parts of the current flow are in other parts of the network. Therefore, the packet loss detector process **704** notes how many packets were actually successfully transmitted, as well as lost, and optionally their sequence numbers. These values can be compared to other values from other monitors **702** to establish whether or not there had been packet loss for the flow through the network.

This indication, could be converted into Network Accounting Records thus would be coupled to a process e.g. the accounting process **14** that reports statistics on that particular flow to provide a summary of how many packets were lost relative to how many packets were actually successfully transmitted on the flow. In the accounting process **14**, the network accounting records are correlated, aggregated, enhanced and so forth to identify network flows. This information can be used to determine the records that correspond to a particular network flow and whether a determined network flow lost any packets.

Capturing Quality of Service

Referring now to FIG. **30**, a process **730** for capturing quality of service in a network system **11**, (FIG. **1**), is shown. The capturing quality of service process **730** allows an administrator to configure **732** the network **11** with a policy that corresponds to a first quality of service. The process **730** also includes an optimization process that assigns or develops **734** the policy, defines the policy being used, and enforces the policy by deploying a policy dictated configuration into various policy enforcement devices in the network **11**. The capturing quality of service process **730** allows the administrator to observe **736** the actual service delivered by the network **11** to a customer on the network **11** to determine if the quality of service provided matches that specified by the policy **740**.

The capturing quality of service process **730** uses an accounting process **738** to collect information from the network. A preferred accounting process is accounting process **14** described above. The accounting process **14** collects data from the network **11** as part of the observation process **736**. The accounting process collects different kinds of metrics from the network, correlates these metrics to specified network flows, via the use of NARS, and maps collected, correlated information i.e., NARs back to the policy that was defined and actually deployed in the network. Because the accounting process **14** performs this observation function, the accounting process can provide an indication **738***a* whether or not the policy **740** is being satisfied.

By deploying the accounting process **14** to observe service quality, the capturing quality of service process **730** can validate performance of service level agreements (not shown). If the capturing quality of service process **730** detects that the policy level specified in a service level agreement is not being enforced, then the policy can be reassessed, redefined, and redeployed **742**. The capturing

quality of service process **730** can again observe **737**. Through the observation **736**, the capturing quality of service process **730** can determine whether reassessment and redefining of the deployed policy was successful. Several cycles of this quality of service optimization process could be required.

An important component of quality of service includes determining whether there has been packet loss. The packet detector monitor described in conjunction with FIGS. **29A** and **29B** can be used to access packet loss. The packet detection monitor **702** can be deployed in the network and generate NARs that can be used to determine packet loss as discussed above. This information can be used in the capturing quality of service process **730** to assess whether the policy specified by the service level agreement was provided to the customer. Additionally, so called Differentiated Service "DivServe technology" that a known quality of service solution that has been proposed for the Internet as well as enterprise networks. In contrast to a per-flow orientation of some types of quality of service solutions such as Int-serv and RSVP, DiffServ enabled networks classify packets into one of a small number of aggregated flows or "classes", based on bits set in the type of service (TOS) field of each packet's IP header. This is a quality of service technology for IP networking is designed to lower the statistical probability of packet loss of specific flows. The capturing quality of service process **730** establishes DivServ policy, that is decomposed into a collection of DivServ configurations. The DivServ configurations are deployed to a collection of routers or switches that the customer would have access to in the network **11** as part of the enforcement/deployment process **732**. Because packet loss is a statistical phenomenon, the capturing quality of service process **730** observes **736** a large number of network flows. The capturing quality of service process **730** can observe network traffic because of the use of the accounting process **14** and the resulting NARs at the granularity in which the DivServe policies are actually being deployed. The DivServe policies are generally deployed at the source and destination IP address, protocol and possibly destination port level.

By observing **736** network flows at the same granularity as a DivServe policy enforcement mechanism, if the capturing quality of service process **730** detects packet loss at that granularity, then there will be a direct feedback coupling to determine whether the policy is actually being enforced or not. If the policy is not being enforced, then an administrator will can reassess the policy, redefine the policy, and redeploy **742** new enforcement strategies. The capturing quality of service process **730** again will observe **736**.

As mentioned, because IP network quality of service is a statistical phenomenon, the capturing quality of service process **730** obtains a large number of samples, over a long period of time. Through this optimizing capturing quality of service process **730** and DivServe deployment **734**, the customer will get beneficial policy deployment for this service.

Service Management

Referring now to FIG. **31**, a service management loop **750** includes a service provisioning application **752**, a policy enabled network server **754** and an accounting process **756**. In a typical example, an Internet Service Provider (ISP) and a customer will enter into a service agreement or contract **751** that will specify a level of service for the network. The contract **751** has requirements and conditions that are enforced by the policy enabled network **754**. The service contract **751** is decomposed by the policy server to produce a template that defines the service represented by the agreement **751**. The template is fed to the service provisioning application **752** that actually produces a configuration file **752***a* that is sent out to the network **10** to configure network for a level of service based upon that contract **751**.

A service management feedback process **750** therefore includes three components, service provisioning **752**, policy server **754** and service accounting **756**. The role of service provisioning **752** is to send requests **752***b* to the policy server **754** to obtain an appropriate active policy, and obtaining rules and domain information **754***a* from the policy server. The provisioning system can communicate with appropriate network management systems and element management systems (not shown) to configure the network **10** for an end-to-end service. When the configuration **752***a* is deployed at the various network devices (not shown) at that point, the service is produced. The level of service is monitored or audited by the accounting system **756** which can be the accounting process **14** described above. The accounting process **14** monitors the level of service by producing appropiate network accounting records. The network accounting records NARs are used by a billing application to adjust billing based on the level of service that was provided as determined by the accounting system **14**. The accounting system **14** also can compare the policies produced by the policy server to the actual levels of service provided to the customer by examining NARs that are produced by the customer's usage of the network.

In addition, levels of service might change, and the system takes changes into account so that the service management can modify the charge or account differently for those changes in levels of service. The service accounting also uses the active policy information from the policy server to deliver billing information to a billing system or to a chargeback system that can may adjustments to billings for the service.

A policy enable network **754** is build on the capabilities of address management, domain name management and so forth. Essentially in a policy enabled network, policy services produce a set of rules and applys those rules to a domain or problem set. The policy server communicates the rules to the accounting process **14** so that the accounting process **14** can determine what kind of records to generate. All of the information is described using data flows.

As an example, a service contract may specify that a company "X" will be given 100% availability of a particular network device e.g., a router (not shown) and its corresponding service. In order to assure that level of service, the policy server **754** sends that requirement in a template to the provisioning service **752** to produce a configuration file **752***a* to configure the router to give company "X" preferred use for the router. Therefore, every time a packet from company "X's" network comes across the router, the packet will always be transmitted unless there is something wrong with the router. This may occur even if a packet of company "Y" which has a lower service level than company "X" is waiting in the router to be transmitted. The packet from company "Y" will wait because company "Y" is not paying for the quality of service that company X" is paying for.

In that case, the provisioning service configures **752** the policy enforcement mechanism that was put into the router in the network. How the policy was defined to the provisioning equipment is that there is a one-to-one relationship between the policy and what the accounting process **14** will monitor in the network. The accounting process **14** will be aware that company "X" contracted to have 100% availability from the router.

The accounting process **14** will then take every source of information it has available and will construct an accounting

record that reflects the level of service actually delivered to company "X." The accounting records produce are relative to the two components, i.e., the router and the customer. The accounting process **14** is flexible and can generate accounting records of any flow abstraction. In this process **750**, the policy server **754** sends a flow based policy to the provisioning server **752**. The provisioning server **752** uses a flow based policy to configure the network. That same flow based policy is passed to the accounting process **14** which can generate network accounting records NARs having metrics that can be used to match the same level of those flows. The output of the accounting process **14** will determine whether the quality of service, availability, etc. that was contracted for in the contract **751** was provided. Therefore the service management process **750** provides the level of service that was delivered at the same semantic level as the actual contract.

Capturing quality of service as audited by the accounting process **14** includes detecting of packet loss, as mentioned above. Each of the components managed by the service management process **750** require information. Therefore, the service provisioning has to provision these various quality levels. The policy server **754** thus, keeps what is essentially enforcement of the levels of quality that are offered by different service types, and the accounting process **756** detects, monitors and audits whether those classes in quality of service are being delivered.

Referring to FIG. **32**, an implementation of the service management provisioning **752** is shown. The service management provisioning **752** extends concepts of device management and network management into a service management layer of functionality. Service management provisioning includes a provisioning core **782**, provisioning modules **784**, and element managers **786**. Service provisioning **752** is user focused rather that network focused as conventional network management. Network management involves communication with network systems and equipment. Service provisioning **752** is orient more towards a user and a user's concepts of services. Service provisioning **752** provides an additional layer of abstraction that relates description of services at a user level to a network's ability to provide those end-to-end services. The architecture **780** of Service provisioning **752** is multi-device **788** at the bottom of the architecture and multi-service **790** at the top of the architecture. The service provisioning **752** is deployed to write commands to the network systems i.e., network elements **788** in order to change configurations of those systems.

Since many end customer services now require that a network operate with multiple, different kinds of network elements in order to provide an end-to-end service, the service provisioning **752** simplifies producing information that is necessary for a service provider to translate a service order from a customer to a network configuration, i.e., all commands necessary for all the different elements in the network in order to create an end-to-end service.

The service provisioning builds on existing systems. That is, in the lower layers there are existing element managers that have a configuration management system to configure at the network layer. The service provisioning adds layering over the conventional network management layer. Service provisioning maps a customer specified end to end service to the network elements that are required to produce that end-to-end service. Mapping of a customer's service orders into the state of the network can have various pieces of workflow necessary to create or completely activate this service order.

OTHER EMBODIMENTS

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

What is claimed is:

1. A method for tracking network accounting records in a accounting process that collects and correlates information derived from network data comprises:

producing a network accounting record that has an identifier that uniquely identifies the record within the accounting process with the identifier including a sequence number that specifies a sequence number for network accounting records that originate from the source device;

determining when there is a break in the sequence numbers of network accounting records produced from the source device; and

requesting missing network accounting records when there is a break in the sequence.

2. The method of claim **1** wherein producing a network accounting record further comprises:

producing a network source identifier that identifies a source device that creates the network accounting record.

3. The method of claim **2** further comprising determining the data collector that produced the missing network accounting records.

4. The method of claim **3** wherein determining the data collector comprises:

examining the network source identifier in a data flow.

5. The method of claim **4** wherein the data flow is identified by aggregating received network accounting records and correlating the received records to identify a flow.

6. A system comprising:

a data collector collecting data from a network device, and producing network accounting records from the collected data; and

a flow aggregation process, that receives network accounting records, the network accounting records including data identifying the data collector and a sequence number, said flow aggregation process detects missing network accounting records by detecting at least one missing sequence number;

wherein upon detecting a missing sequence number, the flow aggregation process retrieves data identifying the data collector from received records that have been correlated to identify a flow associated with the missing records; and

sends a request to the identified data collector to retransmit the missing record corresponding to the missing sequence number.

* * * * *

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Chapman et al.

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(45) **Date of Patent: Dec. 11, 2001**

(54) **TCP ADMISSION CONTROL**

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(73) Assignee: **Nortel Networks Limited**, St. Laurent (CA)

(*) 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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(22) Filed: **Jan. 27, 1998**

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(52) **U.S. Cl.** **370/232**; 370/233; 370/234
(58) **Field of Search** 370/229, 241, 370/230, 231, 232, 233

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Primary Examiner—Hassan Kizou
Assistant Examiner—Thien Tran
(74) *Attorney, Agent, or Firm*—Allan P. Millard

(57) **ABSTRACT**

Congestion at a network node can be aggravated by having too many TCP connections. A simple method of avoiding the bad effects of too many TCP connections is to limit the number of connections. Limiting the number of connections is achieved by an admission control which delays or even discards the connection set-up packets. TCP traffic flows are monitored to generate packet loss characteristics and when a certain condition is met, a connection request queue is disabled.

20 Claims, 6 Drawing Sheets

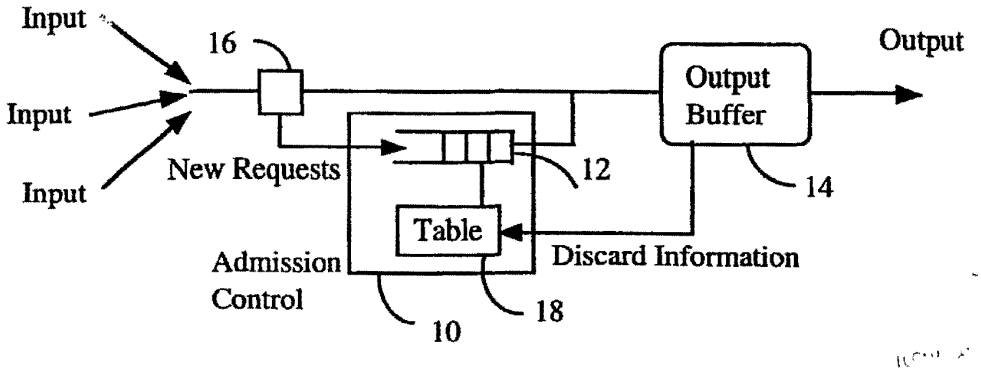
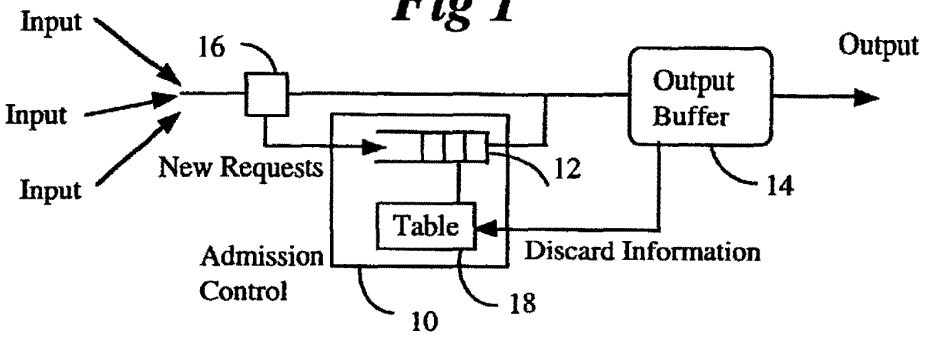


Fig 1



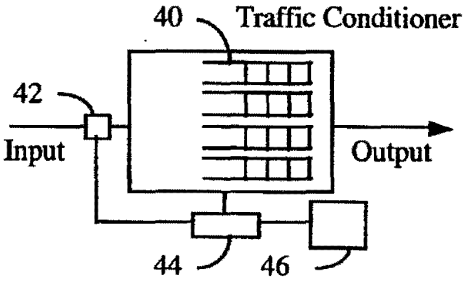


Fig 3

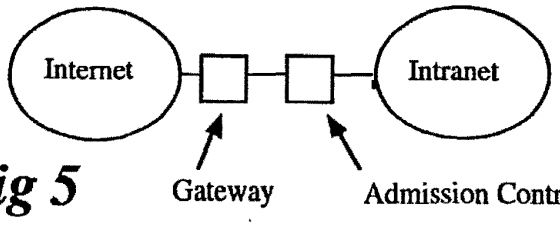


Fig 5

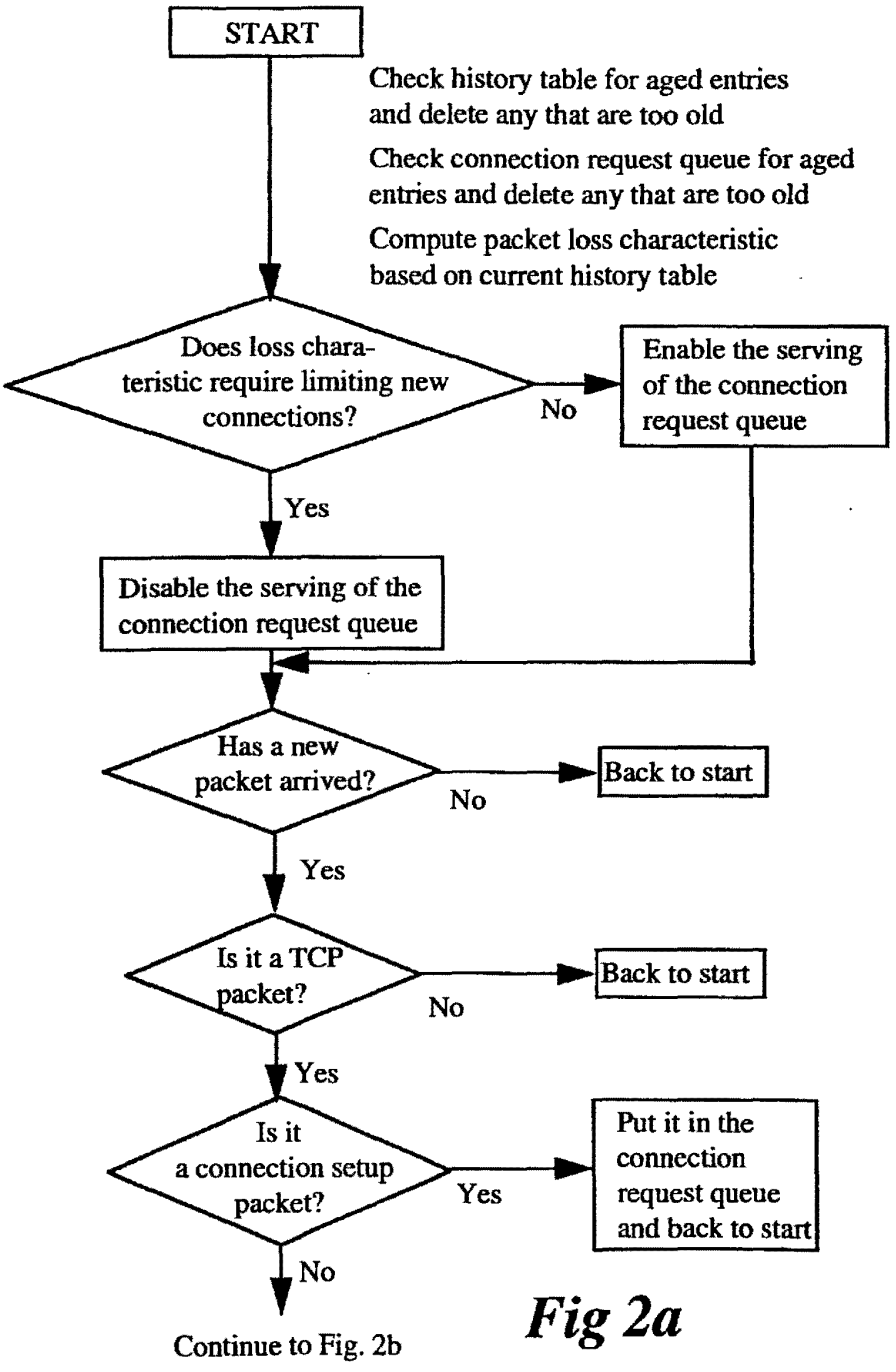

START
Check history table for aged entries and delete any that are too old
Check connection request queue for aged entries and delete any that are too old
Compute packet loss characteristic based on current history table
Does loss characteristic require limiting new connections?
No
Enable the serving of the connection request queue
Yes
Disable the serving of the connection request queue
Has a new packet arrived?
No
Back to start
Yes
Is it a TCP packet?
No
Back to start
Yes
Is it a connection setup packet?
Yes
Put it in the connection request queue and back to start
No
Continue to Fig. 2b

Fig 2a

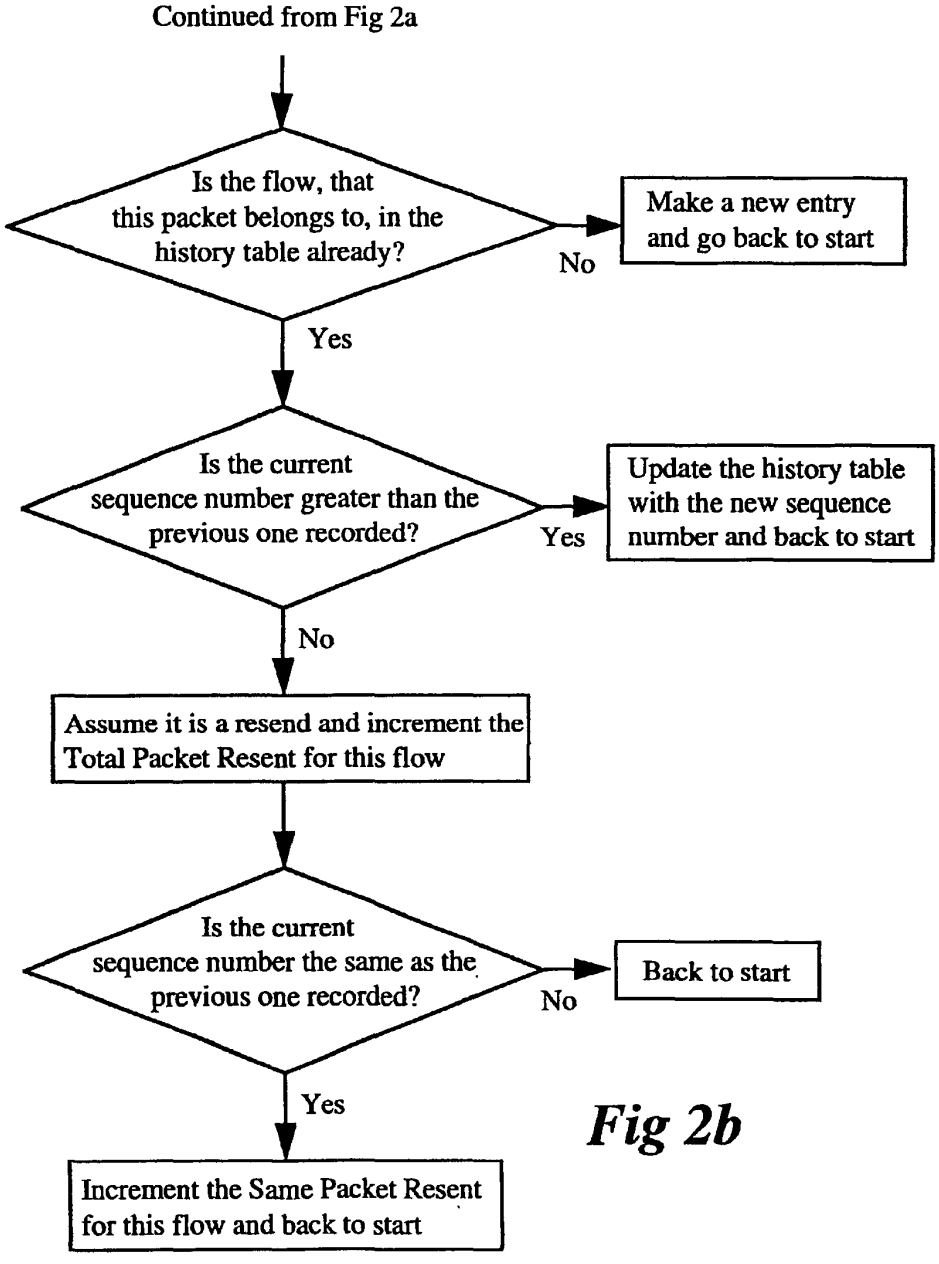

Continued from Fig 2a
Is the flow, that this packet belongs to, in the history table already?
No
Make a new entry and go back to start
Yes
Is the current sequence number greater than the previous one recorded?
Yes
Update the history table with the new sequence number and back to start
No
Assume it is a resend and increment the Total Packet Resent for this flow
Is the current sequence number the same as the previous one recorded?
No
Back to start
Yes
Increment the Same Packet Resent for this flow and back to start

Fig 2b

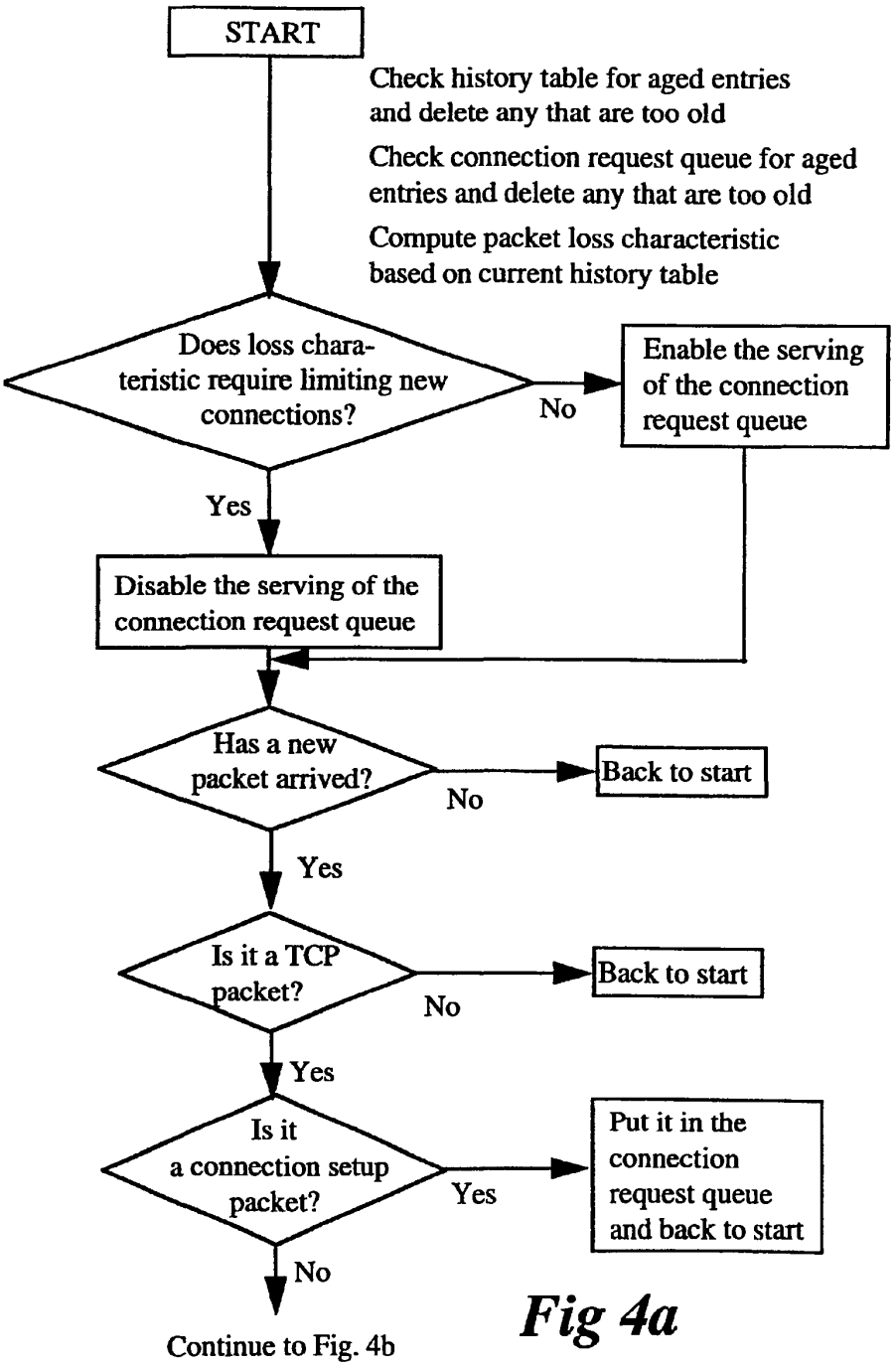

START
Check history table for aged entries and delete any that are too old
Check connection request queue for aged entries and delete any that are too old
Compute packet loss characteristic based on current history table
Does loss characteristic require limiting new connections?
No
Enable the serving of the connection request queue
Yes
Disable the serving of the connection request queue
Has a new packet arrived?
No
Back to start
Yes
Is it a TCP packet?
No
Back to start
Yes
Is it a connection setup packet?
Yes
Put it in the connection request queue and back to start
No
Continue to Fig. 4b

Fig 4a

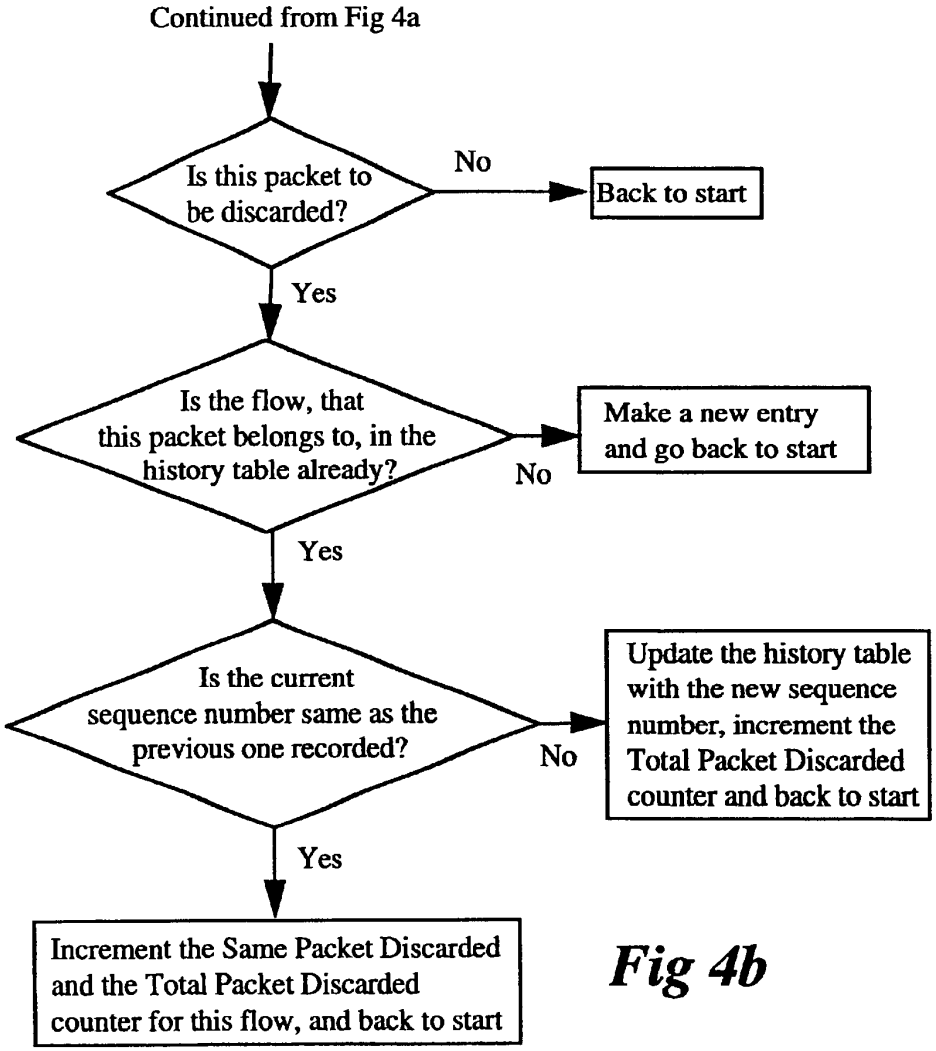

Continued from Fig 4a
Is this packet to be discarded?
No
Back to start
Yes
Is the flow, that this packet belongs to, in the history table already?
No
Make a new entry and go back to start
Yes
Is the current sequence number same as the previous one recorded?
No
Update the history table with the new sequence number, increment the Total Packet Discarded counter and back to start
Yes
Increment the Same Packet Discarded and the Total Packet Discarded counter for this flow, and back to start

Fig 4b

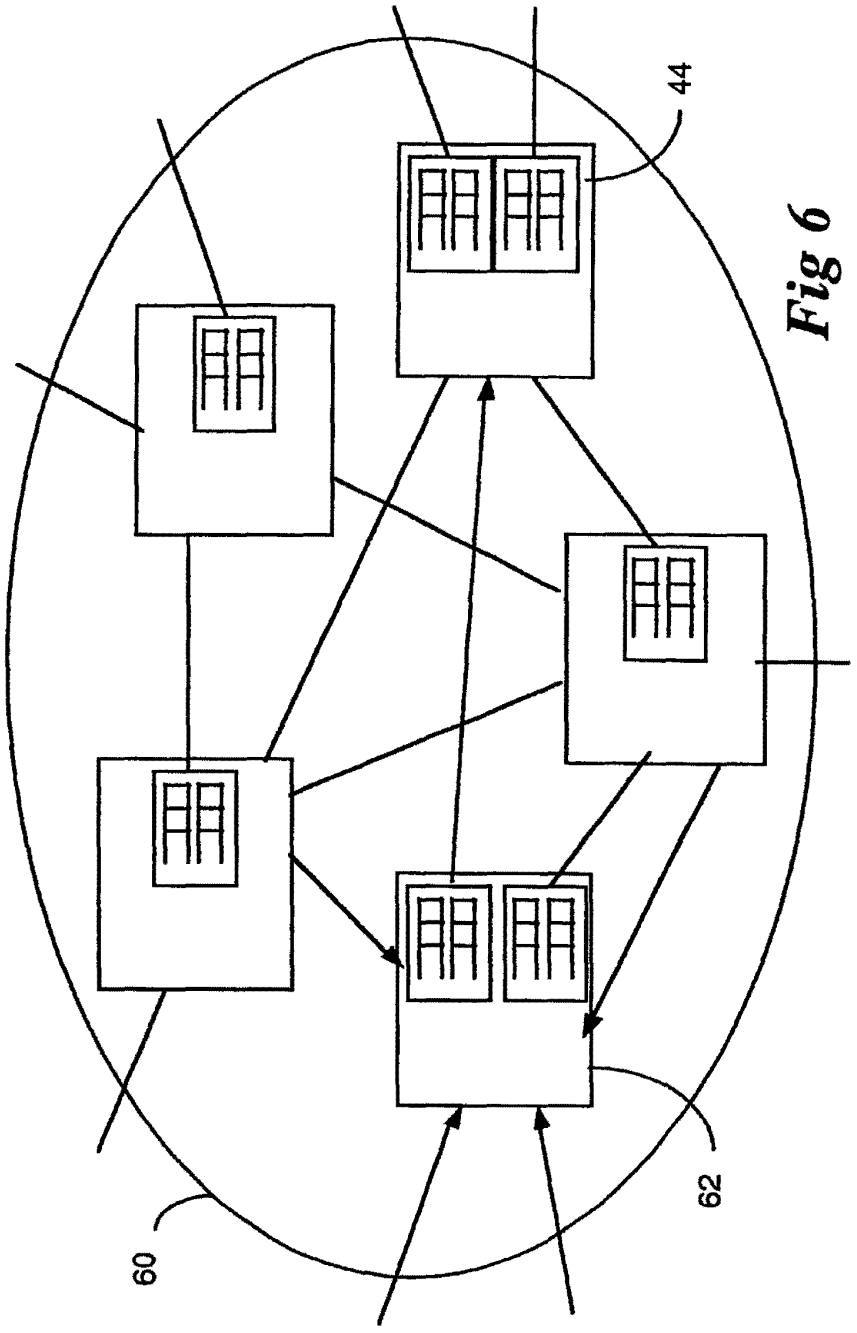


Fig 6

TCP ADMISSION CONTROL

FIELD OF THE INVENTION

The invention relates generally to traffic congestion management of a data network. In particular, it is directed to a technique by which congestion in the data network is controlled by limiting new TCP connection setups based on packet loss characteristics of the data network.

BACKGROUND OF THE INVENTION

The current data networks are handling not only enormous volume of traffic but more and more diversified multi media traffic, causing the data network to become congested more often. When congestion causes an excessive number of packets to be dropped, it can easily impact many traffic flows, and cause many timeouts. By guaranteeing a certain number of traffic flows a minimum bandwidth and treating the remainder as best effort, it is possible to avoid spreading high packet loss over so many flows and to reduce the number of aborted flows. Pending U.S. patent application Ser. No. 08/772,256 filed on Dec. 23, 1996 and Ser. No. 08/818,612 filed on Mar. 14, 1997 by the present inventors describe dynamic traffic conditioning techniques which make use of this concept. The dynamic traffic conditioning techniques described therein allow the network to discover the nature of the service for each traffic flow, classify it dynamically, and exercise traffic conditioning by means of such techniques as admission control and scheduling when delivering the traffic downstream to support the service appropriately.

Congestion at a network node can be aggravated by having too many TCP connections. TCP will adjust to try to share bandwidth among all connections but when the available buffer space is insufficient, time-outs will occur and as the congestion increases there will be an exponentially growing number of packets resent. The effect of having too many connections is that much of the bandwidth in the upstream network is wasted carrying packets that will be discarded at the congested node because there is not enough buffer there.

A simple method of avoiding the bad effects of too many TCP connections is to limit the number of connections or to discard one or more packets from one or more existing connections. Limiting the number of connections is achieved by an admission control which delays or even discards the connection set-up packets. In the case of discarding packets, which packets and from which connection to discard packets are decided by preset algorithms or policies. By invoking this control to limit the number of connections, each packet is inspected to see if it is a connection set-up packet, e.g., TCP SYN packet. This control packet is used to initiate a TCP connection and no traffic can flow until it is acknowledged by the other end of the proposed connection.

In one example, a decision to invoke the admission control, i.e. deciding when to limit the TCP traffic, can be made as follows:

Keep track of all TCP connections and thus keep count of the total number. Apply a calculation to see how many connections the available buffer can support and limit new connections. This is not a good way for a general implementation because it requires keeping state information on all TCP flows and being provided with information on the configured buffer size.

A better solution is when buffers get full and packet loss gets above some configured threshold, an admission control

algorithm will apply some policy to reduce connections or the amount of traffic to keep the loss below the threshold. The reduction can be by discarding traffic from existing connections or, preferably, by preventing new connections from being set up.

The invention performs the admission control algorithm to achieve this effect.

OBJECTS OF INVENTION

It is therefore an object of the invention to provide a method of managing a data network for congestion.

It is a further object of the invention to provide a method of continuously monitoring the TCP traffic flows for congestion in a data network.

It is another object of the invention to provide a method of managing the data network by performing admission control for TCP traffic.

It is yet an object of the invention to provide a method of managing the data network by exercising the connection admission control for a new TCP connection request based on the packet loss characteristic.

SUMMARY OF THE INVENTION

Briefly stated, the invention resides in a packet data network for multimedia traffic having one or more nodes in which network one or more packets are discarded to control congestion. According to one aspect, a method of performing admission control to connection oriented traffic flows comprises steps of monitoring packets of all the traffic flows, deriving a packet loss characteristic of the traffic flows and disabling the serving of a new connection request when the packet loss characteristic matches a predefined pattern.

In another aspect, a method of performing admission control to TCP traffic flows comprises steps of storing all TCP connection setup packets in a connection request queue, monitoring packets of all active TCP traffic flows according to their port numbers and sequence numbers, and recording the count of either resent or discarded packets for any TCP traffic flows. The method further includes steps of building a history table containing the history of the sequence numbers, port numbers, and the count of either resent or discarded packets, computing a packet loss characteristic using the contents of the history table, and deciding enabling or disabling the connection request queue based on the packet loss characteristic with respect to a predefined pattern.

In a further aspect, the invention is directed to a TCP admission control apparatus for controlling congestion of a data network. The apparatus comprises a TCP output buffer for buffering and inspecting all the TCP packets of an incoming traffic flow, and a connection request queue for storing new connection requests. The apparatus further includes a history table for storing traffic information with respect to the TCP packets inspected above to derive a packet loss characteristic, and a queue controller for enabling or disabling the connection request queue upon detecting the matching of the packet loss characteristic with a predefined pattern.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of the admission control according to an embodiment of the invention.

FIGS. 2*a* and 2*b* are a flow chart for the case where TCP admission control is applied in a traffic link.

FIG. 3 illustrates the relationship of admission control with the traffic conditioner.

FIGS. 4*a* and 4*b* are a flow chart for the case where TCP admission control is applied in a router.

FIGS. 5 and 6 show possible locations of admission control of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Referring to FIG. 1, the TCP admission control apparatus **10**, according to one embodiment of the invention, includes a connection request queue **12**. It is located at or near the output buffer **14** of a node of a data network. It should be noted that an admission control apparatus can be a separate device or can be made integral with or to reside in any node or link equipment. It should also be understood that TCP traffic flows as a whole can be processed by an apparatus or separate apparatus can be provided for each traffic flow or a group of traffic flows in one class. Every packet of an input stream is inspected and TCP packets are identified at the output buffer **1** using, for example, source and destination IP addresses, source and destination port numbers and protocol. All new connection requests are read at a connection reader **16** and are stored at the connection request queue **12**. The connection request queue **12** is a FIFO. If admission control is not invoked then the new connection requests will be served immediately by enabling the connection request queue. If admission control is switched on then they will be delayed.

The admission control detects the packets that are being discarded and looks for multiple successive packets from the same flow or multiple instances of the same packet, the latter being the result of packet resends due to packet loss or discard. The admission control derives some pattern of packet discards by using a discard measure. For convenience, this measure is called packet loss characteristic in this specification. It is possible that other parameters can be used to indicate the state of congestion in a data network. If certain criteria are met or the packet loss characteristic matches a predefined pattern, admission control is invoked and any new connection requests (connection set-up packets) will be delayed by disabling the connection request queue or packets belonging to one or more existing connections will be discarded until the problem clears. If a connection set-up packet is delayed too long (e.g., one second), it will be discarded from the queue.

When the packet loss characteristic shows that new connections can be accepted the servicing of the connection request queue is enabled. Waiting connection requests can be served immediately or can be released at a controlled pace according to a predefined algorithm.

The admission control apparatus therefore includes a small history table **18** and information about discarded packets is entered into it. When a packet is discarded, the flow identity (source and destination IP plus TCP socket number) is extracted and compared with current table entries. If the flow already has an entry then the history is updated. If the flow does not have an entry and there is room for a new entry, the new entry is made. If there is no room for a new entry the information is discarded.

The admission control can be performed on a traffic link or at a router.

In the case where the admission control is performed on the traffic link, the history table contains, for each active flow (or as many flows as can be handled), the following entries:

The first entry is a count of resent packets for that flow (Total Packet Resent).

The second entry is a count of how many times the currently recorded packet (that is the currently stored sequence number) has been resent (Same Packet Resent).

The third entry is the time that the most recent update was made for that flow. After some period of inactivity the flow is taken out of the table.

This information is used to look for patterns of discard that indicate congestion problems. It is assumed that if the sequence number on an arriving packet is lower than or equal to the stored value, then it must be a resend. The total number of resends as a fraction of the total number of packets is a measure of downstream congestion. In this embodiment, this measure is used as the packet loss characteristic.

Seeing the same packet resent multiple times will suggest that the connection is experiencing time-out or at least a very high loss rate. It is not usual for a packet to be discarded multiple times. Normally the TCP protocol will adjust its window to fit the available bandwidth and will only lose one packet before reducing that window. Although TCP relies on packet loss to constantly test for available bandwidth, a packet that is discarded once will almost certainly be forwarded when it is retransmitted. Multiple instances of the same packet will suggest that the TCP source is experiencing time-out.

There will be many variations on what information is stored and what algorithm is used to assess whether new connections should be enabled.

It is not necessary to keep information on all flows since a sampled history is sufficient to detect problem conditions.

Entries in the history table are removed after a period of time. Also, whenever admission control is invoked, the history table is cleaned out and starts fresh to get a good picture of the new loss characteristic. The history table would be purged, in any case, at regular intervals to keep the history reflecting current loss characteristics. The interval would be configurable depending on line rates and expected number of flows, etc.

FIGS. 2*a* and 2*b* are a flow chart for the case where TCP admission control is applied in a traffic link rather than in a router.

As mentioned earlier, the applicant's pending applications describe traffic conditioners and FIG. 3 shows one of such conditioners. In the Figure, a traffic conditioner **40** includes a plurality of queues **42**, at least one for each class of TCP traffic. Every packet of an input stream is inspected and identified at **44** using, for example, IP addresses, ports, etc. A controller **46** characterises the flow (using rate, duration, etc.) and assigns it a class. The controller refers to a database **48** and uses output scheduling to allocate bandwidth among classes. It can implement an admission control policy of the present invention for a class before delivering an output stream toward downstream nodes or to peripherals. In this case it is necessary to work out whether a packet has been discarded, by looking for a second copy of it passing through the link.

In another embodiment, the admission control is performed in the router where the discarded packets can be inspected directly as the discard decision is made at the buffer of the router.

In this case the history table contains, for each active flow (or as many flows as can be handled), the following entries:

The first entry is a count of discarded packets for that flow (Total Packet Discarded).

The second entry is a count of how many times the currently recorded packet (that is the currently stored sequence number) has been discarded (Same Packet Discarded).

The third entry is the time that the most recent update was made for that flow. After some period of inactivity the flow is taken out of the table.

This information is used to look for patterns of discard that indicate congestion problems. The total number of discards as a fraction of the total number of packets is a measure of buffer congestion.

Seeing the same packet resent multiple times will suggest that the connection is experiencing time-out or at least a very high loss rate.

There will be many variations on what information is stored and what algorithm is used to assess whether new connections should be enabled.

In another embodiment, if the admission control is performed at the router, packets from one or more existing connections can be discarded to control congestion at its buffer. The discarding action can be taken together with action of limiting the set-up of new connections, latter having been described above.

FIGS. *4a* and *4b* are a flow chart for the case where TCP admission control is applied in a router rather than in a traffic link.

Like the traffic conditioning of the pending applications, the admission control can take place at various places in the data network and can be biased toward certain kinds of TCP traffic. For example, as gateways are often a bottleneck and bulk flows can decrease response times for interactive users, an admission control can be located at a place shown in FIG. **5** which will alleviate this problem. In FIG. **6**, traffic conditioners are located at a plurality of IP switches which form a data network **60**.

What is claimed is:

1. In a packet data network for multimedia traffic having one or more nodes in which network one or more packets are discarded to control congestion; a method of performing admission control to TCP traffic flows comprising steps of;

storing all TCP connection setup packets in a connection request queue;

monitoring packets of all active TCP traffic flows according to their port numbers and sequence numbers;

recording the count of either resent or discarded packets for any TCP traffic flows;

building a history table containing the history of the sequence numbers, port numbers, and the count of either resent or discarded packets;

computing a packet loss characteristic using the contents of the history table; and

deciding enabling or disabling the connection request queue based on the packet loss characteristic with respect to a predefined pattern.

2. The method of performing admission control to TCP traffic flows according to claim **1** wherein the step of computing a packet loss characteristic comprises step of:

deriving the total number of either resends or discards as a fraction of the total number of TCP packets of the TCP traffic flow.

3. The method performing admission control to TCP traffic flow according to claim **2**, comprising the further step of:

deciding to disable the connection request queue when the fraction reaches a preset threshold.

4. The method of performing admission control to TCP traffic flows according to claim **1**, comprising a further step of:

enabling the connection request queue at a controlled pace.

5. A TCP admission control apparatus for controlling congestion of a data network, comprising:

a TCP output buffer for inspecting all the TCP packets of an incoming traffic stream according to their port numbers and sequence numbers;

a connection request queue for storing new connection requests;

a history table for recording the sequence numbers, port numbers and a count of either recent or discarded packets in order to compute a packet loss characteristic; and

a queue controller for enabling or disabling the connection request upon detecting the matching of the packet loss characteristic with a predefined pattern.

6. The TCP admission control apparatus according to claim **5** wherein the history table contains the total number of packets of the TCP traffic flow.

7. The method of performing admission control to TCP traffic flows according to claim **1** wherein the step of recording further comprises recording the time that the most recent update was made for a specified TCP traffic flow.

8. The method of performing admission control to TCP traffic flows according to claim **7** wherein the specified TCP traffic flow is removed from the history table after a predefined period of inactivity.

9. The method of performing admission control to TCP traffic flows according to claim **1** wherein the method is performed in a router.

10. The method of performing admission control to TCP traffic flows according to claim **1** wherein the method is performed in a controller integral to a traffic conditioner.

11. The method of performing admission control to TCP traffic flows according to claim **1** further comprising the step of clearing all entries of the history table whenever the connection request queue is re-enabled.

12. The method of performing admission control to TCP traffic flows according to claim **1** further comprising the step of purging all entries in the history table periodically from time to time or after a certain preset period.

13. The TCP admission control apparatus according to claim **5** wherein the history table records the time that the most recent update was made for a specified TCP traffic flow.

14. The TCP admission control apparatus according to claim **13** wherein the specified TCP traffic flow is removed from the history table after a predefined period of inactivity.

15. The TCP admission control apparatus according to claim **5** wherein the apparatus is a router.

16. The TCP admission control apparatus according to claim **5** wherein the history table clears all entries whenever the connection request queue is re-enabled.

17. The TCP admission control apparatus according to claim **5** wherein the history table all entries periodically from time to time or after a certain preset period.

18. The TCP admission control apparatus according to claim **5** wherein the packet loss characteristic is computed by deriving the total number of either resends or discards as a fraction of the total number of TCP packets of the TCP traffic flow.

19. The TCP admission control apparatus according to claim **18** wherein the queue controller disables the connection request queue when the fraction reaches a preset threshold.

20. The TCP admission control apparatus according to claim **5** wherein the connection request queue is enabled at a controlled pace.

* * * * *

US006651099B1

(12) **United States Patent**
Dietz et al.

(10) **Patent No.: US 6,651,099 B1**
(45) **Date of Patent: Nov. 18, 2003**

(54) **METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK**

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(21) Appl. No.: **09/608,237**

(22) Filed: **Jun. 30, 2000**

Related U.S. Application Data

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(51) **Int. Cl.**[7] **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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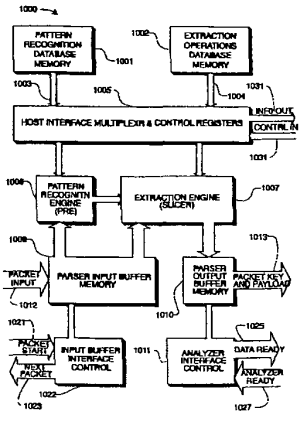
Primary Examiner—Moustafa M. Meky
(74) *Attorney, Agent, or Firm*—Dov Rosenfeld; Inventek

(57) **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.

10 Claims, 18 Drawing Sheets



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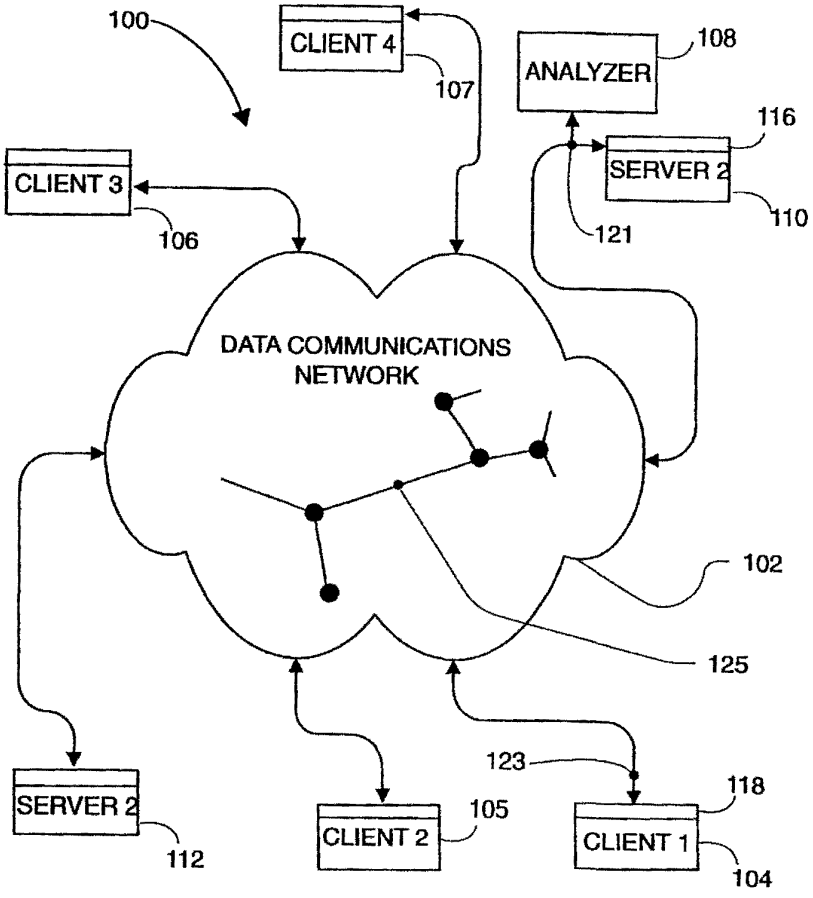
100
CLIENT 4
107
ANALYZER
108
116
SERVER 2
110
121
CLIENT 3
106
DATA COMMUNICATIONS NETWORK
102
125
123
118
SERVER 2
112
CLIENT 2
105
CLIENT 1
104

FIG. 1

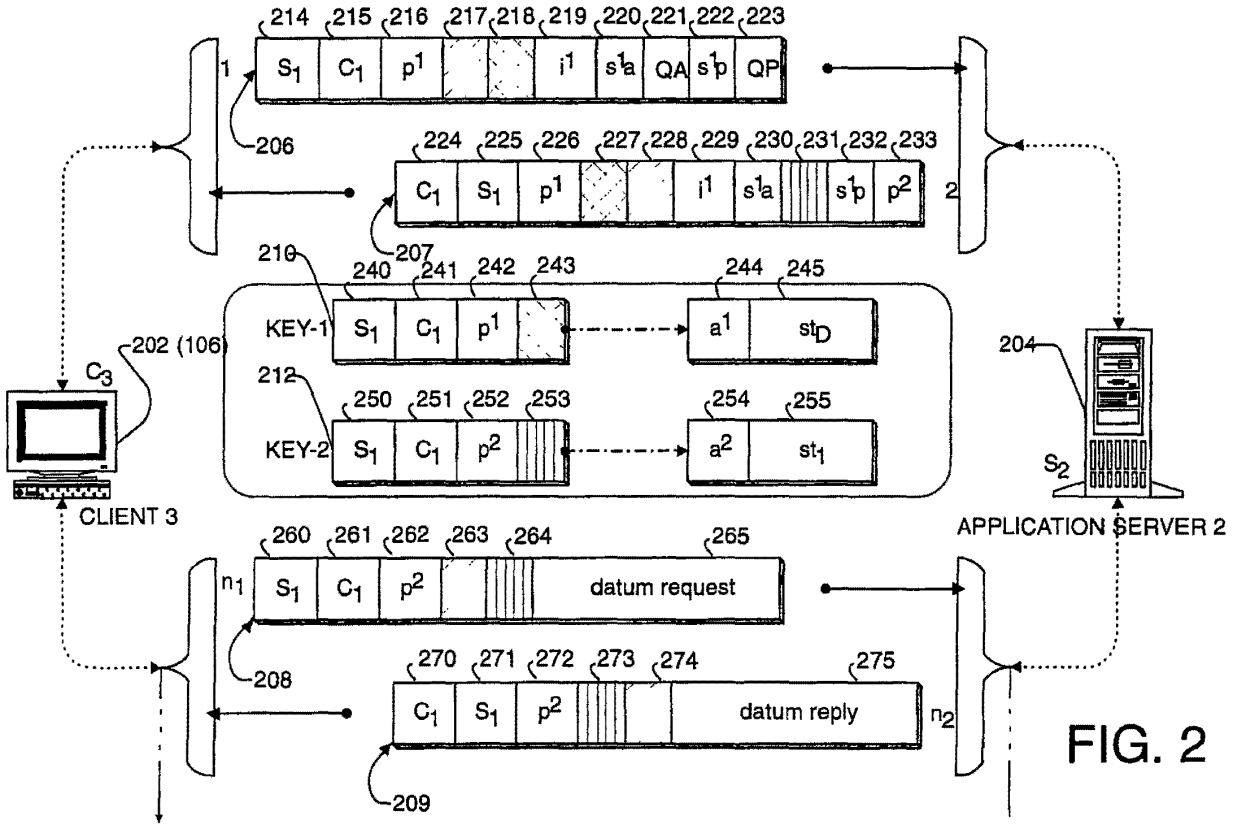
214 215 216 217 218 219 220 221 222 223
S1 C1 p1 i1 s1a QA s1p QP
1
206
224 225 226 227 228 229 230 231 232 233
C1 S1 p1 i1 s1a s1p p2
2
207
210
240 241 242 243 244 245
KEY-1 S1 C1 p1 a1 stD
212
250 251 252 253 254 255
KEY-2 S1 C1 p2 a2 st1
202 (106)
C3
CLIENT 3
204
S2
APPLICATION SERVER 2
260 261 262 263 264 265
n1 S1 C1 p2 datum request
208
270 271 272 273 274 275
C1 S1 p2 datum reply
n2
209

FIG. 2

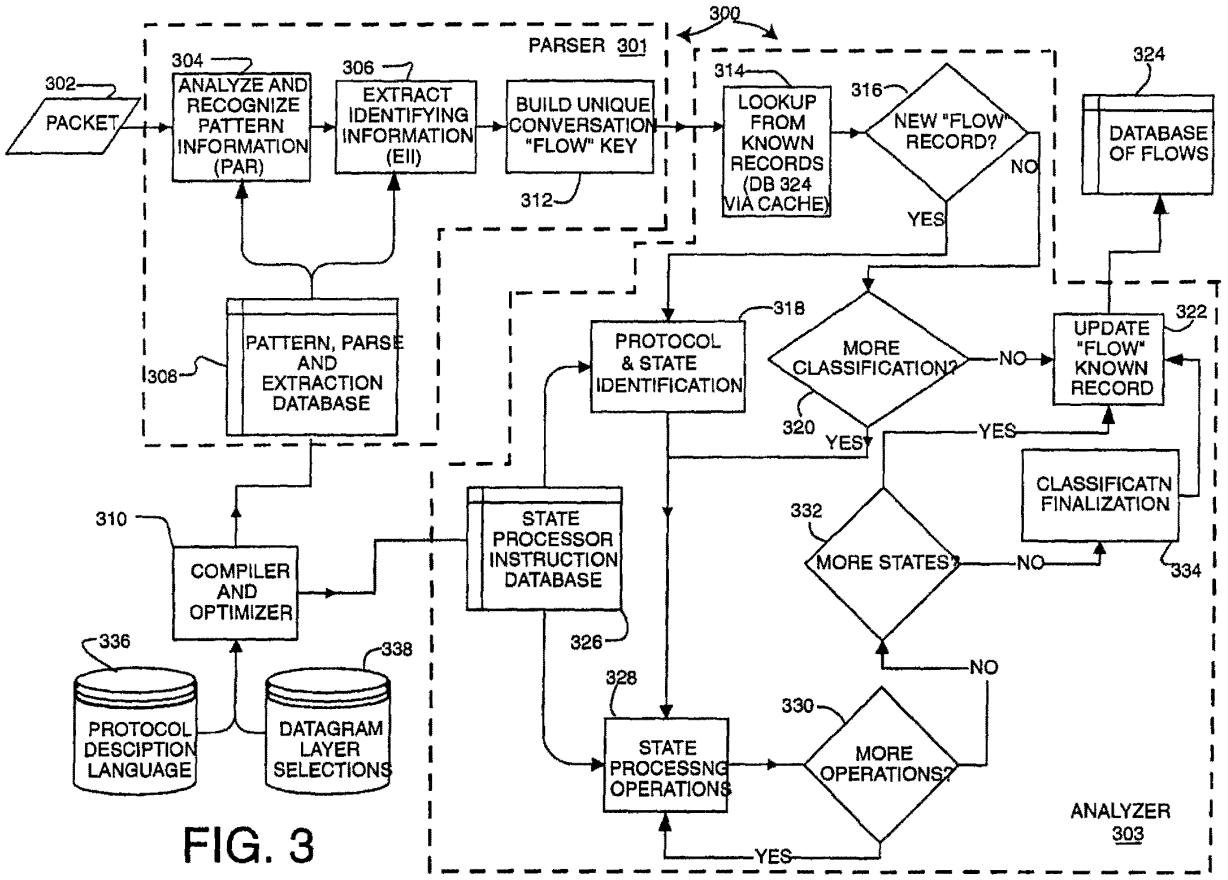
300
PARSER 301
302
PACKET
304
ANALYZE AND RECOGNIZE PATTERN INFORMATION (PAR)
306
EXTRACT IDENTIFYING INFORMATION (EII)
BUILD UNIQUE CONVERSATION "FLOW" KEY
312
314
LOOKUP FROM KNOWN RECORDS (DB 324 VIA CACHE)
316
NEW "FLOW" RECORD?
NO
YES
324
DATABASE OF FLOWS
308
PATTERN, PARSE AND EXTRACTION DATABASE
318
PROTOCOL & STATE IDENTIFICATION
MORE CLASSIFICATION?
NO
320
YES
322
UPDATE "FLOW" KNOWN RECORD
YES
CLASSIFICATN FINALIZATION
334
310
COMPILER AND OPTIMIZER
STATE PROCESSOR INSTRUCTION DATABASE
326
332
MORE STATES?
NO
336
PROTOCOL DESCIPTION LANGUAGE
338
DATAGRAM LAYER SELECTIONS
328
STATE PROCESSNG OPERATIONS
330
MORE OPERATIONS?
NO
YES
ANALYZER 303

FIG. 3

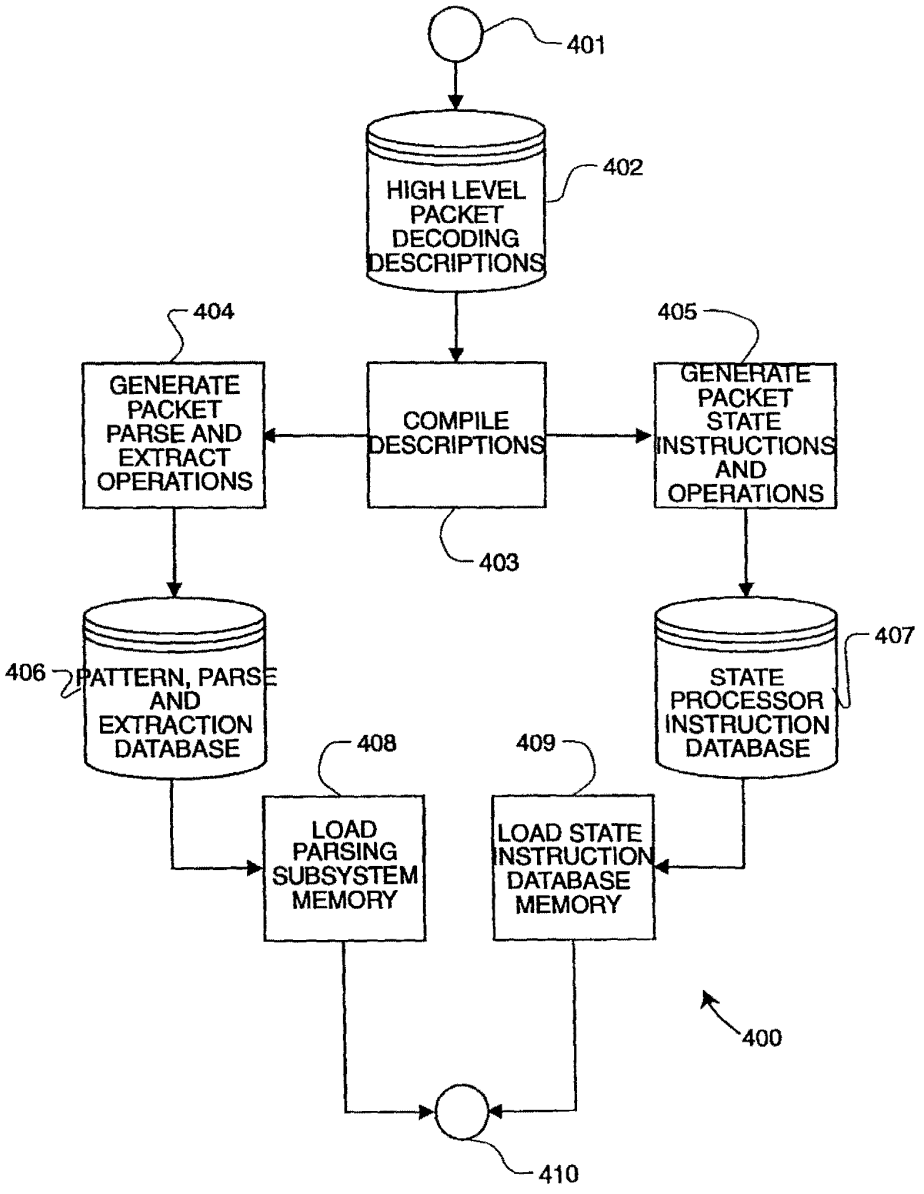
401
HIGH LEVEL PACKET DECODING DESCRIPTIONS
402
404
405
GENERATE PACKET PARSE AND EXTRACT OPERATIONS
COMPILE DESCRIPTIONS
GENERATE PACKET STATE INSTRUCTIONS AND OPERATIONS
403
406
PATTERN, PARSE AND EXTRACTION DATABASE
407
STATE PROCESSOR INSTRUCTION DATABASE
408
409
LOAD PARSING SUBSYSTEM MEMORY
LOAD STATE INSTRUCTION DATABASE MEMORY
400
410

FIG. 4

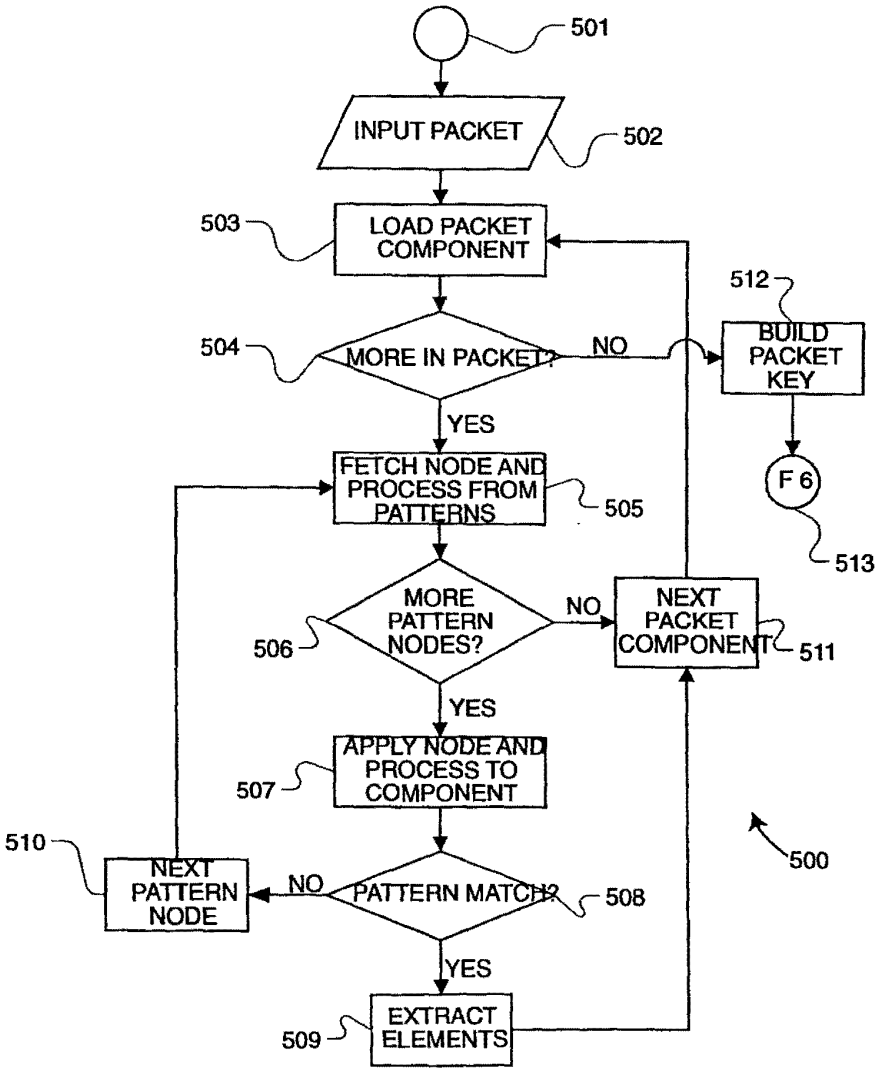
501
INPUT PACKET
502
503
LOAD PACKET COMPONENT
504
MORE IN PACKET?
NO
512
BUILD PACKET KEY
F 6
513
YES
FETCH NODE AND PROCESS FROM PATTERNS
505
MORE PATTERN NODES?
506
NO
NEXT PACKET COMPONENT
511
YES
APPLY NODE AND PROCESS TO COMPONENT
507
500
510
NEXT PATTERN NODE
NO
PATTERN MATCH?
508
YES
EXTRACT ELEMENTS
509

FIG. 5

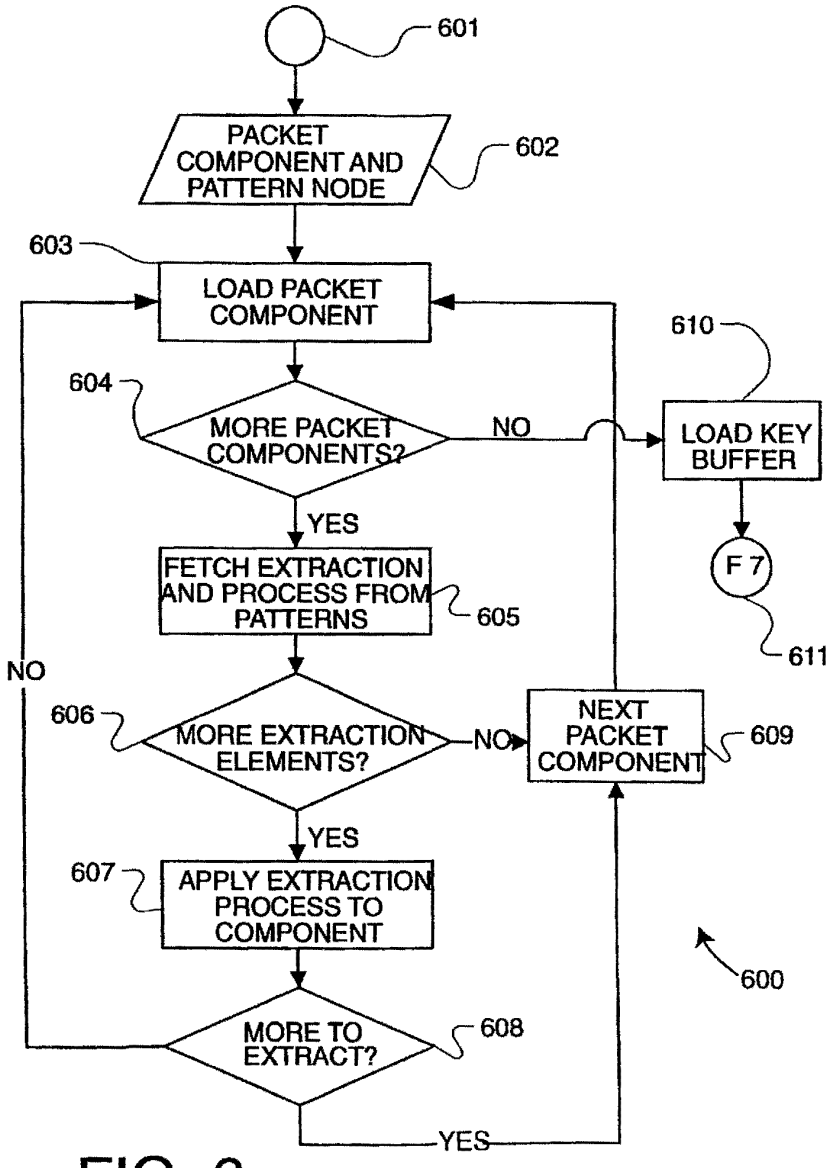
601
PACKET COMPONENT AND PATTERN NODE
602
603
LOAD PACKET COMPONENT
610
604
MORE PACKET COMPONENTS?
NO
LOAD KEY BUFFER
YES
F 7
611
FETCH EXTRACTION AND PROCESS FROM PATTERNS
605
NO
606
MORE EXTRACTION ELEMENTS?
NO
NEXT PACKET COMPONENT
609
YES
607
APPLY EXTRACTION PROCESS TO COMPONENT
600
MORE TO EXTRACT?
608
YES

FIG. 6

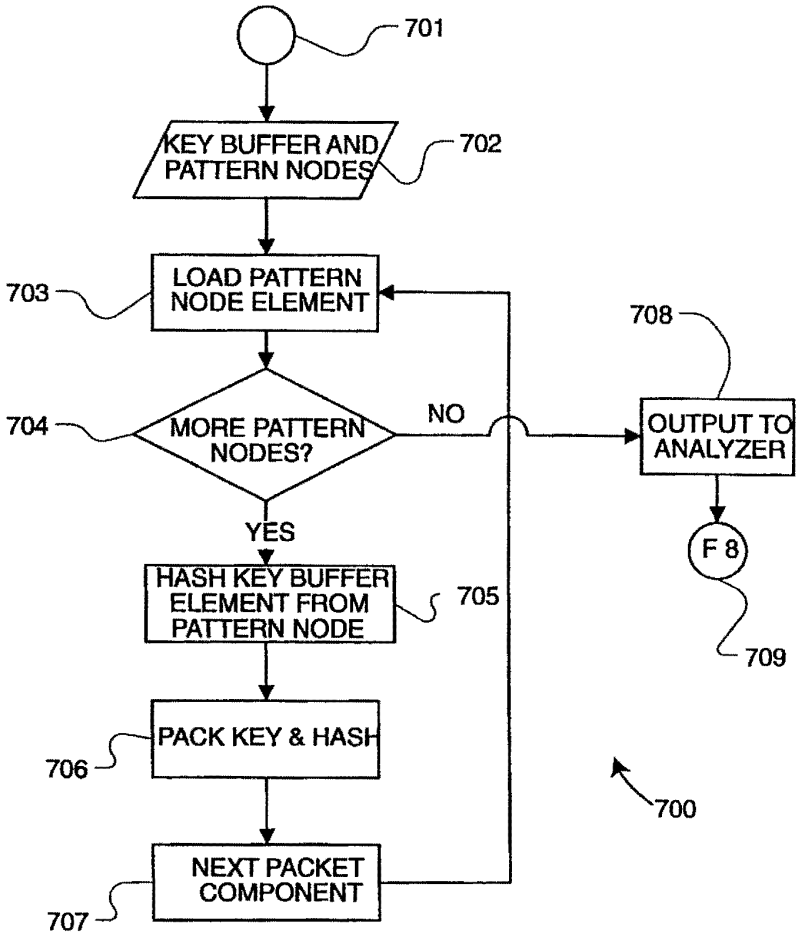
701
KEY BUFFER AND PATTERN NODES
702
LOAD PATTERN NODE ELEMENT
703
MORE PATTERN NODES?
704
NO
YES
OUTPUT TO ANALYZER
708
F 8
709
HASH KEY BUFFER ELEMENT FROM PATTERN NODE
705
PACK KEY & HASH
706
NEXT PACKET COMPONENT
707
700

FIG. 7

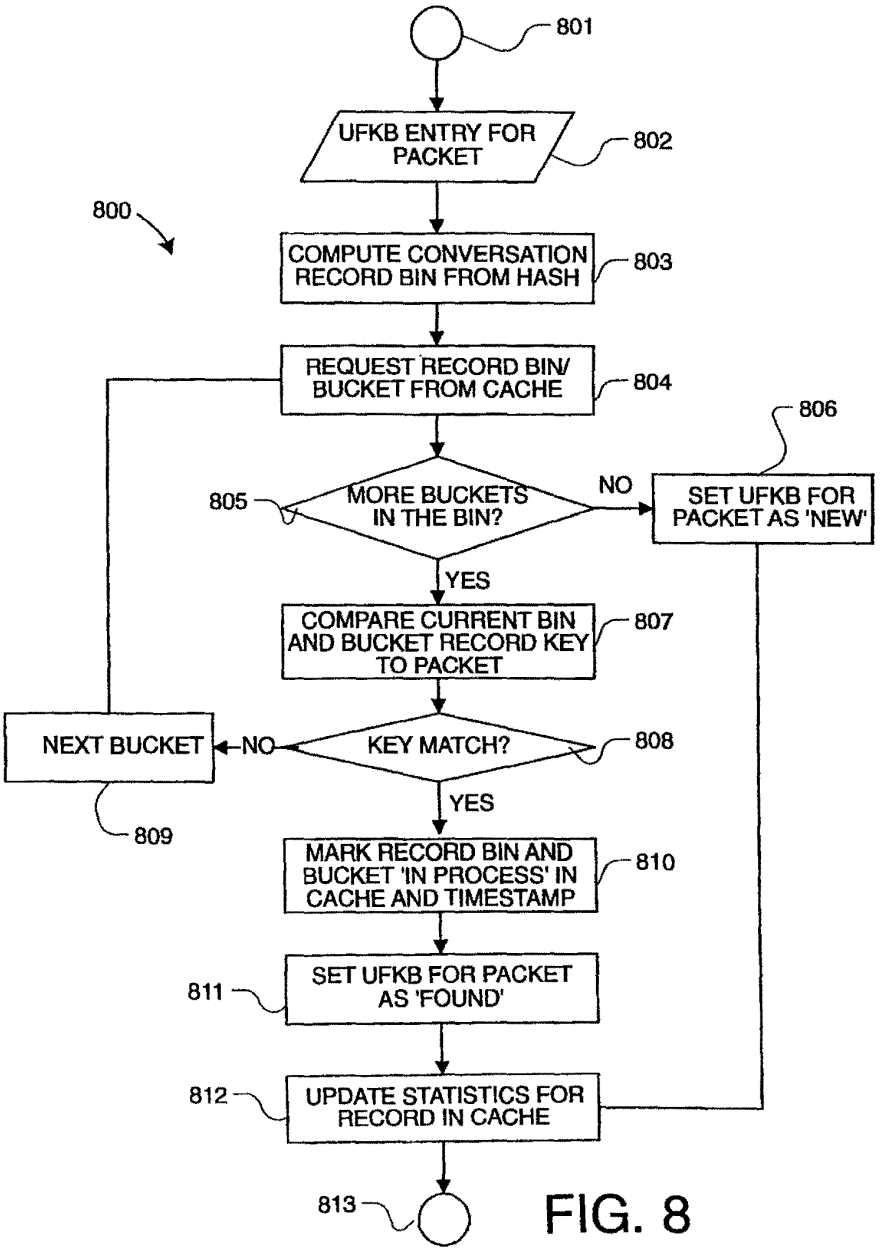
801
UFKB ENTRY FOR PACKET
802
800
COMPUTE CONVERSATION RECORD BIN FROM HASH
803
REQUEST RECORD BIN/ BUCKET FROM CACHE
804
806
805
MORE BUCKETS IN THE BIN?
NO
SET UFKB FOR PACKET AS 'NEW'
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
807
NEXT BUCKET
NO
KEY MATCH?
808
YES
809
MARK RECORD BIN AND BUCKET 'IN PROCESS' IN CACHE AND TIMESTAMP
810
SET UFKB FOR PACKET AS 'FOUND'
811
812
UPDATE STATISTICS FOR RECORD IN CACHE
813

FIG. 8

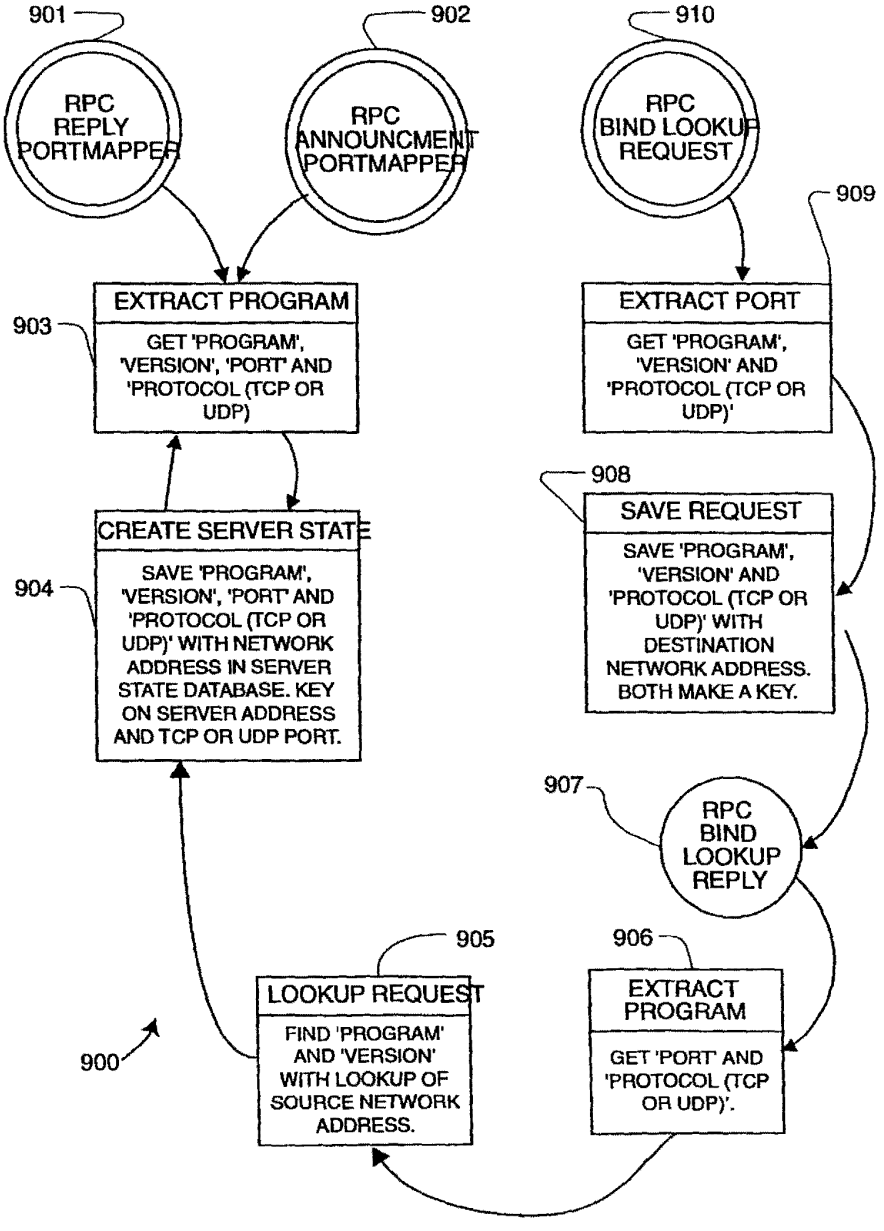
901
RPC REPLY PORTMAPPER
902
RPC ANNOUNCMENT PORTMAPPER
910
RPC BIND LOOKUP REQUEST
909
EXTRACT PROGRAM
GET 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)
903
EXTRACT PORT
GET 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'
908
SAVE REQUEST
SAVE 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)' WITH DESTINATION NETWORK ADDRESS. BOTH MAKE A KEY.
CREATE SERVER STATE
SAVE 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)' WITH NETWORK ADDRESS IN SERVER STATE DATABASE. KEY ON SERVER ADDRESS AND TCP OR UDP PORT.
904
907
RPC BIND LOOKUP REPLY
905
906
LOOKUP REQUEST
FIND 'PROGRAM' AND 'VERSION' WITH LOOKUP OF SOURCE NETWORK ADDRESS.
EXTRACT PROGRAM
GET 'PORT' AND 'PROTOCOL (TCP OR UDP)'.
900

FIG. 9

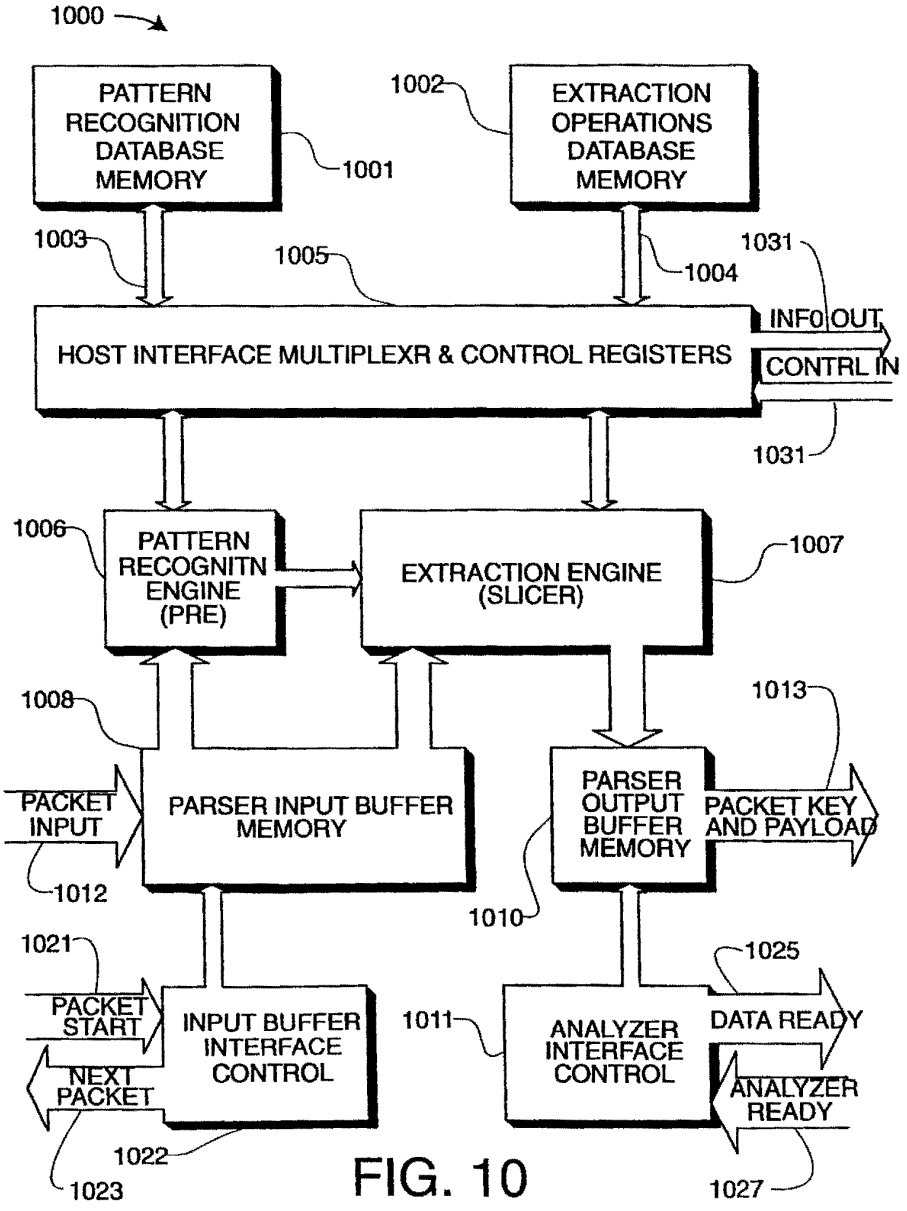
1000
PATTERN RECOGNITION DATABASE MEMORY
1001
1002
EXTRACTION OPERATIONS DATABASE MEMORY
1003
1005
1004
1031
INFO OUT
CONTRL IN
HOST INTERFACE MULTIPLEXR & CONTROL REGISTERS
1031
1006
PATTERN RECOGNITN ENGINE (PRE)
EXTRACTION ENGINE (SLICER)
1007
1008
1013
PACKET INPUT
PARSER INPUT BUFFER MEMORY
PARSER OUTPUT BUFFER MEMORY
PACKET KEY AND PAYLOAD
1012
1010
1021
1025
PACKET START
NEXT PACKET
INPUT BUFFER INTERFACE CONTROL
1011
ANALYZER INTERFACE CONTROL
DATA READY
ANALYZER READY
1022
1023
1027

FIG. 10

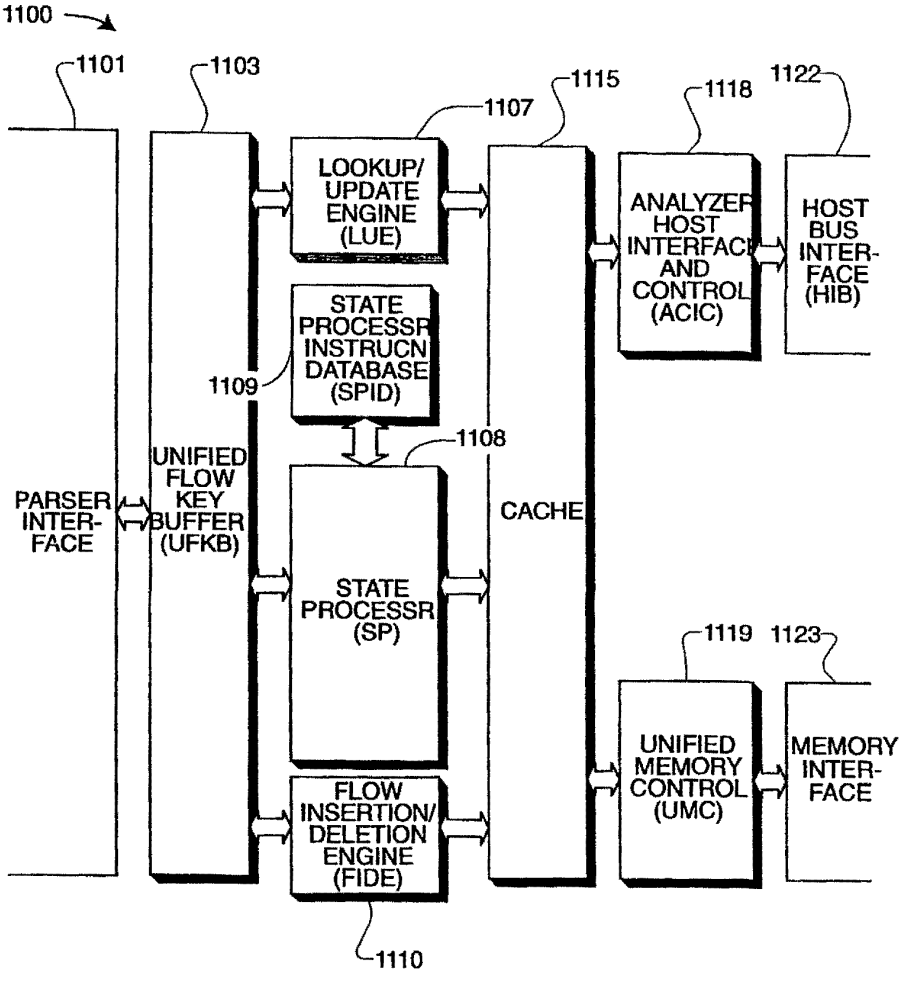
1100
1101
1103
1107
1115
1118
1122
LOOKUP/ UPDATE ENGINE (LUE)
ANALYZER HOST INTERFACE AND CONTROL (ACIC)
HOST BUS INTER-FACE (HIB)
STATE PROCESSR INSTRUCN DATABASE (SPID)
1109
1108
PARSER INTER-FACE
UNIFIED FLOW KEY BUFFER (UFKB)
STATE PROCESSR (SP)
CACHE
1119
1123
UNIFIED MEMORY CONTROL (UMC)
MEMORY INTER-FACE
FLOW INSERTION/ DELETION ENGINE (FIDE)
1110

FIG. 11

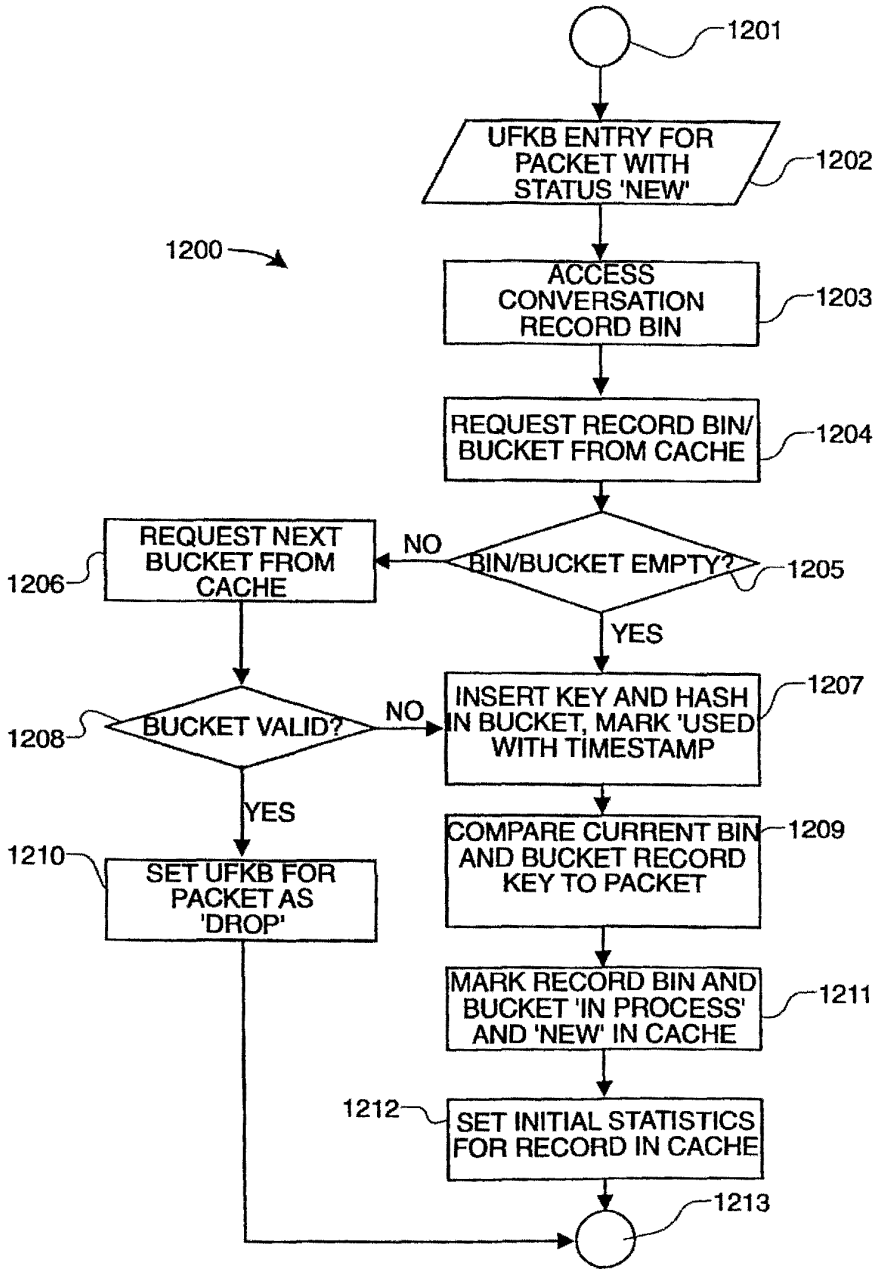
1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
REQUEST NEXT BUCKET FROM CACHE
1206
NO
BIN/BUCKET EMPTY?
1205
YES
BUCKET VALID?
1208
NO
INSERT KEY AND HASH IN BUCKET, MARK 'USED WITH TIMESTAMP
1207
YES
1210
SET UFKB FOR PACKET AS 'DROP'
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
1209
MARK RECORD BIN AND BUCKET 'IN PROCESS' AND 'NEW' IN CACHE
1211
1212
SET INITIAL STATISTICS FOR RECORD IN CACHE
1213

FIG. 12

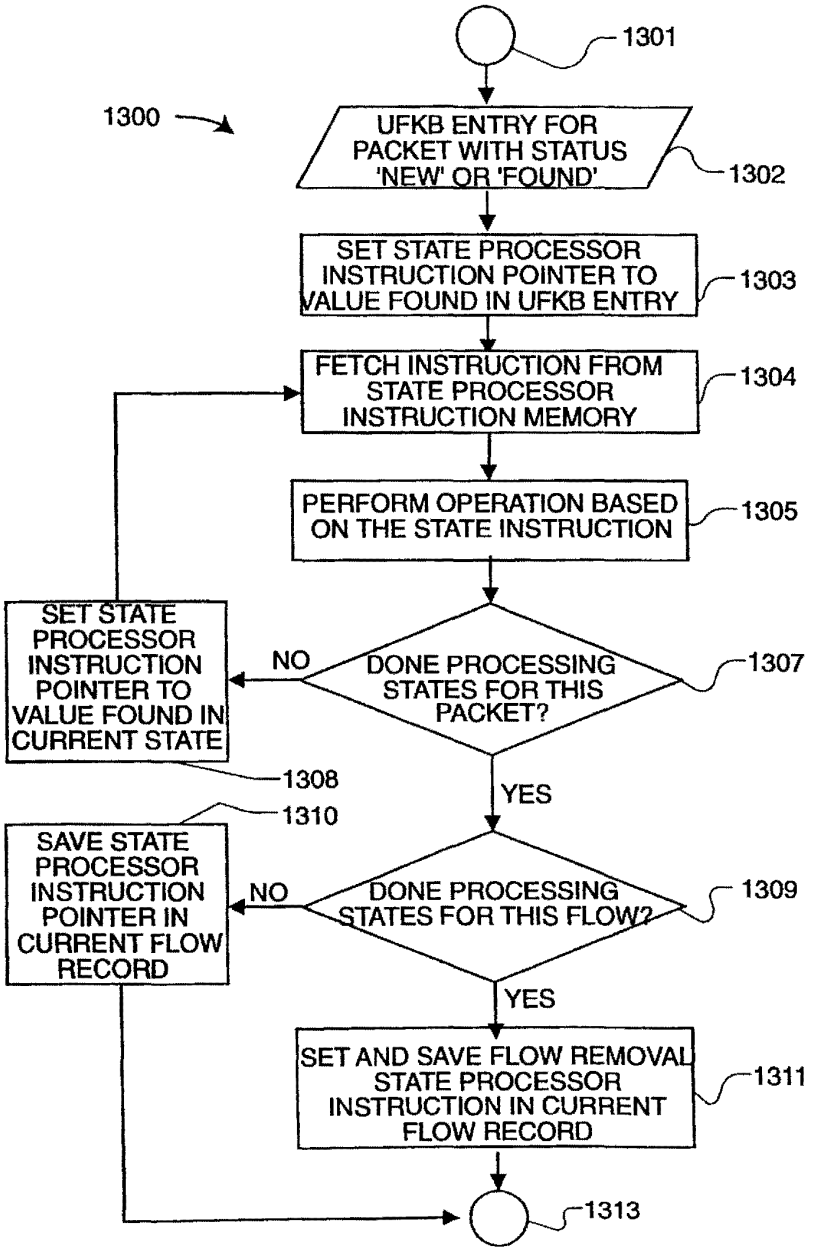
1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
DONE PROCESSING STATES FOR THIS PACKET?
1307
NO
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN CURRENT STATE
1308
YES
DONE PROCESSING STATES FOR THIS FLOW?
1309
NO
SAVE STATE PROCESSOR INSTRUCTION POINTER IN CURRENT FLOW RECORD
1310
YES
SET AND SAVE FLOW REMOVAL STATE PROCESSOR INSTRUCTION IN CURRENT FLOW RECORD
1311
1313

FIG. 13

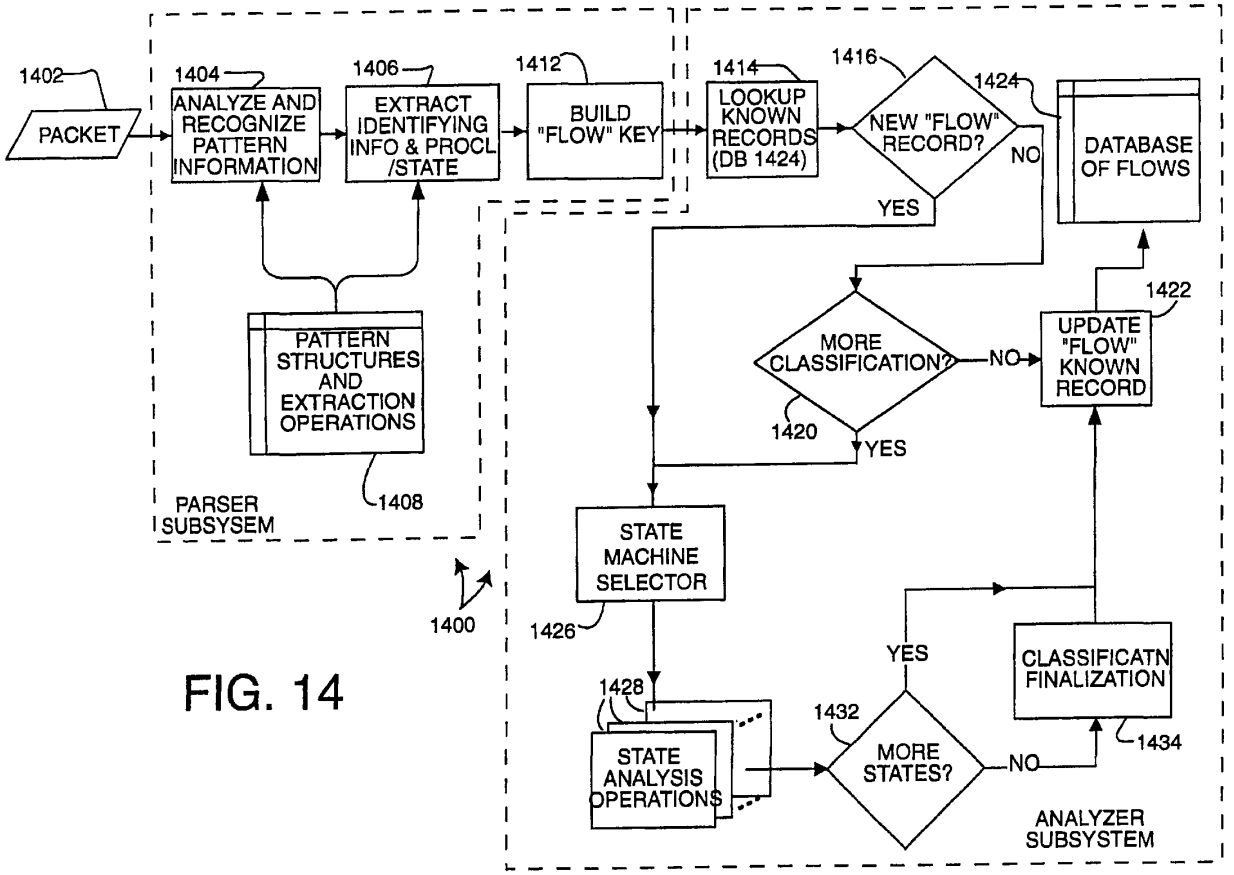
1402
PACKET
1404
ANALYZE AND RECOGNIZE PATTERN INFORMATION
1406
EXTRACT IDENTIFYING INFO & PROCL /STATE
1412
BUILD "FLOW" KEY
1414
LOOKUP KNOWN RECORDS (DB 1424)
1416
NEW "FLOW" RECORD?
NO
YES
1424
DATABASE OF FLOWS
PATTERN STRUCTURES AND EXTRACTION OPERATIONS
1408
PARSER SUBSYSEM
MORE CLASSIFICATION?
1420
NO
YES
1422
UPDATE "FLOW" KNOWN RECORD
1400
STATE MACHINE SELECTOR
1426
1428
STATE ANALYSIS OPERATIONS
1432
MORE STATES?
YES
NO
CLASSIFICATN FINALIZATION
1434
ANALYZER SUBSYSTEM

FIG. 14

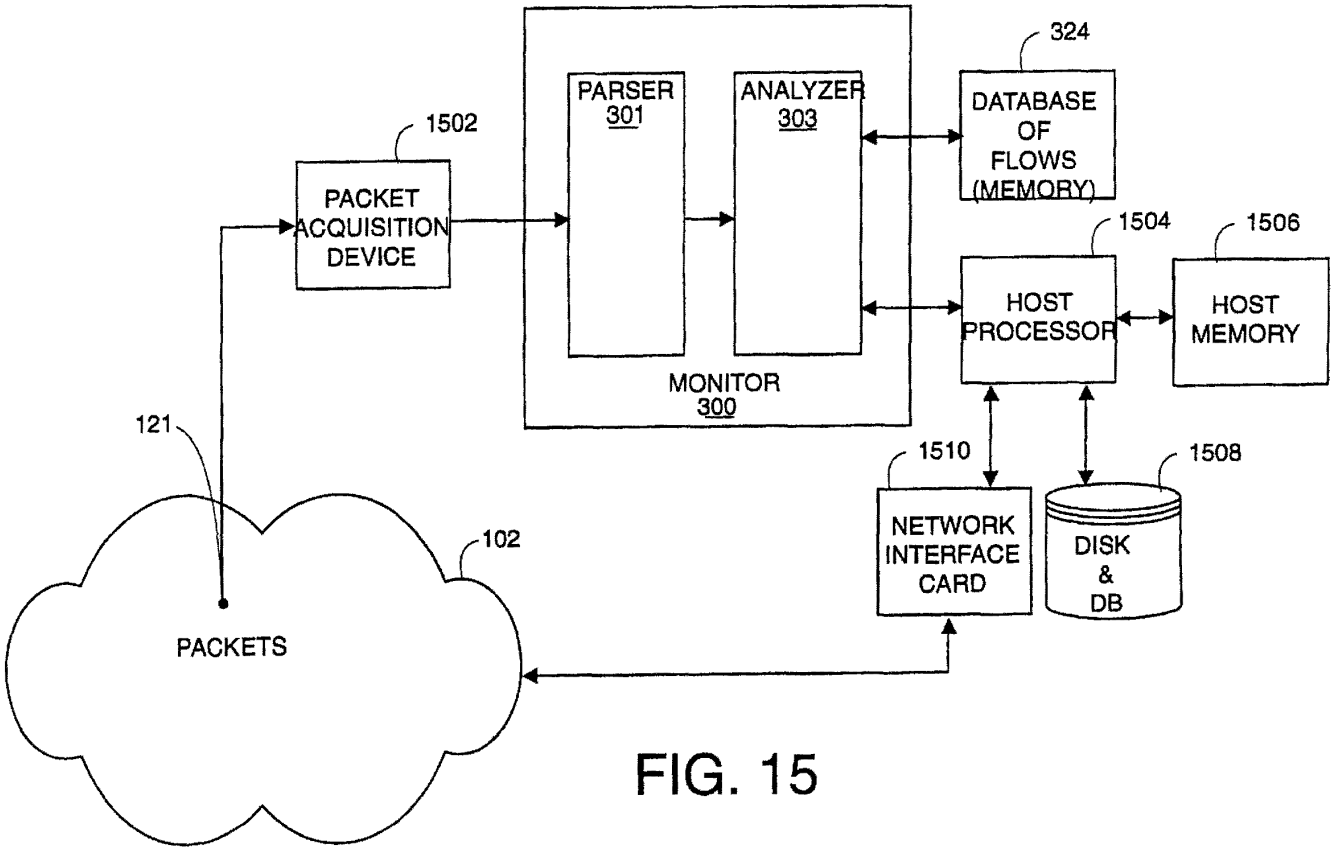
1502
PACKET ACQUISITION DEVICE
PARSER 301
ANALYZER 303
MONITOR 300
324
DATABASE OF FLOWS (MEMORY)
1504
HOST PROCESSOR
1506
HOST MEMORY
121
102
PACKETS
1510
NETWORK INTERFACE CARD
1508
DISK & DB

FIG. 15

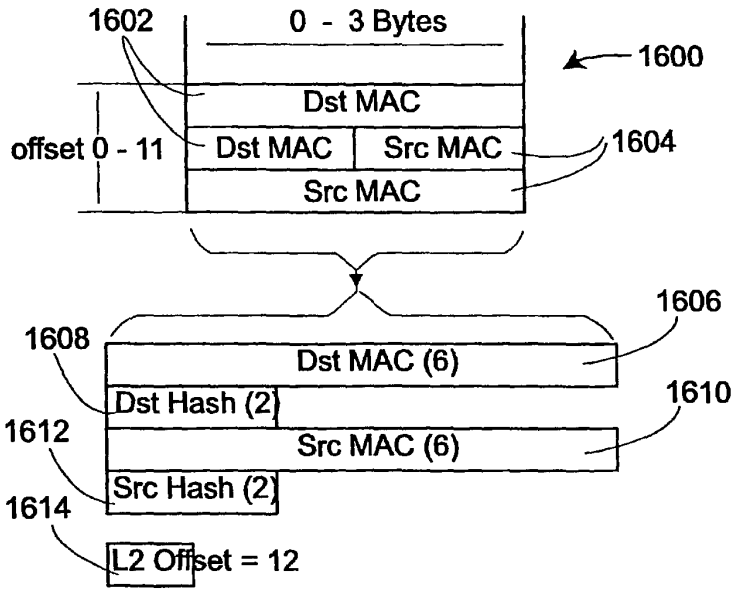
1602
0 - 3 Bytes
1600
Dst MAC
offset 0 - 11
Dst MAC
Src MAC
1604
Src MAC
1606
1608
Dst MAC (6)
Dst Hash (2)
1610
1612
Src MAC (6)
Src Hash (2)
1614
L2 Offset = 12

FIG. 16

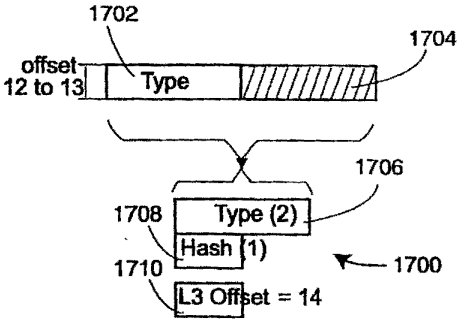

FIG. 17A

1712

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

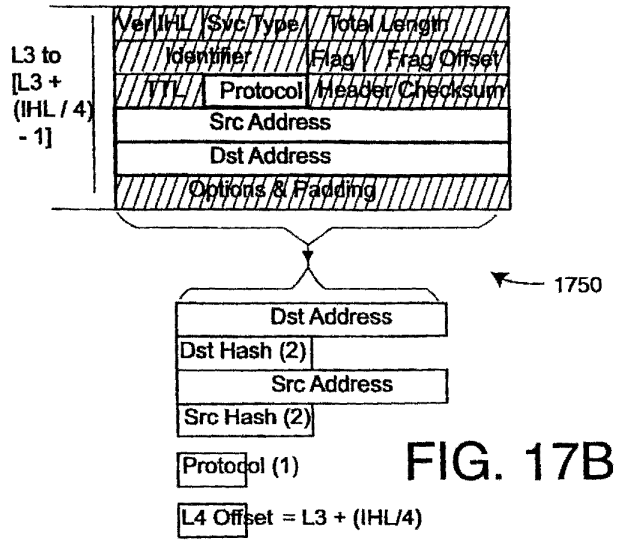

FIG. 17B

1752

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

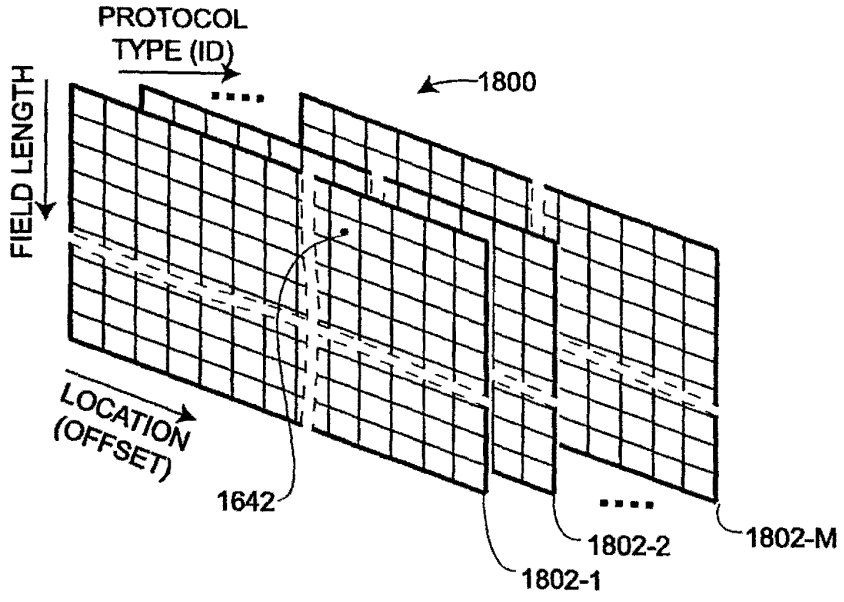

FIG. 18A

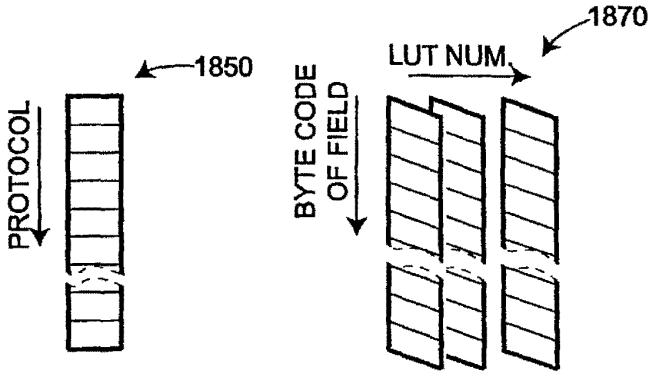

FIG. 18B

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 LOOKUPS AND UPDATES OF FLOW RECORDS IN A NETWORK MONITOR, to inventors Sarkissian, et al., filed Jun. 30, 2000, still penting, 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 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.

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 lo 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 features 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 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/sever 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 Ethertype 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 than 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 Ethertype 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 Ethertype 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,"0 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 **106** 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

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 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 an 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 none 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 if 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 is 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 form 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-

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.

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 Ethertype 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.

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. **17**A now shows the header information for the next level (level-2) for an Ethertype packet **1700**. For an Ethertype 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 Ethertype packet as indicated by what child recognition pattern is found offset **12**. FIG. **17**B 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. **18**A 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. **18**B. Thus, like the 3-D structure of FIG. **18**A, 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 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. **18**A 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. **18**B.

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

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.

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 form 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 be 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 exists 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 subsystem **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_1". If such address identifies the server **110** (shown also as server **204**), the label used in the drawing is "S_1". The first two fields **214** and **215** in packet **206** are "S_1" and "C_1" because packet **206** is provided from the server **110** and is destined for the client **106**. Suppose for this example, "S_1" is an address numerically less than address "C_1". A third field "p^1" **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^1" **219** is an element that is being requested by the client from the server. A seventh field denoted "s_1a" **220** is the service requested by the client from server **110**. The

following eighth field "QA" **221** (for question mark) indicates that the client **106** wants to know what to use to access application "s_1a". 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_1" and "S_1", 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^1" is used as indicated in field **226**. The request "i^1" is in field **229**. Values have been filled in for the application port number, e.g., in field **233** and protocol "p^2" 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_1"<"C_1", the order is address "S_1" followed by client address "C_1". 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^1". 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^1 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^1" (Sun RPC Bind Lookup), and a next-state that the state processor should proceed to for more complex recognition jobs, denoted as state "st_D" 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_D". The operations for state "st_D" 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_1" followed by (the numerically higher address) client "C_1". A protocol field **252** defines the protocol to be used, e.g., "p^2" 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^2". 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^1". 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^2". 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_1" followed by client "C_1". 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_1 and C_1, in a pair of fields **260** and **261**. A field **262** defines the protocol as "p^2", 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^2" 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_1" 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 or 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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Galand et al.

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(45) **Date of Patent: *Jul. 23, 2002**

(54) **METHOD AND SYSTEM FOR IMPLEMENTING CONGESTION DETECTION AND FLOW CONTROL IN HIGH SPEED DIGITAL NETWORK**

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(*) 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.

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(52) **U.S. Cl.** **370/231**; 370/253; 370/400; 709/235

(58) **Field of Search** 370/229–235, 370/400, 419, 420, 463, 252, 253, 522; 709/235, 239

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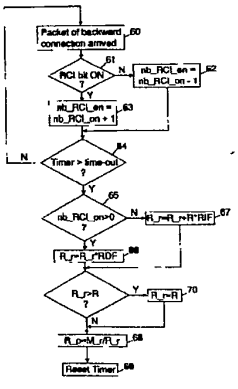
(74) *Attorney, Agent, or Firm*—Cesari and McKenna, LLP

(57) **ABSTRACT**

This system is made to perform congestion detection and flow control in high speed digital packet switching network (22) carrying discardable and non-discardable traffic. Forward traffic received at a destination system over a first connection from a source system is monitored. If a congestion-indicating bit is detected in a received packet, a backward congestion indicator is set in packets flowing from the destination system to the source system over a second connection. The source system integrates the number of backward congestion indicators received over successive periods of time using a count-up, count-down counter. Specific congestion control actions are taken at the source system as a function of the counter state at the end of each of the successive periods of time. The congestion control actions may include increasing or decreasing the bandwidth allocated to discardable traffic intended to be delivered over the first connection.

15 Claims, 8 Drawing Sheets



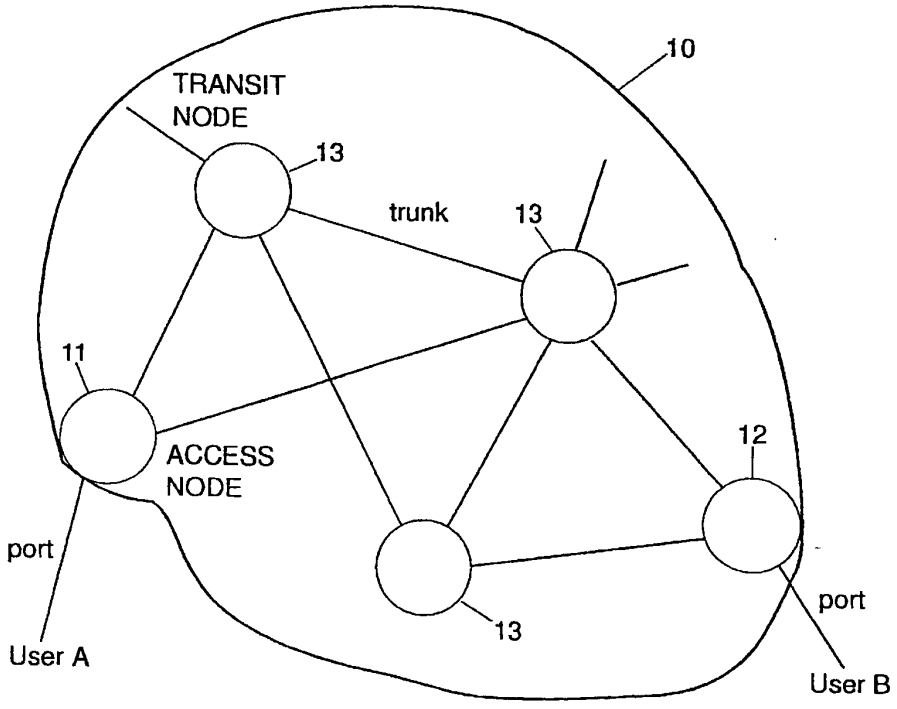

10
TRANSIT
NODE
13
trunk
13
11
ACCESS
NODE
12
port
User A
13
port
User B

FIG.1

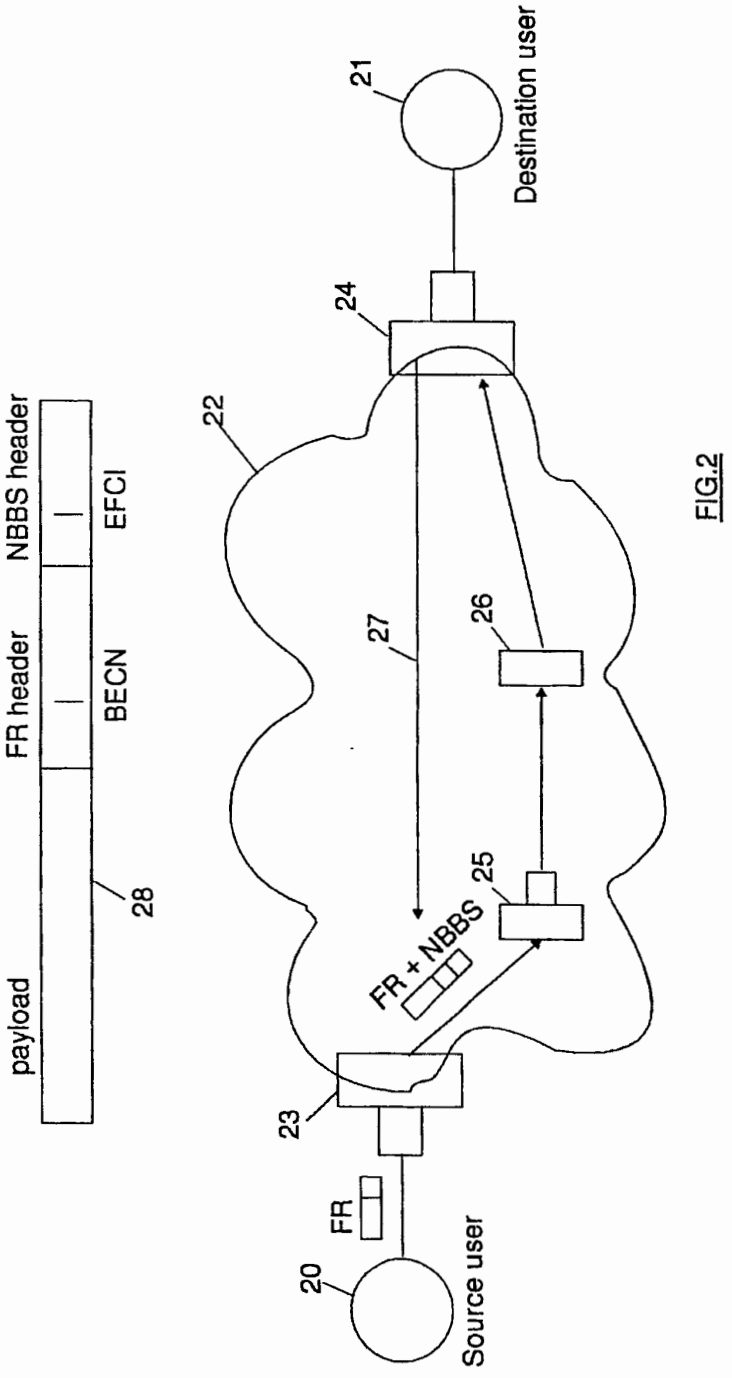

21
Destination user
24
22
NBBS header
EFCI
FR header
BECN
payload
28
27
26
25
FR + NBBS
23
FR
20
Source user

FIG.2

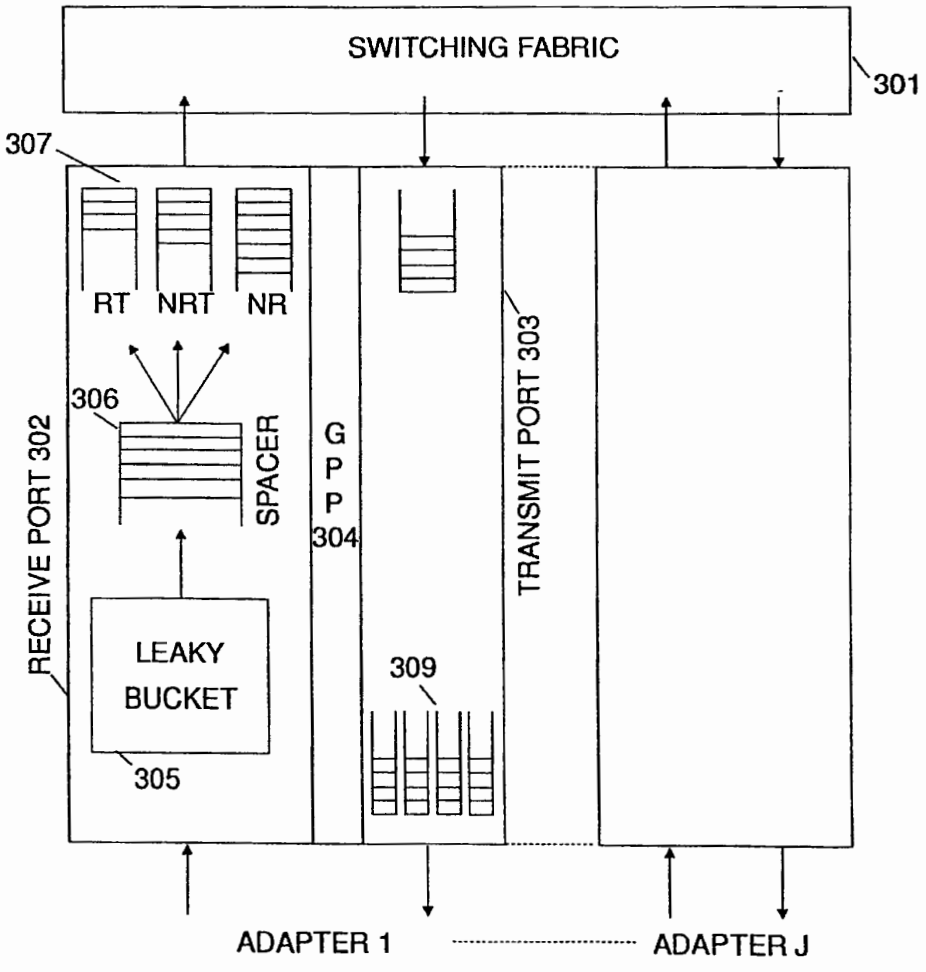

SWITCHING FABRIC
301
307
RT
NRT
NR
306
SPACER
G
P
P
304
TRANSMIT PORT 303
RECEIVE PORT 302
LEAKY
BUCKET
305
309
ADAPTER 1
ADAPTER J

FIG.3

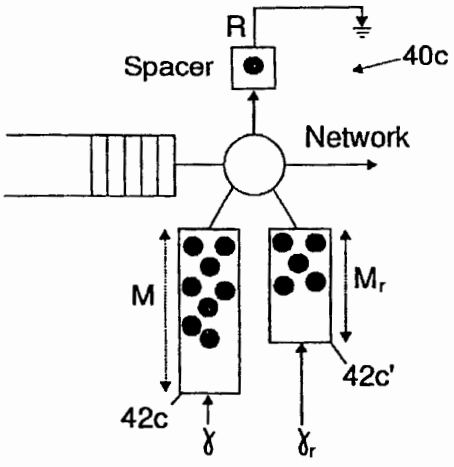


FIG.4c

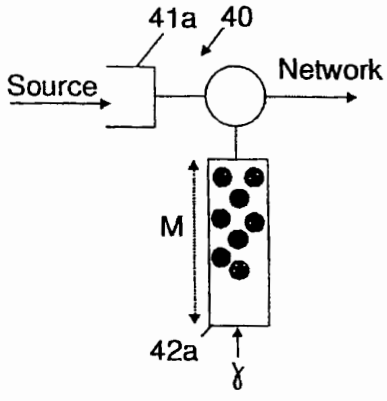


FIG.4a

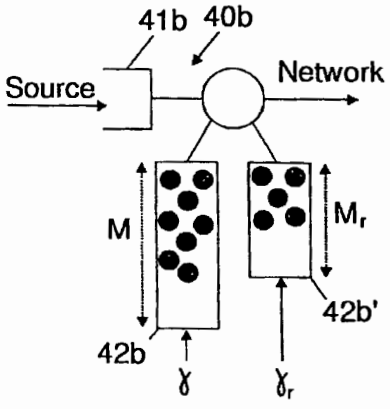


FIG.4b

FIG.4

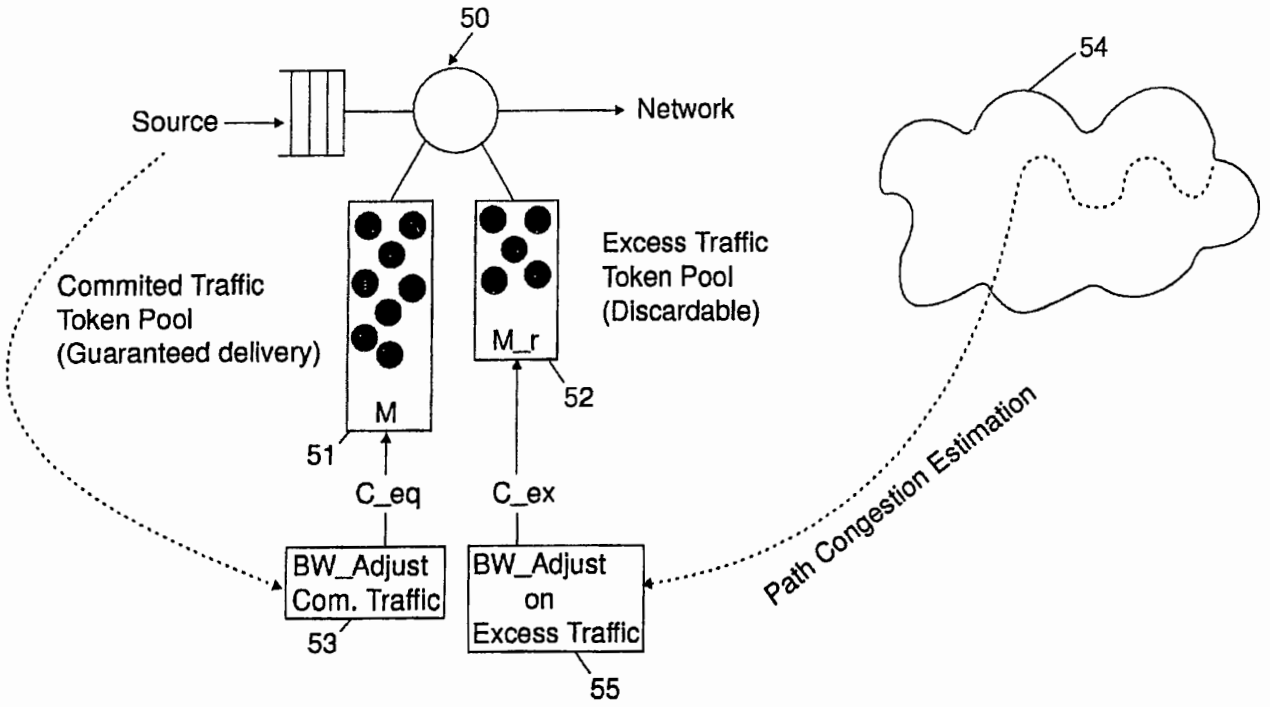

50
Source
Network
54
Commited Traffic
Token Pool
(Guaranteed delivery)
M
51
M_r
52
Excess Traffic
Token Pool
(Discardable)
C_eq
C_ex
BW_Adjust
Com. Traffic
53
BW_Adjust
on
Excess Traffic
55
Path Congestion Estimation

FIG.5

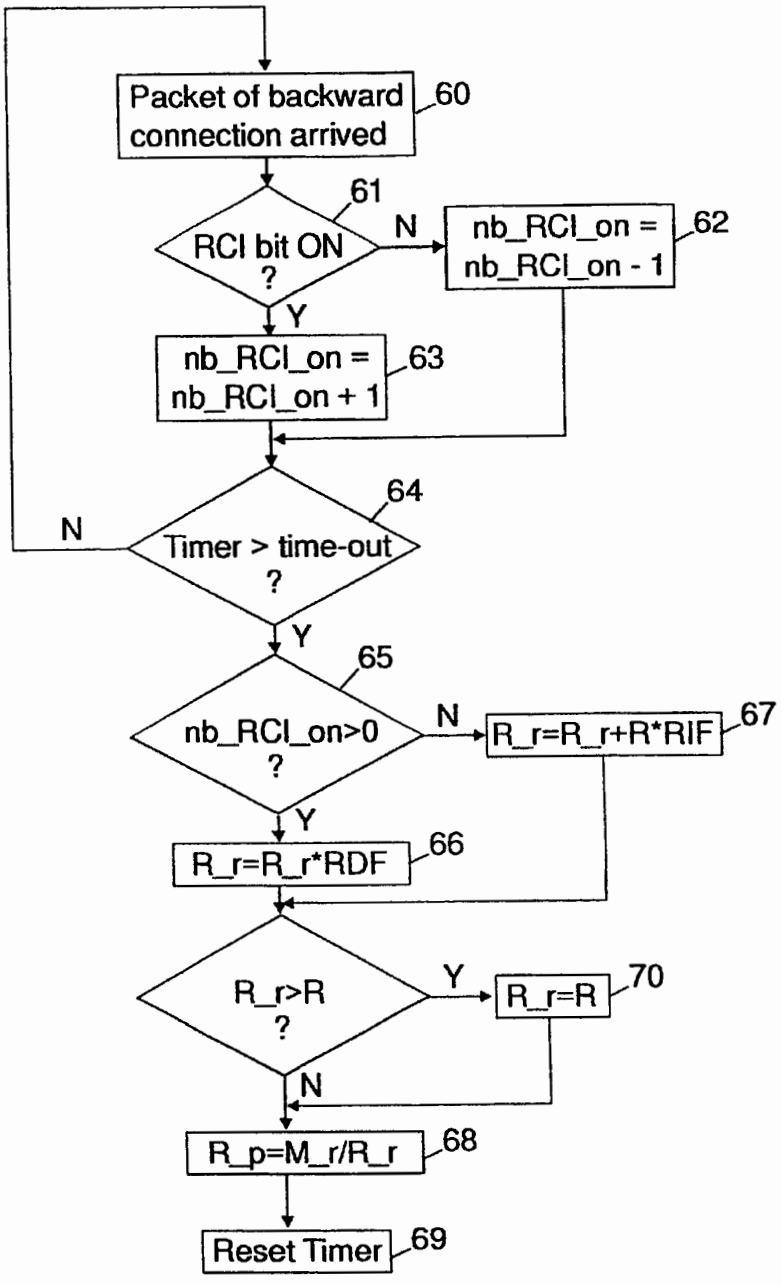

Packet of backward connection arrived
60
RCI bit ON ?
61
N
nb_RCI_on = nb_RCI_on - 1
62
Y
nb_RCI_on = nb_RCI_on + 1
63
Timer > time-out ?
64
N
Y
nb_RCI_on>0 ?
65
N
R_r=R_r+R*RIF
67
Y
R_r=R_r*RDF
66
R_r>R ?
Y
R_r=R
70
N
R_p=M_r/R_r
68
Reset Timer
69

FIG.6

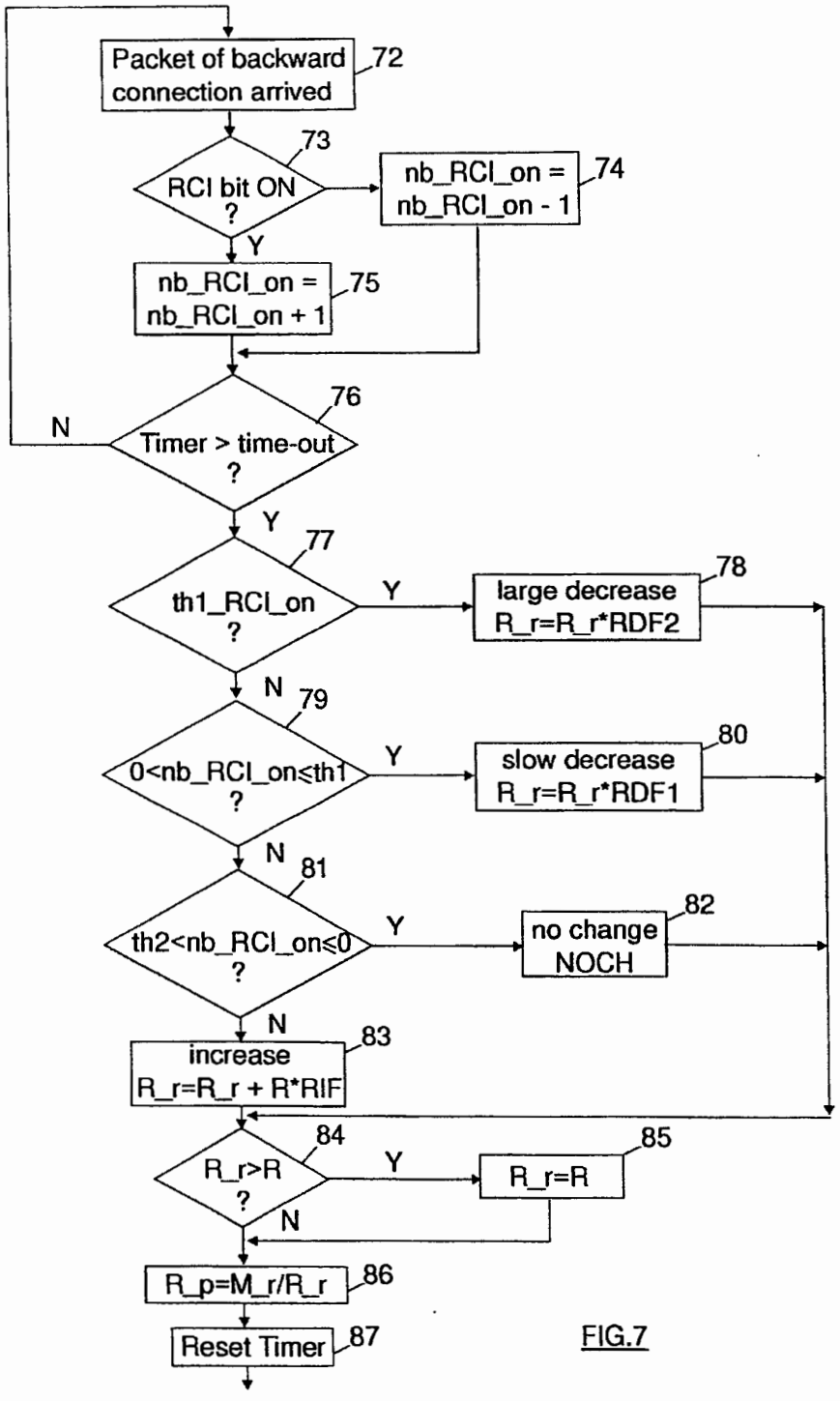

Packet of backward connection arrived
72
RCI bit ON ?
73
nb_RCI_on = nb_RCI_on - 1
74
Y
nb_RCI_on = nb_RCI_on + 1
75
Timer > time-out ?
76
N
Y
th1_RCI_on ?
77
Y
large decrease R_r=R_r*RDF2
78
N
0<nb_RCI_on≤th1 ?
79
Y
slow decrease R_r=R_r*RDF1
80
N
th2<nb_RCI_on≤0 ?
81
Y
no change NOCH
82
N
increase R_r=R_r + R*RIF
83
R_r>R ?
84
Y
R_r=R
85
N
R_p=M_r/R_r
86
Reset Timer
87

FIG.7

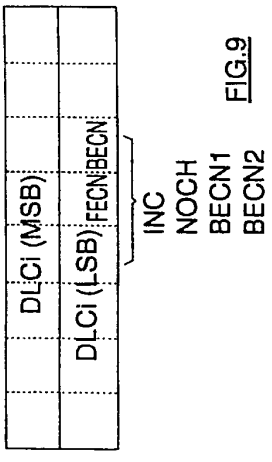

byte 1
byte 2
DLCI (MSB)
DLCI (LSB)
FECN
BECN
INC
NOCH
BECN1
BECN2

FIG.9

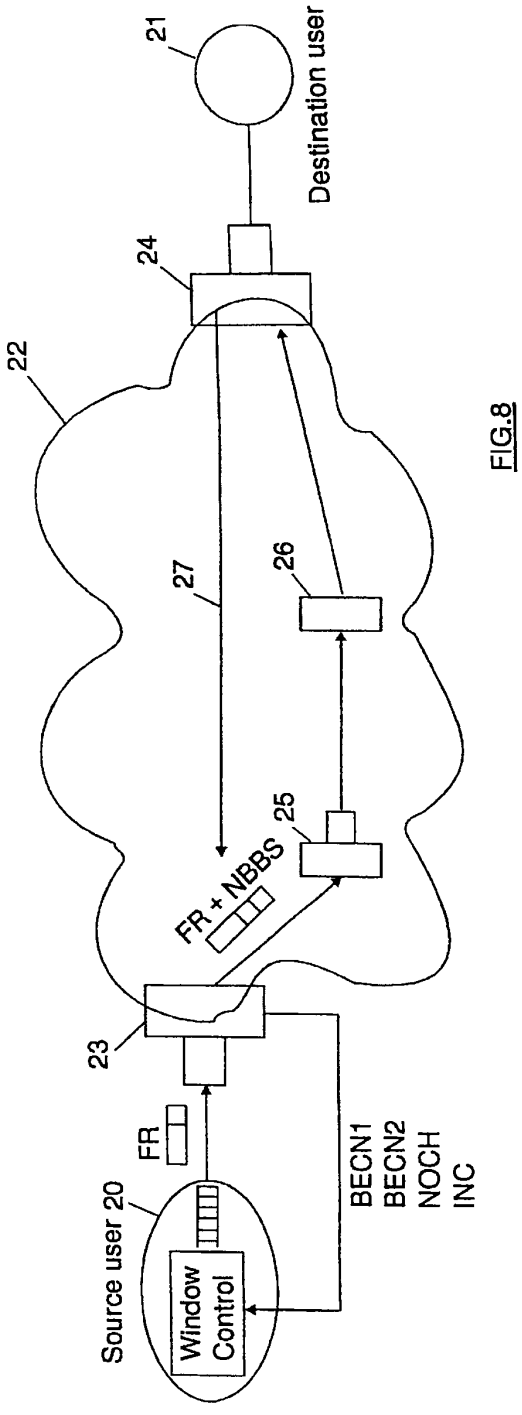

21
Destination user
24
22
27
26
25
FR + NBBS
23
FR
Source user 20
Window Control
BECN1
BECN2
NOCH
INC

FIG.8

METHOD AND SYSTEM FOR IMPLEMENTING CONGESTION DETECTION AND FLOW CONTROL IN HIGH SPEED DIGITAL NETWORK

FIELD OF THE INVENTION

This invention relates to congestion detection and flow control in high speed packet switching networks and more particularly to methods and apparatus for implementing congestion detection and flow control for low priority traffic with optimized cost efficiency.

BACKGROUND ART

Modern digital networks often operate in a multimedia environment and interconnect, upon demand, very large numbers of users and applications through fairly complex digital communication network topologies.

Due to the variety of users' demands and the growth of distributed applications, network traffic is consuming more bandwidth, becoming more non-deterministic and requiring more connectivity. These changes have been the driver for the emergence of fast packet switching network architectures in which data, voice and video information are digitally encoded, chopped into fixed or variable length packets (also named "cells in ATM or Asynchronous Transfer Mode networks) and transmitted through a common set of nodes and links interconnected to constitute the network communication facilities.

The need for efficient transport of mixed traffic streams on very high speed lines (sometimes referred to as links or trunks), means, imposes a set of performance and resource consumption requirements including very high throughput, very short packet processing time, the flexibility to support a wide range of connectivity options and efficient flow and congestion control. Congestion is generally defined as a condition during which network performance is degraded due to saturation of network resources such as communication links, processor cycles, memory buffers, etc.

One of the key requirements for high speed packet switching networks is reduction of end to end delay in order to satisfy real time delivery constraints and to achieve the necessary high nodal throughput for the transport of voice and video. Increases in link speeds have not been matched by proportionate increases in the processing speeds of communication nodes. The fundamental challenge for high speed networks is to minimize the processing time and to take full advantage of the high speed/low error rate technologies. Most of the transport and control functions provided by the new high bandwidth network architectures are performed on an end to end basis.

One basic advantage of packet switching techniques (as opposed to so-called circuit switching techniques) is that it allows statistical multiplexing of the different types of data over a line, which optimizes the utilization of transmission bandwidth. One drawback, however, is that packet switching introduces delays and jitters which might be detrimental for transmission of isochronous data, like video or voice. Methods have been proposed to control the network in such a way that delays and jitters are bounded for every new connection that is set up across the packet switched network.

Such methods are described, for instance, in a published European Application number 0000706297 and include establishing a path through the network high speed lines and nodes, via an entry node port of said network, making optimal use of the available transmission bandwidth of the network along the path to the indicated destination.

Because different type of traffics need to be treated differently to maintain their usefulness at a destination, choices have to be made among the different types by assigning different specific priorities. In other words, when a source terminal requests a connection to a destination terminal via the network (i.e., a call is set-up), a quality of service (QoS) is assigned to the call in terms of maximum permissible delay (T_{13} max) and packet loss probability (P_loss).

The QoS and traffic characteristics (e.g., peak data rate, mean data rate and average packet length) are used to compute the amount of bandwidth (i.e. equivalent capacity or Ceq) to be reserved on every line on the route or path assigned to the traffic between the source terminal and the destination terminal, in order to guarantee a packet loss probability which is smaller than the loss probability (P_loss) that has been specified for the connection. However, in operation, the network traffic must be controlled dynamically which means that some packets may have to be dropped or discarded within the network to avoid traffic congestion.

In practice, it is common to reserve bandwidth for high priority packets (e.g. so-called Real Time or RT traffic) allowing such packets are transmitted in preference to lower priority packets derived from discardable traffic (e.g. Non Real Time or NRT traffic or more particularly Non Reserved or NR traffic). Lower priority packets may be sent at rates greater than their declared rate to dynamically take advantage of any bandwidth remaining after all the higher priority traffic has been served. This remaining bandwidth can vary widely depending on the actual activity of the high priority traffic sources. It is therefore of considerable importance to manage the low priority traffic so as to optimize the use of the widely varying left-over bandwidth in the network while avoiding any congestion which would reduce network throughput. This obviously requires providing the network (and eventually also the sources) with congestion detection and flow control facilities.

Various mechanisms for controlling the flow of NR traffic have been proposed. In particular, an Available Bit Rate (ABR) flow control mechanism has been proposed for Asynchronous Transfer Mode (ATM) networks. ABR flow control is based on use of a particular flow control cell, the so-called Resource Management or RM cell. RM cells are used to collect congestion information from network node switches along connection paths and to send such information back to the traffic sources. While ABR flow control seems to be very efficient, it is complex to implement. End systems must generate RM cells periodically, provide scheduling for RM cells to be sent among data cells, and shape their traffic in response to congestion indications conveyed by received RM cells. Intermediate systems (switches along the paths) must be able to differentiate RM cells from regular data cells, extract RM cells and update these with congestion information. These complexities limit the cost effectiveness of this solution.

Moreover, the above solution requires that all so-called non-reserved (i.e. low priority) sources connected to a network be treated using the ABR mechanism. In fact, if a mix of ABR sources and non-ABR sources are connected to the network, the ABR sources will be disadvantaged as compared to the non-ABR sources which need not be capable of sending RM cells. The customer must therefore update the hardware of all the end systems before using ABR support, which is an additional drawback from an engineering standpoint.

Finally, there is no description, in the ABR standard, of a policing function which could be used to protect the network from misbehaving sources or from non ABR sources.

Other mechanisms have been proposed, with flow control which can be used on ATM or PTM (Packet Transfer Mode, including variable length packets) traffic and offer good performance. These flow control mechanisms add complexity to network equipment. Access nodes or ports need to store tables of values and must have the capability of adding a time-stamp to the data packets or to specific control packets. The overhead on the lines is also increased as at least a time stamp must be added to some transmitted packets.

A further improvement was disclosed in U.S. Pat. No. 5,313,454 which made the system transparent to the user (source) by providing an internal congestion avoidance method. To that end, congestion is identified throughout the network and transferred by setting an indicator in the packet header. Then congestion indications are used in the destination node to generate a rate control message which is fed back to the entry node. This prior art still adds overhead to the feedback flow if smooth and flexible congestion control is sought. Otherwise, the flow regulation would be quite rigid and basic.

These functions are generally configured at connection setup and remain static. A more flexible solution is necessary to be able to use the available bandwidth left by the reserved traffic while avoiding high packet loss inside the network.

SUMMARY OF THE INVENTION

The present invention is a method for performing congestion detection and flow control operations for data traffic, including both discardable and non-discardable traffic, in a high speed digital packet switching network including access and transit nodes interconnected by links or trunks. Any source end-user attached to said network via an entry access node can request its traffic to be transported toward a destination end-user also attached to said network via an exit access node. So-called in-going (or forward) and return (or backward) paths are set from the entry node to the exit node and, in the opposite direction, from the exit node to the entry node. The paths might include network transit nodes.

The method includes the step of monitoring the data flow in each transit node in the forward path from the entry node to the exit node for detecting traffic congestion in the transit node. When flow congestion being detected therein, a Congestion Indication (CI) bit is set in a first predefined header field of data packets transported on the forward path to the exit node. Data packets entering the exit node are monitored. Where a set CI bit is detected, a congestion indication is fed back to the entry node by setting a Return Congestion Indication (RCI) bit in a second predefined header field in the data packets of the traffic of the backward path; RCI bits in packets received in the entry node are integrated over a predefined period of time by adding or subtracting one unit depending on the binary value of each received RCI bit. At the end of each of the predefined time periods, the value of the integrated RCI indication is checked. The communication bandwidth assigned to discardable traffic on the forward path, is adjusted as a function of the value of the integrated RCI indications.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of a high speed digital network wherein the invention shall be incorporated.

FIG. **2** is a basic representation of a network implementing the invention.

FIG. **3** is a schematic representation of a network node in which a preferred embodiment of the invention can be implemented.

FIG. **4** (consisting of FIGS. **4A**, **4B** and **4C**) shows leaky bucket arrangements to be used in the invention.

FIG. **5** is a schematic representation of the invention as implemented with a leaky bucket.

FIG. **6** is a flow-chart of the algorithm used in the invention.

FIG. **7** is a flow-chart of an improved algorithm for providing enhanced operation of the invention;

FIG. **8** is a schematic representation of a further improvement enabling source cooperation in the flow control mechanism.

FIG. **9** is a detailed representation of the header used in the implementation according to FIG. **8**.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

FIG. **1** is a general block diagram of a packet transmission system **10** showing access nodes/ports **11** and **12** and intermediate or transit nodes (**13**), the nodes being interconnected by links or trunks. The links or trunks may provide permanent or selectively enabled (dial-up) connections between pairs of nodes. A network transit node may be attached to one or several access (entry or exit) nodes.

Each network node includes input/output adapters (including) buffers interconnected by a switch fabrics, together with data processing facilities providing data communication and network control services in the network node. Data packets (including control data) received on an input adapter may be selectively routed on one or more of the outgoing communication links or trunks through the output adapters. Routing decisions are made in response to information in header sections of the packets. The network node also provides additional services such as calculation of new paths between entry and access nodes, the provision of access control to packets entering the network, and the provision of directory services and topology database maintenance.

A network access node may operate either as a source (entry) of digital data to be transmitted to another end node, or as a data sink (exit node), or both. User A, for instance, acting as a data source utilizes an access node **11** to access the packet switching network **10**. The access node translates the user's data into packets formatted for transmission on the network and also generates headers used to route said packets through the network. At call set-up, the entry node processing facilities calculates a path or route through the network from the source node (entry node) to the destination node (exit node). To avoid overload on any of the links on the path, the path is selected using an algorithm that ensures that adequate bandwidth is available for the new connection, while optimizing the overall throughput within the network.

The act of selecting a path for a particular connection implies the allocation of network resources to users in order to guarantee their Quality of Service (QoS) requirements. Various quality levels of service may be specified, some of them in order to satisfy real-time delivery constraints, others related to non real time data traffic transfer. To that end, the origin node computes a path to the destination node that is capable of carrying the new connection and providing the level of service required by the new connection. The Path Selection process uses data describing the current traffic load in the entire network (nodes and links). Such data are stored in a topology database located in each node of the network. If no suitable path can be found to meet all requirements, the connection is rejected. Once, the origin node has found a

suitable path, a set-up message is generated which traverses the selected route, updating the resource allocations (including bandwidth occupancy) for each link visited by the set-up message.

To maintain high network throughput, a path is selected and resources are reserved only at the time of the connection establishment. The Path Selection process takes into account various constraints which come both from the user (quality of service requirements, user's traffic characteristics) and from the current network topology and bandwidth allocation. In addition, the algorithm maximizes the network throughput by choosing a path with the least number of hops and which tends to achieve an even distribution of the traffic among the links. Once an appropriate path has been selected, the network connection establishment process takes place, and only then are the resources along the path reserved.

Accordingly, the connections established for different sources may require different levels of bandwidth, different delay guarantees, and/or different loss probabilities. Real time signals such as voice or video, for example, require being assigned higher priority levels than non-real time signals.

As already mentioned, such connection characteristics are negotiated along with the bandwidth requirements and enforced by assigning higher priorities to the transmission of real time signals and, in case of congestion occurring, discarding non-reserved packets before discarding reserved ones. In other words network management must distinguish between guaranteed delivery traffic and so-called discardable traffic. Nevertheless, optimizing the transmission of lower priority traffic is important.

Therefore and due to the bursty nature of data traffic, traffic should be continously monitored and a mechanism provided for adjusting low priority traffic or any excess traffic in excess, and controlling the assigned bandwidth dynamically. For instance 85% of the total link bandwidth may be reserved for committed traffic, which leaves 15% of said bandwidth for dynamic assignment.

The present invention is a method and apparatus for optimizing the transmission of lower priority traffic while avoiding congestion in the network.

The design of adequate congestion schemes is extremely difficult for the following reasons:

- Overhead: A congestion scheme should not increase the traffic too much, in particular when the network is congested. Even proposals of positive feedback schemes, i.e. schemes that give feedback when the network is congested, do not resolve the problem totally as they also consume resources.
- Fairness: When the demands of all users cannot be satisfied, the share of satisfied demands should be fairly distributed. But neither the definition of "fairly" is trivial, nor the meaning of what is considered to be fair is invariable.
- Responsiveness: The quality of the available resource is often changing dynamically. A congestion scheme has to react quickly to changes by asking users to increase or to decrease their sending rates. On the other hand, in order to maintain good throughput, only persistent congestion should be taken into account. Short term loading of the queue due to traffic bursts should be differentiated from a persistent state of congestion.
- Bad environments: Under congestion, packets can be dropped, changed or delivered out of order. Despite such problems, the scheme has to continue to work.
- Consideration of the totality: The final aim of a congestion scheme is to optimize the overall network performance. Schemes that optimize the throughput of one user or one trunk, do not always maximize the overall performance.
- Complexity: In high speed environments there are often only a few clock cycles to process a packet in a node. Therefore, a flow control scheme has to be simple. This criteria can also be called Implementability.
- Misbehaving sources: Some congestion control schemes suppose that all users are able and willing to cooperate. These schemes do often not work with misbehaving users. Greedy users can degrade the QoS for other users or can even drive the network into long term congestion.

The aim of the system of this invention is to check the traffic by detecting congestion in any node of the network and then monitor the traffic flow accordingly on a port-to-port basis, while optimizing the network by complying with the requirements to avoid the drawbacks as indicated in the prior listed criteria, e.g. by minimizing traffic overhead, and yet enabling a smooth and flexible congestion control; being insensitive to misbehaving source users, and yet enabling a control of behaving sources at almost no additional cost; being perfectly implementable and rather not complex.

FIG. **2** is a schematic representation of a network implementing the invention. It shows a connection set between a source end-user **20** and a destination end-user **21** through a digital communication network **22**. The network includes an entry access node/port **23** through which the source user **20** is attached to the network **22**, while the destination user **21** is attached to the network **22** via exit access node/port **24**. Assume that, at call set-up, the source end-user's request for a connection had been executed by setting a forward path via transit nodes **25** and **26**. Since the traffic works both ways, Assume that the return path between user **21** and user **20** was established as indicated by arrow **27** also through a series of transit nodes (not shown in the figure). Consider first traffic originating at user **20**. As already mentioned, in a packet switching system, source traffic is split into packets including a data payload and a header containing control information. Packets may either be of fixed length as in Asynchronous Transfer Mode (ATM) of operation or be of variable length as in Frame Relay (FR) mode of operation. According to this invention, the packets flows are monitored throughout the forward path, in each intermediate transfer node on the path. As soon as traffic congestion is detected in one of the nodes, a predefined header field is marked or set to indicate congestion has been detected. When a congestion indication is detected in exit node **24**, each packet in the return path **27** is marked further congestion.

Again, we must say that this invention applies whatever be the type of traffic, be it organized in Asynchronous Transfer Mode (ATM) or in Frame Relay (FR) mode. But the mode of operation selected herein to describe the invention is the FR type (see FIG. 2). Accordingly, each packet of data provided by the source (**20**) traffic includes a payload section and a Frame Relay header section (FR header)(see packet **28**). Now, for the purpose of this invention, each packet entering access node **23** is provided therein with a header. The fields selected for both marking congestion indication (CI), through a so-called Explicit Forward Congestion Indication (EFCI) in any network node along the forward path going through nodes **25, 26, . . .** , and for Returning said Congestion Information (RCI), have herein been selected to be in the header and in said Frame Relay (FR) header, respectively. Also, and for optimizing traffic efficiency, these

fields have been limited to be one-bit long each in the best mode of implementation of this invention. Naturally, those field locations and lengths selection shall by no means be considered as limiting the scope of this invention. A person skilled in the art understands that longer fields shall enable carrying more detailed flow congestion information while increasing network complexity and increasing operating cost, as shall be explained further in this description.

As already known in the art of digital communication, and disclosed in several European Applications (e.g. Publication Number 0000719065 and Application Number 95480182.5) each network node basically includes input and output adapters interconnected via a so-called node switch. Each adapter includes a series of buffers or shift registers where the node transiting packets are stored. Traffic monitoring is generally operated via preassigned buffer threshold(s) helping monitoring shift register queues, as shall be described with reference to FIG. **3**.

Represented in FIG. **3** is a simplified block diagram showing a network node with the corresponding facilities used to implement the invention. Basically, it includes a series of adapters labeled adapter i with i=1, 2, . . . j (j being the number of adapters), and a high speed packet switching fabric (**301**). Each adapter is connected to a network link/trunk. Each adapter includes a receive port section (**302**), a transmit port section (**303**) and processing facilities herein designated as General Purpose Processor (GPP) (**304**). The packets arriving on the node via the receive port are oriented toward the appropriate node adapter (transmit section) to finally reach the destination user through the preassigned network connection path. Switching between an adapter receive port and an adapter transmit port is performed via the switching facilities (**301**). To that end, the adapters processing means determine the routing operations to be performed, by using indications provided within the data packet headers. As represented in FIG. **3**, the adapters include queuing facilities for queuing the packets prior to or subsequent to their launch on the switch (**301**).

As mentioned, at connection set-up time, two paths, one for each direction are computed between the original access node and the destination access node attached to the calling source user and the destination user, respectively. The connection set-up and bandwidth reservation process operate to adjust, if the call has been accepted, an access control device (e.g. leaky bucket **305**) according to the network connection characteristics. The leaky bucket may be provided with traffic shaping capabilities; e.g., spacer **306**) A more detailed description of both possible implementations and operations of the leaky bucket means shall be provided later with reference to FIG. **4**.

Once exiting the leaky bucket/spacer means, the data packets are oriented toward different queuing elements (**307**) based on the assigned priorities. In the preferred embodiment of this invention, three different priorities have been assigned, i.e. in decreasing priority order: one for so called Real Time (RT) traffic, one for Non Real Time (NRT) traffic, and the third one for Non Reserved (NR) traffic. Traffic congestion is declared when predefined threshold(s) are reached in the transmit adapter port (**303**) queues (**309**).

Now returning to FIG. **2**, let's for the moment assume one single threshold level for denoting congestion in a network node has been assigned to the system. As soon as this threshold is reached in anyone of the network nodes of the in-going (forward) path between source (**20**) and destination **21** (e.g. in node **25**), a congestion indication EFCI bit is set to "1" in the header of the packet actually issuing the queue, down to exit node **24**. In the node **24**, and prior to removing the header from the received packet, the congestion indication EFCI bit is monitored. When an EFCI bit at binary level "1" is detected, the destination port (**24**) marks each packet in the backward flow, i.e. from port **24** acting now as a source for user **21** back to original source user's port **23**, with the Returned Congestion Information (RCI), by setting to "1" the BECN bit in the FR packet header (see **28**). When the source port receives a packet with the BECN bit at binary level "1", a predefined flow control action is taken. For ATM/ABR traffic the RCI bit may be selected in the RM cell.

Several flow control operating algorithms might be defined but efficient algorithms should preferably provide a mechanism for dropping the transmission rate on the congested path in a single large step and then enable slowly going back to full rate step by step.

Thus, in the preferred mode of implementation of this invention, the action to be taken upon reception of a packet indicating congestion, i.e with the RCI (BECN) bit set (i.e at binary level "1"), is based on an additive increase and a multiplicative decrease of the considered sending rate, and this control action is performed in the entry node **23** directly under network control rather than source control, therefore neutralizing any burden due to a misbehaving source user. The parameter for the increase is called Rate Increase Factor (RIF) and is expressed as a quantile of predefined peak rate. The factor for the decrease is called Rate Decrease Factor (RDF) and is a quantile of the actual rate.

Now as far as implementation is concerned various flow regulating devices are already known in the art. They are based on so-called usage parameter control (UPC) made to prevent connections from sending with different characteristics than those negotiated in the traffic contract, whether this is done on purpose or not.

One of these flow regulating systems utilizes a so-called leaky bucket (see FIG. **4** representing three different leaky bucket implementations (**4***a*; **4***b* and **4***c*)) including an admission shift register (e.g. **41** *a*) wherein the data packets are buffered and a so-called leaky bucket mechanism to control their passing further to the network.

The Leaky Bucket label describes a family of algorithms with the same basic principle, based on the consumption of credits designated as tokens (see FIG. **4**). The tokens are generated at a rate γ and can be accumulated in a token pool or bucket (**42***a*) with the size M. When the token pool is full, no more tokens are generated.

Each packet generated at a source has to pass the Leaky Bucket (see **40***a*) before entering the network and needs a certain number of tokens to pass. The number of tokens can correspond to the packet size in bytes or for ATM, one token can correspond to one cell. When no more tokens are available, the packet is dropped rather than being passed.

A full token pool means that a source may send a burst of size M at peak rate without losing a packet in the Leaky Bucket. On the other hand, an empty token pool means that a source may still send at rate γ and all packets arriving at higher rate are dropped.

The Leaky Bucket is determined by the parameters (γ,M). An appropriate setting of these parameters can be used to enforce the usage parameters. For example, a low burst tolerance will be translated by a small M and the peak rate will be an upper bound for γ.

Various extensions to the basic Leaky Bucket represented in FIG. **4***a*, exist. One of the most used is the extension to allow violation tagging. As shown in FIG. **4***b*, two token pools (**42***b*, **42***b*') are used in that case. The second pool(**42***b*') is used to allow excess packets to enter the network, but

marked with lower priority. The parameters γ_r and M_r are used for the second pool, called the red token pool. Accordingly marked packets are called red packets and the tokens are called red tokens. The traffic in the first pool is denoted green and is controlled by green tokens (see pool 42*b*).

For each packet, the green token pool is first checked to see if enough green tokens are available. If there are not enough green tokens, the red token pool is considered. If there are enough red tokens, the packet is assigned a lower priority before being sent into the network, otherwise the packet is dropped.

A third version of the leaky bucket may be implemented, ensuring Traffic Control, Priority Control and Traffic Shaping. It is a Leaky Bucket linked with an entry buffer and a third pool: the spacer (see FIG. 4*c*). Conceptually, the spacer receives the tokens from the leaving packet and is emptied at peak rate R. To send a packet immediately, two conditions must simultaneously be true. The spacer must be empty and there must be enough tokens in the green or the red pool (42*c*42*c*'). In other words, a packet may not leave the system until the spacer is empty, even when there are enough red or green tokens. In this way, the transmission rate can be controlled and can never be higher than R.

The implementation often differs from the concept, as the spacer is implemented as a scheduler. The scheduler calculates the next possible departure time after the last packet with the peak rate R and attributes this time to the current packet.

This kind of mechanism is only applied to delay-insensitive traffic classes.

The general question for Leaky Bucket algorithms concerns the rate γ. Which rate should be used for the reconstitution of the tokens and which bandwidth should be reserved for the connection ? This domain is called Resource Management and is widely documented in the literature. The theory allows calculation, starting from the available buffer space and the traffic descriptor, of all the parameters of the Leaky Bucket. The calculated parameters guarantee a very low loss probability with a certain interval of confidence for the data sent into the network.

With these kinds of arrangements the network may be designed and managed to assign, say 85% of a link nominal capacity to reserved traffic and then dynamically monitor and control the remaining bandwidth and assign it to so-called excess traffic. The invention enables control of excess traffic at the network entry node to avoid network congestion without having to rely on traffic sources behavior.

This principle is schematically represented in FIG. 5. A double token pool (51,52) is again used for controlling the traffic entering the network through leaky bucket mechanism 50 (possibly including a spacer not shown). The token pool 51 is used to manage committed traffic whose delivery has been guaranteed at rate C_eq equal to the equivalent capacity that has been reserved for the considered connection in the network, or with a token rate which fits the minimum guaranteed bandwidth. Any bandwidth (BW) adjustment through leaky bucket control (53) for committed traffic is then left to the source. But for the excess traffic which by nature is discardable, it shall be handled under the path congestion mechanism of this invention using the EFCI/BECN indications provided by the communication network (54) to the network access node involved, to adjust the Excess Traffic (ET) token rate (55) and therefore adjust the excess capacity (C_ex) at network entry without involving the data source, by adjusting the token pool refill rate to R_r as required, to dynamically optimize bandwidth utilization while avoiding network congestion.

In operation, for said excess/discardable traffic, the port algorithm may be designed so that the parameters will be adjusted according to the information of experienced congestion (RCI). The above mentioned adjustments might be performed periodically, or integrated.

The algorithm as implemented in the source and destination ports of the preferred embodiment of this invention is summarized below. It should be remembered that the action to be taken for packets with the RCI (e.g BECN) bit set to one, is based on additive increase or multiplicative decrease of the sending rate. The parameter for the increase (i.e. the Rate Increase Factor (RIF)) is expressed as a quantile of the peak rate, while the Rate Decrease Factor (RDF) is a quantile of the actual rate. A new variable, i.e. the red token Refill rate (R_r) is introduced. This rate is only used to calculate the increase and decrease and is translated into the Refresh period (R_p) at the end of the action per packet. The rate R_r is not a real send rate. It is an upper bound for a possible mean send rate, due to its integration into the leaky bucket behavior.

The source port algorithmic steps for the adjustment of the leaky bucket parameters are as follows:

1. When congestion is detected after integration of the RCI indications, the red token pool size (M_r) is normalized to the maximum packet size (e.g. 2 KB). The refresh period is adjusted by conforming to the new M_r value (which is initially set to the time to send M_r with peak rate). The red token refill rate (R_r) is derived from the red token pool size and the refresh period by the calculation R_r=M_r/R_p.
2. For each congestion detected after integration of the congestion indications in packets, the rate is decreased by the factor RDF (0.85 for example) until the lower bound (5 kbps for example) is reached:
   If (R_r*RDF)>0.005 Then R_r is set to R_r*RDF;
   (the symbol * indicating a multiplication)
3. For status of no congestion, after integration of the congestion indication, the rate is increased by the addition of the RIF multiplied by the peak rate until the peak rate is reached:
   If R_r+(R*RIF)<R Then R_r is set to R_r+(R*RIF);
   where R is the actual access rate,
4. The refresh period is derived from the red token refill rate: R_p:=M_r/R_r;

In other words, the system first starts with a check whether a congestion control action is needed. In case of a positive answer, the red rate in the leaky bucket (i.e: R_r) of the source entry node (23) is decreased by the rate decrease factor (RDF) and the refresh period in the leaky bucket (R_p) is set to (M_r/R_r) wherein M_r designates the size of the red token pool in the leaky bucket. Otherwise, the red rate in the leaky bucket is increased by R*RIF, with R being the actual access rate and RIF the rate increase factor and then the R_r period in the leaky bucket is refreshed. In either case, R_r is limited to R.

Where the destination port (e.g. see 24 in FIG. 2) detects an EFCI bit set at binary value "1", it has to notify the transmit side of same network exit node adapter of the experienced congestion with the noted frequency. The adapter transmit side will then mark all the packets of the connection travelling in the opposite direction (see 27 in FIG. 2) with the congestion indicator, i.e., will set the RCI bit in all the packets sent on the backward connection. In this case, the destination port (24) does not smooth the information. In fact, the value of the EFCI bit of the last packet received in the destination port (24) before the information is sent to the transmit side is decisive for the value of the RCI bit for the connection.

Thus, in the above described implementation no smoothing algorithm was applied on the receive side to convey the information back. This can be explained by the aims of the algorithm: protect the network, i.e. avoid packet loss and use available bandwidth, even when the bandwidth is available for a short time period.

When congestion is experienced, the source port adapter has to be notified immediately to slow down the red token rate in order to avoid excessive packet loss. That means, on the receive side, that when a port adapter receives only the last packet with the EFCI bit set and all the others did not have the EFCI bit set, it has nevertheless to convey the information about the detected congestion back to the source port. On the send side two options can be used. The port adapter may change the parameters of the leaky bucket to limit bandwidth use regardless of the number of RCI bits received at binary level "one". As an alternative, the port adapter may integrate the RCIs to smooth the leaky bucket changes. This smoothing phenomenon is particularly interesting as it enables substantial improvement in the congestion control with a minimal overhead.

The algorithm for implementing the inventive process is represented in FIG. 6. At connection set-up, two parameters of the connection (in each direction), one for the number of set RCIs bits (nb_RCI_on), and the second used as a timer, are initialized. The timer is set to zero and started, while the nb_RCI_on counter is set to zero.

Each time a packet is received in the backward direction (60), the RCI bit is extracted and tested (61). If this RCI bit is OFF, the nb_RCI_on counter is decremented by one unit (62), else, it is incremented (63). Then the timer indication is checked versus a predefined value considered as time-out indication (64). As long as the time-out is not reached, integration over the RCI bit goes on, with the process looping back to step (60). When the timer indicates a time-out, the integrated RCI bit indication is considered. In a preferred embodiment, the congestion status is evaluated as follows: if nb_RCI_on is higher than zero as indicated by test (65), then congestion is declared and the actual red rate (R_r) is decreased as already indicated, by the predefined rate decrease factor (RDF) (see 66). Otherwise no congestion is declared and the red rate in the leaky bucket is incremented by R*RIF (67), with R being the actual access rate and RIF the rate increase factor and then the refresh period in the leaky bucket is amended to R_p=M_r/R_r (68). In both cases the timer is reset (69) and R_r is limited to R (70).

With the use of the timer, the flow control proposed integrates more or less depending on the data flow: if the backward data flow is important there will be a lot of "up-to-date" RCI information to process. To avoid multiple changes in the leaky bucket parameters and useless processing, integration is performed. If the backward data flow is low, each RCI indication is important and the integration is low.

The solution described with reference to FIG. 6 provides a valuable improvement over prior art while minimizing overhead traffic. It can still be improved by providing more precise leaky bucket regulation, assuming several different levels of congestion and different RDF/RIF functions of these levels.

One implementation of such an improved algorithm is represented in FIG. 7. The first series of operations (i.e: 72, 73, 74, 75 and 76) are identical to those described with reference to FIG. 6 (i.e: 62, 63, 64, 65 and 66), but once time-out is declared then the count of nb_RCI_on based on packets received over the feedback path is compared to achieve R_r=R_r*RDF2 with RDF2 being the largest predefined rate decrease factor. Otherwise, if the test (77) is negative, a second test is performed (79) to check whether nb_RCI_on is between zero and th1. If this is the case, then a decrease at slower rate (RDF1) is implemented (80) and R_r is made equal to RDF1*R_r; otherwise a third test is performed (81) versus a negative threshold th2. If the nb_RCI_on is between zero and th2, then the rate is kept unchanged (82), otherwise it is increased (83) to R_r+RIF*R, with a limitation to the peak rate level (84, 85) and the token pool refresh period is refreshed to M_r/R_r, then the timer is reset (87).

Such an improved method and system enables a smoother rate regulation from the network entry access node and further enables driving the source user assigned window adaptation if required. To that end, the rate variations defined here above: i.e. Increase (INC) (83), no change (NOCH) (84), slow decrease (BECN1) (80) and large decrease (BECN2) (78) shall be coded with two bits in the input access node and fed back to the source, as represented in FIG. 8. These two bits may be selected in the two byte long Frame Relay header as defined in the ANSI Standards (see FIG. 9). In a preferred mode of implementation of this invention, these two bits have been selected to be the third and fifth bits of the Least Significant byte (byte 2). INC, NOCH, BECN1 and BECN2 are therefore coded accordingly. With these two bits, the process is thus improved to control the NCP window feeding the source queue as illustrated in FIG. 8.

The four rate variations defined in FIG. 7, steps 78, 80, 82 and 83, while being used in the flow control operated in the network access node 23 in response to the network 22 congestion integration over the considered connection, are also used for source control. This additional control is performed over the NCP window of source user 20. Several window controls may be defined, but in the preferred mode of implementation of this invention, the window adjusments have been made as follows:

- if BECN1 (slow decrease), then the window is adjusted to:
  window=window-n (with n=1).
- if BECN2 (large decrease), then window=window/p (with p=2).
- if NOCH (no change), then window=window.
- if INC (large increase), then window=window+q (with $q \geqq 1$).

Consequently, the single bit added to the overhead in the backward path within the network 22 enables smooth flow control directly from the considered network entry access node thanks to judicious integration of congestion indicators in said access node. Further smoothing for congestion control is possible where combined with multiple thresholding. In addition multiple thresholding operation may be coded into the entry access node and fed back to the source user system to enable further regulating the source generated data flow if required without being bound to non-behaving sources. The method is therefore quite convenient in that it enables a smooth and flexible congestion control releasing the network from any unnecessary additional overhead.

The preferred embodiment of the invention as described herein was limited to two bits for the overall forward and backward congestion indications to limit the overhead on the links. But some improvements to the invention can still be provided by using these bits in a slightly different way.

In effect, when using one threshold only to detect congestion and set and reset the EFCI bit in the packet header, a typical threshold phenomenon can occur with oscillations around this threshold.

These oscillations could be avoided by a second "unset-threshold". When a packet arrives and the queue size is greater than the set-threshold, the EFCI bit is set in all the packets. Only when the queue size gets below the unset-threshold, the EFCI bit won't be set anymore. This "hysteresis" avoids oscillations around one congestion indication threshold.

However, the oscillations might in some cases be ignored if the packets are not discarded at this threshold, they are only equipped with an additional information. Knowing that the information is not translated immediately into the RCI field, but with a certain frequency, it does not matter a lot if there is a mixed sequence of EFCI and non-EFCI packets. In the worst case the source would receive one wrong 'no congestion' information. The buffer in the trunks is supposed to support these short time periods of wrong information.

Once more the delay criterion has to be considered talking about two different thresholds. When the queue size becomes smaller this means that the input rate is smaller than the output rate. When the whole queue is empty, the link would be under-utilized. The unset threshold should therefore be reasonably high, to inform the sources as soon as possible that the congestion situation does not exist anymore. Knowing the already added delay we would tend to fix the unset-threshold higher than the set-threshold, which implies a certain complexity in implementation (the trunk has to keep track of the increase or the decrease of the queue size).

For implementation reasons an unset-threshold would add supplementary delay because it would be lower than the set-threshold, i.e. it would need more time to decrease the queue size to reach the unset-threshold. This added delay would decrease bandwidth utilization as the sources would start later to recover from the experienced congestion.

A simulation performed at T1 link speed to evaluate the impact of two thresholds on the system as compared with one threshold provided the following results:

Criterion	Two threaholds	one threshold	difference
LINK UTILIZATION	82.53%	82.04%	0.49%
PACKETS LOSS AT TRUNK	0.0165%	0.0206%	0.0041%

In conclusion, a second threshold in the forward direction could avoid periods where some packets are marked and others are not. This could theoretically increase fairness and reactivity of the sources. Simulations showed, that there is only a minor difference between the use of one or two thresholds. The oscillation periods are very short as the queue growth has always a clear direction upward or downward.

Some improvements to the invention efficiency might be obtained by focusing on a number of parameters in the implementation.

For instance, a modification in the way the packets are EFCI marked would lead to higher bandwidth utilization. If, instead of being marked in the receive port, when they arrive on the adapter the packets are marked just before they are sent away (i.e. after buffering) the responsiveness of the system would be improved.

Responsiveness of the system might also be optimized by a careful selection of the Rate Decrease Factor (RDF) and Rate Increase Factor (RIF) of the algorithm. For instance, the RDF and RIF values were evaluated for a range of trunk speeds from 128 Kbps to 44.74 Mps. The values optimized for a T1 trunk gave reasonable throughput for all tested speeds with RDF=0.85 and RIF=0.002. In other words, on each intervention the rate shall be decreased to 85% of its old value, or increased by a constant of 0.002*R. The decreases are quasi exponential and the increase almost linear. These values are key points in terms of responsiveness of the system. The aim of the so called excess traffic controlled by the invention is to use even shortly available bandwidth. Therefore the RIF should be preferably selected high enough to enable the system to adapt in few steps to a higher rate. On the other hand, a too high value would increase the rate too fast, allowing the sources to send too much packets when congestion occurs before its notification reaches the source, leading finally to packet loss at the congested trunk.

On the other hand, a too small value would be inappropriate if the number of sources is low.

Therefore a compromise value should be selected carefully, based on the possible number of connections involved.

The RDF value should also be selected carefully to enable optimized adaptation to less available bandwidth.

The decrease of the rate must be done as fast as possible, because the congestion is always detected too late, due to the various delays the propagation of the information suffered from. The exponential character of the decrease provides this fast response, in 1 sec, i.e. after 10 adjustments, the rate is at 20% of its original value.

A local optimization for each trunk speed makes not always sense as computer networks often integrate lines with different transmission speeds.

The red packet discard threshold has a direct impact on the ability to accept bursts and on the queue size, which is translated into added delay for the packets. There are four main ideas behind the value of the red packet discard threshold:

1. Use the available buffer to accept bursts Each trunk is equipped with 256 KByte buffer space for the NRT and NR traffic classes. This buffer can provide a great flexibility for the adapter to accept data bursts.
2. Protect the green packets by leaving them enough space above the red packet discard threshold. Even by discarding red packets, there may be the situation where there are bursts of green packets, leading to queue size values over the red packet discard threshold. It has to be assured, that the queue size never exceeds the available buffer size, to avoid the discarding of green packets. Therefore the red packet discard threshold has to be inferior to the available buffer space.
3. Assure maximum delays for low speed trunks. A queue size of 200 KB implies a sending a delay of 12.5 s at 128 Kbps. This can lead to time-out events for NBBS messages and higher level protocols. The queue size has therefore to be reasonably small to assure maximum sending delays of less than 1 sec per congested trunk at low speed.

With the above solution provided by this invention for monitoring and controlling congestion, a fairly stable mechanism is made possible. It is nearly insensitive against packet loss and reacts to congestion before packets are lost, and, most of all, it is not impacted by non-compliant sources since it is implemented within the network, with adjustments of the traffic source being made possible on top of the basic input node control, both being independent from each other which is quite convenient in case of misbehaving source users. Additionally, the mechanism operates with nearly no added overhead, and can be easily implemented in presently available networks.

What is claimed is:

1. Method for performing congestion detection and flow control operations over data traffics including both discardable traffic and non-discardable traffic, in a high speed digital packet switching network including access and transit nodes interconnected by links or trunks, and wherein for any source end-user attached to said network via an entry access node and requesting its traffic to be vehiculated toward a destination end-user also attached to said network via an exit access node, a connection is established which includes so-called in-going (or forward) and returning (or backward) paths set from said entry node to said exit node and in the opposite direction from said exit node to said entry node respectively, which paths might include network transit nodes, said method including:

monitoring the data flow in each transit node over the forward path from said entry node to said exit node for detecting traffic flow congestion in said monitored transit node and in case of flow congestion being detected therein, setting so-called Congestion Indication (CI) bit in a first predefined so-called header field of data packets on the involved forward path down to the exit node;

said method being further characterized in that it includes:

monitoring the incoming data packets entering said exit node, and in case of a set CI indication being detected therein, feeding this indication back to said entry node by setting a Return Congestion Indication (RCI) bit in a second predefined header field in the data packets of the traffic of said backward path;

monitoring the packets received in said entry node over said returning (backward) path and integrating, in said entry node, said RCI bits indications over a predefined period of time, said integration meaning adding or subtracting one unit depending whether said RCI bit is detected to be at binary value one or zero, respectively, said integration producing an integrated RCI indication;

monitoring said predefined time period, and when said time period is over, checking said integrated RCI indication; and,

adjusting the communication bandwidth assigned to said discardable traffic over said forward path, from said entry node to said exit node in a predefined manner, according to said integrated RCI indications.

2. Method for performing congestion detection and flow control operations over data traffics according to claim 1, further characterized in that said communication bandwidth adjusment includes comparing, in said entry node, said integrated RCI indication bits to at least one predefined threshold levels and adjusting the transmission rate over the involved forward path from said entry node to said exit node, accordingly in a predefined manner.

3. A method for performing congestion detection and flow control operations according to claim 2, further characterized in that said thresholding indications are also fed back to the involved source end-user to enable further controlling the flow of behaving end-user.

4. A method for performing congestion detection and flow control operations according to claim 1, 2 or 3 wherein said non-discardable traffic addresses so-called committed traffic whose delivery is guaranteed while said discardable traffic is accepted on the network path as excess traffic to optimize network bandwidth occupation.

5. A system for performing congestion detection and flow control operations over data traffics in a high speed digital packet switching network including access and transit nodes interconnected by links or trunks, each node including adapters with receive and transmit sections respectively attached to node entering and exiting links or trunks and switching means for transferring data packets from receive to transmit adapter sections, and wherein for any source end-user attached to said network via an entry access node and requesting its traffic to be vehiculated toward a destination end-user also attached to said network via an exit access node, so-called forward and returning (or backward) paths are set from said entry node to said exit node and in the opposite direction from said exit node to said entry node, respectively, which paths might include network transit nodes, each said end-user's traffic being either qualified as high priority level committed traffic whose delivery is guaranteed and assigned predefined transmission rate limits whereby a predefined amount of total transmission bandwidth is being reserved to it accordingly, or qualified low priority level discardable excess traffic and assigned whatever bandwidth is left, said system being characterized in that it includes:

means in said adapter transmit section for dispatching the data packets, each packet including a so-called payload section and a so-called header section, toward output queues based on said priority levels;

means for monitoring the data flow in said output queues in each node over the forward path from said entry node to said exit node, for detecting traffic congestion in said monitored queues and in case of flow congestion being detected therein, setting a so-called Congestion Indication (CI) bit field selected for carrying Explicit Forward Congestion Information (EFCI) in a first predefined header section of forward data packets, on the involved path down to the exit node;

means for monitoring the incoming data packet entering said exit node, and in case of a set CI indication being detected therein setting a Return Congestion Indication (RCI) bit in a second predefined header section field in the data packets of the traffic flowing over said backward path;

means in said entry node for monitoring the packets received from said backward path and for integrating monitored RCi bits over a predefined time-out period;

means for monitoring said time period and at time-out indication, comparing said integrated RCI indication to at least one predefined threshold level and for controlling accordingly the bandwidth adjustment means in the involved receive adapter section of said entry node for adjusting the communication bandwidth assigned to said discardable traffic over said forward path, from said entry node to said exit node in a predefined manner.

6. A system for performing congestion detection and flow control operations over data traffics in a high speed digital packet switching network according to claim 5 further characterized in that said means for monitoring the data flow in said output queues in each node over the forward path from said entry node to said exit node, for detecting traffic congestion in said monitored queues involves means for monitoring at least one predefined queue threshold level.

7. A system for performing congestion detection and flow control operations over data traffics in a high speed digital packet switching network according to claim 6 wherein a set and a reset threshold levels are predefined, whereby the EFCI is set in all packets when a packet arrives and the queue size is greater than the set-threshold and only when

the queue size gets below the unset-threshold the EFCI won't be set anymore.

8. A system for performing congestion detection and flow control operations over data traffics in a high speed digital packet switching network according to claim 6 or 7 characterized in that said bandwidth adjustment means includes:

leaky bucket means assigned to discardable traffic data and provided with so-called red token pool means sized at a predefined value M_r, and having a token refill rate R_r, a red token peak rate R and a token refresh period R_p;

means for decreasing R_r to R_r*RDF, RDF being selected among at least one predefined Rate Decrease Factor smaller than one, for each packet received with a congestion indication set, and for setting the red token refresh period R_p to M_r/R_r, wherein M_r is the size of said red token pool; and,

means for increasing R_r by a predefined amount (RIF) of the peak rate R.

9. For use in a packet switching network wherein a first connection is established to enable transmission of packets from a first node to a second node and a second connection is established to enable transmission of packets from the second node to the first node, wherein said second node monitors each packet received on the first connection for the presence of congestion indicators and responds to such indicators by setting a congestion indicator in packets later transported on the second connection and wherein packets may be designated as low priority or high priority packets, a congestion control method implemented in the first node comprising the steps of:

integrating the number of congestion indicators detected in packets received on the second connection over a predefined period of time; and

adjusting the bandwidth allocated to low priority traffic on the first connection as a function of the results of the integrating step.

10. A method as set forth in claim 9 wherein the bandwidth adjusting step comprises the further steps of:

comparing the results of the integrating step to at least one predefined threshold level; and

adjusting the bandwidth in a first predetermined manner if the results exceed the threshold level and in a second predetermined matter if the results don't exceed the threshold level.

11. A method as set forth in claim 10 including the further step of notifying the source of the traffic on the first connection if the predefined threshold level is exceeded to enable the source to further control the flow of traffic to the first node.

12. A method as set forth in any of claims 9–11 wherein the step of adjusting the bandwidth comprises the step of, if the integration results exceed a first level, decreasing the currently allocated bandwidth to a value R*RDF where R is a predefined peak rate and RDF is a predefined Rate Decrease Factor or, if the integration results do not exceed the first level, of incrementing the currently allocated bandwidth by an amount equal to R *RIF where RIF is a predefined Rate Increase Factor.

13. For use in a packet switching network wherein a first connection is established to enable transmission of packets from a first node to a second node and a second connection is established to enable transmission of packets from the second node to the first node, wherein said second node monitors each packet received on the first connection for the presence of congestion indicators and responds to such indicators by setting a congestion indicator in packets later transported on the second connection and wherein packets may be designated as low priority or high priority packets, a congestion control system implemented in the first node comprising:

a timer that times out at the conclusion of successive predetermined periods of time;

an integrating circuit which maintains an integration result reflecting the number of congestion indications detected in packets received on said second connection;

congestion detection logic responsive at the conclusion of each of the successive predetermined periods of time to obtain the current integration result and to reset the integrating circuit; and

bandwidth control logic which adjusts the bandwidth allocated to low priority traffic on the first connection as a function of the obtained current integration result.

14. A system as set forth in claim 13 wherein the bandwidth control logic further comprises:

a leaky bucket mechanism for receiving low priority traffic intended for the first connection, the leaky bucket mechanism maintaining a red token pool of predetermined size and having a predefined token refill rate, a predefined red token peak rate R and a predetermined token refresh period, said mechanism including logic for decreasing the token refill rate by a predetermined factor for each packet received on the second connection with a congestion indicator and for setting the red token refresh rate equal to M/R_r where M is the size of the red token pool and R_r is the token refill rate.

15. For use in a packet switching network wherein a first connection is established to enable transmission of packets from a first node to a second node and a second connection is established to enable transmission of packets from the second node to the first node, wherein said second node monitors each packet received on the first connection for the presence of congestion indicators and responds to such indicators by setting a congestion indicator in packets later transported on the second connection and wherein packets may be designated as low priority or high priority packets, a computer program product for use in the first node comprising a computer usable medium having computer readable program code embodied therein for performing congestion control at the first node, the computer readable program code comprising code for integrating the number of congestion indicators detected in packets received on the second connection over a predefined period of time, and adjusting the bandwidth allocated to low priority traffic on the first connection as a function of the results of the integrating operation.

* * * * *

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Vaidya

(10) **Patent No.: US 6,279,113 B1**
(45) **Date of Patent: Aug. 21, 2001**

(54) **DYNAMIC SIGNATURE INSPECTION-BASED NETWORK INTRUSION DETECTION**

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(73) Assignee: **Internet Tools, Inc.**, Fremont, CA (US)

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(21) Appl. No.: **09/090,774**

(22) Filed: **Jun. 4, 1998**

Related U.S. Application Data

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(51) **Int. Cl.**[7] **H04L 9/00**

(52) **U.S. Cl.** **713/201**; 713/154; 709/229

(58) **Field of Search** 713/201, 200, 713/202, 151, 152, 153, 154–176, 177, 178; 709/229; 707/9

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* cited by examiner

Primary Examiner—Robert Beausoleil
Assistant Examiner—Scott Baderman
(74) *Attorney, Agent, or Firm*—Luce, Forward, Hamilton & Scripps LLP

(57) **ABSTRACT**

A signature based dynamic network intrusion detection system (IDS) includes attack signature profiles which are descriptive of characteristics of known network security violations. The attack signature profiles are organized into sets of attack signature profiles according to security requirements of network objects on a network. Each network object is assigned a set of attack signature profiles which is stored in a signature profile memory together with association data indicative of which sets of attack signature profiles correspond to which network objects. A monitoring device monitors network traffic for data addressed to the network objects. Upon detecting a data packet addressed to one of the network objects, packet information is extracted from the data packet. The extracted information is utilized to obtain a set of attack signature profiles corresponding to the network object based on the association data. A virtual processor executes instructions associated with attack signature profiles to determine if the packet is associated with a known network security violation. An attack signature profile generator is utilized to generate additional attack signature profiles configured for processing by the virtual processor in the absence of any corresponding modification of the virtual processor.

20 Claims, 12 Drawing Sheets

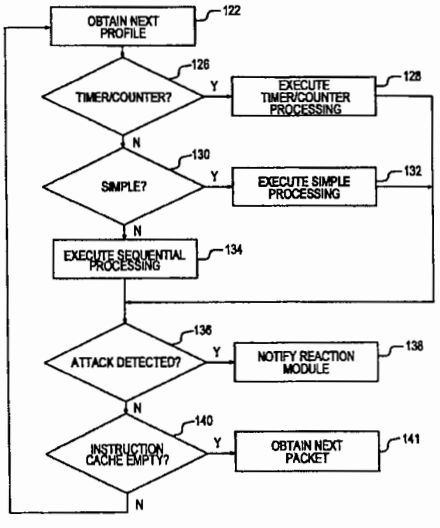
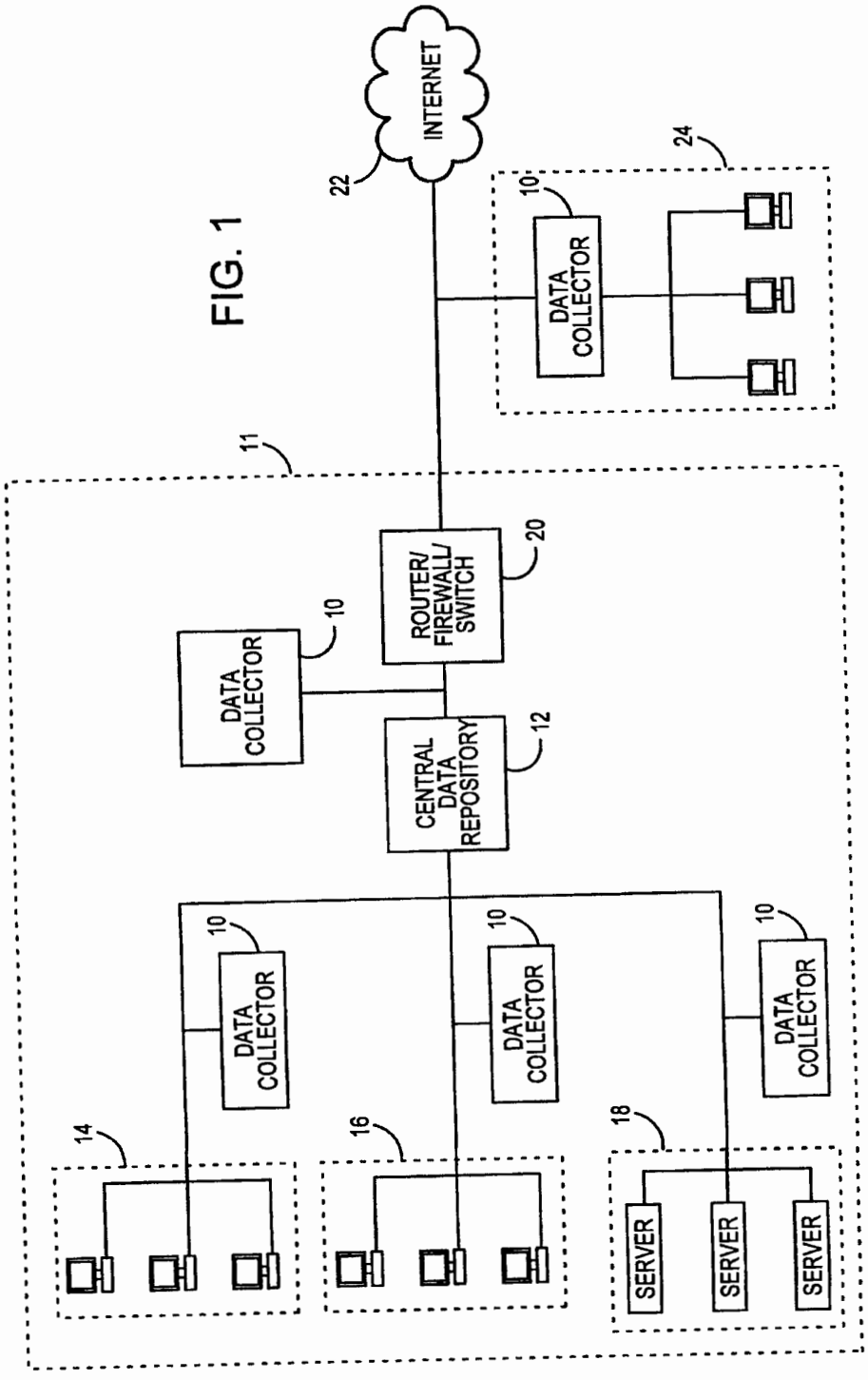


FIG. 1


INTERNET
22
24
10
DATA COLLECTOR
11
ROUTER/ FIREWALL/ SWITCH
20
10
DATA COLLECTOR
CENTRAL DATA REPOSITORY
12
10
DATA COLLECTOR
10
DATA COLLECTOR
10
DATA COLLECTOR
14
16
18
SERVER
SERVER
SERVER

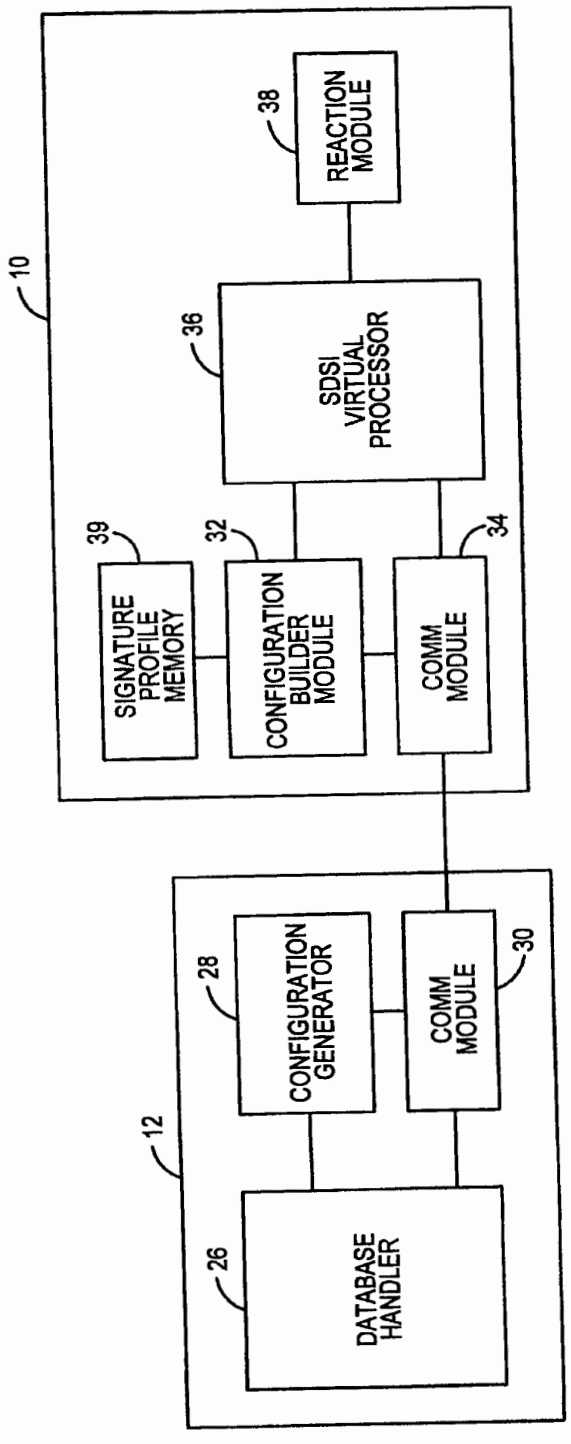

10
38
REACTION MODULE
36
SDSI VIRTUAL PROCESSOR
39
SIGNATURE PROFILE MEMORY
32
CONFIGURATION BUILDER MODULE
34
COMM MODULE
12
28
CONFIGURATION GENERATOR
30
COMM MODULE
26
DATABASE HANDLER

FIG. 2

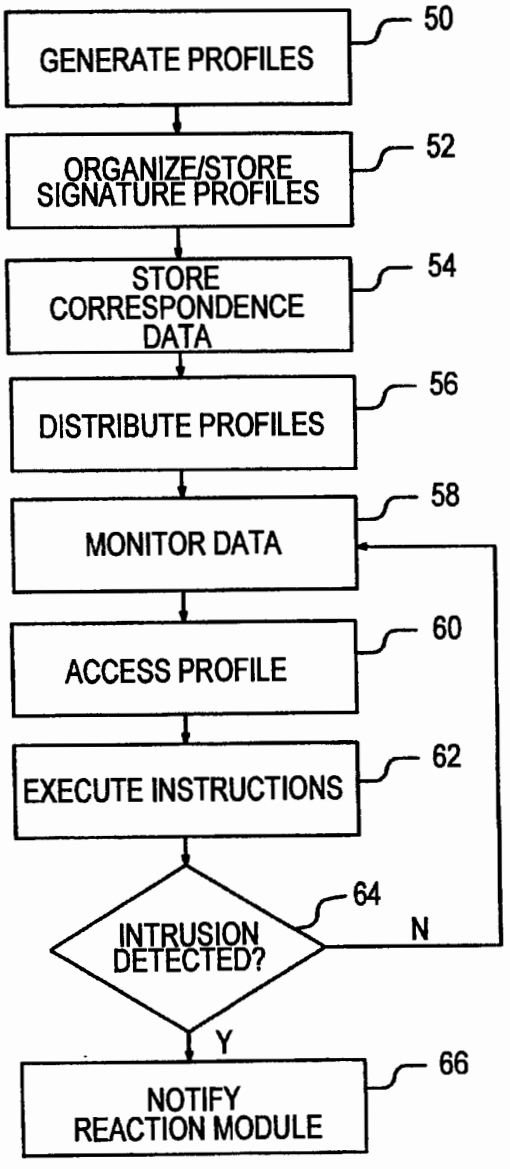

GENERATE PROFILES
50
ORGANIZE/STORE SIGNATURE PROFILES
52
STORE CORRESPONDENCE DATA
54
DISTRIBUTE PROFILES
56
MONITOR DATA
58
ACCESS PROFILE
60
EXECUTE INSTRUCTIONS
62
INTRUSION DETECTED?
64
N
Y
NOTIFY REACTION MODULE
66

FIG. 3

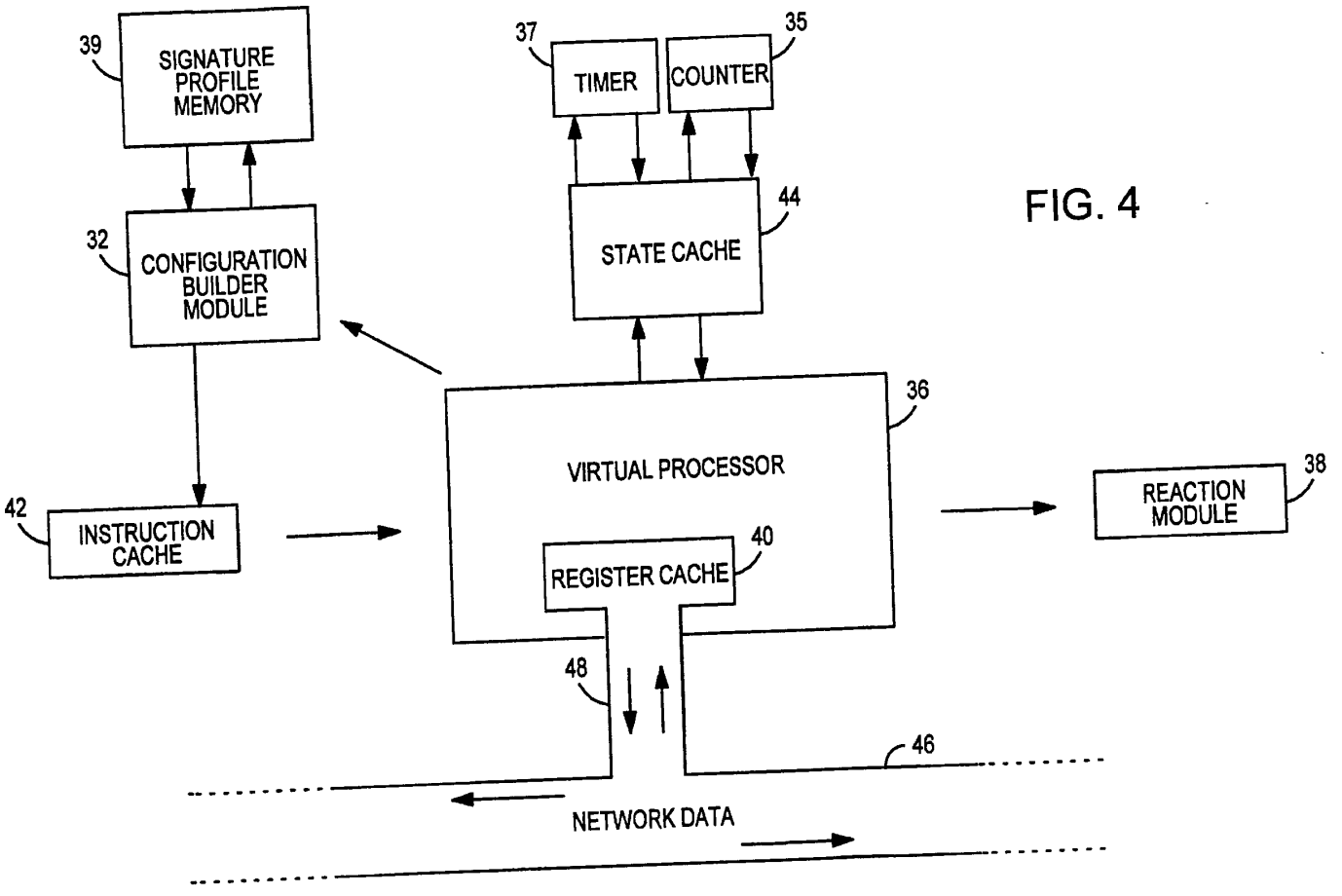

39
SIGNATURE PROFILE MEMORY
37
TIMER
35
COUNTER
44
STATE CACHE
32
CONFIGURATION BUILDER MODULE
36
VIRTUAL PROCESSOR
38
REACTION MODULE
42
INSTRUCTION CACHE
40
REGISTER CACHE
48
46
NETWORK DATA

FIG. 4

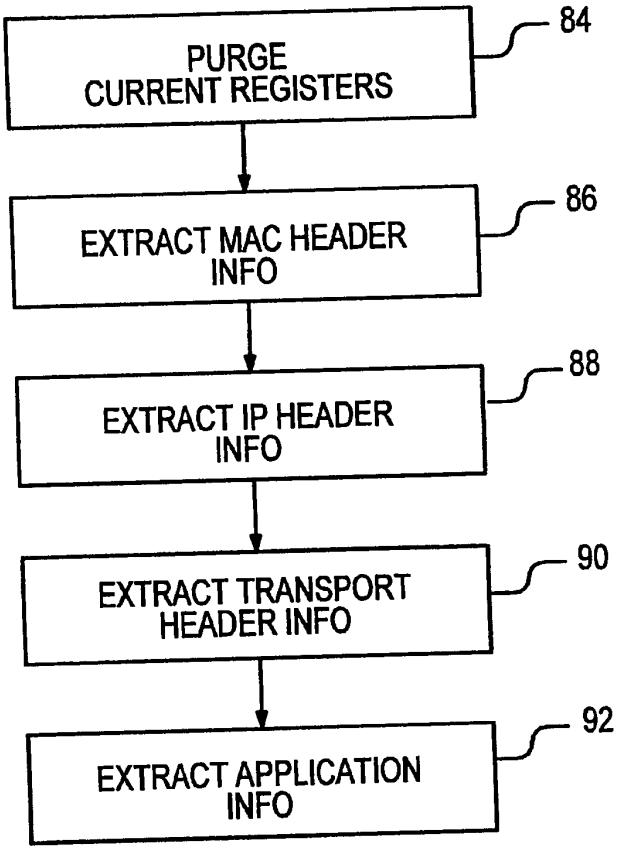

PURGE CURRENT REGISTERS
84
EXTRACT MAC HEADER INFO
86
EXTRACT IP HEADER INFO
88
EXTRACT TRANSPORT HEADER INFO
90
EXTRACT APPLICATION INFO
92

FIG. 5

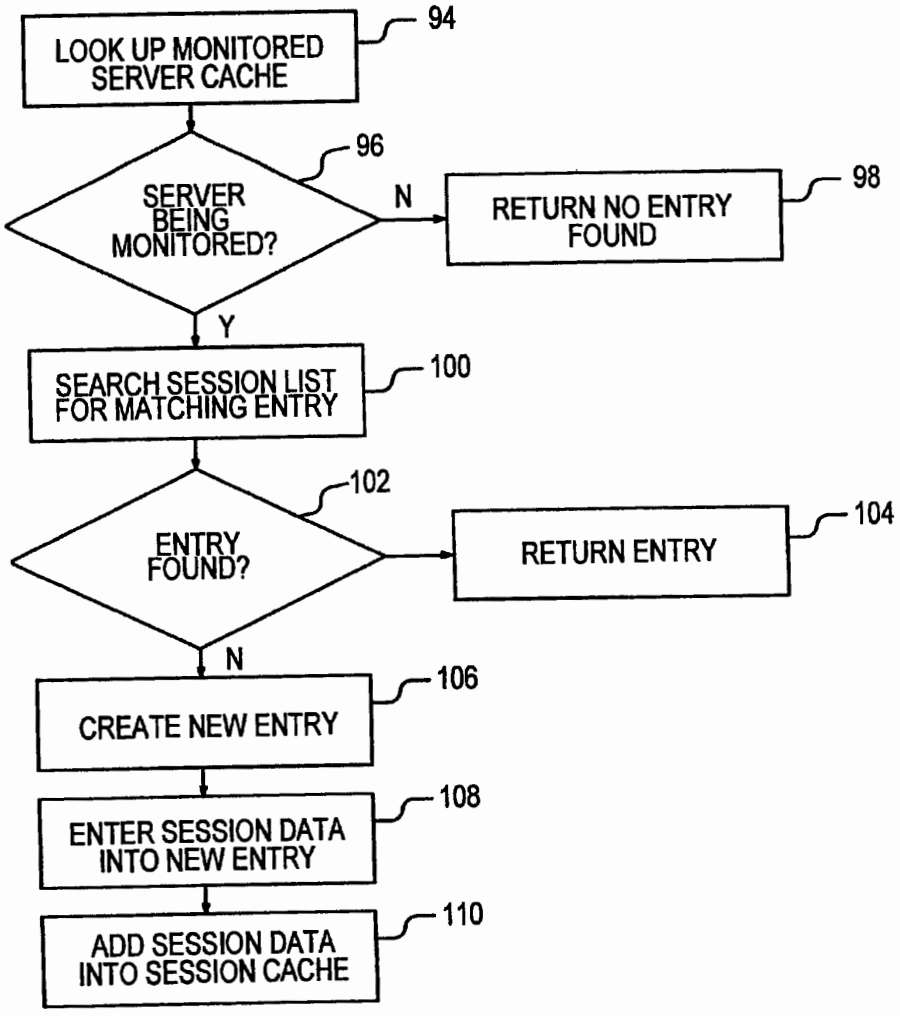

LOOK UP MONITORED SERVER CACHE
94
SERVER BEING MONITORED?
96
N
RETURN NO ENTRY FOUND
98
Y
SEARCH SESSION LIST FOR MATCHING ENTRY
100
ENTRY FOUND?
102
RETURN ENTRY
104
N
CREATE NEW ENTRY
106
ENTER SESSION DATA INTO NEW ENTRY
108
ADD SESSION DATA INTO SESSION CACHE
110

FIG. 6

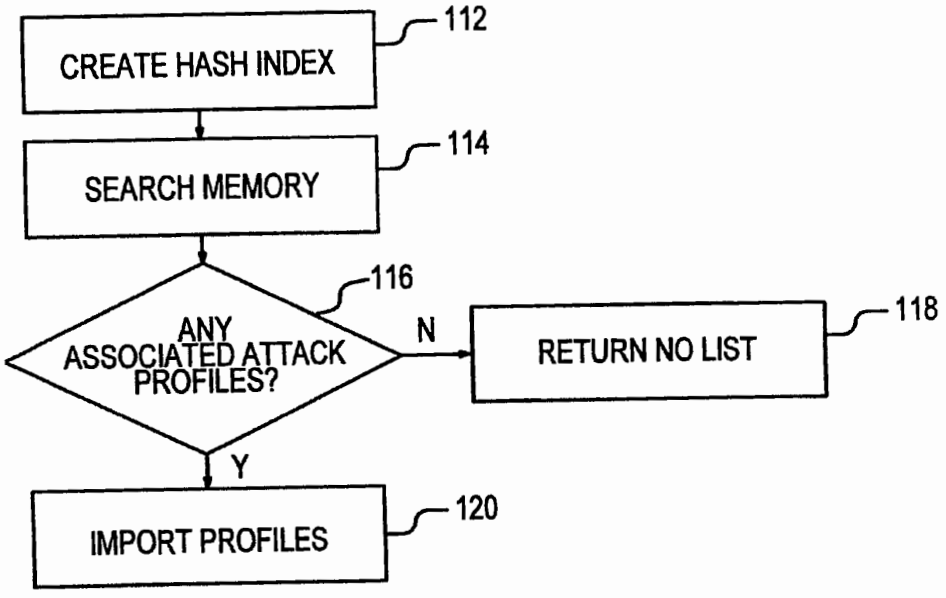

CREATE HASH INDEX
112
SEARCH MEMORY
114
ANY ASSOCIATED ATTACK PROFILES?
116
N
RETURN NO LIST
118
Y
IMPORT PROFILES
120

FIG. 7

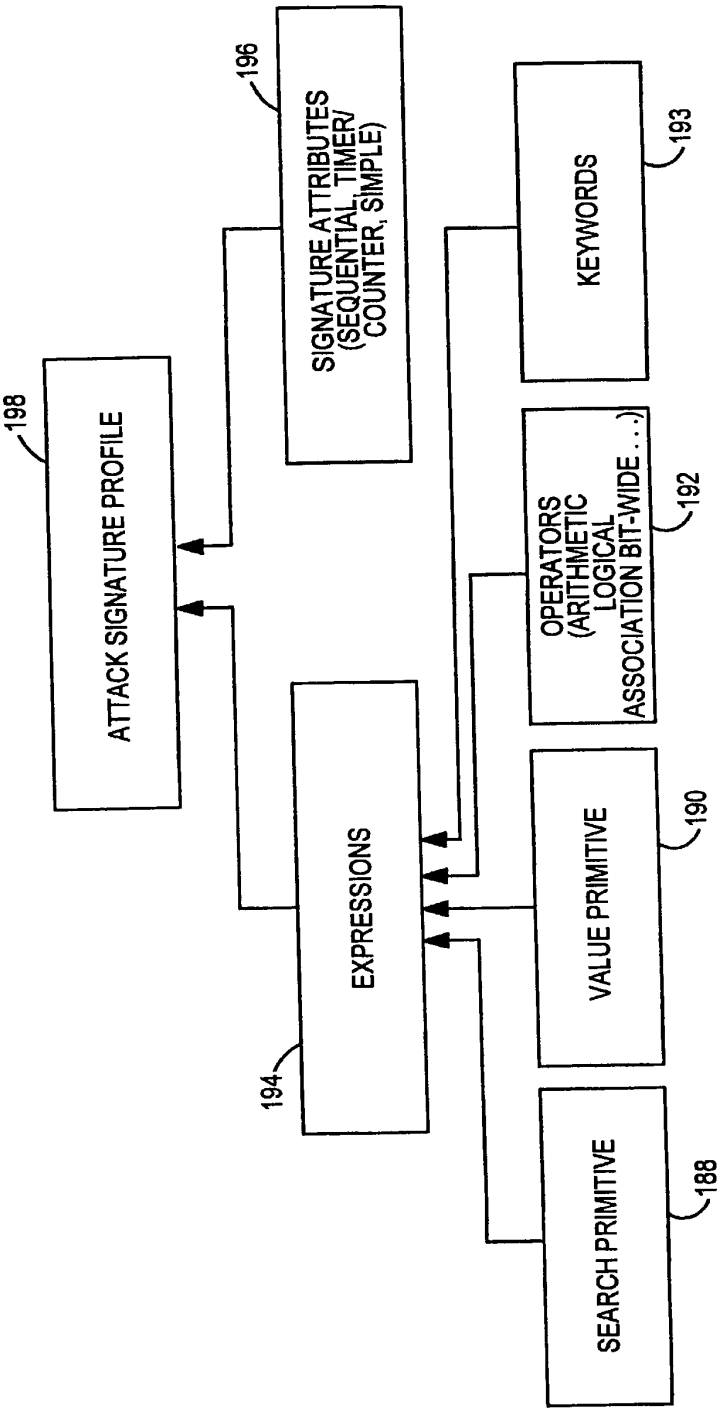

ATTACK SIGNATURE PROFILE
198
SIGNATURE ATTRIBUTES (SEQUENTIAL, TIMER/ COUNTER, SIMPLE)
196
KEYWORDS
193
OPERATORS (ARITHMETIC LOGICAL ASSOCIATION BIT-WIDE . . .)
192
EXPRESSIONS
194
VALUE PRIMITIVE
190
SEARCH PRIMITIVE
188

FIG. 8

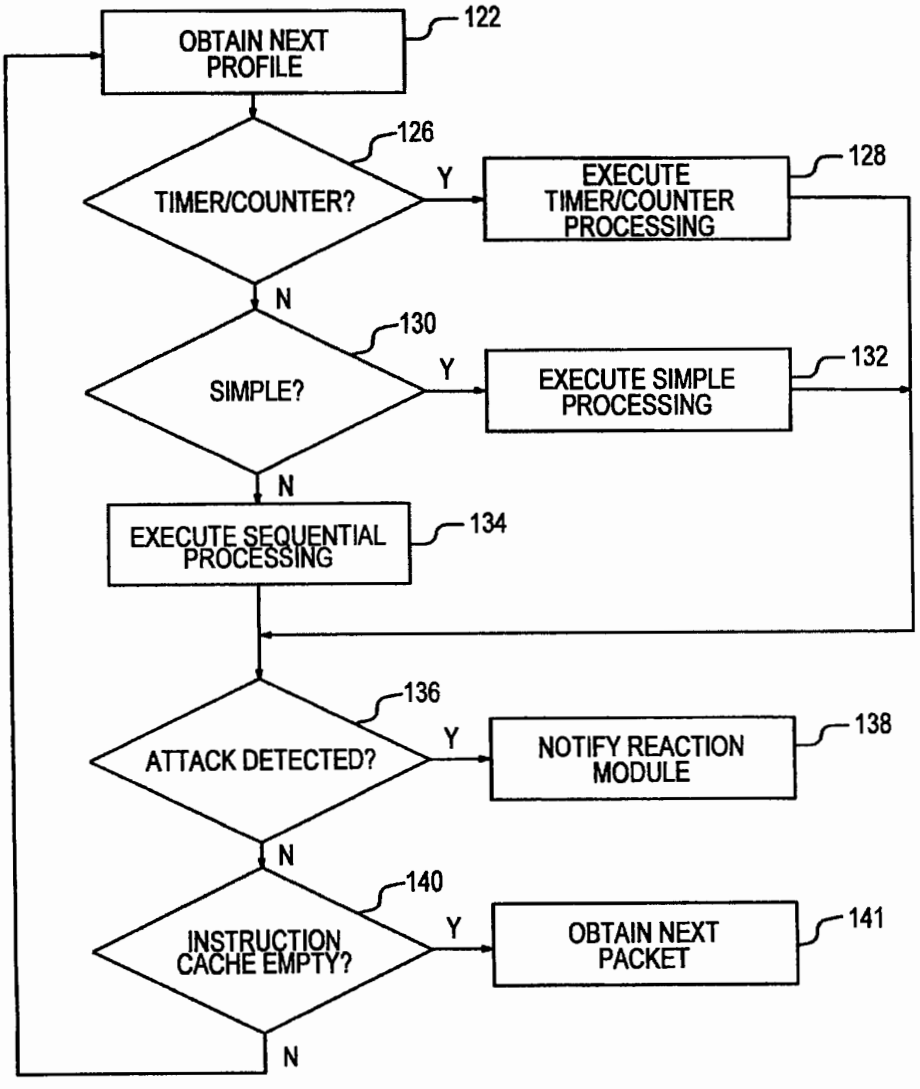

OBTAIN NEXT PROFILE
122
TIMER/COUNTER?
126
Y
EXECUTE TIMER/COUNTER PROCESSING
128
N
SIMPLE?
130
Y
EXECUTE SIMPLE PROCESSING
132
N
EXECUTE SEQUENTIAL PROCESSING
134
ATTACK DETECTED?
136
Y
NOTIFY REACTION MODULE
138
N
INSTRUCTION CACHE EMPTY?
140
Y
OBTAIN NEXT PACKET
141
N

FIG. 9

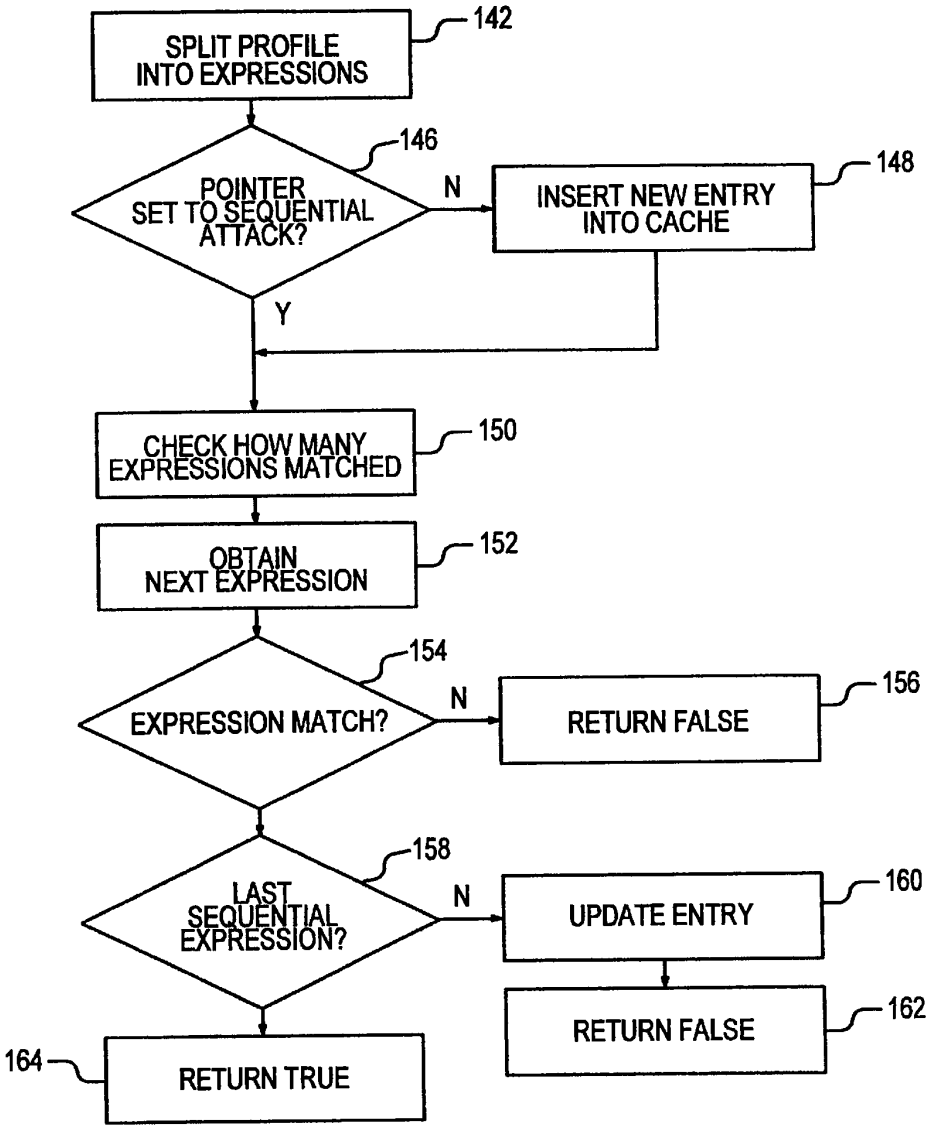

SPLIT PROFILE INTO EXPRESSIONS
142
POINTER SET TO SEQUENTIAL ATTACK?
146
N
INSERT NEW ENTRY INTO CACHE
148
Y
CHECK HOW MANY EXPRESSIONS MATCHED
150
OBTAIN NEXT EXPRESSION
152
EXPRESSION MATCH?
154
N
RETURN FALSE
156
LAST SEQUENTIAL EXPRESSION?
158
N
UPDATE ENTRY
160
RETURN FALSE
162
RETURN TRUE
164

FIG. 10

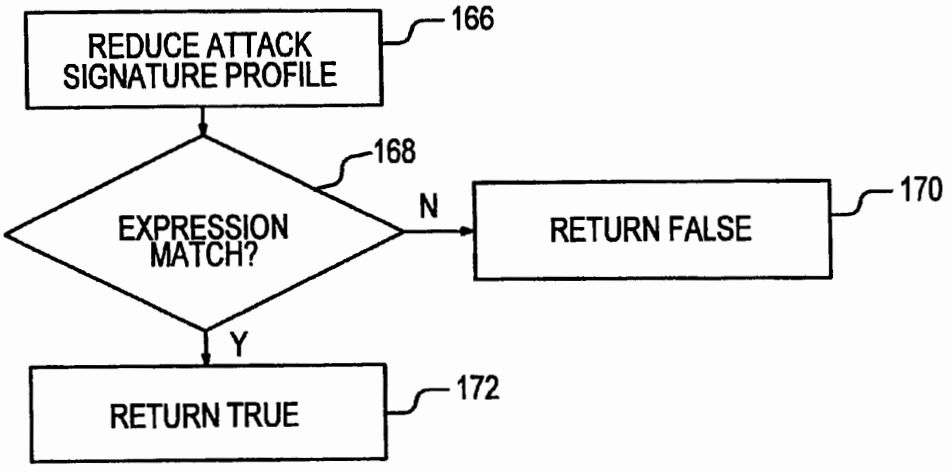

REDUCE ATTACK SIGNATURE PROFILE
166
EXPRESSION MATCH?
168
N
RETURN FALSE
170
Y
RETURN TRUE
172

FIG. 11

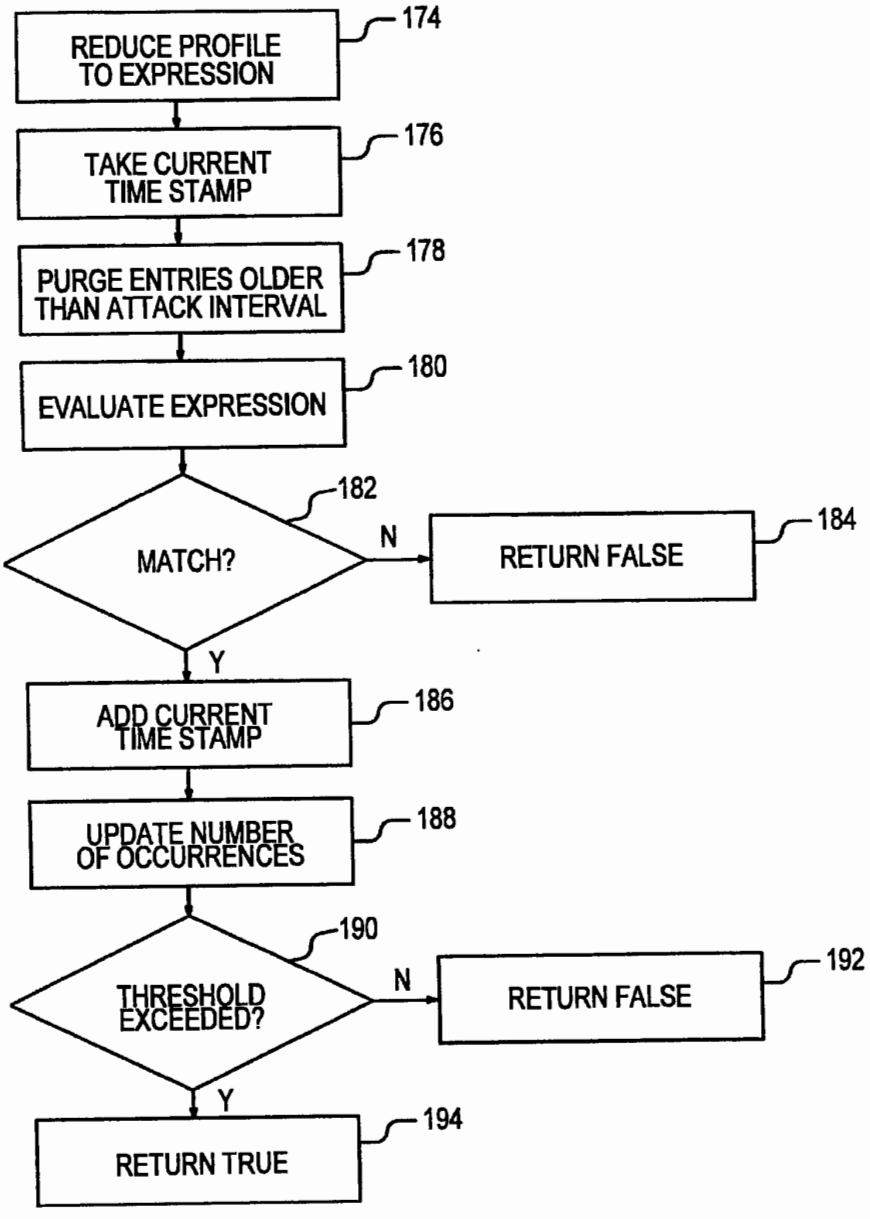

REDUCE PROFILE TO EXPRESSION
174
TAKE CURRENT TIME STAMP
176
PURGE ENTRIES OLDER THAN ATTACK INTERVAL
178
EVALUATE EXPRESSION
180
MATCH?
182
N
RETURN FALSE
184
Y
ADD CURRENT TIME STAMP
186
UPDATE NUMBER OF OCCURRENCES
188
THRESHOLD EXCEEDED?
190
N
RETURN FALSE
192
Y
RETURN TRUE
194

FIG. 12

DYNAMIC SIGNATURE INSPECTION-BASED NETWORK INTRUSION DETECTION

This application claims the benefit of U.S. Provisional Application No. 60/078,759, filed Mar. 16, 1998, and U.S. Provisional Application No. 60/078,328, filed Mar. 17, 1998.

TECHNICAL FIELD

The present invention relates generally to a method and system for providing security on a communication system and, more particularly, the invention relates to detecting intrusion attempts into system resources by monitoring for attack signatures.

DESCRIPTION OF THE RELATED ART

Computer networks enable multiple communication devices such as computers, fax machines, and modems to communicate with each other. In systems which employ a client-server computing model, server devices can generally be viewed as being a service provider and client devices are consumers of the services. Instead of each device on a network being self-sufficient, resources are contained in servers, which extend capabilities throughout the network. Client devices access the resources necessary to perform functions from the servers. For instance, a user might use a client application to obtain a compound document, perhaps an annual sales report containing spread sheet graphs and explanatory text, where part of the document is located on a first server (the text) and another part is located on a second server (the graphs).

Although the client-server system can provide an efficient means for managing resources of a computer system, significant security issues arise regarding control of access to sensitive material stored on the servers. Large corporate networks often include servers storing sensitive material, access to which must be closely regulated. Often the set of client objects which are permitted access to a particular server application will change over time. A significant need remains for a security system which regulates access to certain objects on a computer system and which provides the flexibility to allow for the changing requirements of security of the system.

U.S. Pat. No. 5,720,033 to Deo describes a security platform for networked processors which limits access to system resources by implementing a rules based system for types of access of security interests to one or more served application programs. The platform provides rule sets, each of which associates an access type with a subject. An example of a subject is a particular user. Optionally, the rule sets also associate an access type with a set of objects, which are specific system resources to which access is sought. Access demands made by a particular served application are compared to the rule sets to determine whether the access demanded is permissible. The platform permits access by a subject to an object if a rule is found for (a) the access type or (b) an access class to which the access type belongs which defines access between (A) either (i) the subject or (ii) a superclass to which the subject belongs and (B) either (i) the object or (ii) the superclass to which the object belongs.

Although the security platform described above provides a partial solution to the network security problem by enabling detection of unauthorized access attempts which are based in the application layer of the OSI model, the security platform is unable to detect network intrusions

based in lower levels of the OSI model. The security platform might be unable to detect an attempt to deliver a malicious data packet capable of causing a malfunction in a network object upon delivery because the security platform regulates access to a network object based on the identity of a subject. Consequently, a subject which is authorized to access a network object can deliver a malicious packet to that network object without being detected. The security platform described above is designed for access control to an object residing on a particular UNIX server. However, the platform is ineffective for detection of network security breaches unrelated to access control, such as transmission of malicious data packets.

U.S. Pat. No. 5,727,146 to Savoldi et al. describes a source address security system for both training and non-training objects, wherein network access to a port is secured by monitoring the source address of packets that are sent as a device attempts to transmit to the port over the network. If the source address of a packet matches an authorized source address assigned to the port, then the device is permitted to access the network. The source address security system requires that the address of all devices authorized to access a network be known so that the source address of a device which has transmitted a particular packet can be compared to source addresses of all authorized devices to determine if the device in question is permitted to access the network. Only if the source address of a device is known to the security system will the device be allowed to access the network.

A static signature database intrusion detection system (IDS) overcomes some of the above described limitations by providing a static signature database engine which includes a set of attack signature processing functions, each of which is configured to detect a specific intrusion type. Each attack signature is descriptive of a pattern which constitutes a known security violation. The system monitors network traffic by sequentially executing every processing function of a database engine for each data packet received over a network. Each processing function of the database engine is integrally associated with a corresponding attack signature making it problematic to incorporate new attack signatures into an existing static signature database. An entirely new database engine must be constructed in order to incorporate a new attack signature. This limitation also results in the built-in IDS not being able to allow addition and customization of new signatures. Furthermore, a built-in database IDS suffers from performance loss due to the sequential execution of every processing function for each packet received over the network. The IDS performance degrades further as more signatures are added to the database engine because of the resulting delay caused by the sequential processing by the static database engine.

What is needed is a network intrusion detection system which provides efficient extensibility to include newly discovered network attack signatures and which allows modifications to recognize new attack signatures without substantially affecting performance of the network intrusion detection.

SUMMARY OF THE INVENTION

A dynamic signature inspection-based network intrusion detection system and method include a processor which is configured such that it is mutually independent from configuring storage of attack signature profiles. In a preferred embodiment, the processor may be implemented either as a virtual processor in software or as an actual hardware

processor. The mutual independence of the processor from the attack signature profiles allows additional attack signature profiles to be integrated into the intrusion detection system without requiring any corresponding modification of the processor. The mutual independence of the processor from the attack signature profiles also enables the system to allocate processing requirements of network monitoring for attack signatures among various sites on the network according to a distribution of network objects in order to maintain high performance of the dynamic signature inspection-based network IDS.

The dynamic signature-based network IDS includes multiple attack signature profiles which are each descriptive of identifiable characteristics associated with particular network intrusion attempts associated with network objects located on the network. Network intrusion attempts include unauthorized attempts to access network objects, unauthorized manipulation of network data, including data transport, alteration or deletion, and attempted delivery of malicious data packets capable of causing a malfunction of a network object. The attack signature profiles can include generic attack and/or customized attack signature profiles for particular network objects on the network. Customized attack signature profiles can be added to a set of generic attack signature profiles without having to modify the processor, thereby facilitating efficient customization of the IDS.

The attack signature profiles are organized into sets of attack signature profiles which are assigned to network objects based on security requirements of the network objects, and these sets of signature profiles are stored in a signature profiles memory. The signature profile memory of a network defines the network data signaling patterns which constitute network intrusion attempts with regard to that network. Association data is stored in the signature profile memory and corresponds each of the network objects to associated set or subset of signature profiles, such that multiple sets of signature profiles are assigned to the set of network objects.

Data transmitted over the network is monitored by a data monitoring device to detect data addressed to the network objects. Upon detecting data addressed to one of the network objects, a set of signature profiles corresponding to that network object is accessed from the signature profile memory based on the association data. At least one attack signature profile from the set of profiles is processed by the processor to determine if the data addressed to the network object is associated with a network intrusion.

In a preferred embodiment multiple data collectors, each of which includes a data monitoring device, an attack signature profile memory, and a processor, are deployed at multiple sites in different segments of the network. A network configuration generator assigns sets of attack signature profiles to each data collector based on the network objects located on the network segment on which each data collector is deployed. A particular data collector monitors network data only for data addressed to the network objects located on that data collector's network segment. By distributing the network monitoring responsibilities among multiple data collectors, high performance of the dynamic signature-based network IDS is maintained. Instead of a single data collector monitoring the entire network data for network intrusion attempts, each data collector only monitors a network segment on which it is located or a point of entry from an open network, such as the Internet.

The dynamic signature-based network IDS employs at least three different types of attack signature profiles: a sequential, a simple, and a timer-counter based attack signature profile. A simple attack signature profile provides instructions to the processor which, when executed, can detect a single occurrence of an event associated with a network intrusion attempt. If processing of a simple attack signature profile reveals an occurrence of the event, a network intrusion attempt has been detected.

A sequential attack signature profile directs the processor to sequentially execute a series of instructions on data which constitutes at least a portion of an application session. The series of instructions is configured to detect a corresponding sequence of events which collectively are associated with a network intrusion attempt. Upon detecting each event associated with each instruction, the processor stores data indicative of the occurrence of that event in a state cache. The state cache is accessed by the processor to determine whether the entire series of events associated with the network intrusion attempt has occurred.

The timer-counter based attack signature profile directs the processor to execute an instruction which is configured to detect a particular event. The instruction is executed on each packet associated with an application session. A time stamp entry and a counter entry is made for each event detected by executing the instruction. If the number of times the event occurs within a predetermined time interval exceeds a preselected threshold, a network intrusion attempt has been detected.

An advantage of the present invention is that all seven layers of the OSI model are monitored and so an attack based in any of the layers can be detected. Another advantage is that the mutual independence of the processor and the attack signature profile enables efficient customization of the IDS according to the security requirements of a network. Yet another advantage of the present invention is the high performance which the IDS is able to provide on large networks by allocating network monitoring responsibilities to multiple monitoring devices at multiple sites on the network.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a network on which a network IDS according to the current invention is deployed.

FIG. **2** is a block diagram of a data repository and a data collector employed in the operation of the network IDS shown in FIG. **1**.

FIG. **3** is a process flow for an operation of a network IDS shown in FIG. **2**.

FIG. **4** is a schematic diagram illustrating the operation of a virtual processor shown in FIG. **2**.

FIG. **5** is a process flow of a method for building a register cache during the operation of the virtual processor shown in FIG. **4**.

FIG. **6** is a process flow for a method of extracting a state cache entry during the operation of the virtual processor shown in FIG. **4**.

FIG. **7** is a process flow for a method for building an instruction cache with applicable attack signature profiles.

FIG. **8** is a schematic diagram of the components of an attack signature profiles.

FIG. **9** is a process flow for a method of processing attack signature profile from an instruction cache.

FIG. **10** is a process flow for a method for processing a sequential attack signature profile.

FIG. **11** is a process flow for a method for processing a simple attack signature profile.

FIG. 12 is a process flow for a method for processing a timer/counter based attack signature profile.

DETAILED DESCRIPTION

Referring to FIG. 1, a preferred embodiment of a dynamic network-based signature inspection network Intrusion Detection System (IDS) includes a central data repository 12 and multiple data collectors 10 located on a network such as a Local Area Network 11 (LAN). Although the data collectors 10 are illustrated as stand-alone devices, the function of a data collector can be included on other devices in the network, such as a server or a router/firewall/switch 20. Multiple data collectors 10 are preferred when the LAN 11 includes multiple network objects which the IDS must monitor for network intrusions. As will be discussed in greater detail below, allocating monitoring responsibilities among multiple data collectors 10 in such situations tends to maintain a high performance of the IDS. Two of the data collectors 10 are deployed on first and second LAN segments 14 and 16 each of which includes multiple workstations, a third data collector 10 is located on a server backbone 18 of the LAN 11 to monitor network traffic to and from the servers, a fourth data collector 10 is located proximate to the router/firewall/switch 20 to monitor incoming data to the LAN 11, and a fifth data collector monitors incoming data to a remote network 24.

The data repository 12 polls the data collectors 10 to obtain network security data, which the data repository 12 handles. The data repository 12 also provides an interface for an administrator of the IDS to establish a configuration of network objects on the LAN 11 and to distribute attack signature profiles to the data collectors 10 based on the network configuration. The attack signature profiles are adapted for detecting network data patterns associated with network intrusions which include unauthorized attempts to access network objects, unauthorized manipulation of network data, including data transport, alteration or deletion, and attempted delivery of malicious data packets capable of causing a malfunction in a network object. The remote network 24 is connected to the LAN 11 and is equipped with a data collector 10 which monitors work stations located on the remote network 24 and transmits network security data specific to the remote network back to the data repository 12. Both the remote network 24 and the LAN 11 are connected to the global communications network referred to as the Internet 22.

Referring to FIG. 2, the data repository 12 includes a database handler 26 which polls the data collectors 10 for intrusion detection data and stores the data for future reference. The database handler 26 also generates reports regarding intrusion detection history. A configuration generator 28 is connected to the database handler to enable the network administrator to define the configuration of network objects on the LAN 11 and the remote network 24. The configuration generator 28 also enables the administrator to define the connection of both the LAN 11 and the remote network 24 to the Internet 22. The network objects include devices such as the servers and workstations, as well as routers, firewalls and switches. Network objects further include applications and files stored in memory within those devices. Based on the network configuration data generated by the configuration generator 28, the database handler 26 assigns sets of attack signature profiles to each data collector 10. A communication module 30 is used by the data repository 12 to transmit and receive data to and from the data collectors 10. For example, the communication module 30 downloads network configuration data to the data collectors 10.

Each data collector 10 includes a communication module 34 for transmitting and receiving information to and from the data repository 12. A configuration builder module 32 assigns a set of signature profiles to each network object and stores data representative of associations between network objects and attack signature profile sets in a signature profile memory 39. The configuration builder module 32 accesses the appropriate attack signature profile sets during operation of the data collector 10 and provides the attack signature profiles to a stateful dynamic signature inspection (SDSI) virtual processor 36. The attack signature profiles include a set of instructions which the virtual processor 36 executes to determine whether a particular data packet is associated with a network intrusion. Although a preferred embodiment of the processor employs the software based virtual processor 36 to execute attack signature profiles, a hardware based processor can be employed in the place of the virtual processor 36. If the virtual processor 36 determines that a network intrusion has occurred, it alerts a reaction module 38, which initiates one of several reactions depending on the nature of the attack. The reaction module 38 can either terminate an application session associated with the network intrusion, trace the session, and/or alert the network administrator of the attack. The reaction module 38 is configured to automatically notify the network administrator via e-mail, fax, an SMNP trap, and/or by pager.

With reference to FIGS. 2 and 3, a method for the operation of the dynamic signature inspection network IDS includes the step 50 of generating attack signature profiles. The attack signature profiles can be generic in that they describe generic network intrusion attempts which are common to most networks, or the attack signature profiles can be generated to be specific to a particular network by, for instance, indicating which network objects are not permitted to access other network objects. In step 52 sets of attack signature profiles are organized according to security requirements of each network object. In step 54, corresponding data that are indicative of which objects corresponds to which sets of attack signature profiles are stored in memory of the data repository 12. As noted above, network objects include servers, workstations, applications, files within applications, and devices such as routers, firewalls and switches.

The configuration generator 28 of the data repository 12 is utilized to establish a configuration of network objects. If more than one data collector 10 is deployed on a network, the configuration generator 28 stores information regarding which objects reside on each segment that a data collector 10 is monitoring and the sets of attack signature profiles required by each data collector. In step 56 the communication module 30 of the data repository 12 distributes the signature profiles to the various data collectors 10 throughout the network. Upon receiving a set or sets of attack signature profiles, each data collector 10 stores the set or sets of profiles it receives from the data repository 12 in its signature profile memory 39.

Each data collector 10 monitors network data in step 58 to detect packets addressed to network objects on the network segment on which the data collector 10 is located. For example, referring briefly to FIG. 1, the data collector 10 located on the first network segment 14 monitors network data for packets addressed to those workstations on the first network segment 14. When the data collector 10 detects a data packet addressed to a network object having an associated attack signature profile set in the signature profile memory 39, the data collector accesses the attack signature profile set in step 60 and processes attack signature profiles

in step 62 to determine if the packet is associated with a network intrusion in step 64. The attack signature profile type can be either simple, sequential or a timer/counter based. If in step 64 the data collector 10 determines that the data packet is not associated with a network intrusion, the data collector continues to monitor data in step 58. If a network intrusion is detected, the reaction module is notified in step 66. The reaction module 38 takes steps to trace the application session associated with the data packet, to terminate the session, and/or to notify the network administrator.

With reference to FIG. 4, the operation of the virtual processor 36 includes monitoring network data 46 to determine whether the data is associated with a network intrusion. A register cache 40 temporarily stores information extracted from a data packet which determines which signature profile(s) will be accessed from the signature profile memory 39. The virtual processor 36 obtains a data packet from a queue and extracts MAC header information, IP header information, transport header information, and application information from the data packet. Extraction of the packet information enables the data collector 10 to detect network intrusions based in the different layers of the OSI model.

The virtual processor 36 uses the extracted packet information to determine to which server and application the packet is addressed. The virtual processor 36 communicates the server/application information to the configuration builder module 32, which accesses the applicable set of attack signature profiles from the signature profile memory 39.

The configuration builder module 32 temporarily stores the applicable attack signature profiles in an instruction cache 42. The virtual processor 36 processes the attack signature profiles to determine whether the packet is associated with a network intrusion attempt. A simple attack signature profile might provide instructions to determine if a data packet, which is addressed to server X for access to application Y, has a source address of user Z. In this example, a network administrator has determined that user Z is not authorized to access application Y on server X. If, upon executing the simple attack profile instructions the virtual processor 36 recognizes that the source address for the data packet is user Z, the virtual processor 36 notifies the reaction module 38, which then takes an appropriate action.

Simple attack signature profiles include only a single expression. In the example above the expression can be described as "is source address user Z?" Two other types of attack signature profiles, sequential and timer/counter based, require sequential execution of an instruction or instructions associated with an attack signature profile.

The sequential attack signature profiles include multiple expressions. For instance, these expressions might include "is source address user Z?" and "is user Z attempting to access file A?" Instructions associated with the first expression are executed on a first packet associated with an application session to determine that the packet has the user Z source address. However, if this first packet does not include information that user Z is attempting to access file A in application X, a subsequent packet associated with the same application session will have to be analyzed to determine if user Z is attempting to access file A. An entry is made into a state cache 44 to indicate that the first expression was satisfied. The state cache 44 satisfies the need for a record to be made indicating which expressions in the sequential attack signature profile have been matched in the current application session.

The next packet which the virtual processor 36 determines to be associated with the same application session will cause the virtual processor 36 to fill the instruction cache 42 with the sequential attack signature profile. The sequential attack signature profile includes information which causes virtual processor 36 to access the entry from a state cache 44 indicating that user Z has accessed application Y on server W. Based on the state cache entry, the virtual processor 36 executes instructions associated with the expression "is user Z attempting to access file A?" If the virtual processor 36 determines that this second packet associated with the application session includes data representative of an attempt to access file A, the second expression is satisfied and an unauthorized access attempt by user Z into file A has been recognized.

A timer/counter based attack signature profile directs the virtual processor 36 to execute instructions associated with a single expression on every data packet associated with a particular application session to determine whether an event has occurred a threshold number of times within a predetermined time interval. For instance, a timer/counter based attack signature profile might direct the virtual processor 36 to execute an instruction associated with the expression "is user Z attempting to access file A?" on every packet associated with a session application Y. The instructions also direct the virtual processor 36 to determine whether the number of attempts user Z makes to access file A exceeds 5 attempts within any 10 minute period. The first packet which the virtual processor 36 recognizes as being associated with an attempt by user Z to access file A causes the virtual processor 36 to activate a timer 37 and to set a counter 35 to one. The timer and counter information are entered into the state cache 44. Each subsequent detection of an attempt by user Z to access file A triggers the virtual processor 36 to access the timer and counter information from the state cache 44 and to determine whether the threshold has been met. If the threshold is met, a network intrusion has been detected and the virtual processor 36 notifies the reaction module 38.

Referring to FIG. 5, a method for building a register cache 40 during the operation of the virtual processor 36 includes purging the packet information in the current register in step 84 upon accessing a data packet from the packet queue. In step 86 the MAC header information is extracted from the packet, in step 88 the IP header information is extracted, in step 90 the transport header information is extracted from the packet, and in step 92 the application information is extracted from the data packet. All of the extracted packet information is entered into the register cache 40. The extracted packet information is utilized to create a session cache entry, which is essentially an application session history, and to access an appropriate set of attack signature profiles. The different types of packet information enable generation of attack signatures profiles which can recognize network intrusions based in the different layers of the OSI model.

Referring to FIG. 6, a method for extracting a session entry in the state cache 44 includes utilizing a serve IP address to look up the server in a monitored client/server cache (not shown) in step 94 to determine in step 96 whether the server is being monitored. If the server is not being monitored, in step 98 the virtual processor 36 is alerted that no entry was found for the server. If no entry is found for the server, the server is not being monitored for network intrusions and no further steps are taken. If the network object to which the data packet is directed is a client workstation instead of a server, the virtual processor 36 looks up the

workstation in the client/server cache to determine whether the workstation is being monitored.

If the server is being monitored, in step **100** a session list in the state cache **44** is searched for a matching entry. Application information and the server IP address extracted from the packet into the register cache **40** are used to calculate a hash index, and the hash index is used to search for a matching entry from the session list. In step **102**, it is determined whether a matching session entry was found. If a matching session entry is found, the entry is returned to the virtual processor **36** in step **104**. The session entry might contain a record of timer/counter expressions executed on packets associated with the application session. For instance, the entry might reflect that within the application session a particular file within the application has been accessed ten times in the past twenty minutes. The virtual processor **36** uses this timer/counter information to determine whether a network intrusion is associated with the particular packet. The state cache **44** is also utilized to create a record of executed expressions in a sequential attack signature profile.

If no session entry is found in step **102**, a new session entry is created in the session cache **44** in step **106**. Session data, which includes any matches identified by executing attack signature profile instructions on a data packet, are entered into the new session entry in step **108** and the session entry is entered into the state cache **44** in step **110**.

Referring to FIG. **7**, a method for building the instruction cache **42** includes the step **112** of creating a hash index based on the server IP address and the application information in the register cache **40**. Alternatively, if the network object being monitored is a workstation, the hash index can be created using an IP address of the workstation. In step **114** the hash index is used to search the signature profile memory **39** for a set of attack signature profiles corresponding to the server and application associated with the packet information in the register cache **40**. In step **116** it is determined whether the server and application associated with the packet information correspond to a set of attack signature profiles. If the search reveals no corresponding profile, the virtual processor **36** is informed of the negative search result in step **118** and no further steps are taken with regard to executing attack signature profile instructions on the data packet. If the search identifies a corresponding profile, the attack signature profiles signatures are imported into the instruction cache in step **120**.

With reference to FIG. **8**, an attack signature profile **198** can be represented as at least one expression **194** in combination with a signature attribute **196**, wherein the expressions can be composed of search primitives **188**, value primitives **190**, and operators **192**. In a preferred mode, the expressions also include keywords **193**. An example of an expression might be as follows: (IP AND S1 and (V1>200)), wherein "IP" is a keyword referring to a packet utilizing IP/TCP protocol, "S1" is a search primitive referring to user A, "AND" is a conjunctive operator, ">200" is an operator for indicating a value greater than 200, and "V1" is a value primitive referring to a packet length. Taken together, the entire expression describes a data packet which utilizes IP/TCP protocol, has a source address of user A and which has a packet length of greater than 200 bits.

The attribute **196** of an attack signature can be either sequential, timer/counter based, or simple. A simple attack signature attribute indicates that a attack signature profile consists of a single expression with an instruction is executed by the virtual processor **36** only once. A timer/counter based signature indicates that a single expression instruction is executed sequentially on each data packet associated with an application session until either the session is terminated or an intrusion is recognized. The timer **37** is used to enter a time stamp into a state cache entry each time an execution of a timer/counter expression instruction detects an event associated with an application session. The counter **35** logs and tracks the number of events within the predetermined time interval each time an event is detected by an execution of the timer/counter based instruction. Upon each execution of the timer/counter based instruction, a state cache entry associated with the application session being monitored is referenced to determine whether previous executions of the timer/counter based instruction together with the present execution have caused the threshold number of events to be reached within the predetermined time interval.

The sequential signature attribute refers to multiple expressions which are sequentially executed on successively transmitted data packets associated with an application session. If each of the expressions detects the event it was designed to detect, a network intrusion has been detected.

A more formal description of an attack signature in a loose BNR parsing grammar follows:

```
Pattern          := Hex or ASCII string of characters
Offset           := integer
Protocol         := one of the communication protocols, ie. MAC-layer
                    Network-layer, Transport-layer, or Application-layer
Extract_Type:= Byte, Word, Long Word or String
Header_Field:= Predefined keywords for communication
                    protocol header fields
Variable_Name:= ASCII character string Name
SP               :=<Pattern, Offset, Protocol> . . . Search Primitive
VP               :=<Extract_Type, Offset, Protocol> . . . Value Primitive
OP               :=<Logical> | <Arithmetic> | <Bit-wide> |
                    <Association> | . . . Operators
Basic_Expression:= <SP>|<OP>|<Header_Field|<SP OP SP>
                    | <SP OP VP | <SP OP Header_Field>
Assignment := <Variable_Name> "=" <Basic_Expression>
Complex_Expression := {(<Basic_Expression> OP <Basic
                    Expression>) . . . }
Expression       := <Complex_Expression> | <Complex_Expression>";"
                    {(<Assignment>";") . . . }
Signature_Attributes := <Simple> | <Counter-Timer-Based> |
                    <Sequential-occurrence>
Attack_Signature := <Signature_Attribute> { <Expression> . . . .}
```

With reference to FIG. **9**, a method for processing attack signature profiles includes obtaining an attack signature profile from the instruction cache **42** in step **122**. As previously noted, the attack signature profiles in the instruction cache **42** were accessed from the signature profile memory **39** based on the IP address of the server to which the packet was addressed and the application in the server to which the packet was directed. It is not necessary that the monitored network object be an application within a server. The object could be any network object, such as a particular server, a workstation, a firewall or a router, or a particular file within an application of the workstation.

In step **126** the virtual processor **36** determines if the attack signature profile has a timer/counter based attribute. If the attack signature profile has a timer/counter based attribute, in step **128** the virtual processor **136** executes timer/counter processing. If the profile's attribute is not timer/counter based, and if in step **130** the virtual processor **36** determines that the attack signature profile has a simple attribute, the virtual processor **36** executes simple signature processing in step **132**. If the signature attribute is neither simple nor timer/counter based, the virtual processor **36**

executes sequential processing in step **134**. Although only simple, sequential, and timer/counter based attributes have been discussed, other signature attributes can be incorporated into the present invention.

In step **136** the virtual processor **36** determines if the execution of the attack signature has revealed a network intrusion. If the data collector **10** recognizes a network intrusion, in step **138** the reaction module **38** is notified. If no attack has been detected, in step **140** the virtual processor **36** determines if the instruction cache **42** is empty. If the instruction cache is not empty, the virtual processor **36** returns to step **122** and accesses the next attack signature profile. If the instruction cache **42** is empty, the next packet in the queue **48** is obtained in step **141** to extract packet information into the register cache **40**.

Referring to FIG. **10**, a method for processing a sequential attack signature profile includes the step **142** of splitting the attack signature profile into expressions. As previously discussed, a sequential attack signature profile is composed of multiple component expressions which are sequentially evaluated to determine if each expression matches a data packet associated with a particular application session. In step **146** the virtual processor **36** determines whether a pointer is set to the sequential attack signature profile in the state cache **44**. If the pointer is not set to the sequential attack signature profile, in step **148** an entry is made in the state cache **44** so that a pointer is set to the sequential attack signature profile and the entry parameters are initialized. In step **150**, the virtual processor **36** references a state cache entry **44** to determine how many of the expressions have already been matched to data packets associated with the currently monitored application session.

In response to the state cache entry, the virtual processor **36** obtains the next sequential expression from an expression list in step **152**. For example, an attack signature profile might include expressions A, B, and C. Expression instruction A was executed and found to match a first packet associated with an application session and expression instruction B was executed and found to match a second packet associated with the application session. Upon receiving a third packet associated with the application session and after referencing the state cache entry to obtain the information that expressions A and B have been matched, the virtual processor **36** obtains the third expression to determine if it matches the third packet. It should be noted that expressions A, B, and C need not be found to match three consecutive data packets associated with an application session. Rather, expression A must be found to match a packet which precedes a packet found to match expression B or C, and B must be found to match a data packet which precedes a packet found to match expression C.

In step **154**, after executing an expression instruction, the virtual processor **36** determines whether the expression matches the data packet. If the expression does not match, the virtual processor **36** returns a false value in step **156**. If the expression matches, a determination is made in step **158** whether the expression was the last sequential expression. In step **160**, the virtual processor **36** updates the entry in the state cache **44** to reflect the match of the expression to the data packet if it is determined that the executed expression is not the last sequential expression and in step **162** the virtual processor returns a value of false. If the expression is the last sequential expression, in step **164** the virtual processor **36** returns a value of true to indicate that a network intrusion has been detected.

The processing of a simple attack signature profile is similar to the processing of a single expression of a sequential attack signature. Referring to FIG. **11**, the attack signature profile is reduced to an expression in step **166**. After executing the expression instruction, the virtual processor **36** determines whether the expression matches a data packet associated with an application session in step **168**. If the expression matches the packet, in step **172** the virtual processor **36** returns a value of true and the reaction module **38** is notified of a network intrusion. If the expression does not match, the virtual processor **36** returns a value of false in step **170**.

With reference to FIG. **12**, a method for processing a timer/counter based attack signature profile includes the step **174** of reducing the profile to an expression. In step **176** the virtual processor **36** utilizes the timer **37** to make a current time stamp for the data packet being evaluated. Entries in the state cache **44** that are older than an attack interval are purged from the state cache **44** in step **178**. Purging stale entries involves comparing a time interval between time stamps associated with entries and the current time. If the actual time interval associated with an entry is greater than the attack signature time interval, that entry is purged from the state cache **44**.

In step **180** the expression is evaluated to determine in step **182** if the expression matches the packet currently being analyzed. If the expression does not match, the virtual processor **36** returns a value of false in step **184**. If the expression matches the packet, the virtual processor returns a value of true and adds the current time stamp to the application session entry in the state cache **44** in step **186**. In step **188** the counter **35** is utilized to update the number of events recognized by execution of the timer/counter expression instruction on data packets associated with the current application session. A determination is made in step **190** whether, after the number of event occurrences has been updated, the threshold number of events has been detected within the predetermined time interval. A value of false is returned in step **192** if the threshold has not been reached. If the threshold has been reached, in step **194**, the virtual processor **36** returns a true value to indicate that a timer/counter based network intrusion has been detected.

What is claimed is:

1. A method for detecting network intrusion attempts associated with network objects on a communications network including the steps of:

storing a list of attack signature profiles descriptive of attack signatures associated with said network intrusion attempts;

storing corresponding data representative of a correspondence between subsets of said attack signature profiles and said network objects such that each network object has a corresponding stored subset of attack signature profiles and more than one subset of attack signature profiles corresponds to network objects;

monitoring network traffic transmitted over said communications network for data addressed to one of said network objects;

in response to detecting said data addressed to said network object, accessing a subset of attack signature profiles corresponding to said network object based on said correspondence data; and

executing at least one attack signature profile included in said subset corresponding to said network object to determine if said data addressed to said network object is associated with a network intrusion attempt.

2. The method of claim **1** wherein said executing step includes utilizing a processor to execute said at least one

attack signature profile, the method further comprising the step of generating additional attack signature profiles to be added to said subsets of attack signature profiles in the absence of modifying said processor.

3. The method of claim 2 wherein said generating step includes generating an additional attack signature profile configured to recognize an occurrence of a predetermined threshold number of events within a predetermined time interval, said occurrence of said predetermined threshold number of events within said predetermined time interval constituting said network intrusion attempt.

4. The method of claim 1 wherein said executing step includes determining whether a particular sequence of events occurs which constitutes said network intrusion attempt.

5. The method of claim 1 wherein said steps of storing said list of attack signature profiles and storing said correspondence data include storing said subsets of said attack signature profiles and subsets of said correspondence data at a plurality of sites in different segments of said networks according to a distribution of said network objects on said network.

6. The method of claim 5 wherein said monitoring step includes monitoring network traffic at one of said plurality of sites for data addressed to a subset of said plurality of network objects having corresponding subsets of said attack signature profiles and corresponding subsets of said correspondence data stored at said site.

7. The method of claim 1 further comprising the step of alerting a network administrator if it is determined in said executing step that said data addressed to said network object is associated with said network intrusion attempt.

8. A network-based dynamic signature inspection system for detecting attack signatures on a network comprising:

a data monitoring device configured to detect network data addressed to a first set of network objects, said monitoring device having an input for receiving said data and an output for signaling a detection of said data;

signature profile memory including:

a) attack signature profiles descriptive of network signaling patterns which constitute said attack signatures, each attack signature profile being configured to enable recognition of one of said attack signatures, each attack signature being associated with a known network security violation; and

b) association data corresponding each of said first set of network objects to an associated subset of said attack signature profiles such that more than one of said subsets of said attack signature profiles corresponds to said first set of network objects; and

processor means, responsive to said detection signaling, for processing an attack signature profile included in a subset of said signature profiles assigned to one of said first set of network objects, reception of a detection signal indicative of a detection by said monitoring device of data addressed to said network object triggering access by said processor means to said subset of said signature profiles assigned to said network object based on said association data.

9. The system of claim 8 further comprising an attack signature profile generator enabled to generate additional attack signature profiles to be included in said subsets of attack signature profiles, said additional attack signature profiles being configured for processing by said processor means in the absence of any corresponding modification of said processor means.

10. The system of claim 9 wherein said attack signature profile generator is further configured to generate said additional attack signature profiles for said first set of network objects based on security requirements of said first set of network objects.

11. The system of claim 9 further comprising a state cache connected to said processor means, said state cache having memory for storage of data representative of attack signature profile processing results.

12. The system of claim 11 wherein said attack signature profile generator is configured to generate a sequential attack signature profile with directions to said processor means to sequentially execute a set of instructions and to store results of each instruction execution in said state cache, a sequential occurrence of events detected by said execution of said instructions being indicative of a known network security violation.

13. The system of claim 8 further comprising an intrusion detection alert mechanism in communicative contact with said processing means, said detection alert mechanism being configured to perform a predetermined act if said processing of said attack signature profile reveals a network intrusion, said predetermined act being one of alerting a network administrator, denying access to said network object, or tracing an application session associated with said network intrusion.

14. A network-based dynamic signature inspection system for detecting attack signatures on a network comprising:

a data monitoring device configured to detect network data addressed to a first set of network objects, said monitoring device having an input for receiving said data and an output for signaling a detection of said data;

signature profile memory including:

a) attack signature profiles descriptive of network signaling patterns which constitute said attack signatures, each attack signature profile being configured to enable recognition of one of said attack signatures, each attack signature being associated with a known network security violation; and

b) association data corresponding each of said first set of network objects to an associated subset of said attack signature profiles such that more than one of said subset of said attack signature profiles corresponds to said first set of network objects; and

processor means, responsive to said detection signaling, for processing an attack signature profile included in a subset of said signature profiles assigned to one of said first set of network objects, reception of a detection signal indicative of a detection by said monitoring device of data addressed to said network object triggering access by said processor means to said subset of said signature profiles assigned to said network object based on said association data wherein said data monitoring device, said signature profile memory, and said processor means are all contained in a first data collector located on a first network segment on which said first set of said network objects reside, said system further comprising:

a second data collector including a second data monitoring device, a second signature profile memory, and second processor means, said second data collector being located on a second network segment including a second set of said network objects, said second processor means being a duplicate of said first processor means; and

a network configuration generator configured to assign a first plurality of said signature profile subsets to said first data collector based on a configuration of said first

set of network objects and to assign a second plurality of signature profile subsets to said second data collector based on a configuration of said second set of network objects.

15. A method for providing network intrusion detection on a network including first and second network objects comprising the steps of:

storing first and second sets of attack signature profiles associated respectively with first and second network objects at a first site on said network, each attack signature profile being configured to detect a network signaling pattern associated with a known network security violation;

monitoring network traffic at said first site for data addressed to one of said first and second network objects;

upon detecting data addressed to said first network object, accessing said first set of attack signature profiles;

utilizing a processor to execute an attack signature profile from said first set of attack signature profiles;

determining whether said execution of said attack signature profile reveals a known network security violation; and

generating additional attack signature profiles configured to be executed by said processor in the absence of modifying said processor.

16. The method of claim **15** further comprising the steps of:

deploying a duplicate of said processor at a second site on said network;

storing a third set of attack signature profiles associated with a third network object at said second site;

monitoring said network traffic at said second site for network data addressed to said third network object; and

executing at least one attack signature profile in said third set of attack signature profiles at said second site upon detecting said network data addressed to said third network object.

17. The method of claim **15** wherein said executing step includes determining whether a predetermined number of events occur within a predetermined time interval.

18. The method of claim **15** wherein said step of utilizing said processor to execute said attack signature profile includes:

translating said attack signature profile into a set of instructions to be sequentially executed to enable recognition of a set of sequentially occurring events which collectively constitute said known network security violation;

sequentially executing said set of instructions; and

upon recognizing each of said set of events, storing data representative of an occurrence of said each event.

19. The method of claim **18** wherein said determining step includes determining whether said known security violation has occurred based on said stored data representative of said occurrence of said each event.

20. A computer system comprising:

a plurality of attack signature profiles comprising machine readable data corresponding to attack signatures associated with network intrusion attempts; and

corresponding data comprising machine readable data representative of a correspondence between a plurality of network objects and subsets of attack signature profiles.

* * * * *

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(54) **LOW OVERHEAD CONTINUOUS MONITORING OF NETWORK PERFORMANCE**

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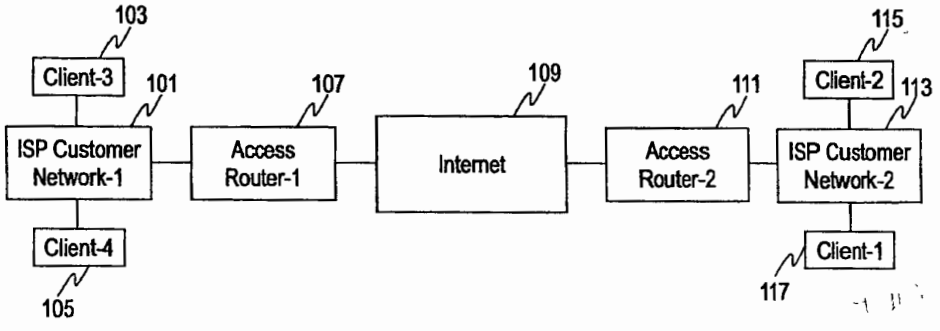
(57) **ABSTRACT**

A method, apparatus, article of manufacture and computer product for low-overhead continuous monitoring of network performance in an intranet or Internet topology. Probe packets are sent from ingress access routers where they are received and processed by egress access routers. Probe packets are generated by copying every Nth packet being sent by an ingress access router. In the event an access router does not receive the probe packet, the probe packet is discarded through normal network delivery mechanisms. Network delay is determined by subtracting the time that a probe packet was received with the time stamp enclosed in the probe packet. Round trip time is established by reflecting the probe packet back to the originating access router and computing the round trip time. Bandwidth monitoring is achieved by using the number of probe packets received to estimate the expected amount of network traffic to be received. Fault monitoring is accomplished by comparing the number of probe packets received with the number of actual packets received. When the low overhead mechanisms indicate that network delays or faults exist, a heavy weight monitoring protocol is started between two access routers in question.

70 Claims, 12 Drawing Sheets



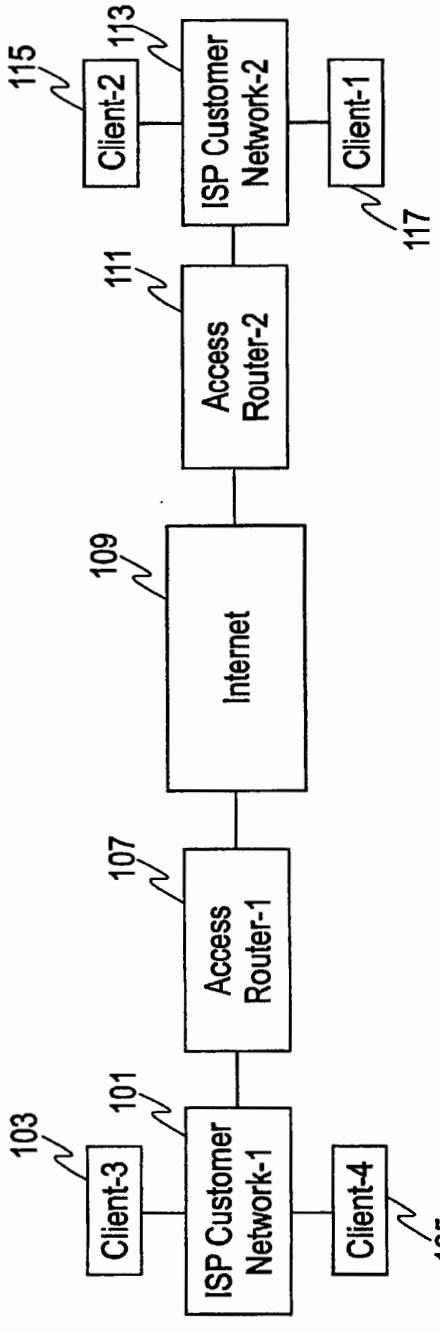

115
Client-2
113
ISP Customer Network-2
Client-1
117
111
Access Router-2
109
Internet
107
Access Router-1
103
Client-3
101
ISP Customer Network-1
Client-4
105

Fig. 1

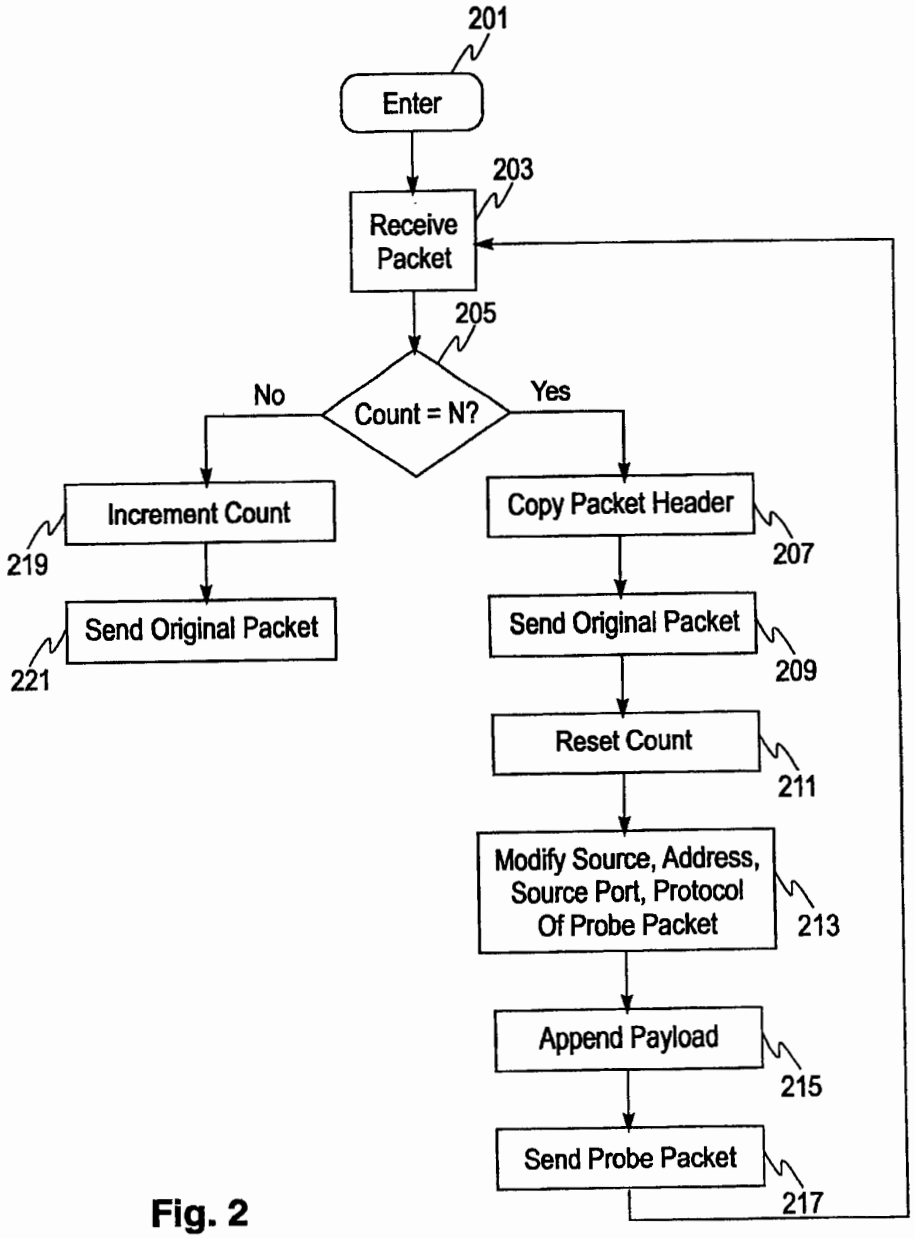

201
Enter
203
Receive Packet
205
Count = N?
No
Yes
Increment Count
219
Send Original Packet
221
Copy Packet Header
207
Send Original Packet
209
Reset Count
211
Modify Source, Address, Source Port, Protocol Of Probe Packet
213
Append Payload
215
Send Probe Packet
217

Fig. 2

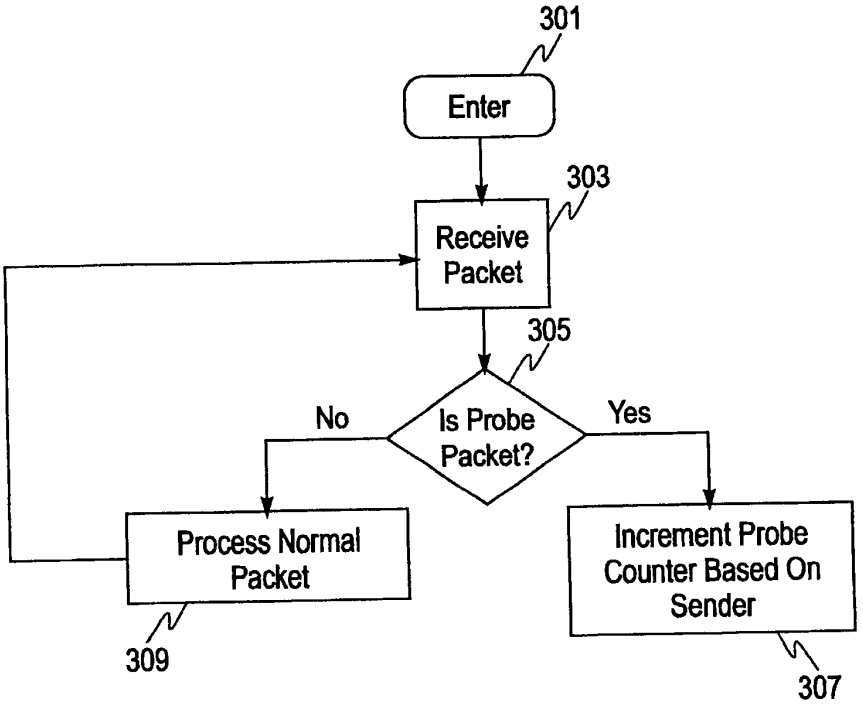

301
Enter
303
Receive Packet
305
Is Probe Packet?
No
Yes
Process Normal Packet
309
Increment Probe Counter Based On Sender
307

Fig. 3

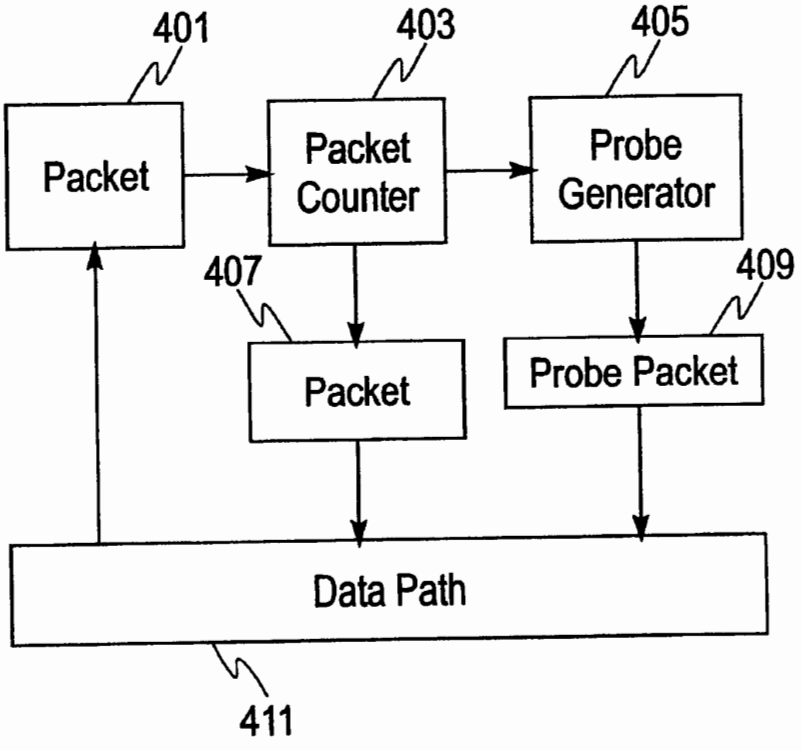

401
403
405
Packet
Packet Counter
Probe Generator
407
409
Packet
Probe Packet
Data Path
411

Fig. 4

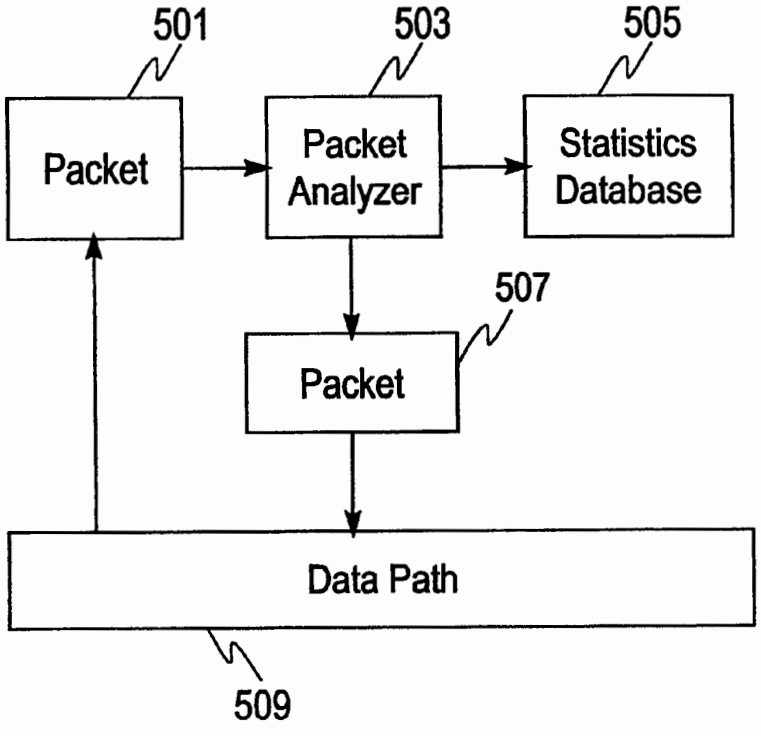

501
503
505
Packet
Packet Analyzer
Statistics Database
507
Packet
Data Path
509

Fig. 5

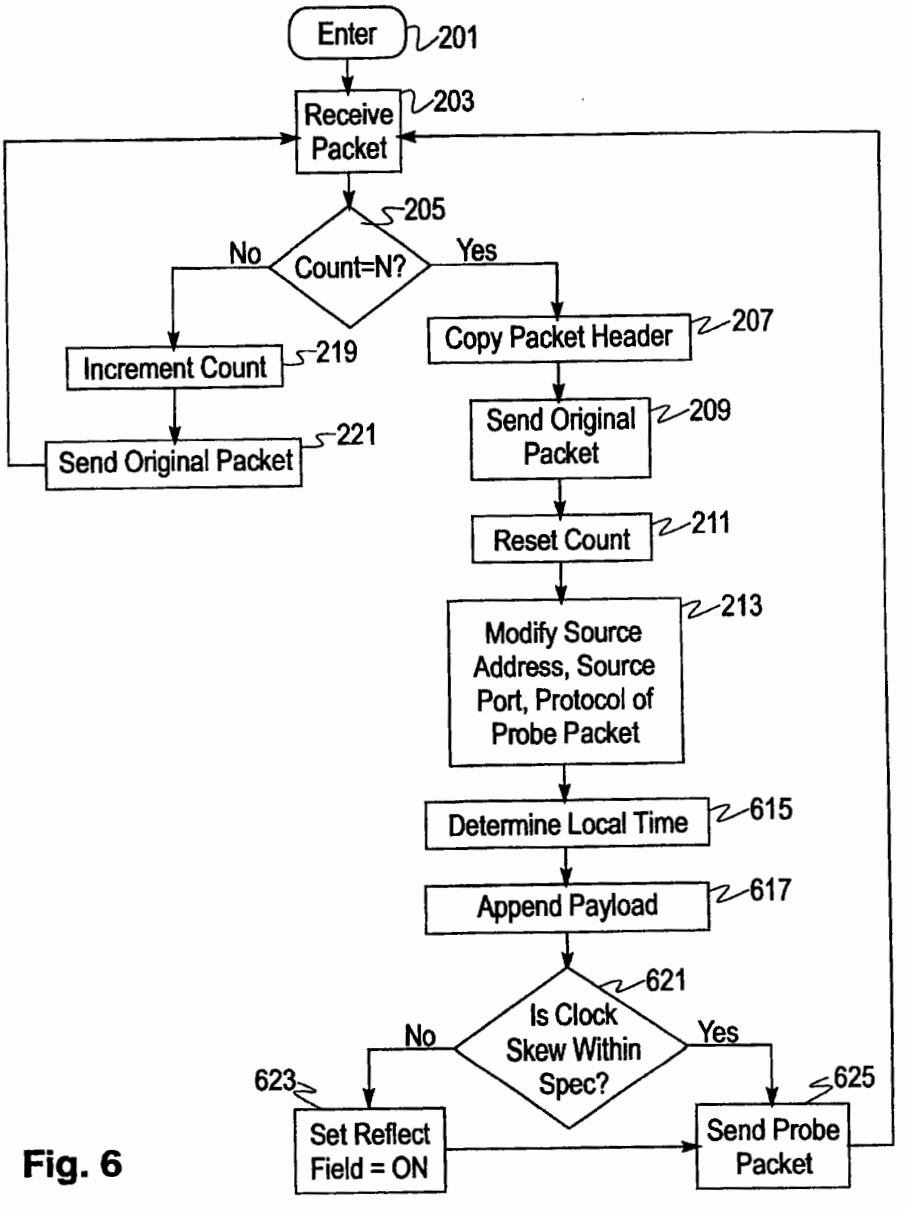

Enter
201
Receive Packet
203
205
Count=N?
No
Yes
Increment Count
219
Send Original Packet
221
Copy Packet Header
207
Send Original Packet
209
Reset Count
211
Modify Source Address, Source Port, Protocol of Probe Packet
213
Determine Local Time
615
Append Payload
617
621
Is Clock Skew Within Spec?
No
Yes
623
Set Reflect Field = ON
625
Send Probe Packet

Fig. 6

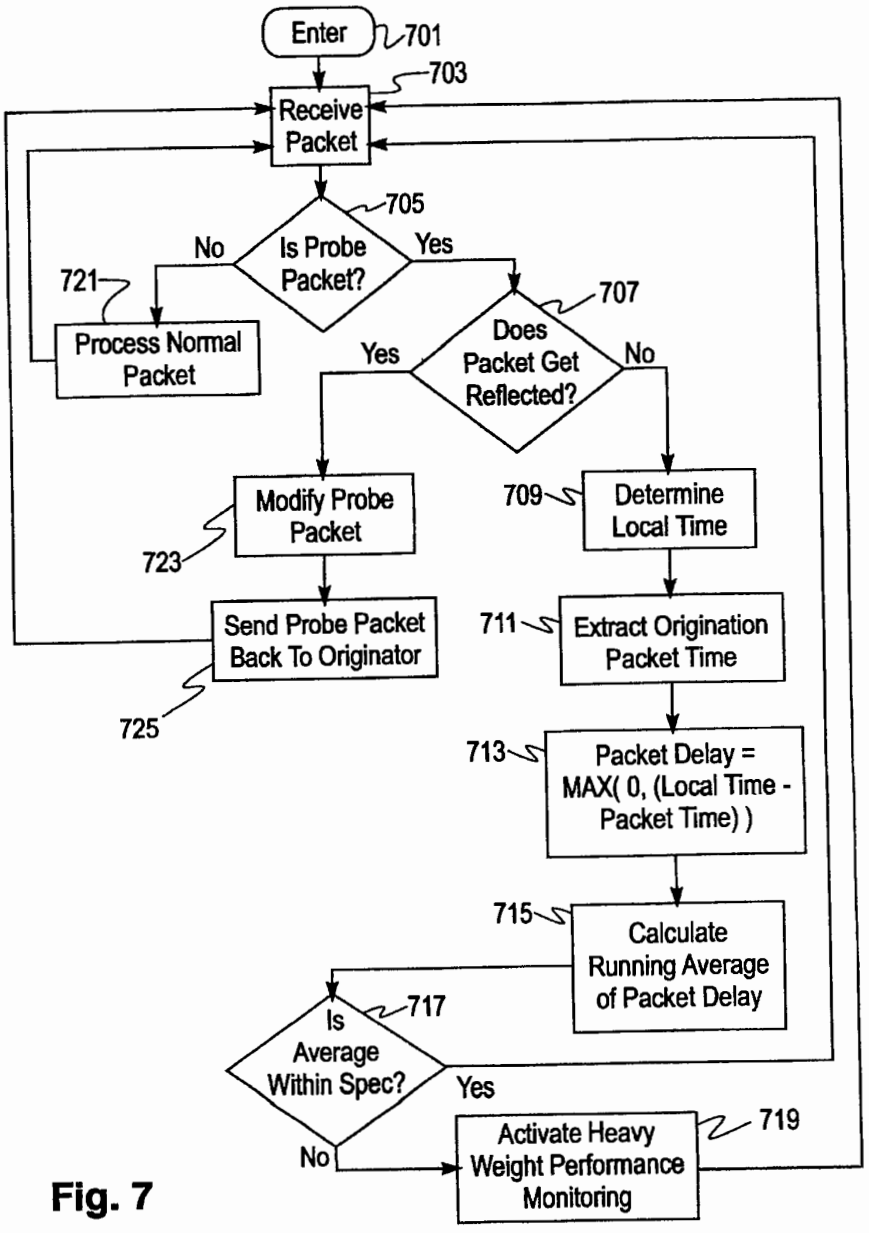

Enter
701
703
Receive Packet
705
Is Probe Packet?
No
Yes
721
Process Normal Packet
707
Does Packet Get Reflected?
Yes
No
Modify Probe Packet
723
Send Probe Packet Back To Originator
725
709
Determine Local Time
711
Extract Origination Packet Time
713
Packet Delay = MAX(0, (Local Time - Packet Time))
715
Calculate Running Average of Packet Delay
717
Is Average Within Spec?
Yes
No
719
Activate Heavy Weight Performance Monitoring

Fig. 7

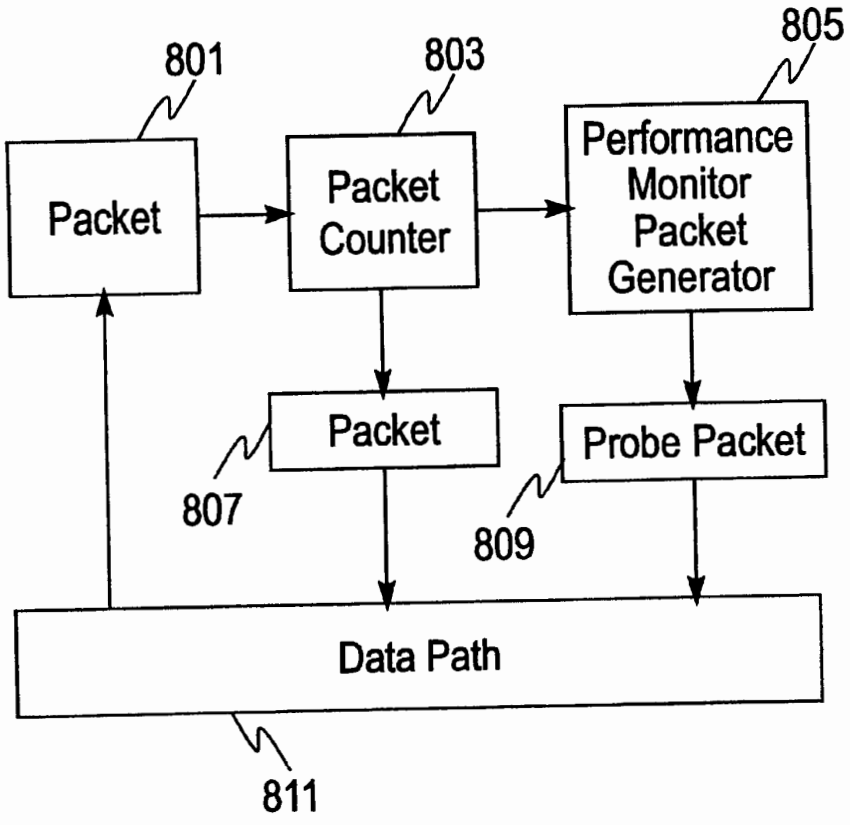

801
803
805
Packet
Packet Counter
Performance Monitor Packet Generator
Packet
Probe Packet
807
809
Data Path
811

Fig. 8

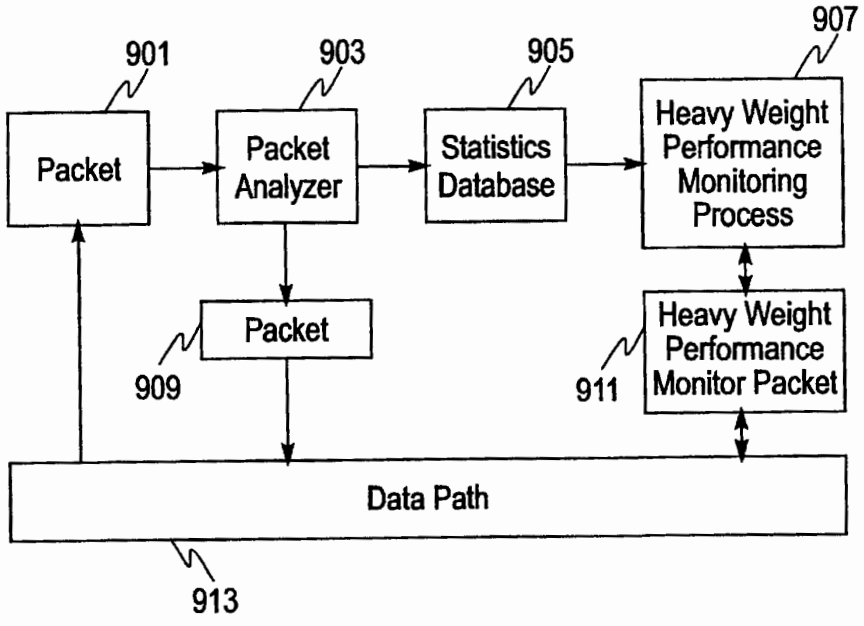

901
903
905
907
Packet
Packet Analyzer
Statistics Database
Heavy Weight Performance Monitoring Process
Packet
909
911
Heavy Weight Performance Monitor Packet
Data Path
913

Fig. 9

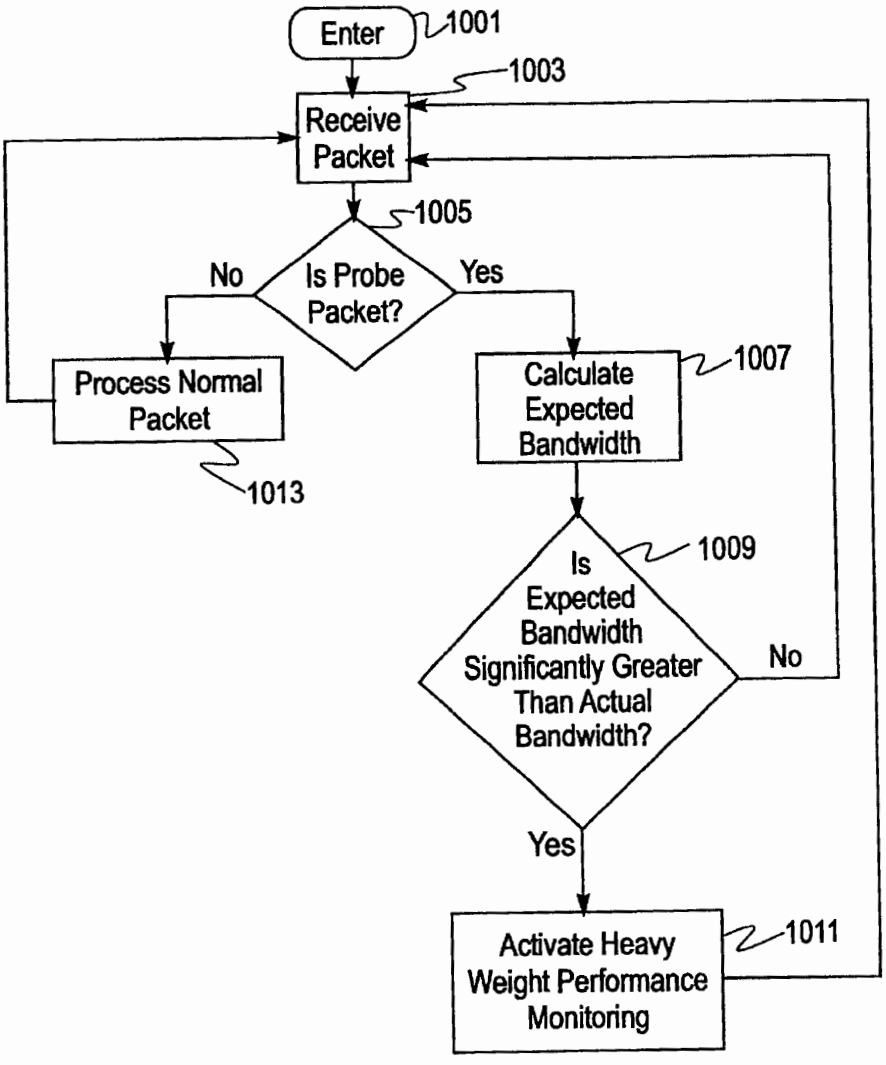

Enter
1001
1003
Receive Packet
1005
Is Probe Packet?
No
Yes
Process Normal Packet
1013
Calculate Expected Bandwidth
1007
Is Expected Bandwidth Significantly Greater Than Actual Bandwidth?
1009
No
Yes
Activate Heavy Weight Performance Monitoring
1011

Fig. 10

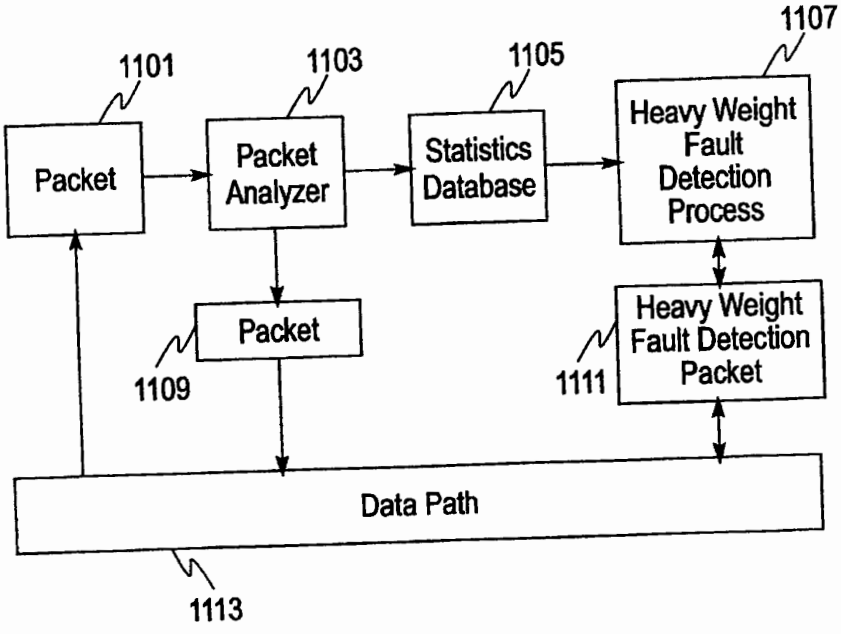

1101
1103
1105
1107
Packet
Packet Analyzer
Statistics Database
Heavy Weight Fault Detection Process
Packet
1109
Heavy Weight Fault Detection Packet
1111
Data Path
1113

Fig. 11

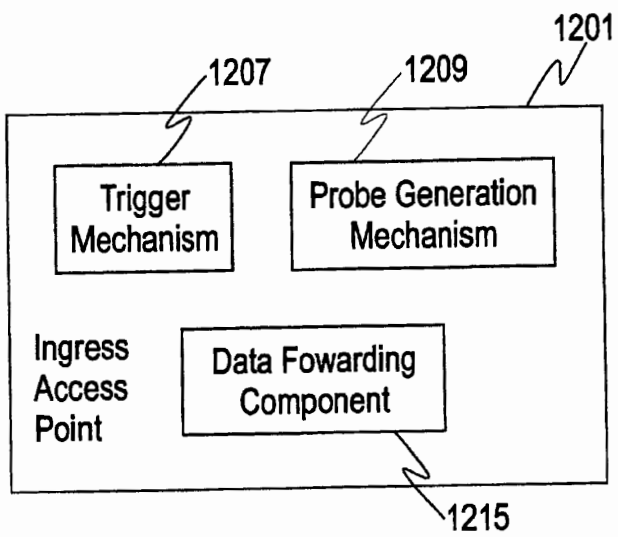


Fig. 12a

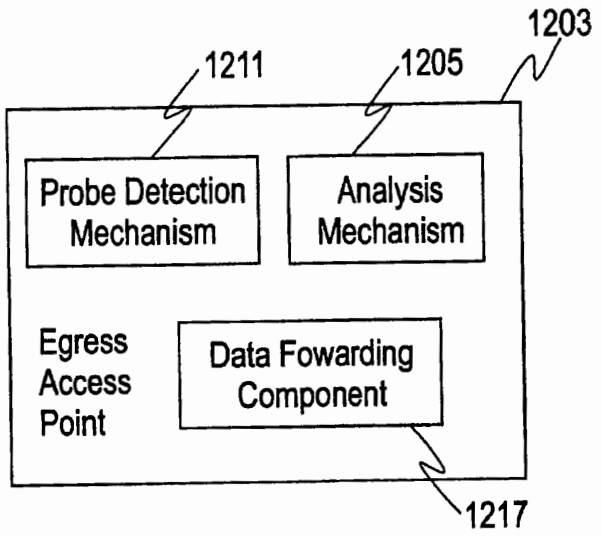


Fig. 12b

LOW OVERHEAD CONTINUOUS MONITORING OF NETWORK PERFORMANCE

FIELD OF THE INVENTION

The present invention is directed to the field of computer networks. It is more specifically directed to monitoring network performance metrics.

BACKGROUND OF THE INVENTION

There is a growing demand for communication via networks. This is especially so, for networks that are based on the TCP/IP protocol. This is both within the context of a corporate intranet as well as the context of an ISP providing Internet services to a group of users. A typical network provider may connect different campus networks belonging to a customer via its backbone network. As a provider of network services, the provider is interested in monitoring and ensuring that the network performs according to the guidelines and limits specified in the service level agreement between itself and the customer. The need for monitoring may be felt by the network operator, the customer or both.

The network operator is typically interested in monitoring the performance of the network, which is in its domain of control. Thus, he would like to measure the performance between all the access points that a customer uses to connect to his network. One way to measure the performance would be to execute a traditional performance measurement tool on a pair of access points.

Current performance monitoring techniques involve the use of 'ping', 'traceroute', 'netperf', data accessed through SNMP, etc. These methods are disadvantageous in that they add extra traffic load in the network between all of the access points. These methods also add additional packet processing on the network routers. These traditional network performance measurement mechanisms tend to be relatively heavy weight and generally rely on sending a continuous sequence of ping packets or other network probes between an end-point to all the other end-points. This process creates a large increased load on the network. The traditional normally high overhead network performance measurement mechanisms are herein referred to as 'heavy weight' mechanisms.

A typical ISP or a corporate intranet backbone has a very large number of network end-points. It is not typical to have a continuous monitoring of network performance between all of the end-points. The problem is compounded by the fact that the access points that may be controlled by the network operator are usually intermediate points in the network, and do not constitute either the source or destination of the traffic.

Consider a network operator with N access points provided to a customer. These access points are intermediaries along the path that a packet takes from the customer network. Performance monitoring of the network operation requires monitoring the N×(N−1) simplex channels between the pair-wise access points, and determining performance metrics such as delay between these access points. Another useful metric is the determination of the bandwidth that is being used between the different access points. The bandwidth usage is often a component in the price charged to the customer by the operator.

The measurement of bandwidth between the access points is difficult to do for an ISP. An IP packet only contains the final source and destination addresses, and standard routing information only provides the next outgoing interface from

an ingress access router. Thus, determining the egress access router of a packet requires building a duplicate overlay routing infrastructure within the ingress access router. This introduces additional processing delays in the forwarding of an IP packet, and also requires additional space for storage of overlay routing information.

A different issue arises when performance metrics (e.g. delays) are being monitored between the access points. An ISP would like to proactively monitor the delays between two access points belonging to a customer to verify if the delays exceed the desired bounds. Using heavy weight probes to do this monitoring across all access points is not a viable solution due to the additional load generated on the network. However, a continuous monitoring of network performance is desirable to determine the level of service provided and/or to determine if there are any problems between two network access points.

SUMMARY OF THE INVENTION

It is therefore an aspect of the present invention to provide a low overhead method for monitoring bandwidth in a corporate intranet or an ISP controlled portion of the Internet.

It is also an aspect of the invention to provide a low overhead method for performance monitoring in a corporate intranet or an ISP controlled portion of the Internet.

It is a further aspect of the invention to provide a low overhead method for fault monitoring in a corporate intranet or an ISP controlled portion of the Internet.

It is a further aspect of the invention to provide apparatus, a computer product and an article of manufacture comprising a computer usable medium having computer readable program code means embodied therein for causing a computer to perform a low overhead method for a network which includes originating and receiving access routers. The method is such that bandwidth monitoring, performance monitoring and fault monitoring are all possible. In an example implementation of the invention, network probe packets are generated by copying normal outbound packets and modifying these packets such that the destination address remains in tact. Recipient nodes can identify probe packets by their protocol number and UDP header pattern. Probe packets that are sent to nodes that are not aware of the probe packet format, discard these packets through normal network mechanisms.

Still a further aspect of the present invention is an apparatus to monitor network performance characteristic between a first and a second access point in the network. The apparatus including: a trigger mechanism at the first access point for determining a time to generate a probe packet; a probe generation mechanism at the first access point for generating a probe packet based on contents of a data packet and probe generating criteria; a probe detection mechanism at the second access point for detecting the probe packet; and an analysis mechanism to compare the probe packet detected at the second access point to the probe packet generated at the first access point.

In an embodiment of the apparatus the trigger mechanism and probe generation mechanism are located in a path of forwarding packets and/or wherein the probe detection mechanism is located in the path of forwarding packets, and/or the probe detection mechanism performs the additional function of removing probe packets from a data stream, and/or the trigger mechanism and probe generation mechanism are located outside of the data forwarding path of the packets, and monitor the flow of packets through the

first access point, and/or the probe detection mechanism is located outside of the data forwarding path of packets, and operates by monitoring the flow of packets through the second access point.

Still a further aspect of the present invention is a method for providing bandwidth measurement between an ingress and an egress access router in a network. The method including the steps of: counting a plurality of packets at the ingress access-router; generating a probe packet whenever a packet count reaches a specified value N; and counting the probe packets received at the egress access-router.

In a particular embodiment of the method the step of discarding the probe packets through normal network mechanisms if an egress edge device is not found at a specified destination address of the probe packet, and/or the step of generating includes probe packets copying every Nth packet and changing the source address of the Nth packet to that of an originating access router; changing the protocol number to a reserved protocol number, attaching a UDP header with a reserved pattern, and attaching a data segment as the UDP payload which includes a probe number and a local time-stamp, and/or the step of the egress access-router identifying probe packets by the reserved protocol number and the UDP header pattern, and/or a delay between two endpoints can be determined through use of a common clock and probe packets, and/or the step of counting a first number of probe packets received, and comparing the first number to a second number of packets that should have been received.

Still a further aspect of the present invention is a method for providing bandwidth accounting between a first and a second ISP access point in a network. The method including: configuring at least one ingress access point to have a first packet count of 'N-in'; the at least one ingress access point keeping track of a second packet count 'N-out' of packets sent into the network; and generating a probe packet whenever 'N-out'='N-in', wherein the probe packets being given a destination address of an Nth packet sent into the network, and being given a source address of an ingress router associated with the at least one ingress point.

Still a further aspect of the present invention is a method for measuring network characteristics between a first and a second router in a network. The method including the steps of: configuring at least one ingress access point on the first router to generate a plurality of probe packets; generating each of the probe packets based on the contents of a next data packet passing through the ingress access point; configuring at least one egress access point on the second router to detect the probe packet; and correlating each of the probe packets received at the egress access point with each of the probe packets sent by the ingress access point to determine the network characteristics between the ingress and egress access points. In some cases the probe packets are generated after a preset number of data packets have passed through the ingress access point.

Still a further aspect of the present invention is to provide an article of manufacture comprising a computer usable medium having computer readable program code means embodied therein for determining network characteristics between a first and a second access point in a network. The computer readable program code means in the article of manufacture comprising computer readable program code means for causing a computer to effect the steps of configuring the first access point as an ingress access point to generate a plurality of probe packets; generating each of the probe packets based on contents of a data packet and preset criteria; configuring the second access point as an egress access point to detect the probe packets; and correlating each of the probe packets received at the egress access point with one of the probe packets sent by the ingress access point to determine the network characteristics between the two access points. In some cases the network characteristics include a round-trip delay between two endpoints and the step of generating includes marking the probe packet with a time of generation, and the computer readable program code means in the article of manufacture further comprising computer readable program code means for causing a computer to effect the steps of the egress access point reflecting a probe packet back to the ingress access point; and the ingress access point comparing the time of generation to a time when the probe was received back.

Still a further aspect of the present invention is to provide a computer program product comprising a computer usable medium having computer readable program code means embodied therein for forming a plurality of probes packets in an network. The computer readable program code means in the computer program product comprising computer readable program code means for causing a computer to effect: marking a protocol field in an header of each probe packet with a reserved protocol number; filling a source port field in a UDP header for each probe packet with the reserved pattern; and filling a destination probe field with the probe number.

In a particular embodiment of the computer program product, the computer readable program code means in the computer program product further comprising the step of using the reserved protocol number at an egress access router to identify each probe packet, and/or the computer readable program code means in the computer program product further comprising the step of extracting each probe packet based on an identification obtained in the step of using.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects, features, and advantages of the present invention will become apparent upon further consideration of the following detailed description of the invention when read in conjunction with the drawing figures, in which:

FIG. **1** shows an example block diagram of two Internet service providers (ISP) and their respective customer networks in which each ISP network has one access router connecting the network to the Internet backbone;

FIG. **2** shows an example flow diagram that illustrates steps taken when sending a probe packet by an access router for determining bandwidth statistics in accordance with the present invention;

FIG. **3** shows an example flow diagram that illustrates steps taken when receiving a probe packet by an access router for bandwidth monitoring in accordance with the present invention;

FIG. **4** shows an example block diagram that illustrates the components and the relationships between them for a process of sending probe packets for bandwidth statistics in accordance with the present invention;

FIG. **5** shows an example block diagram that illustrates the components and the relationships between them for the purpose of receiving probe packets for statistical bandwidth data gathering in accordance with the present invention;

FIG. **6** shows an example flow diagram that illustrates the steps taken when sending a probe packet for delay and performance monitoring in accordance with the present invention;

FIG. 7 shows an example flow diagram that illustrates the steps taken when receiving a probe packet for delay and performance monitoring in accordance with the present invention;

FIG. 8 shows an example block diagram that illustrates the components and the relationships between them for the process of sending probe packets for delay and performance monitoring in accordance with the present invention;

FIG. 9 shows an example block diagram that illustrates the components and the relationships between them for the process of receiving probe packets for delay and performance monitoring in accordance with the present invention;

FIG. 10 shows an example flow diagram that illustrates the steps taken when receiving a probe packet for fault monitoring in accordance with the present invention;

FIG. 11 shows an example block diagram that illustrates the components for receiving a fault monitoring probe packet in accordance with the present invention; and

FIG. 12 shows an example of the components used for a system to perform the low overhead continuous monitoring in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The network context within which this invention applies is shown in FIG. 1. It shows two ISP customer networks **101** and **113**, that are connected to the Internet **109**. Connectivity to the Internet **109** is obtained via the access router-1 **107** and access router-2 **111**. Both access routers **107** and **111** serve as gateways to the ISP customer networks **101** **113**, and interface these networks with the Internet **109**. When network traffic flows from the clients **103** and **105** on ISP customer network-1 **101** to the clients **115** and **117** on ISP customer network-2 **113**, the traffic goes through these access routers making access router-1 **107** an ingress node and access router-2 **111** an egress node. An access router can alternately serve as both an ingress node and an egress node depending on the direction of the flow of the traffic. FIG. **1** also shows clients on the two ISP customer networks **107** and ill, which communicate with each other. Clients **103** and **105** are connected to ISP customer network-1 **101**, and may communicate with clients **115** and **117** that are connected to the ISP customer network-2 **113**. A similar context arises in a corporate intranet, wherein the Internet **109** is replaced by the corporate network instead of the Internet. Other applications would operate in a similar fashion. This includes, for instance, implementing this invention where one of the access points is at an entity firewall.

Within this context, one needs to monitor the bandwidth, delay and loss characteristics of a network between two access points. This needs a bandwidth monitoring protocol which determines the amount of bandwidth used between a pair of access points. For example, a bandwidth monitoring protocol may work as follows. Each ingress access point is configured with a specific count number (say N). This count can be a count of packets sent, bytes sent or time elapsed. The count is incremented based on preset criteria. The preset criteria is usually the occurrence of a type of event. The event may be a number of packets being sent, a number of bytes being sent, time elapse, and/or a dynamically changing event. The ingress access point keeps track of the count as it sends packets into the network. After every N events, it generates a new probe packet into the network. The probe packet is given the same destination (e.g. IP) address as the Nth packet into the network, but it is given a source (e.g. IP) address that is of the ingress access router. The probe packet contains special data that identifies it as a probe packet in the network. Additional data in the probe packet can be used for network monitoring.

At the egress router, the probe packets are identified and removed from the network data stream. They are sent to a local process, which analyzes the information contained in the probe packet. For bandwidth accounting, the receiving process needs to simply increment the count of packets received from the ingress access router. At periodic intervals, the accumulated number of packets received from each ingress access routers is converted into an estimate of the total number of packets being sent from that access router.

Examples of the detailed steps of a bandwidth monitoring protocol are shown in FIGS. **2** and **3**. Referring to FIGS. **1** and **2**, the steps shown in FIG. **2** are executed by an ingress access router whenever it obtains a packet from its associated ISP network. For example, it will be executed by software running on access router-1 **107** whenever that router receives a packet from the clients on ISP customer network-1 **101** as shown in FIG. **1**.

FIG. **2** shows an example flow diagram for the creation and transmission of probe packets for bandwidth monitoring. When a packet is received from a client by an ingress access router **203**, the event count is checked **205**. The event count can be based on the number of packets sent, the number of bytes sent, or the duration of time elapsed. If the event count is equal to N, where N is some preconfigured value, the header of the current packet is copied **207** and the original packet is processed and sent **209** through normal network operations. The count is reset to zero **211**. A probe packet is then created **213** with the payload appended **215** to the copied packet header. The probe packet has the same packet header as the copied packet except that the source address is changed to the address of the ingress access router. In addition, the source port is changed to a defined number and the protocol number is changed to a defined number that is not already used by other protocols. The time of the creation of the probe packet is appended in the payload of the probe packet along with some other necessary data. The probe packet is then sent out **217** into the Internet (numbered as **109** in FIG. **1**) to be reached by the final destination. On the other hand, if the event count is not equal to N, the counter is incremented by one **219** and the original packet is processed through normal network operations **221**.

An example of reception of the probe packets by the egress access routers can be seen in the flow diagram shown in FIG. **3**. When a packet is received **303** from the Internet **109** by an egress access router, the protocol field, and/or the UDP source and destination ports (which are formed to contain a special pattern described subsequently) are checked to determine if the packet is a probe packet **305**. If it is not a probe packet, the normal processing of the packet is performed **309**. If it is indeed a probe packet, statistics are collected **307**. This includes data such as incrementing a count of the probe packets received from a certain ingress access point in order to calculate the bandwidth between the two access points.

FIG. **4** shows an example of system components for sending probe packets. It includes the packets **401**, a packet counter **403**, a probe generator **405**, a standard packet **407**, and a probe packet **409** going to the data path **411**.

FIG. **5** shows an example of system components for receiving packets. It includes the packet as received **501**, a packet analyzer **503**, a statistics database **505**, and the processed packet **507** feeding the data path **509**.

While there are multiple ways to create probe packets, we present a scheme, which can be implemented relatively easily on most platforms. In this scheme, the probe packets are created with an IP header and a UDP header. However, the protocol field in the IP header is not marked with the UDP protocol ID, but rather it is marked with a special reserved protocol number. The source port field in the UDP header is filled with a reserved special pattern, and the destination port field is filled with a number that is unlikely to be used at any receiving end-host. This will cause this packet to be discarded through normal IP mechanisms at its destination if an egress edge device is not encountered by the probe packet. This reserved protocol number is used by the egress access router to identify probe packets in order to extract them from the stream. It then matches the reserved special pattern in the source and destination port fields to double-check the probe packet. It replaces the protocol field with the UDP protocol number and the destination port is replaced with a local port number where a monitoring process is active. This allows the egress access router to handle the packet as a normal UDP packet.

A performance monitoring protocol is used in order to monitor the performance of the network. In an example of a performance monitoring protocol the UDP payload of the probe packet is used to carry information about network delays. The source access router includes the time-stamp of the creation in the probe packet. It sometimes also contains an optional indication for the destination access router to reflect the packet back to the source. Example flow diagrams of the steps to implement a typical protocol are given following the description of the protocol.

In this performance monitoring protocol, when the packet is received at the egress access router, the local time-stamp of packet reception is computed. The difference in time between the packet reception and transmission is the delay. This difference is rounded to zero if it happens to be negative. The time difference is smoothed out using a running average, and compared to a target delay stored in a configuration file, or in a directory database. If the smoothed delay exceeds a target delay, or in some cases when it approaches it, a trigger is generated for the ingress and egress access routers to activate the heavy weight performance monitoring protocol available on them. This scheme works well when the target delay amounts exceed the amount of clock skew that is expected among the two routers.

In cases wherein the clock skew (a common time difference between access routers) is an issue, the ingress access router contains an option that probe packets be reflected back to it. The ingress access router then has a smoothed round-trip delay. It activates the heavy weight performance monitoring when the round-trip delay exceeds the target round-trip delays.

Note that the continuous monitoring provides a low overhead trigger that is activated when network performance problems are suspected. A more precise value of network performance is obtained by the heavy weight monitoring protocol, and an appropriate alarm generated for notifying a network operator.

For the following description refer back to FIG. **1**, wherein access router-1 **107** represents an ingress access router for ISP customer network-1 **101**, and access router-2 **111** represents an egress access router for ISP customer network-2 **113**. Client devices **103** and **105** are part of ISP customer network-1 **101** and client devices **113** and **117** are part of ISP customer network-2 **113**. The description assumes that data travels from ISP customer network-1 **101** to ISP customer network-2 **113**. In this case, the access router-1 **107**, receives data from client devices **103** and **105** in the form of (e.g. IP) packets. The combined flows of clients **103** and **105** to access router-1 **107** have a rate 'R' which is the rate measured at any given point in time. Rate 'R' may or may not be continuous. Access router-1 **107** includes an event counter 'E'. This counter is incremented based on a configurable preset criteria. The preset criteria is usually the occurrence of a type of event to increment event counter 'E'. The event may be a number of packets being sent, a number of bytes being sent, time elapse, and/or a dynamically changing event. The criteria is used as a setting which indicates that counter 'E' should be incremented. In a simple embodiment, it is based on the number of packets or bytes which it receives from clients **103** and **105**. It is sometimes based on an amount of time elapsed. Access router-1 **107** increments this counter. When the counter reaches a predetermined value N, access router-1 **107** copies the current packet received (or the next packet if the event is time driven) and then forwards the original packet as normal.

The (e.g. IP) packet that has been copied is altered and converted into a probe packet in the following manner. The source address is replaced with the source address of access router-1 **107**. The protocol number field is changed to a defined value not used by other protocols. The payload section of the copied packet is discarded and is replaced by a UDP header and data section. The destination and source port numbers are set to a well-known port number. The probe packet is formed to also contain additional data to be used for network monitoring. The additional data may include things such as a probe identifier, local time-stamp and reflect field. Access router-1 **107** then forwards this packet onto the Internet **109**.

The probe packet travels over the Internet **109** to be received by access router-2 **111**. Access router-2 **111** recognizes this packet as a probe packet by its protocol number and/or its source port field within the packet header. Access router-2 **111** replaces the protocol field with the UDP protocol number and the destination port with a local port number. The local port is where some process local to access router-2 **111** receives this probe packet in the form of a UDP packet and processes it.

Access router-2 **111** processes the probe packet by extracting the time-stamp included by access router-1 **107** in the data section of the probe packet. The 'reflect' packet field is checked to determine if the probe packet should be reflected back to the source access router-1 **107**. When access router-2 **111**, receives the probe packet, a local time-stamp is compared to the time-stamp included in the packet. The difference between the receive time-stamp and the sent time-stamp is the delay of transmission from access router-1 **107** to access router-2 **111**. This transmission delay is used in a running average, which is compared to a target transmission delay. If the average delay exceeds or approaches the target delay, access router-2 **111** will start a heavy weight performance monitoring protocol between access router-1 **107** and access router-2 **111**. The heavy weight performance monitoring protocol may also be started by access router-1 **107** if probe packets are being reflected back to access router-1 **107** from access router-2 **111** and the round trip delay exceeds a target round trip delay for access router-1 **107**. The results of the heavy weight monitoring mechanism are sent to the network operator.

As each probe packet is being received by access router-2 **111**, access router-2 **111** keeps track of how many probe

packets it has received from each source access router. Using the number of probe packets received, access router-2 **111** can estimate how many packets it expects to receive from the source, access router-1 **107**. The estimated bandwidth can be sent to the network operator.

FIG. **6** shows an example of a flow diagram for the transmission of the probe packets for delay and performance monitoring. In this case, before the probe packet is sent out, the clock skew is checked **621** whether it is within the specified value. If it is, the probe packet is sent out **625**. If it is not, the 'reflect' field of the probe packet is set to 'ON' **623**, before the probe packet is sent out **625**.

FIG. **7** shows an example of a flow diagram for the reception of the probe packets for the delay and performance monitoring. When a packet is received on an egress access router **703**, it is checked to see if it is a probe packet **705**. If it is not, the normal processing of the packet is performed **721**. If the packet is a probe packet, the reflect field is checked to determine if the packet gets reflected **707**. If the reflect field is set, then the probe packet is modified **723** and sent back to the originator **725**. If the field is not set the local time is determined **709** and the origination packet time is extracted **711**. The packet delay is calculated by subtracting the origination transmission time of the packet from the current local time and taking the maximum value of the difference and zero **713**, thereby rounding to zero if the difference is negative. Then, a running average delay is calculated **715**. If this average is within the delay specified by the network operator, then no action is taken. If the average delay is not within the specified delay, a heavy weight performance monitoring process is activated **719**.

The system components for the sending and receiving of the probe packets for the delay and performance monitoring are shown in FIGS. **8** and **9** respectively. FIG. **8** shows the packet as sent **801**, going to a packet counter **803**, and then to a performance monitor packet generator **805**. The probe packet **809** and original packet **807** are put on the data path **811**.

FIG. **9** shows the packets that are received **901**, and analyzed **903**. Normal (non-probe) packets pass through the packet analyzer **903**, forming packet **909**, which is fed onto the data path **913**. The results of the probe packets analysis go to a statistics database **905**. When the statistics indicate that a heavy weight process is needed, the heavy weight performance monitoring process **907** is initiated. The heavy weight performance monitoring process **907** forms a set of performance monitor packets **911**. The performance monitor packets **911** are fed onto the data path **913**. The format and quantity of the performance monitor packets **911** are dependent upon the protocol used within the heavy weight performance monitoring process in ways known to those skilled in the art. These ways are outside the scope of this invention.

The probe packet also serves the purpose of fault monitoring. It is noted that access router-2 **111** has a smoothed average of the number of packets it has received from access router-1 **107**. When the smoothed expected number is significantly more than the actual number of packets received, a heavy weight fault detection protocol is activated. This may be, for example, by running ping between access router-1 **107** and access router-2 **111**. The results of the heavy weight fault detection mechanism are sent to the network operator.

FIG. **10** shows an example of a flow diagram for fault monitoring when receiving the probe packets on the egress access routers. When a packet is received **1003**, it is checked to see if it is a probe packet **1005**. If the received packet is not a probe packet, then the normal processing of the packet is performed **1013**. On the other hand, if the received packet is a probe packet, the expected bandwidth is calculated **1007**. If the expected bandwidth is greater than the actual bandwidth, a heavy weight fault detection process is performed **1011**. If it is not greater than the actual bandwidth, no action is taken and the flow is returned to receive another packet **1003**.

The system components for the reception of the probe packets for fault monitoring are shown in FIG. **11**. Normal packets pass through the packet analyzer **1103**. The analyzer sends normal (non-probe) packets **1109** back onto the data path **1113**. Probe packets are analyzed by the packet analyzer which then forwards the probe packet information to the statistics database **1105**. When the database results indicate that a heavy weight fault detection process is needed, the heavy weight fault detection process **1107** is initiated. The heavy weight fault detection process **1107** forms a set of fault detection packets **1111** which are fed onto the data path **1113**. The format and quantity of the fault detection packets **1111** are dependent upon the protocol used within the heavy weight fault detection process, in ways known to those skilled in the art. These ways are outside the scope of this invention.

The system components for the reception of the probe packets for fault monitoring are shown in FIG. **11**. It shows the received packets **1101**, feeding a packet analyzer **1103**. The analyzer sends the packet **1109** for forwarding on the data path **1113** and also to the statistics database **1105**. When the database results indicate that a heavy weight fault detection process is needed, the heavy weight fault detection process **1107** is initiated. The heavy weight fault detection process **1107** forms a performance monitor packet **1111**. The performance monitor packet **1111** is fed onto the data path **1113**.

FIG. **12** shows an example of the components used for a system to perform the low overhead continuous monitoring described in this application. It shows a way in which an apparatus required for the low overhead continuous monitoring of network performance can be constructed. The apparatus consists of components at each of the two access points of the network. The apparatus **1201** is at the ingress access point and the apparatus **1203** is at the egress access point of the network. The analysis component **1205** is used to analyze probe packets and to determine the final bandwidth performance value. Although the analysis component **1205** is shown to be located at the egress apparatus **1203**, it can be located at either the ingress or the egress access point, or at another machine in the network.

At the ingress access point, the apparatus **1201** includes a trigger mechanism **1207** and a probe generation mechanism **1209**. These components are in addition to the data forwarding component **1215** which is present in any access point. The trigger mechanism **1207** determines when to generate a probe packet. This decision could be made when specific time-intervals elapse, on a count of packets or bytes processed by the data forwarding component **1215**. When the trigger mechanism determines that a probe is to be generated, it activates the probe generation component **1209** which creates a probe packet. The probe packet is created from the contents of the current or the next data packet being processed by the access point.

At the egress point, the apparatus **1203** includes a probe detection mechanism **1211**, an analysis mechanism **1205**, and the data forwarding component **1217** which is present in any access points. The probe detection mechanism **1211**

executes sequential processing in step **134**. Although only simple, sequential, and timer/counter based attributes have been discussed, other signature attributes can be incorporated into the present invention.

In step **136** the virtual processor **36** determines if the execution of the attack signature has revealed a network intrusion. If the data collector **10** recognizes a network intrusion, in step **138** the reaction module **38** is notified. If no attack has been detected, in step **140** the virtual processor **36** determines if the instruction cache **42** is empty. If the instruction cache is not empty, the virtual processor **36** returns to step **122** and accesses the next attack signature profile. If the instruction cache **42** is empty, the next packet in the queue **48** is obtained in step **141** to extract packet information into the register cache **40**.

Referring to FIG. **10**, a method for processing a sequential attack signature profile includes the step **142** of splitting the attack signature profile into expressions. As previously discussed, a sequential attack signature profile is composed of multiple component expressions which are sequentially evaluated to determine if each expression matches a data packet associated with a particular application session. In step **146** the virtual processor **36** determines whether a pointer is set to the sequential attack signature profile in the state cache **44**. If the pointer is not set to the sequential attack signature profile, in step **148** an entry is made in the state cache **44** so that a pointer is set to the sequential attack signature profile and the entry parameters are initialized. In step **150**, the virtual processor **36** references a state cache entry **44** to determine how many of the expressions have already been matched to data packets associated with the currently monitored application session.

In response to the state cache entry, the virtual processor **36** obtains the next sequential expression from an expression list in step **152**. For example, an attack signature profile might include expressions A, B, and C. Expression instruction A was executed and found to match a first packet associated with an application session and expression instruction B was executed and found to match a second packet associated with the application session. Upon receiving a third packet associated with the application session and after referencing the state cache entry to obtain the information that expressions A and B have been matched, the virtual processor **36** obtains the third expression to determine if it matches the third packet. It should be noted that expressions A, B, and C need not be found to match three consecutive data packets associated with an application session. Rather, expression A must be found to match a packet which precedes a packet found to match expression B or C, and B must be found to match a data packet which precedes a packet found to match expression C.

In step **154**, after executing an expression instruction, the virtual processor **36** determines whether the expression matches the data packet. If the expression does not match, the virtual processor **36** returns a false value in step **156**. If the expression matches, a determination is made in step **158** whether the expression was the last sequential expression. In step **160**, the virtual processor **36** updates the entry in the state cache **44** to reflect the match of the expression to the data packet if it is determined that the executed expression is not the last sequential expression and in step **162** the virtual processor returns a value of false. If the expression is the last sequential expression, in step **164** the virtual processor **36** returns a value of true to indicate that a network intrusion has been detected.

The processing of a simple attack signature profile is similar to the processing of a single expression of a sequential attack signature. Referring to FIG. **11**, the attack signature profile is reduced to an expression in step **166**. After executing the expression instruction, the virtual processor **36** determines whether the expression matches a data packet associated with an application session in step **168**. If the expression matches the packet, in step **172** the virtual processor **36** returns a value of true and the reaction module **38** is notified of a network intrusion. If the expression does not match, the virtual processor **36** returns a value of false in step **170**.

With reference to FIG. **12**, a method for processing a timer/counter based attack signature profile includes the step **174** of reducing the profile to an expression. In step **176** the virtual processor **36** utilizes the timer **37** to make a current time stamp for the data packet being evaluated. Entries in the state cache **44** that are older than an attack interval are purged from the state cache **44** in step **178**. Purging stale entries involves comparing a time interval between time stamps associated with entries and the current time. If the actual time interval associated with an entry is greater than the attack signature time interval, that entry is purged from the state cache **44**.

In step **180** the expression is evaluated to determine in step **182** if the expression matches the packet currently being analyzed. If the expression does not match, the virtual processor **36** returns a value of false in step **184**. If the expression matches the packet, the virtual processor returns a value of true and adds the current time stamp to the application session entry in the state cache **44** in step **186**. In step **188** the counter **35** is utilized to update the number of events recognized by execution of the timer/counter expression instruction on data packets associated with the current application session. A determination is made in step **190** whether, after the number of event occurrences has been updated, the threshold number of events has been detected within the predetermined time interval. A value of false is returned in step **192** if the threshold has not been reached. If the threshold has been reached, in step **194**, the virtual processor **36** returns a true value to indicate that a timer/counter based network intrusion has been detected.

What is claimed is:

1. A method for detecting network intrusion attempts associated with network objects on a communications network including the steps of:

storing a list of attack signature profiles descriptive of attack signatures associated with said network intrusion attempts;

storing corresponding data representative of a correspondence between subsets of said attack signature profiles and said network objects such that each network object has a corresponding stored subset of attack signature profiles and more than one subset of attack signature profiles corresponds to network objects;

monitoring network traffic transmitted over said communications network for data addressed to one of said network objects;

in response to detecting said data addressed to said network object, accessing a subset of attack signature profiles corresponding to said network object based on said correspondence data; and

executing at least one attack signature profile included in said subset corresponding to said network object to determine if said data addressed to said network object is associated with a network intrusion attempt.

2. The method of claim **1** wherein said executing step includes utilizing a processor to execute said at least one

15. A method as recited in claims 13, further comprising the step of determining network faults by comparing the expected number of probe packets at a particular egress access point to a number of probe packets actually received at the particular egress access point.

16. A method as recited in claim 1, wherein the network is an IP network.

17. A method as recited in claim 1, wherein the ingress point is located at a campus firewall.

18. A method as recited in claim 1, wherein the ingress and egress points are each located in separate routers.

19. An apparatus to monitor network performance characteristic between a first and a second access point in the network, said apparatus comprising:

a trigger mechanism at the first access point for determining a time to generate a probe packet;

a probe generation mechanism at the first access point for generating a probe packet based on contents of a data packet and probe generating criteria;

a probe detection mechanism at the second access point for detecting the probe packet; and

an analysis mechanism to compare the probe packet detected at the second access point to the probe packet generated at the first access point.

20. An apparatus as described in claim 19, wherein the trigger mechanism and probe generation mechanism are located in a path of forwarding packets.

21. An apparatus as described in claim 19, wherein the probe detection mechanism is located in the path of forwarding packets.

22. An apparatus as described in claim 21, wherein the probe detection mechanism performs the additional function of removing probe packets from a data stream.

23. An apparatus as described in claim 19, wherein the trigger mechanism and probe generation mechanism are located outside of the data forwarding path of the packets, and monitor the flow of packets through the first access point.

24. An apparatus as described in claim 19, wherein the probe detection mechanism is located outside of the data forwarding path of packets, and operates by monitoring the flow of packets through the second access point.

25. A method comprising:

providing bandwidth measurement between an ingress and an egress access router in a network by:

counting a plurality of packets at the ingress access-router;

generating a probe packet based on content of a data packet whenever a packet count reaches a specified value N; and

counting the probe packets received at the egress access-router.

26. A method as recited in claim 25, further comprising the step of discarding the probe packets through normal network mechanisms if an egress edge device is not found at a specified destination address of the probe packet.

27. A method as recited in claim 25, wherein the step of generating includes probe packets copying every Nth packet and changing the source address of the Nth packet to that of an originating access router; changing the protocol number to a reserved protocol number; attaching a UDP header with a reserved pattern; and attaching a data segment as the UDP payload which includes a probe number and a local timestamp.

28. The method of claim 27, further comprising the step of the egress access-router identifying probe packets by the reserved protocol number and the UDP header pattern.

29. A method as recited in claim 25, wherein a delay between two endpoints can be determined through use of a common clock and probe packets.

30. The method as recited in claim 25, further comprising the step of counting a first number of probe packets received, and comparing the first number to a second number of packets that should have been received.

31. The method of claim 25, further comprising the step of determining a delay between two endpoints in the network by reflecting a probe packet back to a source router, and determining the round-trip time between the access routers.

32. The method of claim 25, further comprising the step of determining network faults by keeping a count of a number of probe packets received over a time interval.

33. A method for providing bandwidth accounting between a first and a second ISP access point in a network, the method comprising:

configuring at least one ingress access point to have a first packet count of 'N-in';

said at least one ingress access point keeping track of a second packet count 'N-out' of packets sent into the network; and

generating a probe packet whenever 'N-out'='N-in', wherein said probe packets being given a destination address of an Nth packet sent into the network, and being given a source address of an ingress router associated with the at least one ingress point.

34. A method as recited in claim 33, further comprising:

identifying and removing the probe packet from a network data stream and an egress router associated with the at least one ingress point;

sending the probe packet to a local processor;

analyzing the probe packet at the local processor; and

incrementing a packet count of packets received from the ingress access router.

35. The method of claim 34, further comprising the step of converting the packet count into an estimate of packets sent by the ingress access router.

36. The method as recited in claim 33, further comprising the step of discarding the probe packets that do not encounter an egress access router.

37. The method as recited in claim 33, further comprising the step of adjusting the probe packet according to a change in network statistics.

38. A method for forming a plurality of probes packets in a network, said method comprising:

marking of protocol field in a header of each probe packet with a reserved protocol number;

filling a source port field in a UDP header for each probe packet with the reserved pattern; and

filling a destination probe field with the probe number.

39. A method as recited in claim 38, further comprising the step of using the reserved protocol number at an egress access router to identify each probe packet.

40. The method as recited in claim 39, further comprising the step of extracting each probe packet based on an identification obtained in the step of using.

41. A method comprising:

monitoring performance of a shared network by:

forming a probe packet for each group of packets based on content of a data packet received by a router on the network;

counting the probe packets; and

estimating the network bandwidth based on the packet probe count compared to a preset criteria.

42. A method for measuring network characteristics between a first and a second router in a network, the method comprising:

configuring at least one ingress access point on the first router to generate a plurality of probe packets;

generating each of the probe packets based on the contents of a next data packet passing through the ingress access point;

configuring at least one egress access point on the second router to detect the probe packet; and

correlating each of the probe packets received at the egress access point with each of the probe packets sent by the ingress access point to determine the network characteristics between the ingress and egress access points.

43. A method as recited in claim 42, wherein the probe packets are generated after a preset number of data packets have passed through the ingress access point.

44. A method as recited in claim 42, wherein the network characteristics being measured include network bandwidth, and the step of correlating includes comparing a count of probe packets sent by the first router to the count of probe packets received by the second router.

45. A method as recited in claim 42, wherein the egress access router removes each of the probe packets from normal data traffic after each of the probe packets is detected.

46. A method as recited in claim 42, wherein the probe packets are structured so that they are discarded through normal network mechanisms.

47. A method as recited in claim 42, wherein the step of generating includes forming each of the probe packets as follows:

copying a destination field in a particular data packet passing through the ingress access point to a probe destination field in the header of the probe packet;

forming a probe source address in the header of the probe packet to be a router source address of an originating access router; and

setting fields in the header or payload of the probe packet to be a specific value which enables the egress access point to detect the probe packet.

48. A method as recited in claim 47, wherein the protocol number in the header is changed to a special reserved protocol number.

49. A method as recited in claim 47, wherein an UDP payload is put in the probe packet with a reserved pattern and attaching a data segment as the UDP payload which includes such information as the probe number and local time-stamp.

50. An article of manufacture comprising a computer usable medium having computer readable program code means embodied therein for determining network characteristics between a first and a second access point in a network, the computer readable program code means in said article of manufacture comprising computer readable program code means for causing a computer to effect:

configuring the first access point as an ingress access point to generate a plurality of probe packets;

generating each of the probe packets based on contents of a data packet and preset criteria;

configuring the second access point as an egress access point to detect the probe packets; and

correlating each of the probe packets received at the egress access point with one of the probe packets sent by the ingress access point to determine the network characteristics between the two access points.

51. An article of manufacture as recited in claim 50, wherein the network characteristics include a round-trip delay between two endpoints and the step of generating includes marking the probe packet with a time of generation, and the computer readable program code means in said article of manufacture further comprising computer readable program code means for causing a computer to effect:

the egress access point reflecting a probe packet back to the ingress access point; and

the ingress access point comparing the time of generation to a time when the probe was received back.

52. An article of manufacture as recited in claim 50, the computer readable program code means in said article of manufacture further comprising computer readable program code means for causing a computer to effect the step of the egress access point determining an expected number of probe packets to be obtained from a particular ingress access point on a basis of probe packets being received from the particular ingress access point.

53. A computer program product comprising a computer usable medium having computer readable program code means embodied therein for providing bandwidth measurement between an ingress and an egress access router in a network, the computer readable program code means in said computer program product comprising computer readable program code means for causing a computer to effect:

counting a plurality of packets at the ingress access-router;

generating a probe packet whenever a packet count reaches a specified value N; and

counting the probe packets received at the egress access-router.

54. A computer program product as recited in claim 53, the computer readable program code means in said computer program product further comprising computer readable program code means for causing a computer to effect discarding the probe packets through normal network mechanisms if an egress edge device is not found at a specified destination address of the probe packet.

55. A computer program product as recited in claim 53, wherein the step of generating includes probe packets being generated by copying every Nth packet and changing the source address of the Nth packet to that of an originating access router; changing the protocol number to a reserved protocol number; attaching a UDP header with a reserved pattern; and attaching a data segment as the UDP payload which includes a probe number and a local time-stamp.

56. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for providing bandwidth accounting between a first and a second ISP access point in a network, said method steps comprising:

configuring at least one ingress access point to have a first packet count of 'N-in';

said at least one ingress access point keeping track of a second packet count 'N-out' of packets sent into the network; and

generating a probe packet when 'N-out'='N-in', wherein said probe packets being given a destination address of an Nth packet sent into the network, and being given a source address of an ingress router associated with the at least one ingress point.

57. A program storage device readable by machine as recited in claim 56, said method steps further comprising:

identifying and removing the probe packet from a network data stream and an egress router associated with the at least one ingress point;

sending the probe packet to a local processor;

analyzing the probe packet at the local processor; and

incrementing a packet count of packets received from the ingress access router.

58. A program storage device readable by machine as recited in claim **57**, said method steps further comprising the step of converting the packet count into an estimate of packets sent by the ingress access router.

59. An article of manufacture comprising a computer usable medium having computer readable program code means embodied therein for measuring network characteristics between a first and a second router in a network, the computer readable program code means in said article of manufacture comprising computer readable program code means for causing a computer to effect:

configuring at least one ingress access point on the first router to generate a plurality of probe packets;

generating each of the probe packets based on the contents of a next data packet passing through the ingress access point;

configuring at least one egress access point on the second router to detect the probe packet; and

correlating each of the probe packets received at the egress access point with each of the probe packets sent by the ingress access point to determine the network characteristics between the ingress and egress access points.

60. An article of manufacture as recited in claim **59**, wherein the step of generating includes forming each of the probe packets by effecting the steps of:

copying a destination field in a particular data packet passing through the ingress access point to a probe destination field in the header of the probe packet;

forming a probe source address in the header of the probe packet to be a router source address of an originating access router; and

setting fields in the header or payload of the probe packet to be a specific value which enables the egress access point to detect the probe packet.

61. An article of manufacture as recited in claim **59**, wherein the network characteristics being measured include network bandwidth, and the step of correlating includes comparing a count of probe packets sent by the first router to the count of probe packets received by the second router.

62. An article of manufacture as recited in claim **59**, wherein the network characteristics being measured include network bandwidth, and the step of correlating includes comparing a count of probe packets sent by the first router to the count of probe packets received by the second router.

63. An article of manufacture as recited in claim **59**, wherein the egress access router removes each of the probe packets from normal data traffic after each of the probe packets is detected.

64. An article of manufacture as recited in claim **59**, wherein the probe packets are structured so that they are discarded through normal mechanisms.

65. A computer program product comprising a computer usable medium having computer readable program code means embodied therein for forming a plurality of probes packets in an network, the computer readable program code means in said computer program product comprising computer readable program code means for causing a computer to effect:

marking a protocol field in an header of each probe packet with a reserved protocol number;

filling a source port field in a UDP header for each probe packet with the reserved pattern; and

filling a destination probe field with the probe number.

66. A computer program product as recited in claim **65**, the computer readable program code means in said computer program product further comprising the step of using the reserved protocol number at an egress access router to identify each probe packet.

67. A computer program product as recited in claim **66**, the computer readable program code means in said computer program product further comprising the step of extracting each probe packet based on an identification obtained in the step of using.

68. A computer program product comprising a computer usable medium having computer readable program code means embodied therein for monitoring performance of a shared network, the computer readable program code means in said computer program product comprising computer readable program code means for causing a computer to effect:

forming a probe packet for each group of packets received by a router on the network;

counting the probe packets; and

estimating the network bandwidth based on the packet probe count compared to a preset criteria.

69. A method as recited in claim **8**, wherein the step of generating also includes the step of setting the source address in a probe packet header to the source address of the first access point.

70. A method comprising:

determining network characteristics between a first and a second access point in a network, by:

configuring the first access point as an ingress access point to generate a plurality of probe packets;

generating each of the probe packets based on contents of a data packet and on preset criteria;

configuring the second access point as an egress access point to detect the probe packets; and

correlating each of the probe packets received at the egress access point with one of the probe packets sent by the ingress access point to determine the network characteristics between the two access points.

* * * * *

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[54] NETWORK MONITORING

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[73] Assignee: **Concord Communications, Inc.**, Marlboro, Mass.

[21] Appl. No.: **08/505,083**

[22] Filed: **Jul. 21, 1995**

Related U.S. Application Data

[60] Division of application No. 07/761,269, Sep. 17, 1991, abandoned, which is a continuation-in-part of application No. 07/684,695, Apr. 12, 1991, abandoned.

[51] **Int. Cl.**[7] **H04J 3/16**; H04J 3/22

[52] **U.S. Cl.** **370/469**

[58] **Field of Search** 370/94.1, 85.13, 370/85.14, 94.2, 110.1, 79, 241, 252, 254, 465, 464, 466, 467, 469; 395/200, 183.15, 189.01, 189.04, 200.54, 285, 831; 371/20.1

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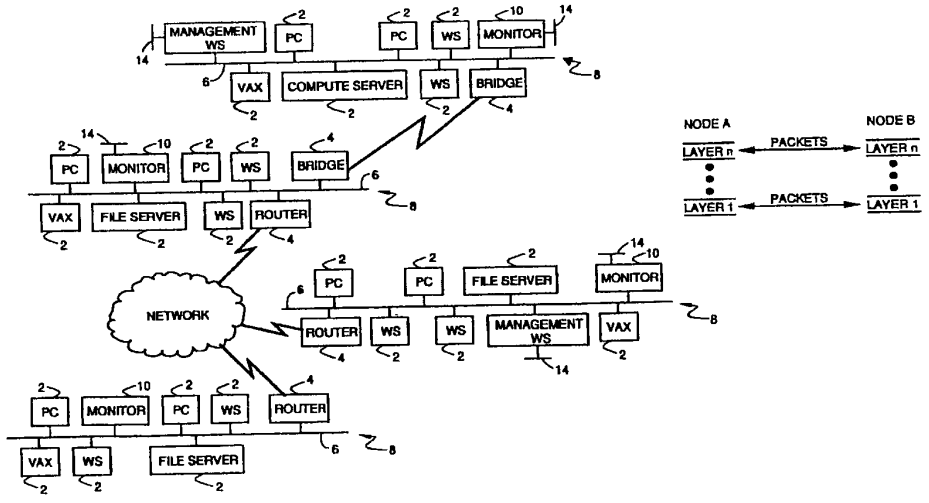
Primary Examiner—Ajit Patel

Attorney, Agent, or Firm—Fish & Richardson P.C.

[57] **ABSTRACT**

Monitoring is done of communications which occur in a network of nodes, each communication being effected by a transmission of one or more packets among two or more communicating nodes, each communication complying with a predefined communication protocol selected from among protocols available in the network. The contents of packets are detected passively and in real time, communication information associated with multiple protocols is derived from the packet contents.

25 Claims, 38 Drawing Sheets



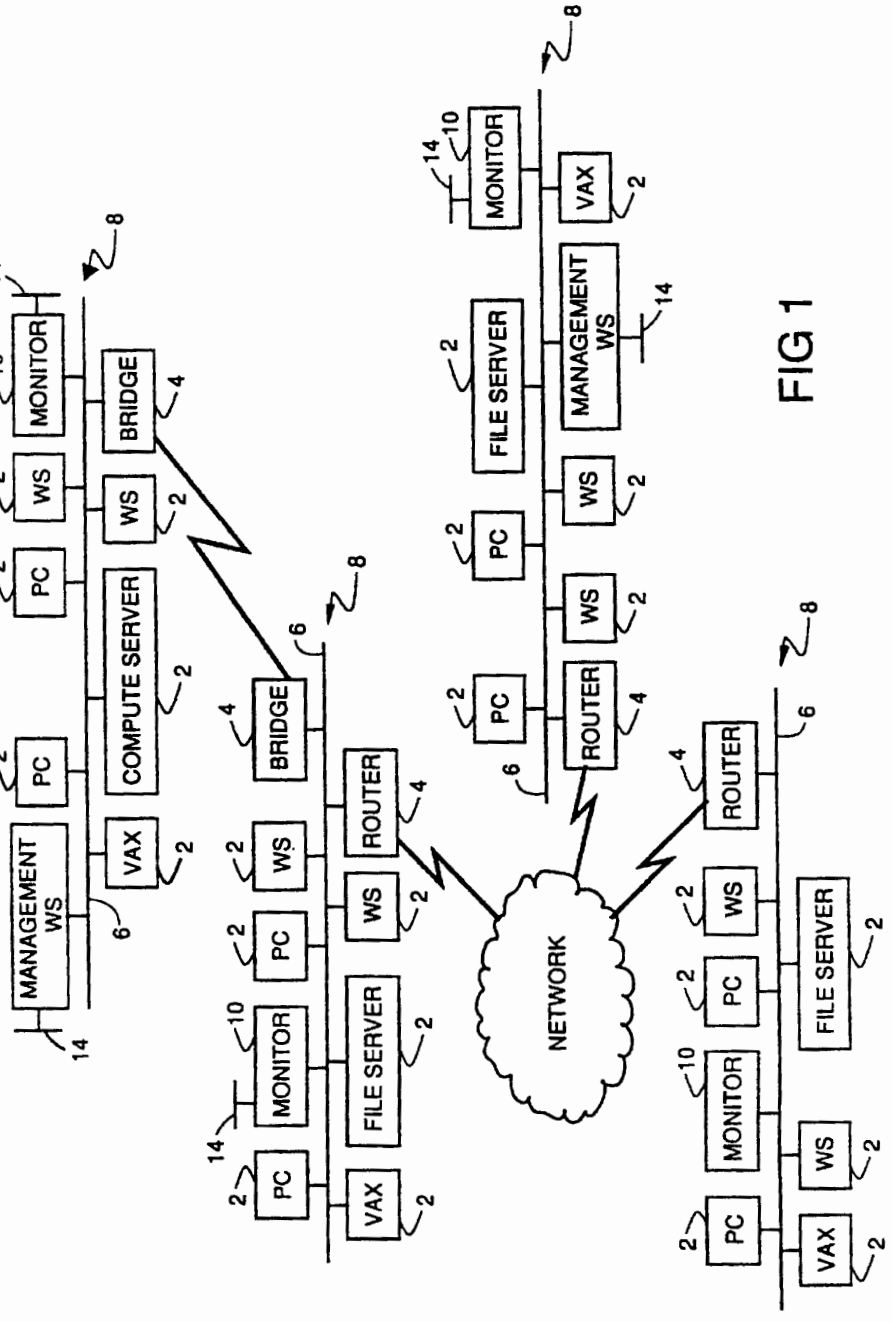

MANAGEMENT WS
PC
VAX
COMPUTE SERVER
WS
BRIDGE
MONITOR
BRIDGE
ROUTER
FILE SERVER
MONITOR
ROUTER
NETWORK
FILE SERVER
MANAGEMENT WS
MONITOR
VAX

FIG 1

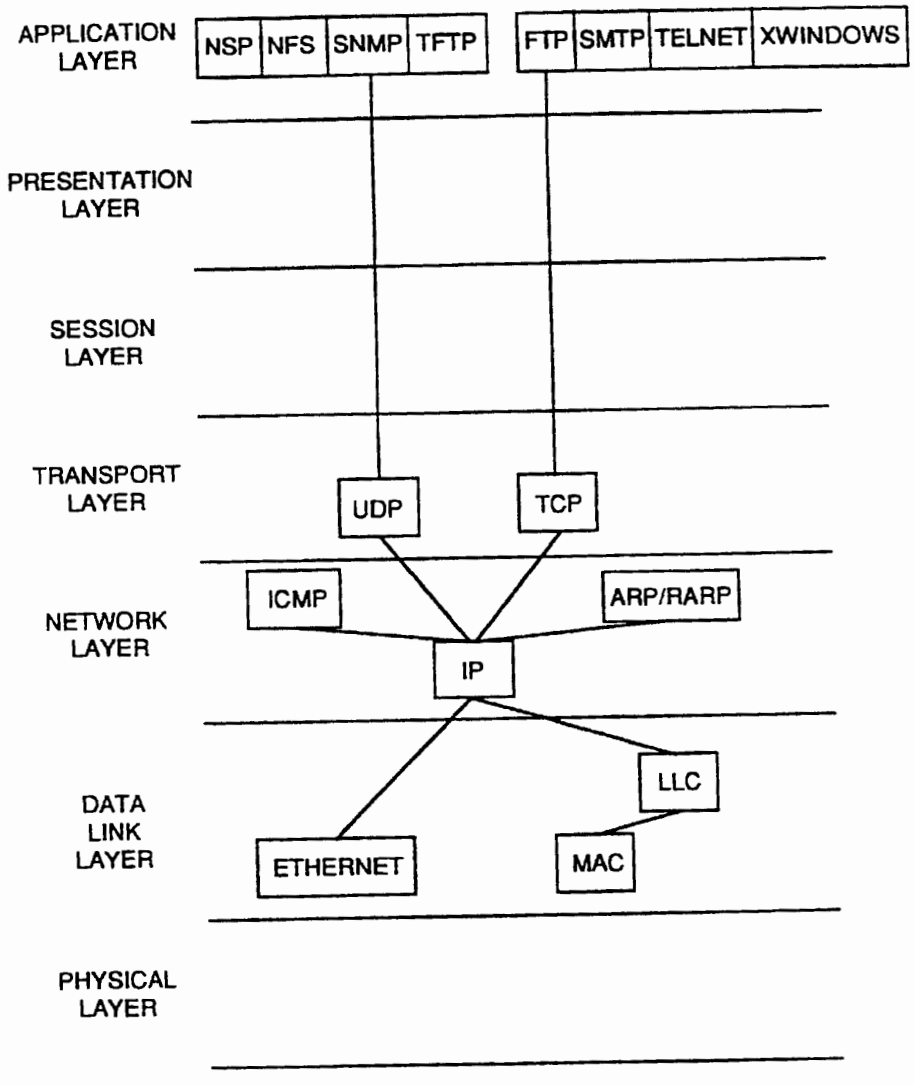

APPLICATION LAYER
NSP
NFS
SNMP
TFTP
FTP
SMTP
TELNET
XWINDOWS
PRESENTATION LAYER
SESSION LAYER
TRANSPORT LAYER
UDP
TCP
NETWORK LAYER
ICMP
ARP/RARP
IP
DATA LINK LAYER
LLC
ETHERNET
MAC
PHYSICAL LAYER

FIG 2

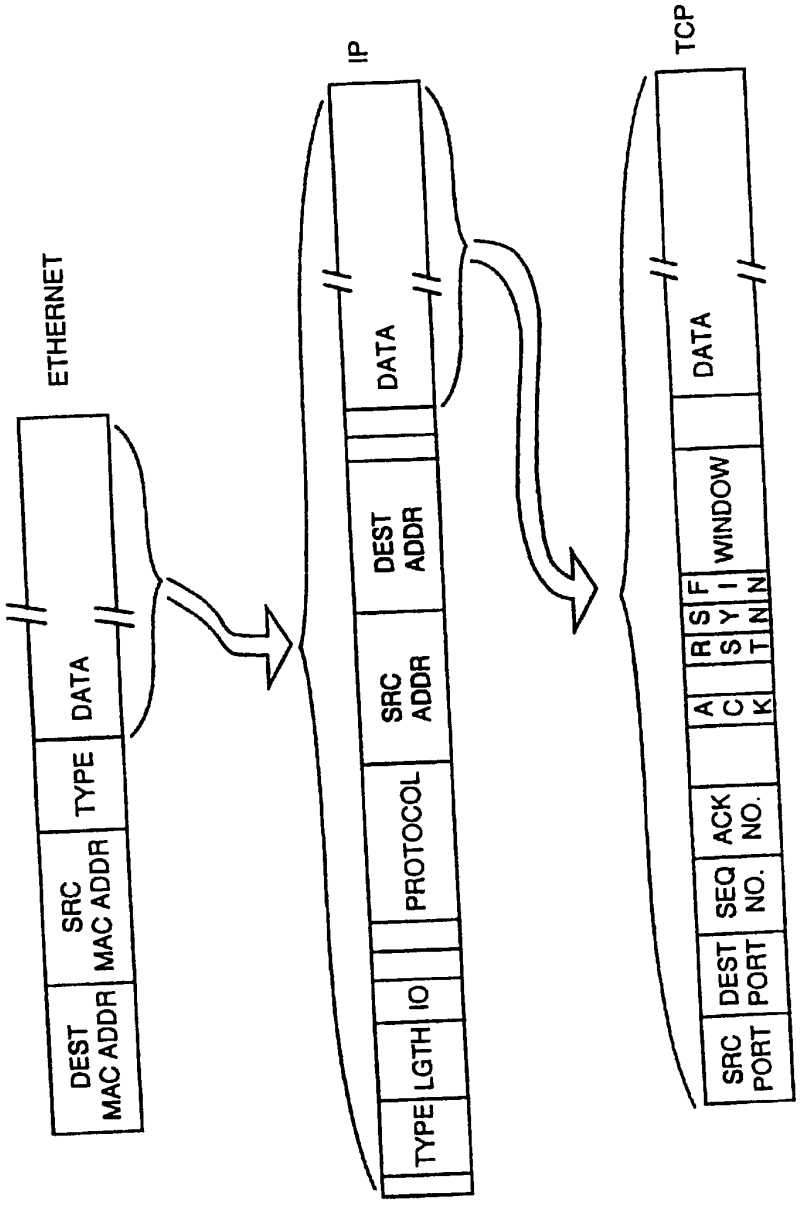

ETHERNET
DEST MAC ADDR
SRC MAC ADDR
TYPE
DATA
IP
TYPE
LGTH
IO
PROTOCOL
SRC ADDR
DEST ADDR
DATA
TCP
SRC PORT
DEST PORT
SEQ NO.
ACK NO.
A C K
R S T
S Y N
F I N
WINDOW
DATA

FIG 3

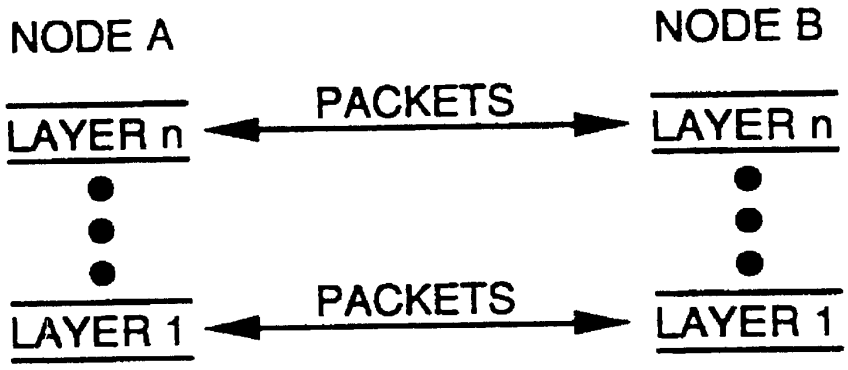


FIG 4

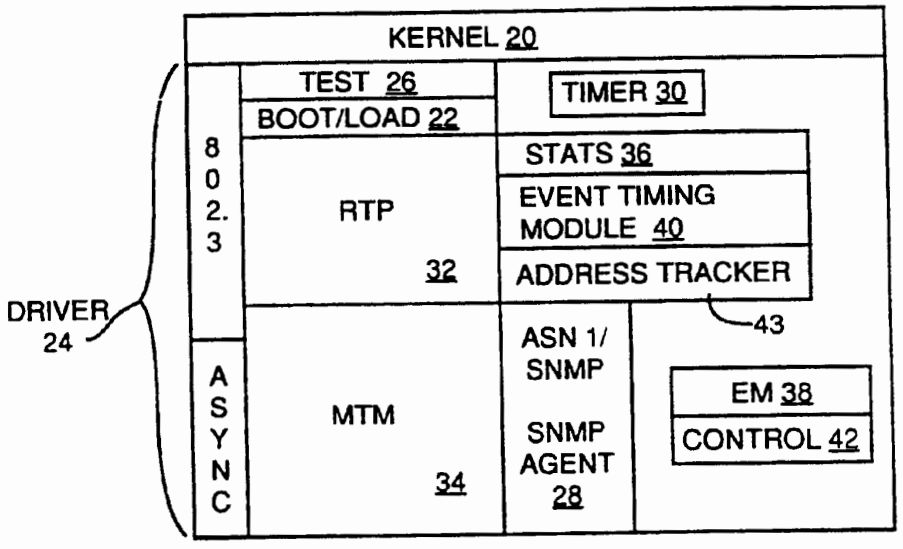

KERNEL 20
TEST 26
BOOT/LOAD 22
TIMER 30
8 0 2. 3
RTP
32
STATS 36
EVENT TIMING MODULE 40
ADDRESS TRACKER
43
DRIVER 24
A S Y N C
MTM
34
ASN 1/ SNMP
SNMP AGENT 28
EM 38
CONTROL 42

FIG 5

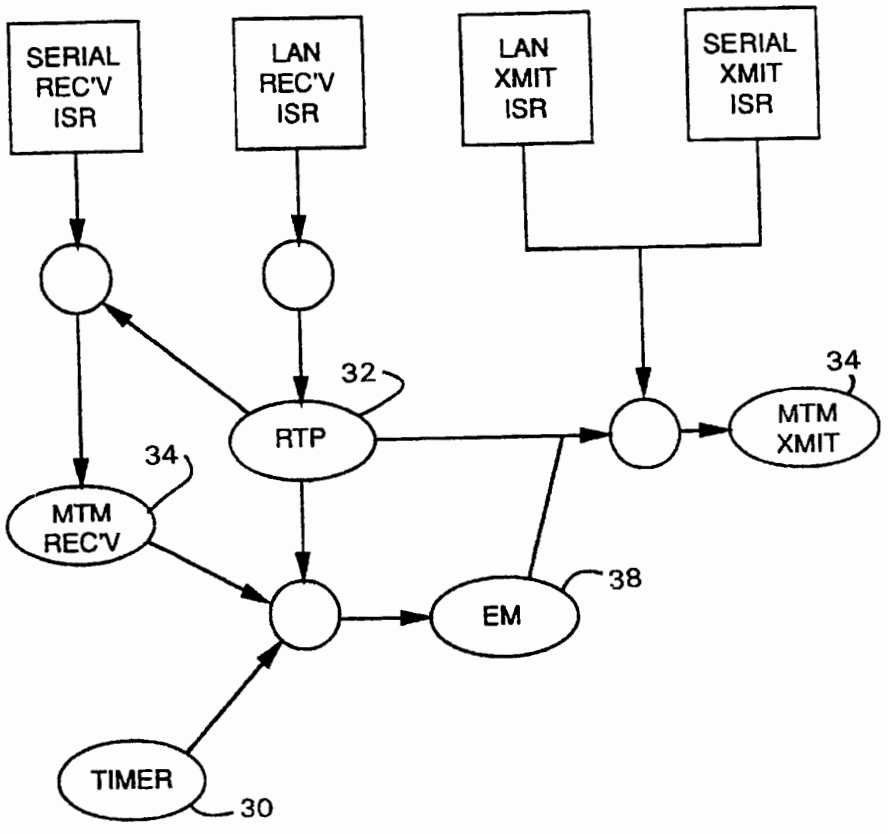

SERIAL REC'V ISR
LAN REC'V ISR
LAN XMIT ISR
SERIAL XMIT ISR
32
RTP
34
MTM XMIT
34
MTM REC'V
38
EM
TIMER
30

FIG 6

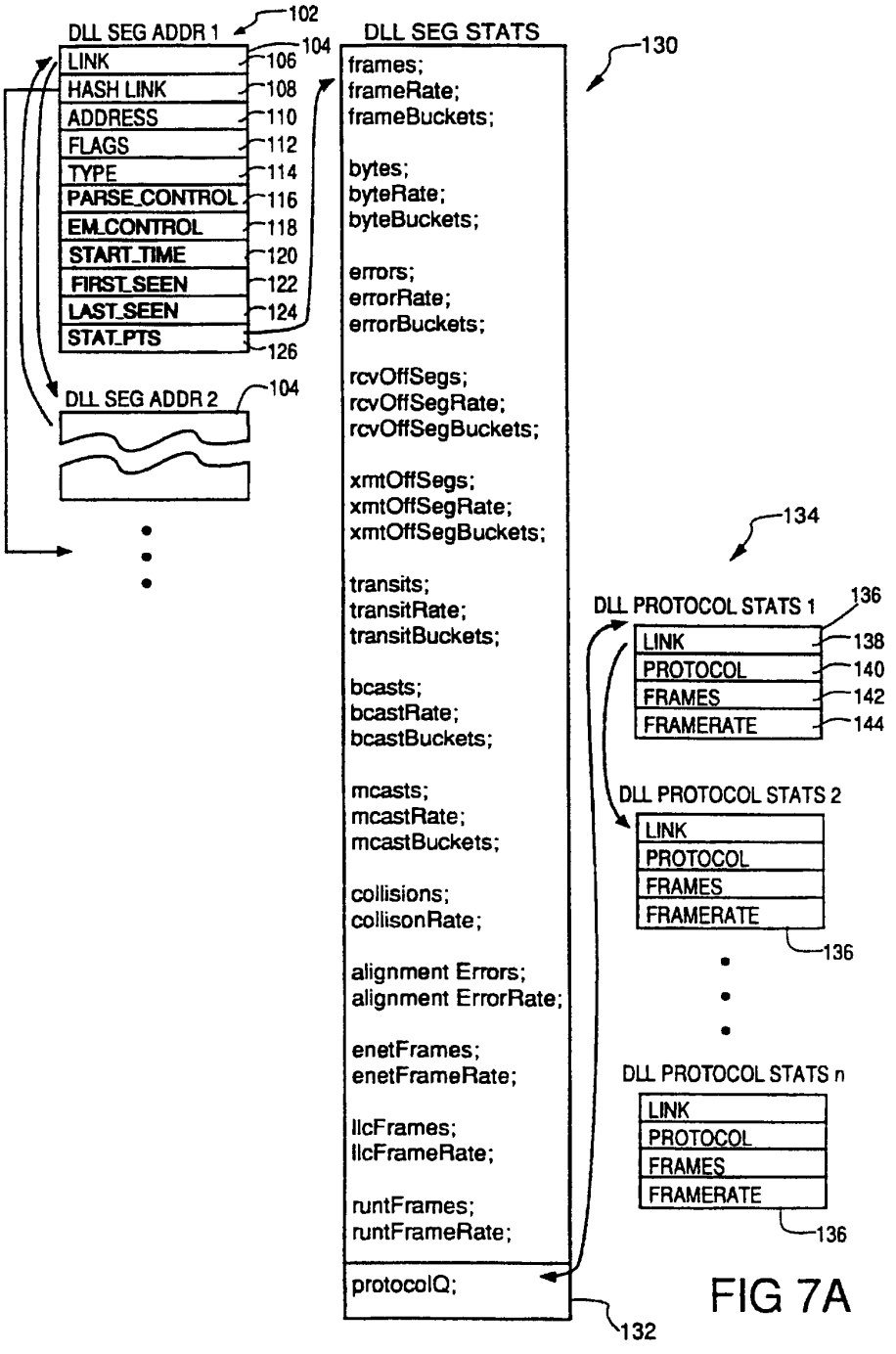

DLL SEG ADDR 1
102
104
LINK
106
HASH LINK
108
ADDRESS
110
FLAGS
112
TYPE
114
PARSE_CONTROL
116
EM_CONTROL
118
START_TIME
120
FIRST_SEEN
122
LAST_SEEN
124
STAT_PTS
126
DLL SEG ADDR 2
104
DLL SEG STATS
130
frames;
frameRate;
frameBuckets;
bytes;
byteRate;
byteBuckets;
errors;
errorRate;
errorBuckets;
rcvOffSegs;
rcvOffSegRate;
rcvOffSegBuckets;
xmtOffSegs;
xmtOffSegRate;
xmtOffSegBuckets;
transits;
transitRate;
transitBuckets;
bcasts;
bcastRate;
bcastBuckets;
mcasts;
mcastRate;
mcastBuckets;
collisions;
collisonRate;
alignment Errors;
alignment ErrorRate;
enetFrames;
enetFrameRate;
llcFrames;
llcFrameRate;
runtFrames;
runtFrameRate;
protocolQ;
132
134
DLL PROTOCOL STATS 1
136
LINK
138
PROTOCOL
140
FRAMES
142
FRAMERATE
144
DLL PROTOCOL STATS 2
LINK
PROTOCOL
FRAMES
FRAMERATE
136
DLL PROTOCOL STATS n
LINK
PROTOCOL
FRAMES
FRAMERATE
136

FIG 7A

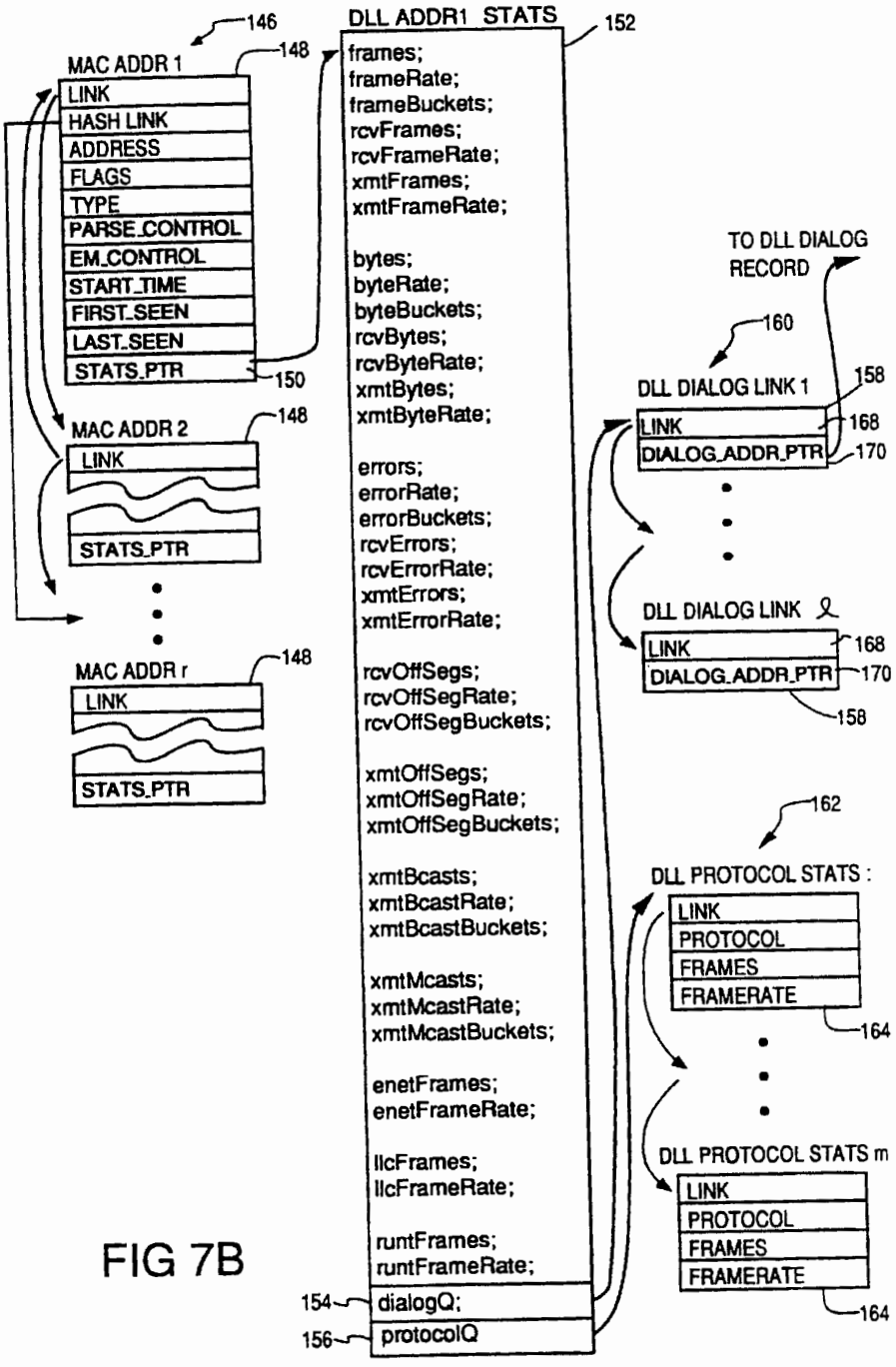

146
MAC ADDR 1
148
LINK
HASH LINK
ADDRESS
FLAGS
TYPE
PARSE_CONTROL
EM_CONTROL
START_TIME
FIRST_SEEN
LAST_SEEN
STATS_PTR
150
MAC ADDR 2
148
LINK
STATS_PTR
MAC ADDR r
148
LINK
STATS_PTR
DLL ADDR1 STATS
152
frames;
frameRate;
frameBuckets;
rcvFrames;
rcvFrameRate;
xmtFrames;
xmtFrameRate;
bytes;
byteRate;
byteBuckets;
rcvBytes;
rcvByteRate;
xmtBytes;
xmtByteRate;
errors;
errorRate;
errorBuckets;
rcvErrors;
rcvErrorRate;
xmtErrors;
xmtErrorRate;
rcvOffSegs;
rcvOffSegRate;
rcvOffSegBuckets;
xmtOffSegs;
xmtOffSegRate;
xmtOffSegBuckets;
xmtBcasts;
xmtBcastRate;
xmtBcastBuckets;
xmtMcasts;
xmtMcastRate;
xmtMcastBuckets;
enetFrames;
enetFrameRate;
llcFrames;
llcFrameRate;
runtFrames;
runtFrameRate;
154
dialogQ;
156
protocolQ
TO DLL DIALOG RECORD
160
DLL DIALOG LINK 1
158
LINK
168
DIALOG_ADDR_PTR
170
DLL DIALOG LINK 2
LINK
168
DIALOG_ADDR_PTR
170
158
162
DLL PROTOCOL STATS 1
LINK
PROTOCOL
FRAMES
FRAMERATE
164
DLL PROTOCOL STATS m
LINK
PROTOCOL
FRAMES
FRAMERATE
164

FIG 7B

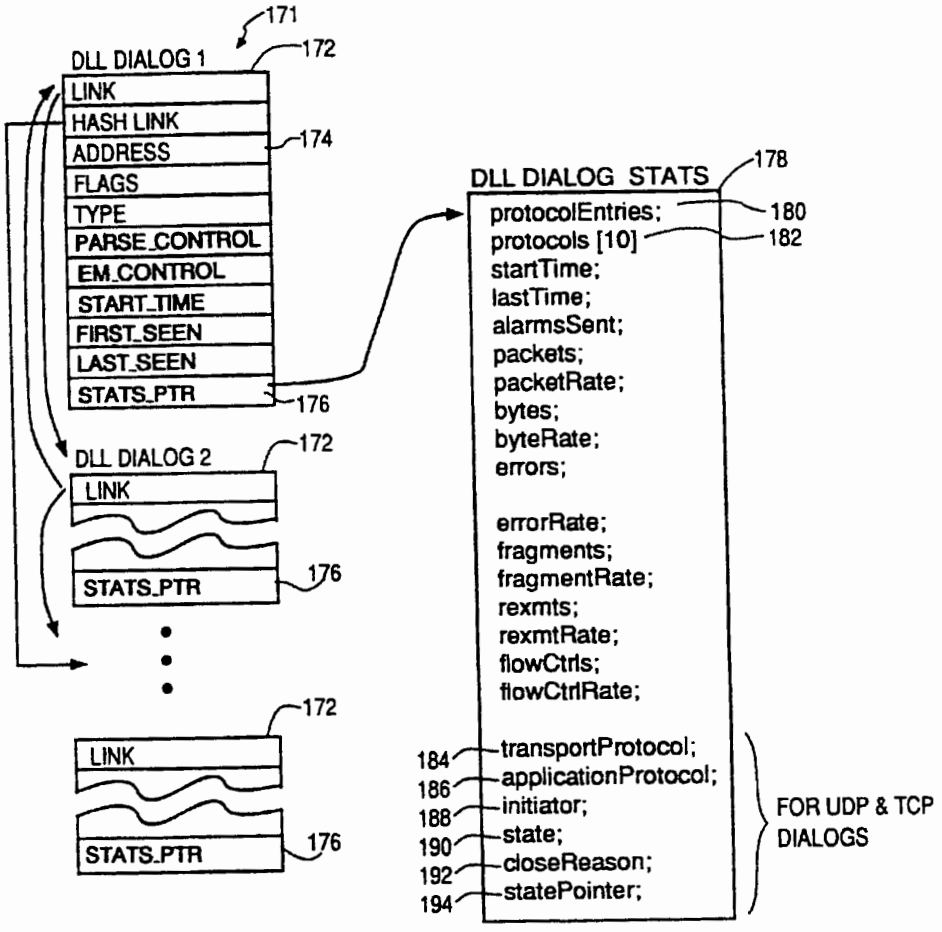

171
DLL DIALOG 1
172
LINK
HASH LINK
ADDRESS
174
FLAGS
TYPE
PARSE_CONTROL
EM_CONTROL
START_TIME
FIRST_SEEN
LAST_SEEN
STATS_PTR
176
DLL DIALOG 2
172
LINK
STATS_PTR
176
172
LINK
STATS_PTR
176
DLL DIALOG_STATS
178
protocolEntries;
180
protocols [10]
182
startTime;
lastTime;
alarmsSent;
packets;
packetRate;
bytes;
byteRate;
errors;
errorRate;
fragments;
fragmentRate;
rexmts;
rexmtRate;
flowCtrls;
flowCtrlRate;
184 transportProtocol;
186 applicationProtocol;
188 initiator;
190 state;
192 closeReason;
194 statePointer;
FOR UDP & TCP DIALOGS

FIG 7C

STATE / EVENT	UNKNOWN	CONNECTING	DATA	CLOSING	CLOSED	INACTIVE
UNKNOWN					S= UNKNOWN AFTER CLOSE ++	S= UNKNOWN
CONNECT REQ OR CONNECT CNF (E.G. TCP SYN)	S= CONNECTING	CONNECTION RETRY ++	S= UNKNOWN OUT OF ORDER++ ACTIVE CONN++	S= UNKNOWN OUT OF ORDER++	S=CONNECTING AFTER CLOSE ++	S=CONNECTING
ABORT (E.G. TCP RST)	S= CLOSED START CLOSE TIMER	S= CLOSED FAILED CONN ++ START CLOSE TIMER	S= CLOSED ACTIVE CONN - - START CLOSE TIMER	S= CLOSED ACTIVE CONN - - START CLOSE TIMER	AFTER CLOSE ++	S= CLOSED START CLOSE TIMER
DATA ACK (E.G. TCP ACK)	LOOK FOR DATA STATE	LOOK FOR DATA STATE	LOOK AT HISTORY	LOOK AT HISTORY	S= UNKNOWN AFTER CLOSE ++	S= UNKNOWN LOOK FOR DATA STATE
RELEASE REQ OR RELEASE CNF (E.G. TCP FIN)	S= CLOSING START CLOSE TIMER	S= CLOSING START CLOSE TIMER	S= CLOSING ACTIVE CONN - - START CLOSE TIMER		S= UNKNOWN AFTER CLOSE ++	S= CLOSING
DATA	LOOK FOR DATA STATE	LOOK FOR DATA STATE	LOOK AT HISTORY	OUT OF ORDER++	S= UNKNOWN AFTER CLOSE ++	S= UNKNOWN LOOK FOR DATA STATE
CLOSE TIMER EXPIRES				S= CLOSED		
INACTIVE TIMER EXPIRES	RECYCLE RESOURCES	RECYCLE RESOURCES FAILED CONN++	RECYCLE RESOURCES ACTIVE CONN --	RECYCLE RESOURCES	RECYCLE RESOURCES	RECYCLE RESOURCES

FIG 8

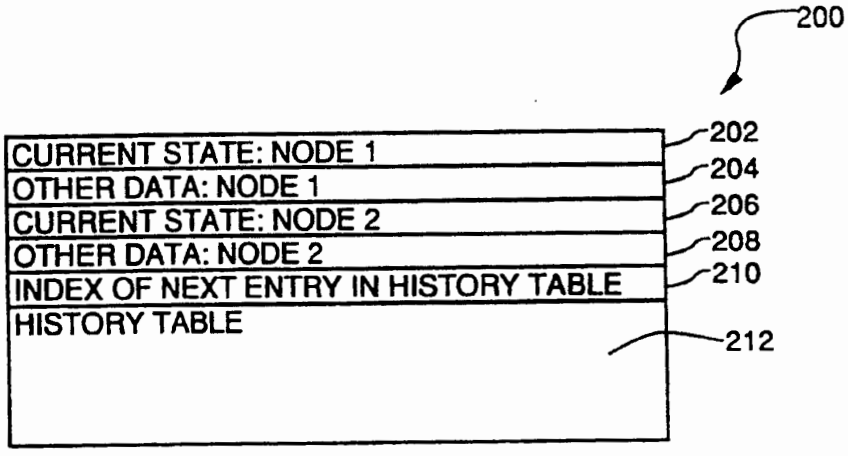

200
CURRENT STATE: NODE 1
OTHER DATA: NODE 1
CURRENT STATE: NODE 2
OTHER DATA: NODE 2
INDEX OF NEXT ENTRY IN HISTORY TABLE
HISTORY TABLE
202
204
206
208
210
212

FIG 9A

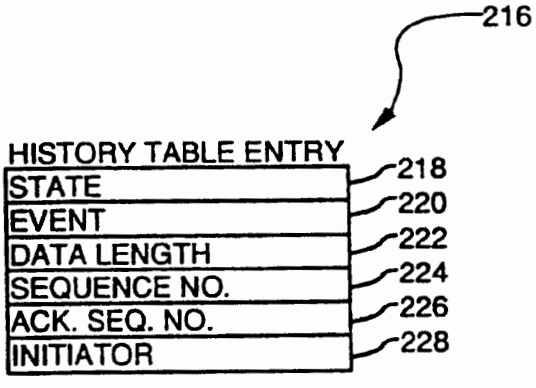

216
HISTORY TABLE ENTRY
STATE
EVENT
DATA LENGTH
SEQUENCE NO.
ACK. SEQ. NO.
INITIATOR
218
220
222
224
226
228

FIG 9B

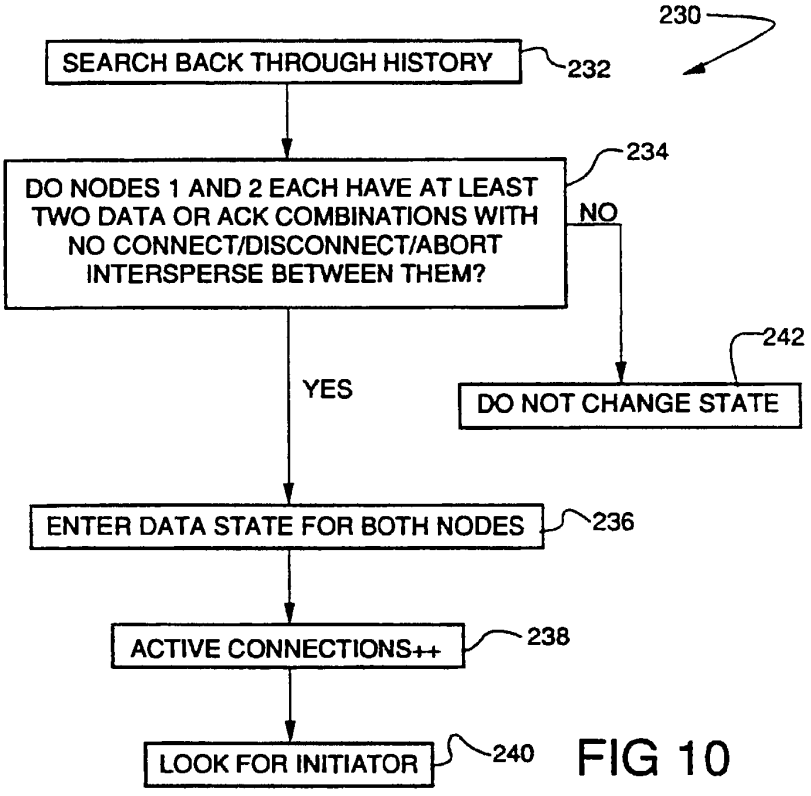

230
SEARCH BACK THROUGH HISTORY
232
DO NODES 1 AND 2 EACH HAVE AT LEAST TWO DATA OR ACK COMBINATIONS WITH NO CONNECT/DISCONNECT/ABORT INTERSPERSE BETWEEN THEM?
234
NO
242
DO NOT CHANGE STATE
YES
ENTER DATA STATE FOR BOTH NODES
236
ACTIVE CONNECTIONS++
238
LOOK FOR INITIATOR
240

FIG 10

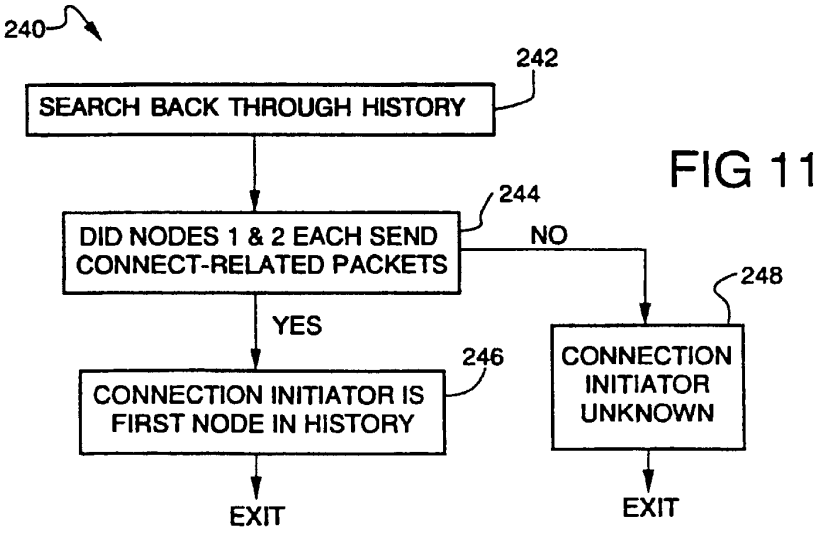

240
242
SEARCH BACK THROUGH HISTORY
244
DID NODES 1 & 2 EACH SEND CONNECT-RELATED PACKETS
NO
248
YES
246
CONNECTION INITIATOR IS FIRST NODE IN HISTORY
CONNECTION INITIATOR UNKNOWN
EXIT
EXIT

FIG 11

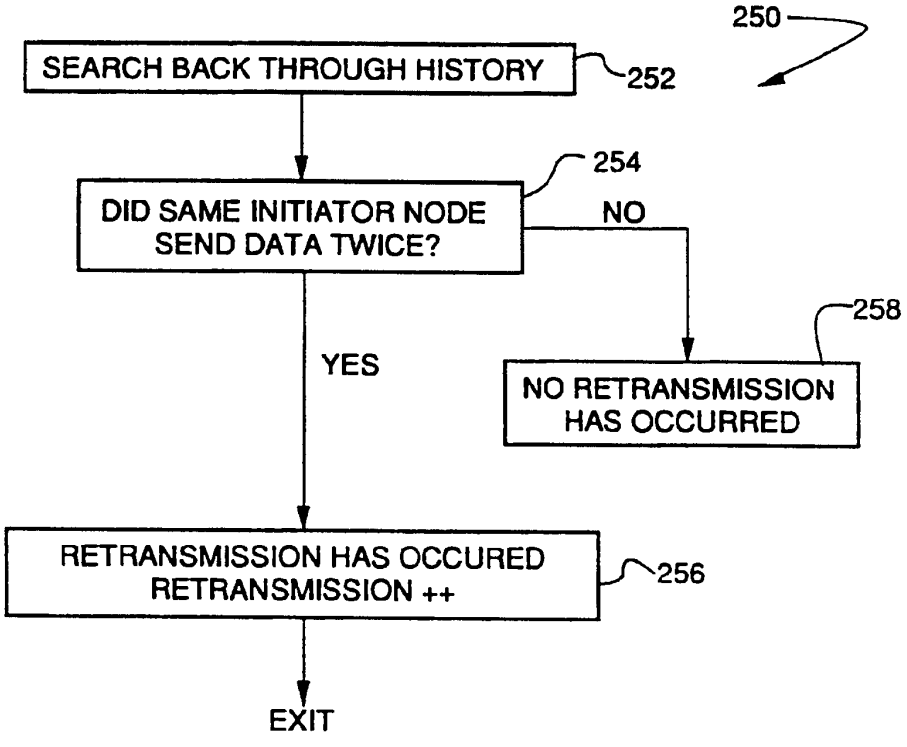

250
SEARCH BACK THROUGH HISTORY
252
254
DID SAME INITIATOR NODE SEND DATA TWICE?
NO
258
NO RETRANSMISSION HAS OCCURRED
YES
RETRANSMISSION HAS OCCURED RETRANSMISSION ++
256
EXIT

FIG 12

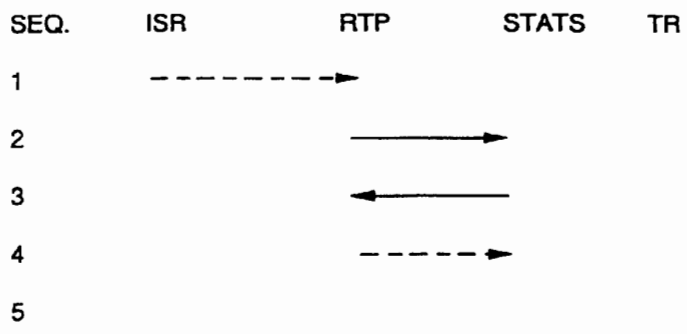

SEQ.
ISR
RTP
STATS
TR
1
2
3
4
5

FIG 13

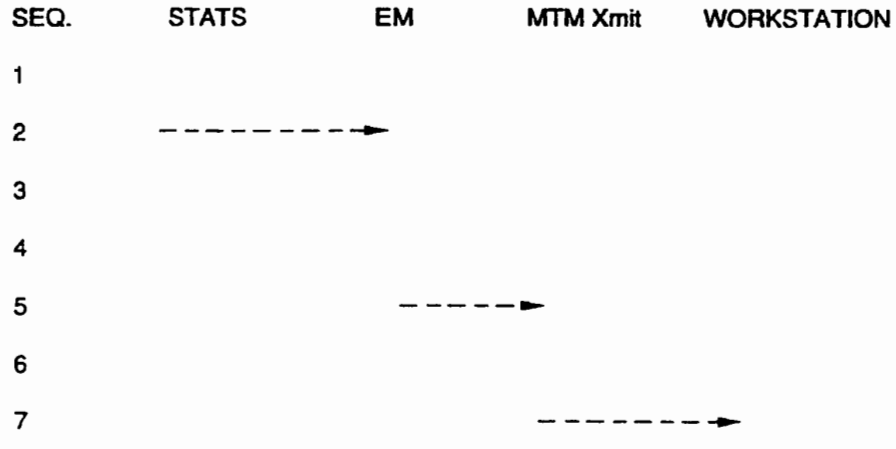

SEQ.
STATS
EM
MTM Xmit
WORKSTATION
1
2
3
4
5
6
7

FIG 14

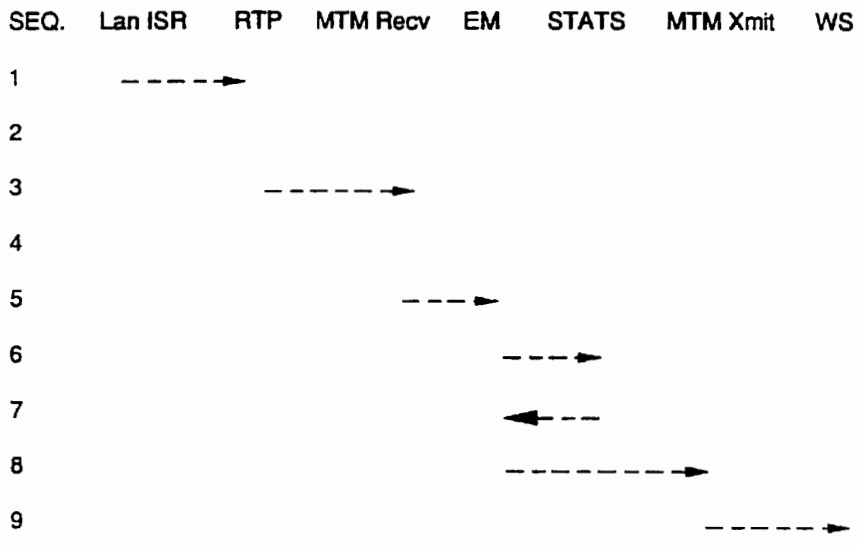

SEQ.
Lan ISR
RTP
MTM Recv
EM
STATS
MTM Xmit
WS
1
2
3
4
5
6
7
8
9

FIG 15

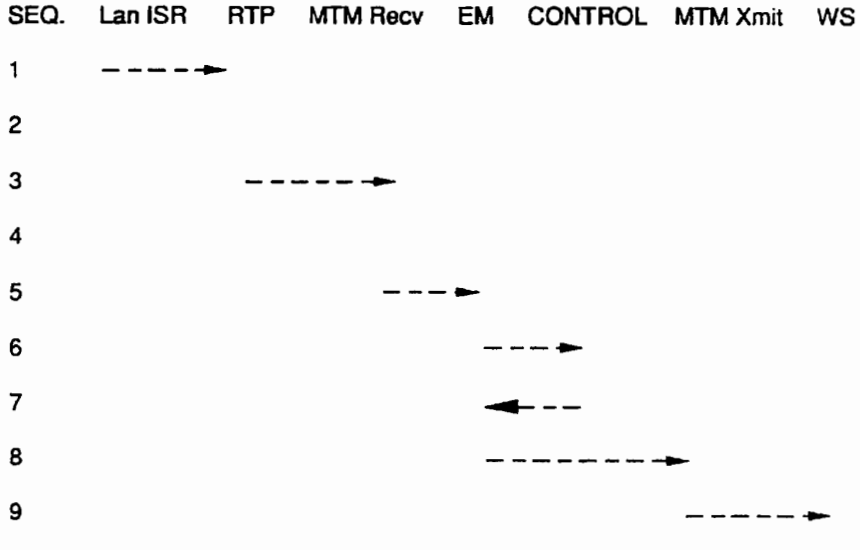

SEQ.
Lan ISR
RTP
MTM Recv
EM
CONTROL
MTM Xmit
WS
1
2
3
4
5
6
7
8
9

FIG 16

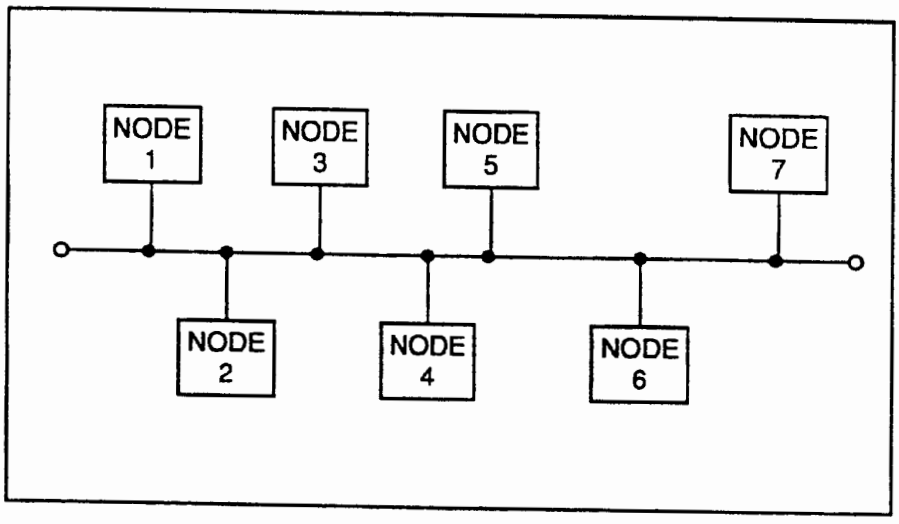


FIG 17

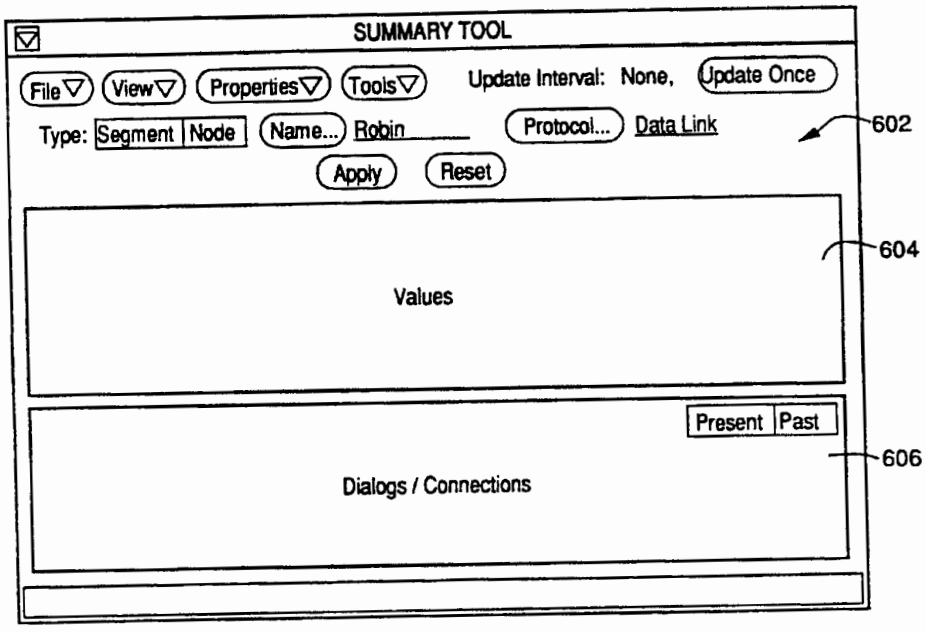

SUMMARY TOOL
File
View
Properties
Tools
Update Interval: None,
Update Once
Type: Segment Node
Name...
Robin
Protocol...
Data Link
602
Apply
Reset
604
Values
Present Past
606
Dialogs / Connections

FIG 18

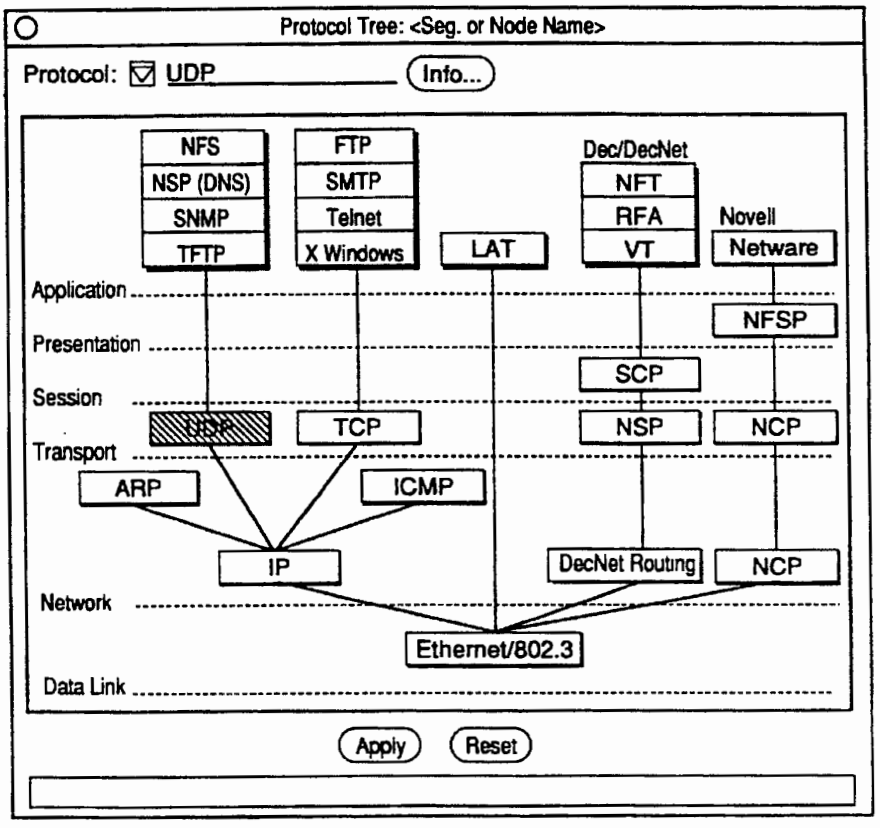

Protocol Tree: <Seg. or Node Name>
Protocol: UDP
Info...
NFS
NSP (DNS)
SNMP
TFTP
FTP
SMTP
Telnet
X Windows
LAT
Dec/DecNet
NFT
RFA
VT
Novell
Netware
Application
Presentation
Session
Transport
Network
Data Link
NFSP
SCP
UDP
TCP
NSP
NCP
ARP
ICMP
IP
DecNet Routing
NCP
Ethernet/802.3
Apply
Reset

FIG 19

Data Link

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Frame Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Broadcast Frm. Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Multicast Frm. Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Off Segment Frames						
In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Protocols (Frm. Rate)		Most Active Nodes (Frm. Rate)	
1234567890123456	nnn %	1234567890123456	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %

Total Segment Bandwidth: nnn %

Total Active Dialogs: nn, nnn

FIG 20A

IP

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Broadcast Pkt. Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Multicast Pkt. Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Flow Controls:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Fragments:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Off Segment Packets						
In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Protocols (Pkt. Rate)		Most Active Nodes (Pkt. Rate)	
1234567890123456	nnn %	1234567890123456	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %

Total Segment Bandwidth: nnn %

Total Active Dialogs: nn, nnn

FIG 20B

UDP

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Flow Controls:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn

Off Segment Packets						
In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Protocols (Pkt. Rate)		Most Active Nodes (Pkt. Rate)	
1234567890123456	nnn %	1234567890123456	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %

Total Segment Bandwidth: nnn %

Total Active Dialogs: nn, nnn

FIG 20C

TCP

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Flow Controls:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Retransmissions:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn

Off Segment Packets						
In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Protocols (Pkt. Rate)		Most Active Nodes (Pkt. Rate)	
1234567890123456	nnn %	1234567890123456	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %
<protocol>	nnn %	<node>	nnn %

Total Segment Bandwidth: nnn %

Total Active Connections: nn, nnn

FIG 20D

ICMP

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn

Off Segment Packets

In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

ICMP Types Seen (Count)

Address Mask: nnn,nnn	Redirect: nnn,nnn	Most Active Nodes (Pkt. Rate)	
Dst. Unreachable: nnn,nnn	Source Quench: nnn,nnn	1234567890123456	nnn %
Echo: nnn,nnn	Time Exceeded: nnn,nnn	<node>	nnn %
Param. Problem: nnn,nnn	Time Stamp: nnn,nnn	<node>	nnn %
		<node>	nnn %
		<node>	nnn %

Total Segment Bandwidth: nnn %

FIG 20E

NFS

	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Flow Controls:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn

Off Segment Packets

In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Nodes (Pkt. Rate)

1234567890123456	nnn %
<node>	nnn %
<node>	nnn %
<node>	nnn %
<node>	nnn %

Total Segment Bandwidth: nnn %

Total Active Dialogs: nn, nnn

FIG 20F

Arp/Rarp	Current	5 Min.	15 Min.	10 Min. Max	60 Min. Max	Accum.Val.
Packet Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Byte Rate:	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	nn,nnn /s	n,nnn,nnn
Errors:	nnn,nnn	nnn,nnn	nnn,nnn	-	-	n,nnn,nnn
Off Segment Packets						
In:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
Out:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn
**Transit:	nnn %	nnn %	nnn %	nnn %	nnn %	n,nnn,nnn

Most Active Nodes (Pkt. Rate)

1234567890123456	nnn %
<node>	nnn %
<node>	nnn %
<node>	nnn %
<node>	nnn %

Total Segment Bandwidth: nnn %

FIG 20G

Start Time	Last Seen	Dir.	Partner Node	Protocols	Packets Summary Rate	%	Count	Errors
hh:mm:ss	hh:mm:ss	1234	1234567890123456	1234567890123456	nn,nnn /s	nnn %	n,nnn,nnn	nnn,nnn
10:23:04	15:31:47	To	robin	XNS,XEROX-PUP	325 /s	6%	2,641	0
07:21:38	13:25:51	From	hawk	DOD-IP, X25	87 /s	3%	127	1
10/31/90	08:22:30	?	hawk	BBN-SIMNET APPLETALK	13 /s	1%	24,192	4

FIG 21

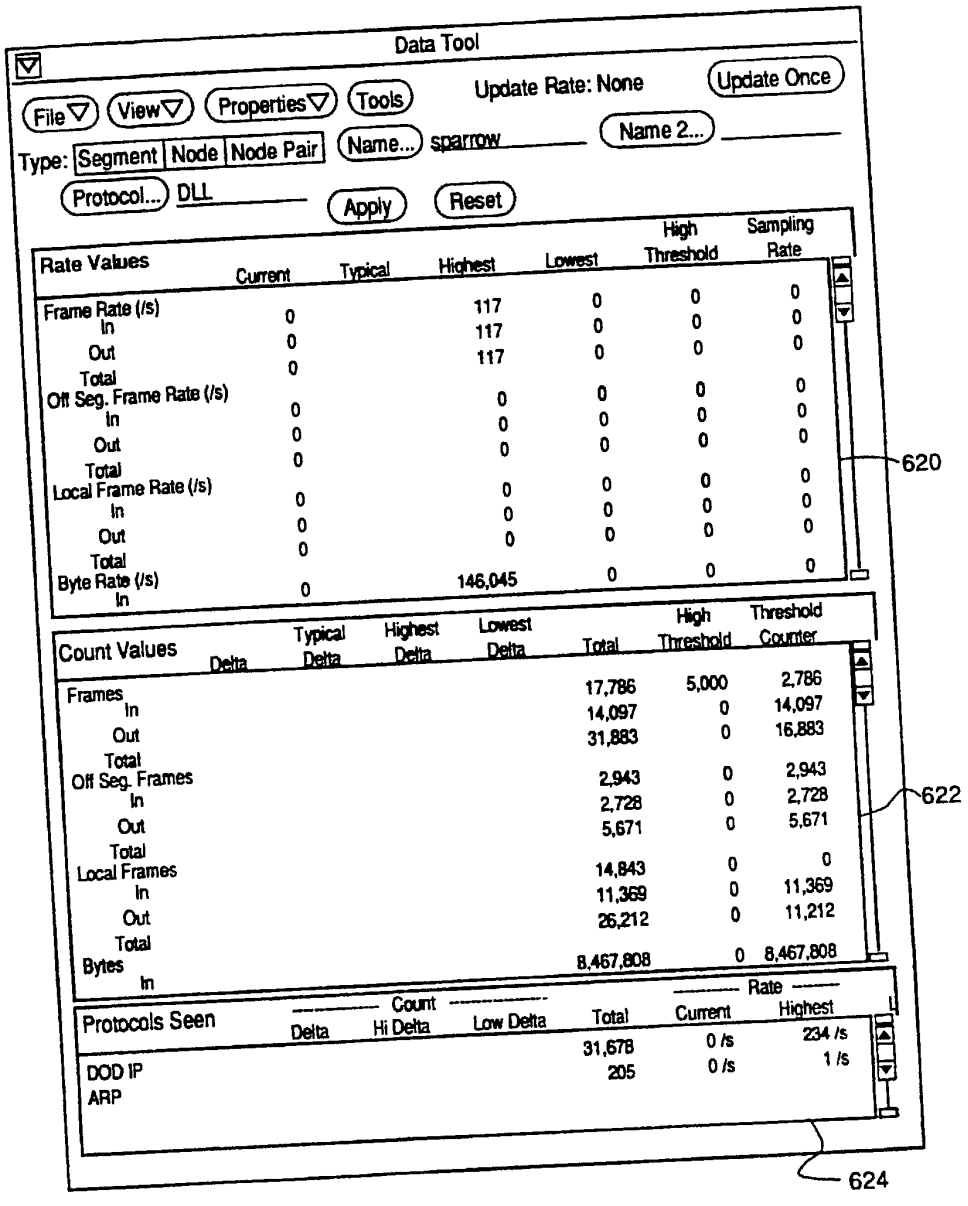

Data Tool
File
View
Properties
Tools
Update Rate: None
Update Once
Type: Segment Node Node Pair
Name... sparrow
Name 2...
Protocol... DLL
Apply
Reset
Rate Values
Current
Typical
Highest
Lowest
High Threshold
Sampling Rate
Frame Rate (/s)
In
Out
Total
Off Seg. Frame Rate (/s)
In
Out
Total
Local Frame Rate (/s)
In
Out
Total
Byte Rate (/s)
In
620
Count Values
Delta
Typical Delta
Highest Delta
Lowest Delta
Total
High Threshold
Threshold Counter
Frames
In
Out
Total
Off Seg. Frames
In
Out
Total
Local Frames
In
Out
Total
Bytes
In
622
Protocols Seen
Count
Delta
Hi Delta
Low Delta
Total
Rate
Current
Highest
DOD IP
ARP
624

FIG 22

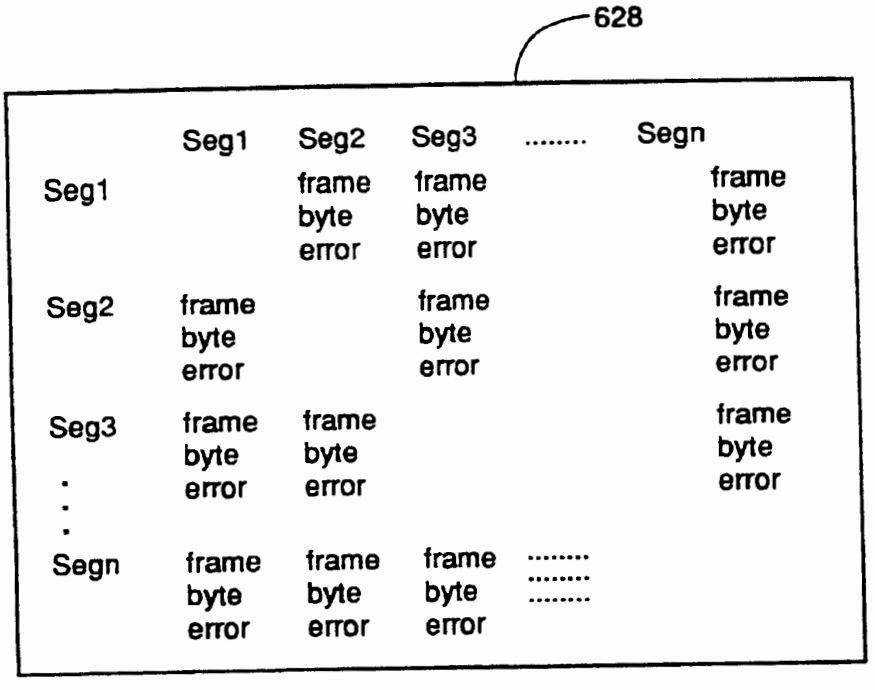

628
Seg1
Seg2
Seg3
.....
Segn
Seg1
frame byte error
frame byte error
frame byte error
Seg2
frame byte error
frame byte error
frame byte error
Seg3
frame byte error
frame byte error
frame byte error
Segn
frame byte error
frame byte error
frame byte error
.....
.....
.....

FIG 23

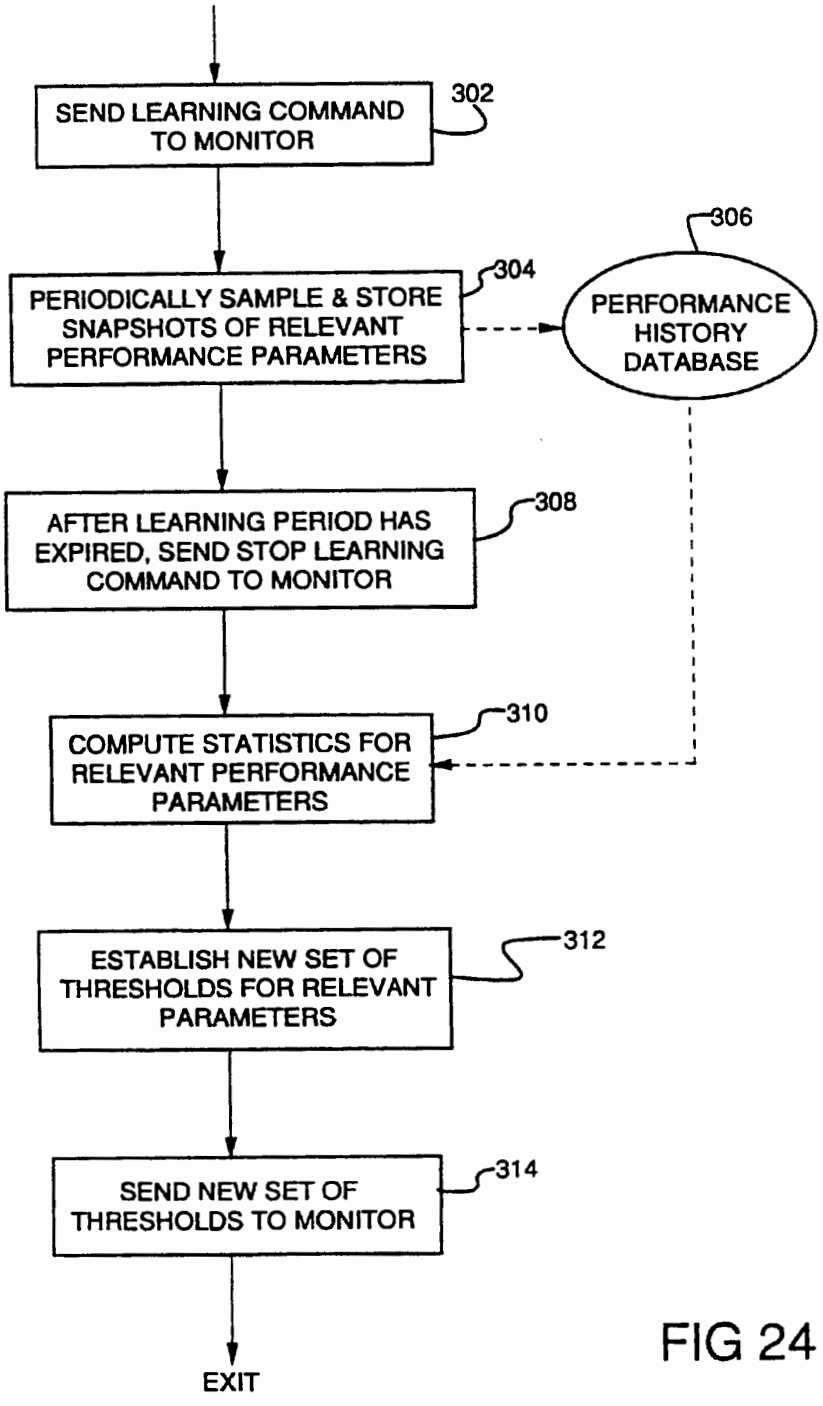

SEND LEARNING COMMAND TO MONITOR
302
PERIODICALLY SAMPLE & STORE SNAPSHOTS OF RELEVANT PERFORMANCE PARAMETERS
304
306
PERFORMANCE HISTORY DATABASE
AFTER LEARNING PERIOD HAS EXPIRED, SEND STOP LEARNING COMMAND TO MONITOR
308
COMPUTE STATISTICS FOR RELEVANT PERFORMANCE PARAMETERS
310
ESTABLISH NEW SET OF THRESHOLDS FOR RELEVANT PARAMETERS
312
SEND NEW SET OF THRESHOLDS TO MONITOR
314
EXIT

FIG 24

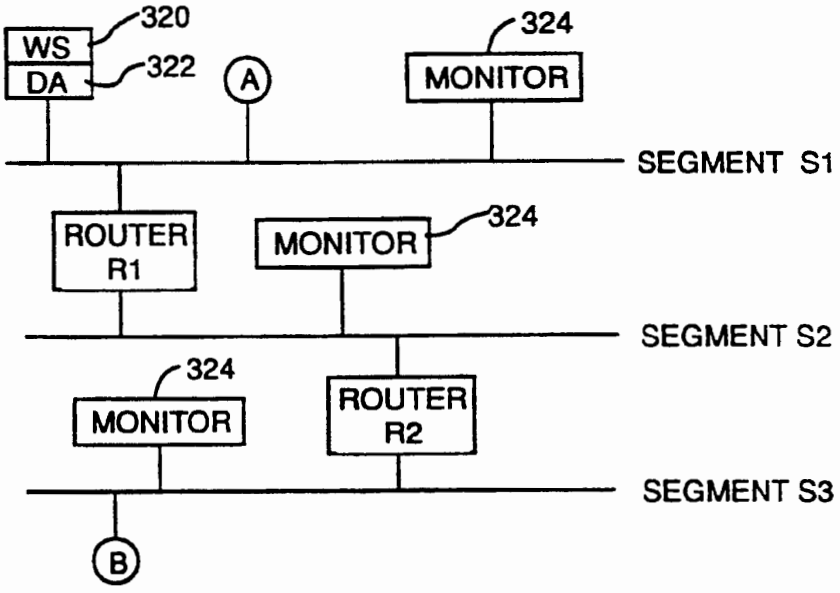

320
WS
322
DA
A
324
MONITOR
SEGMENT S1
ROUTER
R1
MONITOR
324
SEGMENT S2
324
MONITOR
ROUTER
R2
SEGMENT S3
B

FIG 25

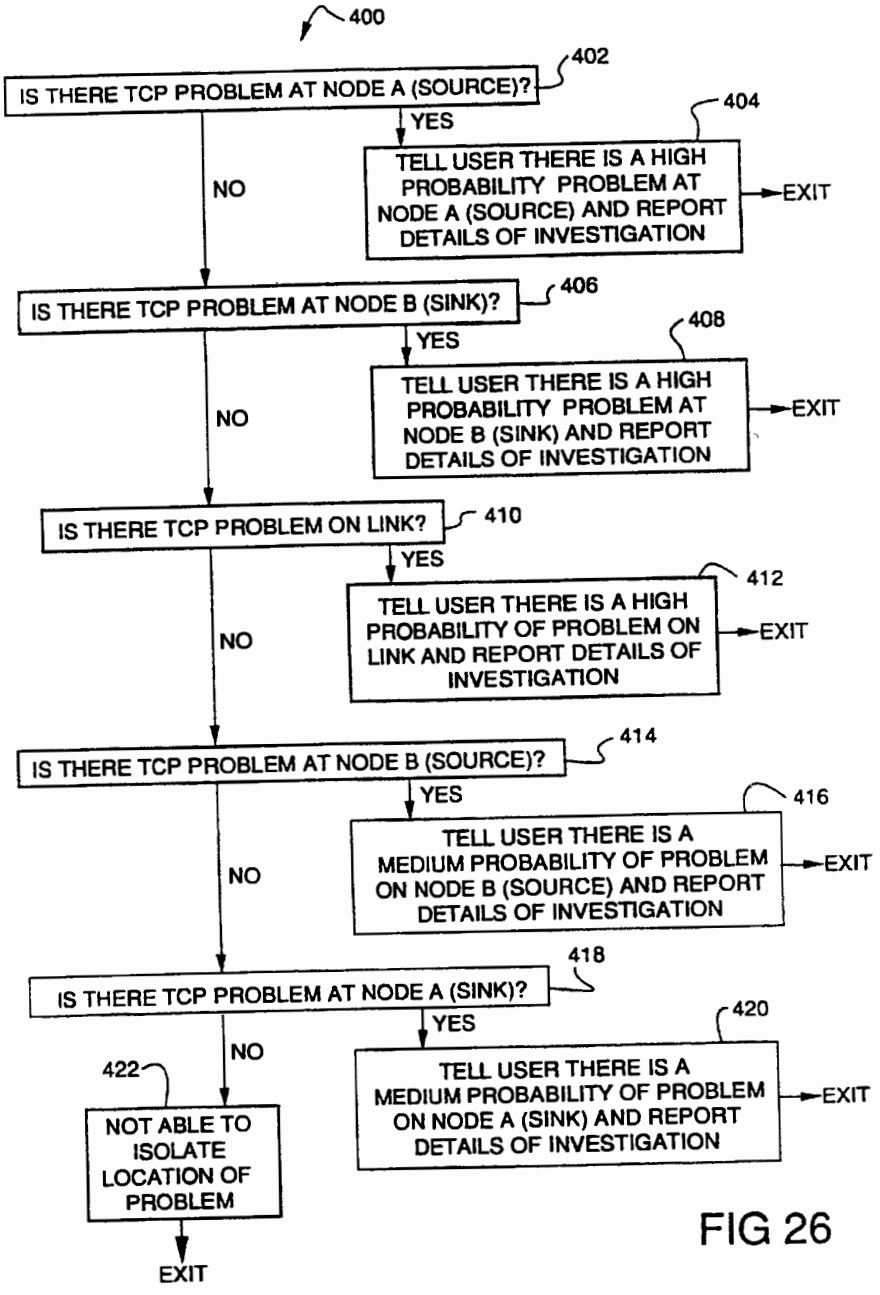

400
IS THERE TCP PROBLEM AT NODE A (SOURCE)?
402
YES
NO
404
TELL USER THERE IS A HIGH PROBABILITY PROBLEM AT NODE A (SOURCE) AND REPORT DETAILS OF INVESTIGATION
EXIT
IS THERE TCP PROBLEM AT NODE B (SINK)?
406
YES
NO
408
TELL USER THERE IS A HIGH PROBABILITY PROBLEM AT NODE B (SINK) AND REPORT DETAILS OF INVESTIGATION
EXIT
IS THERE TCP PROBLEM ON LINK?
410
YES
NO
412
TELL USER THERE IS A HIGH PROBABILITY OF PROBLEM ON LINK AND REPORT DETAILS OF INVESTIGATION
EXIT
IS THERE TCP PROBLEM AT NODE B (SOURCE)?
414
YES
NO
416
TELL USER THERE IS A MEDIUM PROBABILITY OF PROBLEM ON NODE B (SOURCE) AND REPORT DETAILS OF INVESTIGATION
EXIT
IS THERE TCP PROBLEM AT NODE A (SINK)?
418
YES
NO
420
TELL USER THERE IS A MEDIUM PROBABILITY OF PROBLEM ON NODE A (SINK) AND REPORT DETAILS OF INVESTIGATION
EXIT
422
NOT ABLE TO ISOLATE LOCATION OF PROBLEM
EXIT

FIG 26

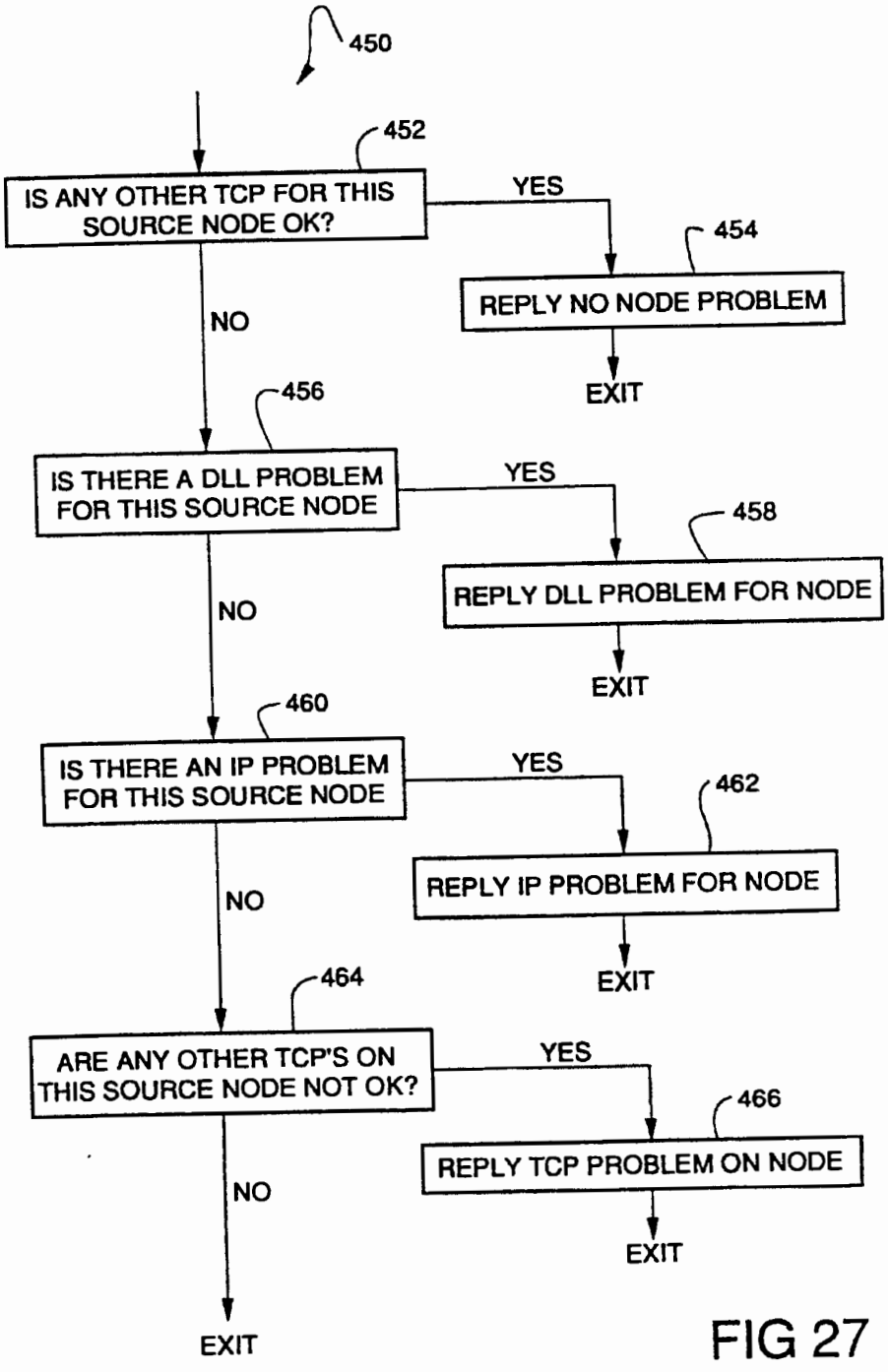

450
452
IS ANY OTHER TCP FOR THIS SOURCE NODE OK?
YES
454
REPLY NO NODE PROBLEM
EXIT
NO
456
IS THERE A DLL PROBLEM FOR THIS SOURCE NODE
YES
458
REPLY DLL PROBLEM FOR NODE
EXIT
NO
460
IS THERE AN IP PROBLEM FOR THIS SOURCE NODE
YES
462
REPLY IP PROBLEM FOR NODE
EXIT
NO
464
ARE ANY OTHER TCP'S ON THIS SOURCE NODE NOT OK?
YES
466
REPLY TCP PROBLEM ON NODE
EXIT
NO
EXIT

FIG 27

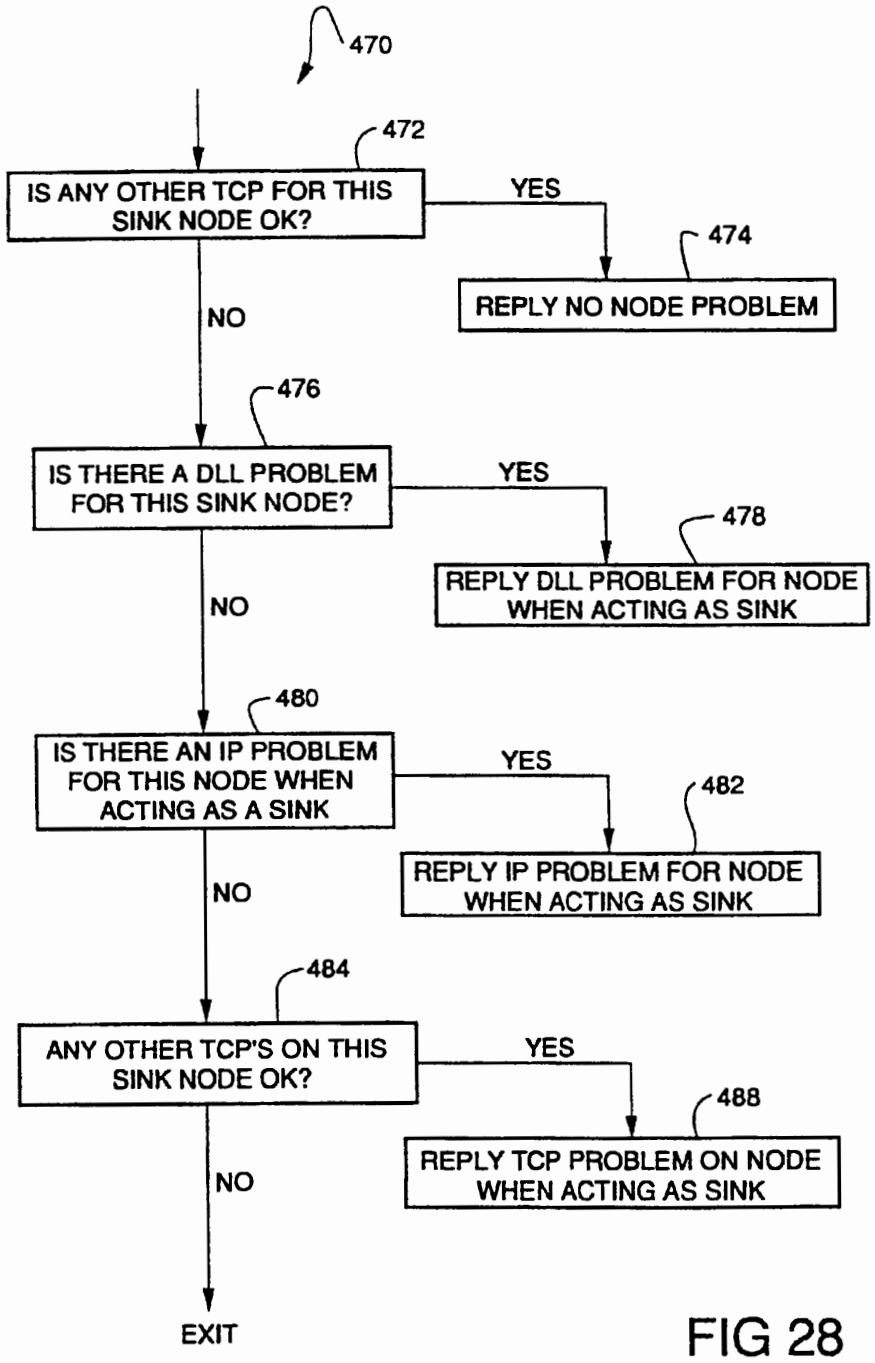

470
472
IS ANY OTHER TCP FOR THIS SINK NODE OK?
YES
474
REPLY NO NODE PROBLEM
NO
476
IS THERE A DLL PROBLEM FOR THIS SINK NODE?
YES
478
REPLY DLL PROBLEM FOR NODE WHEN ACTING AS SINK
NO
480
IS THERE AN IP PROBLEM FOR THIS NODE WHEN ACTING AS A SINK
YES
482
REPLY IP PROBLEM FOR NODE WHEN ACTING AS SINK
NO
484
ANY OTHER TCP'S ON THIS SINK NODE OK?
YES
488
REPLY TCP PROBLEM ON NODE WHEN ACTING AS SINK
NO
EXIT

FIG 28

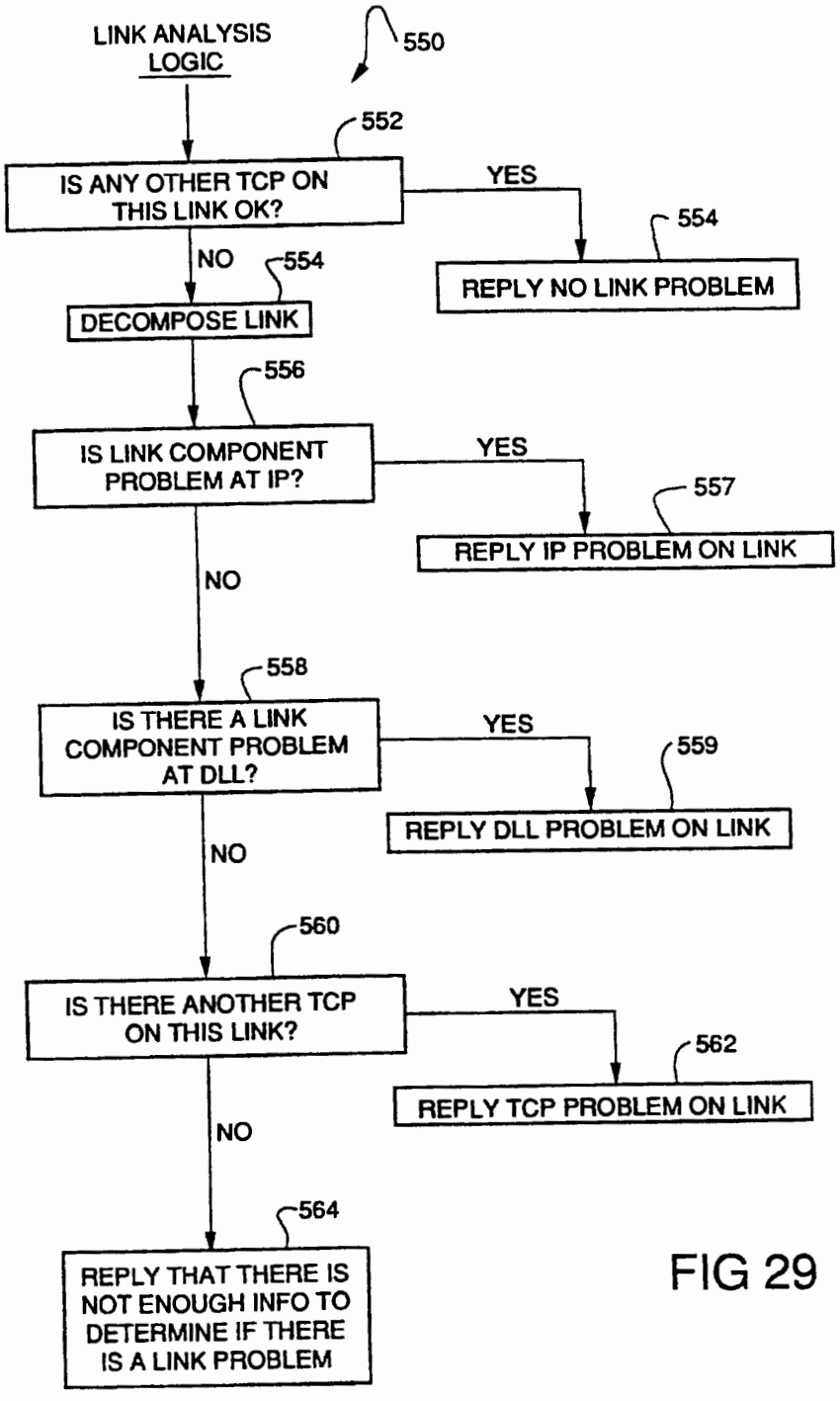

LINK ANALYSIS LOGIC
550
552
IS ANY OTHER TCP ON THIS LINK OK?
YES
554
REPLY NO LINK PROBLEM
NO
554
DECOMPOSE LINK
556
IS LINK COMPONENT PROBLEM AT IP?
YES
557
REPLY IP PROBLEM ON LINK
NO
558
IS THERE A LINK COMPONENT PROBLEM AT DLL?
YES
559
REPLY DLL PROBLEM ON LINK
NO
560
IS THERE ANOTHER TCP ON THIS LINK?
YES
562
REPLY TCP PROBLEM ON LINK
NO
564
REPLY THAT THERE IS NOT ENOUGH INFO TO DETERMINE IF THERE IS A LINK PROBLEM

FIG 29

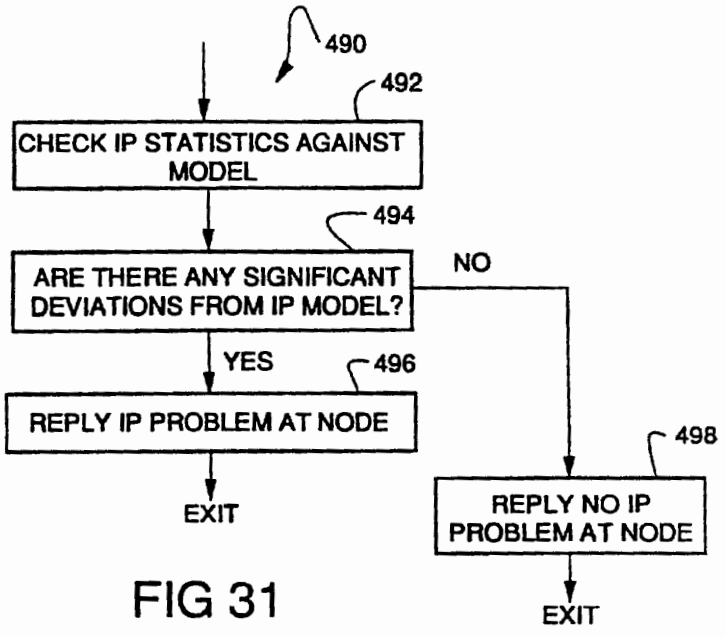

490
492
CHECK IP STATISTICS AGAINST MODEL
494
ARE THERE ANY SIGNIFICANT DEVIATIONS FROM IP MODEL?
NO
YES
496
REPLY IP PROBLEM AT NODE
EXIT
498
REPLY NO IP PROBLEM AT NODE
EXIT

FIG 31

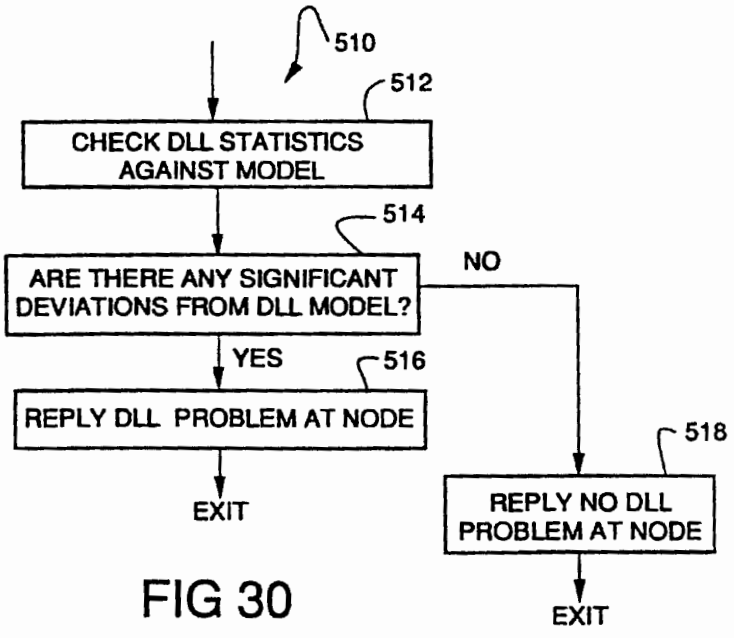

510
512
CHECK DLL STATISTICS AGAINST MODEL
514
ARE THERE ANY SIGNIFICANT DEVIATIONS FROM DLL MODEL?
NO
YES
516
REPLY DLL PROBLEM AT NODE
EXIT
518
REPLY NO DLL PROBLEM AT NODE
EXIT

FIG 30

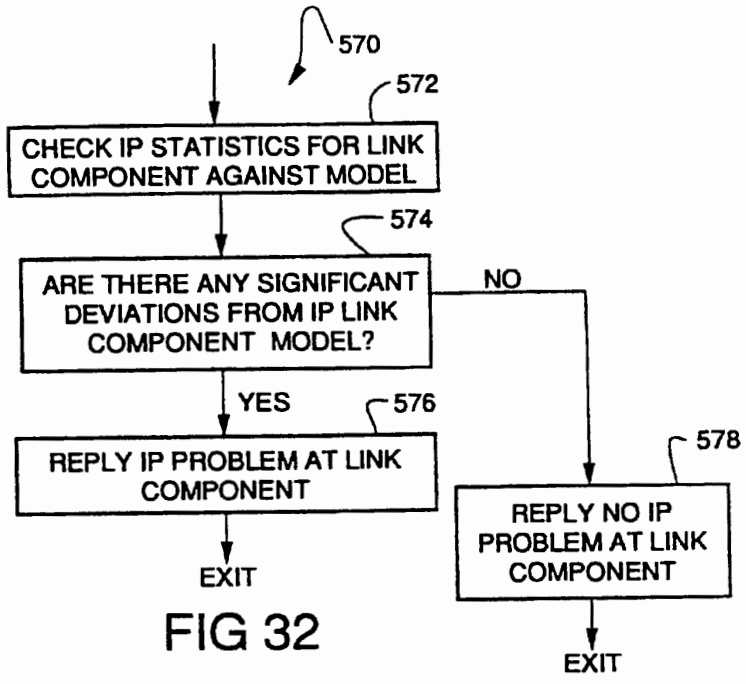

570
572
CHECK IP STATISTICS FOR LINK COMPONENT AGAINST MODEL
574
ARE THERE ANY SIGNIFICANT DEVIATIONS FROM IP LINK COMPONENT MODEL?
NO
YES
576
REPLY IP PROBLEM AT LINK COMPONENT
EXIT
578
REPLY NO IP PROBLEM AT LINK COMPONENT
EXIT

FIG 32

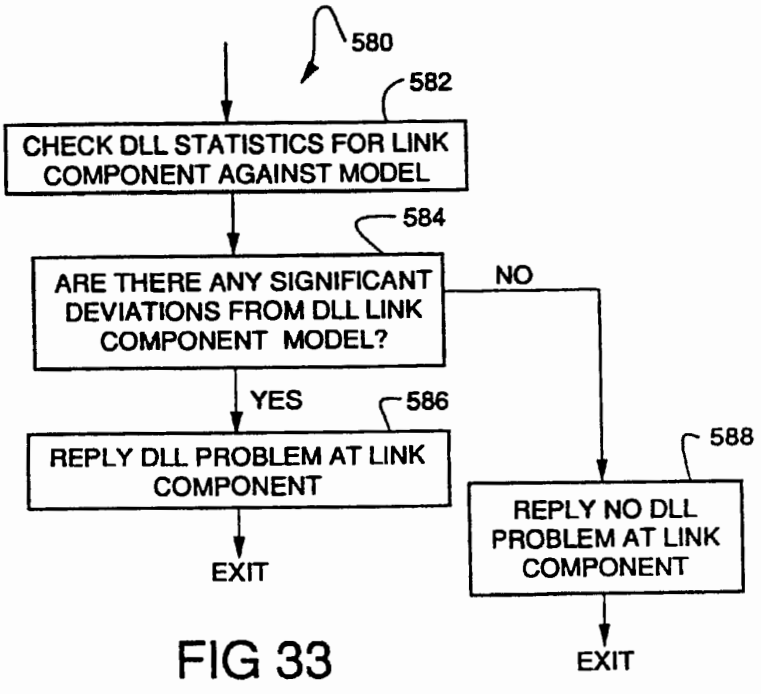

580
582
CHECK DLL STATISTICS FOR LINK COMPONENT AGAINST MODEL
584
ARE THERE ANY SIGNIFICANT DEVIATIONS FROM DLL LINK COMPONENT MODEL?
NO
YES
586
REPLY DLL PROBLEM AT LINK COMPONENT
EXIT
588
REPLY NO DLL PROBLEM AT LINK COMPONENT
EXIT

FIG 33

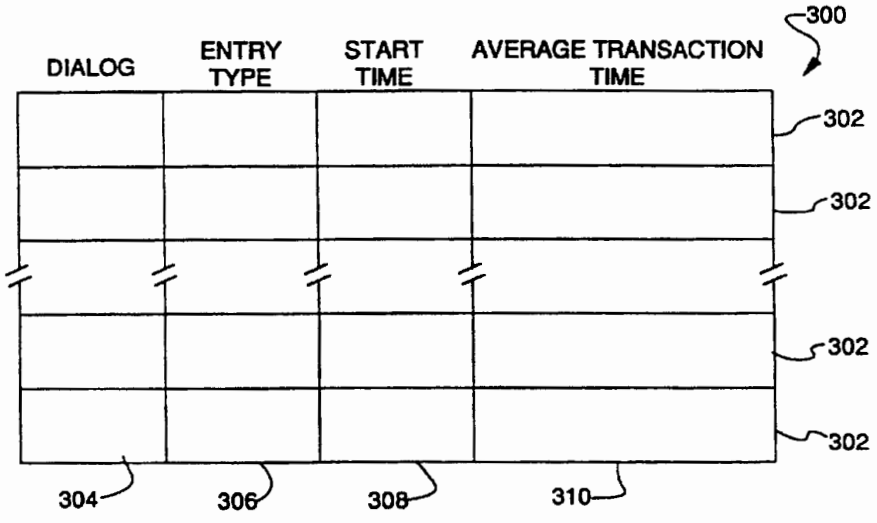

300
DIALOG
ENTRY TYPE
START TIME
AVERAGE TRANSACTION TIME
302
302
302
302
304
306
308
310

FIG 34

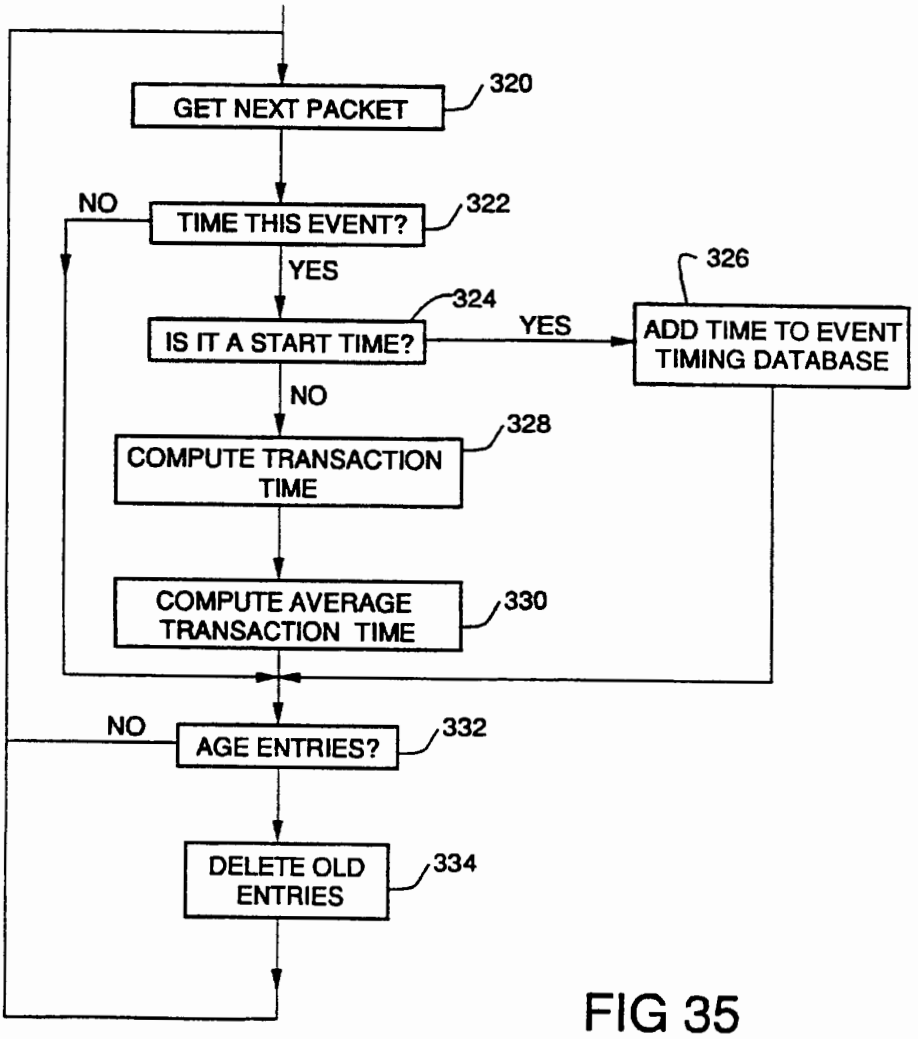

GET NEXT PACKET
320
NO
TIME THIS EVENT?
322
YES
326
IS IT A START TIME?
324
YES
ADD TIME TO EVENT TIMING DATABASE
NO
COMPUTE TRANSACTION TIME
328
COMPUTE AVERAGE TRANSACTION TIME
330
NO
AGE ENTRIES?
332
DELETE OLD ENTRIES
334

FIG 35

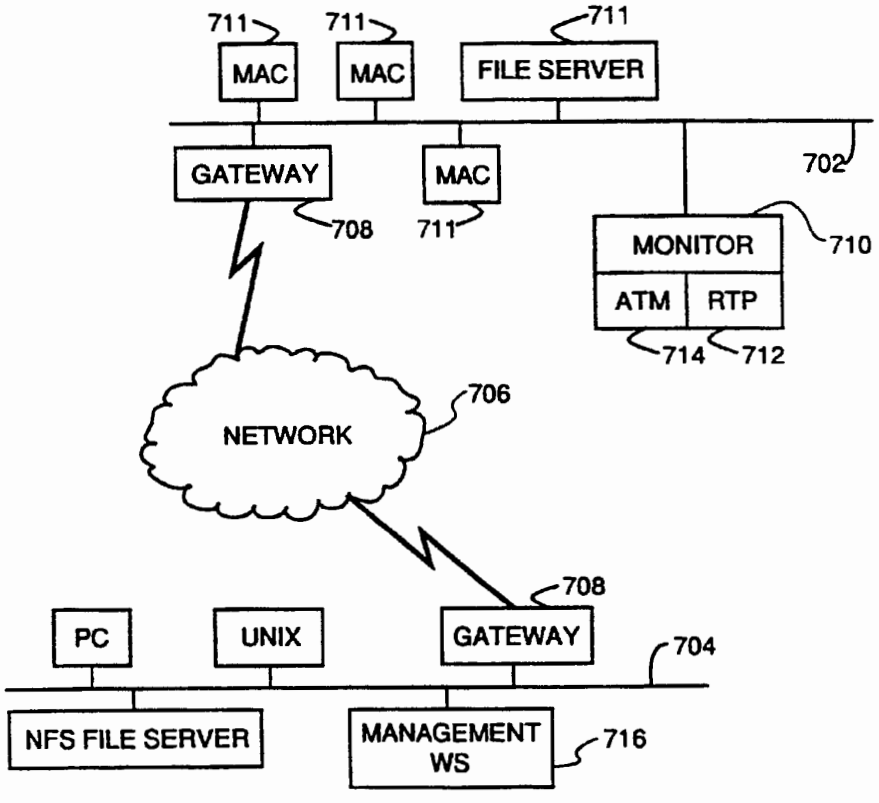

711
711
711
MAC
MAC
FILE SERVER
GATEWAY
MAC
702
708
711
MONITOR
710
ATM
RTP
714
712
NETWORK
706
708
PC
UNIX
GATEWAY
704
NFS FILE SERVER
MANAGEMENT WS
716

FIG 36

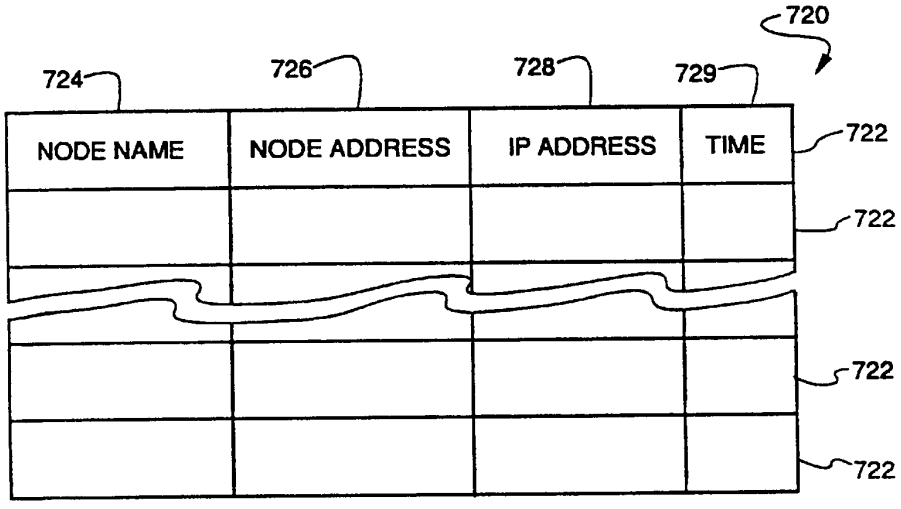

720
724
726
728
729
NODE NAME
NODE ADDRESS
IP ADDRESS
TIME
722
722
722
722

FIG 37

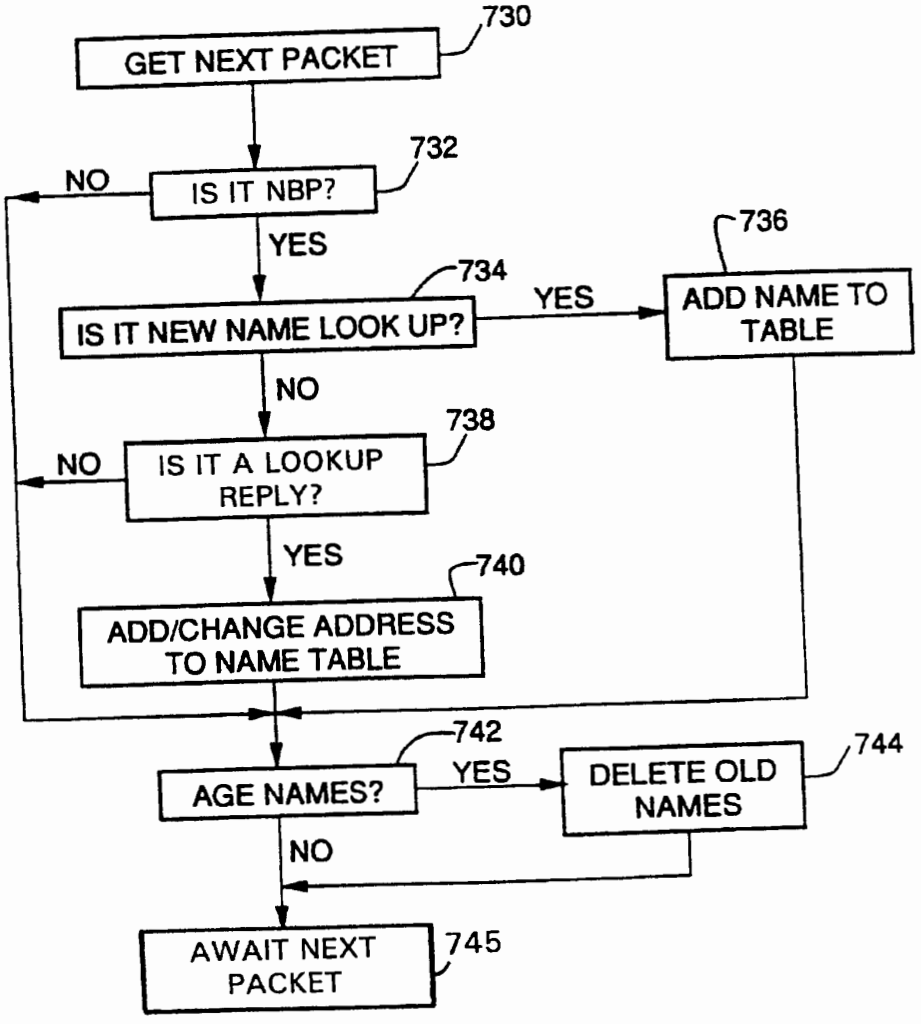

730
GET NEXT PACKET
732
NO
IS IT NBP?
YES
736
734
YES
IS IT NEW NAME LOOK UP?
ADD NAME TO TABLE
NO
738
NO
IS IT A LOOKUP REPLY?
YES
740
ADD/CHANGE ADDRESS TO NAME TABLE
742
744
AGE NAMES?
YES
DELETE OLD NAMES
NO
AWAIT NEXT PACKET
745

FIG 38

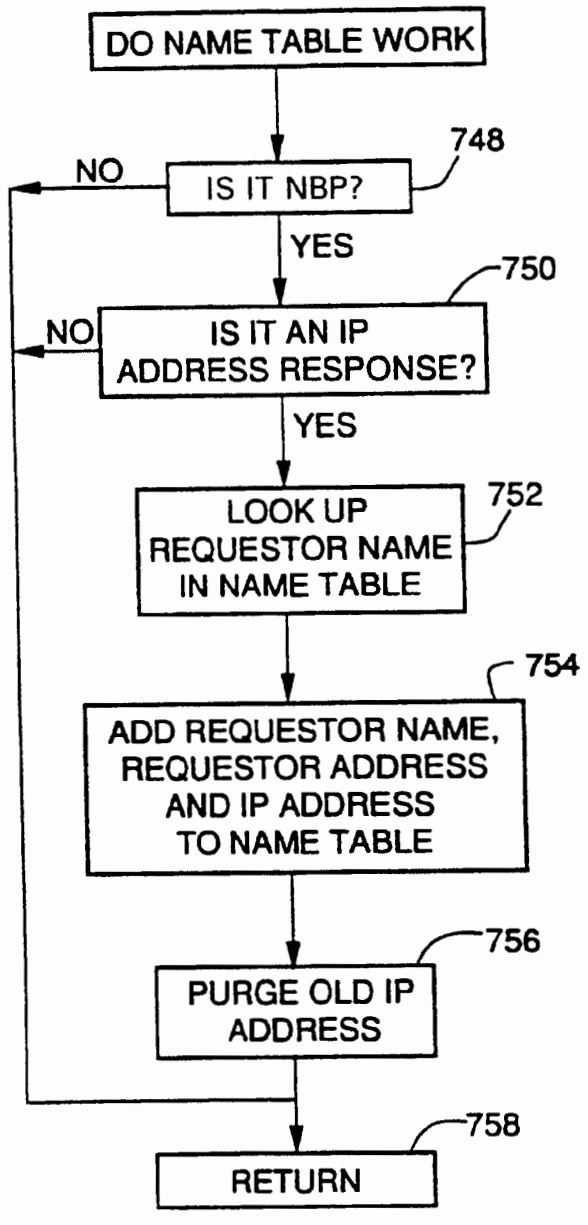

DO NAME TABLE WORK
748
NO
IS IT NBP?
YES
750
NO
IS IT AN IP ADDRESS RESPONSE?
YES
752
LOOK UP REQUESTOR NAME IN NAME TABLE
754
ADD REQUESTOR NAME, REQUESTOR ADDRESS AND IP ADDRESS TO NAME TABLE
756
PURGE OLD IP ADDRESS
758
RETURN

FIG 39

NETWORK MONITORING

CROSS REFERENCE TO RELATED APPLICATION

This is a divisional of application Ser. No. 07/761,269 filed on Sep. 17, 1991, now abandoned, which is a continuation-in-part of U.S. patent application, Ser. No. 07/684,695, filed Apr. 12, 1991, now abandoned.

REFERENCE TO MICROFICHE APPENDIX

A Microfiche Appendix containing fourteen microfiche accompanies this patent application pursuant to 37 CFR §1.96(b) and is designated as Appendix VI. The first thirteen microfiche each contain 49 frames and the fourteenth microfiche contains 18 frames.

BACKGROUND OF THE INVENTION

The invention relates to monitoring and managing communication networks for computers.

Today's computer networks are large complex systems with many components from a large variety of vendors. These networks often span large geographic areas ranging from a campus-like setting to world wide networks. While the network itself can be used by many different types of organizations, the purpose of these networks is to move information between computers. Typical applications are electronic mail, transaction processing, remote database, query, and simple file transfer. Usually, the organization that has installed and is running the network needs the network to be running properly in order to operate its are various controls provided by the different equipment to control and manage the network. Network management is the task of planning, engineering, securing and operating a network.

To manage the network properly, the Network Manager has some obvious needs. First, the Network Manager must trouble shoot problems. As the errors develop in a running network, the Network Manager must have some tools that notify him of the errors and allow him to diagnose and repair these errors. Second, the Network Manager needs to configure the network in such a manner that the network loading characteristics provide the best service possible for the network users. To do this the Network Manager must have tools that allow him visibility into access patterns, bottlenecks and general loading. With such data, the Network Manager can reconfigure the network components for better service.

There are many different components that need to be managed in the network. These elements can be, but are not limited to: routers, bridges, PC's, workstations, minicomputers, supercomputers, printers, file servers, switches and pbx's. Each component provides a protocol for reading and writing the management variables in the machine. These variables are usually defined by the component vendor and are usually referred to as a Management Information Base (MIB). There are some standard MIB's, such as the IETF (Internet Engineering Task Force) MIB I and MIB II standard definitions. Through the reading and writing of MIB variables, software in other computers can manage or control the component. The software in the component that provides remote access to the MIB variables is usually called an agent. Thus, an individual charged with the responsibility of managing a large network often will use various tools to manipulate the MIB's of various agents on the network.

Unfortunately, the standards for accessing MIBs are not yet uniformly provided nor are the MIB definitions complete

enough to manage an entire network. The Network Manager must therefore use several different types of computers to access the agents in the network. This poses a problem, since the errors occurring on the network will tend to show up in different computers and the Network Manager must therefore monitor several different screens to determine if the network is running properly. Even when the Network Manager is able to accomplish this task, the tools available are not sufficient for the Network Manager to function properly.

Furthermore, there are many errors and loadings on the network that are not reported by agents. Flow control problems, retransmissions, on-off segment loading, network capacities and utilizations are some of the types of data that are not provided by the agents. Simple needs like charging each user for actual network usage are impossible.

SUMMARY OF THE INVENTION

In general, in one aspect, the invention features monitoring communications which occur in a network of nodes, each communication being effected by a transmission of one or more packets among two or more communicating nodes, each communication complying with a predefined communication protocol selected from among protocols available in the network. The contents of packets are detected passively and in real time, communication information associated with multiple protocols is derived from the packet contents.

Preferred embodiments of the invention include the following features. The communication information derived from the packet contents is associated with multiple layers of at least one of the protocols.

In general, in another aspect, the invention features monitoring communication dialogs which occur in a network of nodes, each dialog being effected by a transmission of one or more packets among two or more communicating nodes, each dialog complying with a predefined communication protocol selected from among protocols available in the network. Information about the states of dialogs occurring in the network and which comply with different selected protocols available in the network is derived from the packet contents.

Preferred embodiments of the invention include the following features. A current state is maintained for each dialog, and the current state is updated in response to the detected contents of transmitted packets. For each dialog, a history of events is maintained based on information derived from the contents of packets, and the history of events is analyzed to derive information about the dialog. The analysis of the history includes counting events and gathering statistics about events. The history is monitored for dialogs which are inactive, and dialogs which have been inactive for a predetermined period of time are purged. For example, the current state is updated to data state in response to observing the transmission of at least two data related packets from each node. Sequence numbers of data related packets stored in the history of events are analyzed and retransmissions are detected based on the sequence numbers. The current state is updated based on each new packet associated with the dialog; if an updated current state cannot be determined, information about prior packets associated with the dialog is consulted as an aid in updating the state. The history of events may be searched to identify the initiator of a dialog.

The full set of packets associated with a dialog up to a point in time completely define a true state of the dialog at that point in time, and the step of updating the current state in response to the detected contents of transmitted packets includes generating a current state (e.g., "unknown") which

FIG. 14 is a diagram of the major steps in the processing a statistics threshold event;

FIG. 15 is a diagram of the major steps in the processing of a database update;

FIG. 16 is a diagram of the major steps in the processing of a monitor control request;

FIG. 17 is a logical map of the network as displayed by the Management Workstation;

FIG. 18 is a basic summary tool display screen;

FIG. 19 is a protocol selection menu that may be invoked through the summary tool display screen;

FIGS. 20*a–g* are examples of the statistical variables which are displayed for different protocols;

FIG. 21 is an example of information that is displayed in the dialogs panel of the summary tool display screen;

FIG. 22 is a basic data screen presenting a rate values panel, a count values panel and a protocols seen panel;

FIG. 23 is a traffic matrix screen;

FIG. 24 is a flow diagram of the algorithm for adaptively establishing network thresholds based upon actual network performance;

FIG. 25 is a simple multi-segment network;

FIG. 26 is a flow diagram of the operation of the diagnostic analyzer algorithm;

FIG. 27 is a flow diagram of the source node analyzer algorithm;

FIG. 28 is a flow diagram of the sink node analyzer algorithm;

FIG. 29 is a flow diagram of the link analysis logic;

FIG. 30 is a flow diagram of the DLL problem checking routine;

FIG. 31 is a flow diagram of the IP problem checking routine;

FIG. 32 is a flow diagram of the IP link component problem checking routine;

FIG. 33 is a flow diagram of the DLL link component problem checking routine;

FIG. 34 shows the structure of the event timing database;

FIG. 35 is a flow diagram of the operation of the event timing module (ETM) in the Network Monitor;

FIG. 36 is a network which includes an Appletalk® segment;

FIG. 37 is a Name Table that is maintained by the Address Tracking Module (ATM);

FIG. 38 is a flow diagram of the operation of the ATM; and

FIG. 39 is a flow diagram of the operation of the ATM.

Also attached hereto before the claims are the following appendices:

Appendix I identifies the SNMP MIB subset that is supported by the Monitor and the Management Workstation (2 pages);

Appendix II defines the extension to the standard MIB that are supported by the Monitor and the Management Workstation (25 pages);

Appendix III is a summary of the protocol variables for which the Monitor gathers statistics and a brief description of the variables, where appropriate (17 pages);

Appendix IV is a list of the Summary Tool Values Display Fields with brief descriptions (2 pages); and

Appendix V is a description of the actual screens for the Values Tool (34 pages).

Appendix VI is a microfiche appendix presenting source code for the real time parser, the statistics data structures and the statistics modules.

Structure and Operation

The Network:

A typical network, such as the one shown in FIG. 1, includes at least three major components, namely, network nodes 2, network elements 4 and communication lines 6. Network nodes 2 are the individual computers on the network. They are the very reason the network exists. They include but are not limited to workstations (WS), personal computers (PC), file servers (FS), compute servers (CS) and host computers (e.g., a VAX), to name but a few. The term server is often used as though it was different from a node, but it is, in fact, just a node providing special services.

In general, network elements 4 are anything that participate in the service of providing data movement in a network, i.e., providing the basic communications. They include, but are not limited to, LAN's, routers, bridges, gateways, multiplexors, switches and connectors. Bridges serve as connections between different network segments. They keep track of the nodes which are connected to each of the segments to which they are connected. When they see a packet on one segment that is addressed to a node on another of their segments, they grab the packet from the one segment and transfer it to the proper segment. Gateways generally provide connections between different network segments that are operating under different protocols and serve to convert communications from one protocol to the other. Nodes send packets to routers so that they may be directed over the appropriate segments to the intended destination node.

Finally, network or communication lines 6 are the components of the network which connect nodes 2 and elements 4 together so that communications between nodes 2 may take place. They can be private lines, satellite lines or Public Carrier lines. They are expensive resources and are usually managed as separate entities. Often networks are organized into segments 8 that are connected by network elements 4. A segment 8 is a section of a LAN connected at a physical level (this may include repeaters). Within a segment, no protocols at layers above the physical layer are needed to enable signals from two stations on the same segment to reach each other (i.e., there are no routers, bridges, gateways . . .).

The Network Monitor and the Management Workstation:

In the described embodiment, there are two basic elements to the monitoring system which is to be described, namely, a Network Monitor 10 and a Management Workstation 12. Both elements interact with each other over the local area network (LAN).

Network Monitor 10 (referred to hereinafter simply as Monitor 10) is the data collection module which is attached to the LAN. It is a high performance real time front end processor which collects packets on the network and performs some degree of analysis to search for actual or potential problems and to maintain statistical information for use in later analysis. In general, it performs the following functions. It operates in a promiscuous mode to capture and analyze all packets on the segment and it extracts all items of interest from the frames. It generates alarms to notify the Management Workstation of the occurrence of significant events. It receives commands from the Management Workstation, processes them appropriately and returns responses.

Management Workstation 12 is the operator interface. It collects and presents troubleshooting and performance infor-

mation to the user. It is based on the SunNet Manager (SNM) product and provides a graphical network-map-based interface and sophisticated data presentation and analysis tools. It receives information from Monitor **10**, stores it and displays the information in various ways. It also instructs Monitor **10** to perform certain actions. Monitor **10**, in turn, sends responses and alarms to Management Workstation **12** over either the primary LAN or a backup serial link **14** using SNMP with the MIB extensions defined later.

These devices can be connected to each other over various types of networks and are not limited to connections over a local area network. As indicated in FIG. **1**, there can be multiple Workstations **12** as well as multiple Monitors **10**.

Before describing these components in greater detail, background information will first be reviewed regarding communication protocols which specify how communications are conducted over the network and regarding the structure of the packets.

The Protocol Tree:

As shown in FIG. **2**, communication over the network is organized as a series of layers or levels, each one built upon the next lower one, and each one specified by one or more protocols (represented by the boxes). Each layer is responsible for handling a different phase of the communication between nodes on the network. The protocols for each layer are defined so that the services offered by any layer are relatively independent of the services offered by the neighbors above and below. Although the identities and number of layers may differ depending on the network (i.e., the protocol set defining communication over the network), in general, most of them share a similar structure and have features in common.

For purposes of the present description, the Open Systems Interconnection (OSI) model will be presented as representative of structured protocol architectures. The OSI model, developed by the International Organization for Standardization, includes seven layers. As indicated in FIG. **2**, there is a physical layer, a data link layer (DLL), a network layer, a transport layer, a session layer, a presentation layer and an application layer, in that order. As background for what is to follow, the function of each of these layers will be briefly described.

The physical layer provides the physical medium for the data transmission. It specifies the electrical and mechanical interfaces of the network and deals with bit level detail. The data link layer is responsible for ensuring an error-free physical link between the communicating nodes. It is responsible for creating and recognizing frame boundaries (i.e., the boundaries of the packets of data that are sent over the network.) The network layer determines how packets are routed within the network. The transport layer accepts data from the layer above it (i.e., the session layer), breaks the packets up into smaller units, if required, and passes these to the network layer for transmission over the network. It may insure that the smaller pieces all arrive properly at the other end. The session layer is the user's interface into the network. The user must interface with the session layer in order to negotiate a connection with a process in another machine. The presentation layer provides code conversion and data reformatting for the user's application. Finally, the application layer selects the overall network service for the user's application.

FIG. **2** also shows the protocol tree which is implemented by the described embodiment. A protocol tree shows the protocols that apply to each layer and it identifies by the tree structure which protocols at each layer can run "on top of" the protocols of the next lower layer. Though standard abbreviations are used to identify the protocols, for the convenience of the reader, the meaning of the abbreviations are as follows:

ARP	Address Resolution Protocol
ETHERNET	Ethernet Data Link Control
FTP	File Transfer Protocol
ICMP	Internet Control Message Protocol
IP	Internet Protocol
LLC	802.2 Logical Link Control
MAC	802.3 CSMA/CD Media Access Control
NFS	Network File System
NSP	Name Server Protocol
RARP	Reverse Address Resolution Protocol
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
TCP	Transmission Control Protocol
TFTP	Trivial File Transfer Protocol
UDP	User Datagram Protocol

Two terms are commonly used to describe the protocol tree, namely, a protocol stack and a protocol family (or suite). A protocol stack generally refers to the underlying protocols that are used when sending a message over a network. For example, FTP/TCP/IP/LLC is a protocol stack. A protocol family is a loose association of protocols which tend to be used on the same network (or derive from a common source). Thus, for example, the TCP/IP family includes IP, TCP, UDP, ARP, TELNET and FTP. The Decnet family includes the protocols from Digital Equipment Corporation. And the SNA family includes the protocols from IBM.

The Packet:

The relevant protocol stack defines the structure of each packet that is sent over the network. FIG. **3**, which shows an TCP/IP packet, illustrates the typical structure of a packet. In general, each level of the protocol stack takes the data from the next higher level and adds header information to form a protocol data unit (PDU) which it passes to the next lower level. That is, as the data from the application is passed down through the protocol layers in preparation for transmission over the network, each layer adds its own information to the data passed down from above until the complete packet is assembled. Thus, the structure of a packet resembles that of an onion, with each PDU of a given layer wrapped within the PDU of the adjacent lower level.

At the ethernet level, the PDU includes a destination address (DEST MAC ADDR), a source address (SRC MAC ADDR), a type (TYPE) identifying the protocol which is running on top of this layer, and a DATA field for the PDU from the IP layer.

Like the ethernet packet, the PDU for the IP layer includes an IP header plus a DATA field. The IP header includes a type field (TYPE) for indicating the type of service, a length field (LGTH) for specifying the total length of the PDU, an identification field (ID), a protocol field (PROT) for identifying the protocol which is running on top of the IP layer (in this case, TCP), a source address field (SRC ADDR) for specifying the IP address of the sender, a destination address field (DEST ADDR) for specifying the IP address of the destination node, and a DATA field.

The PDU built by the TCP protocol also consists of a header and the data passed down from the next higher layer. In this case the header includes a source port field (SRC PORT) for specifying the port number of the sender, a destination port field (DEST PORT) for specifying the port number of the destination, a sequence number field (SEQ NO.) for specifying the sequence number of the data that is being sent in this packet, and an acknowledgment number

field (ACK NO.) for specifying the number of the acknowledgment being returned. It also includes bits which identify the packet type, namely, an acknowledgment bit (ACK), a reset connection bit (RST), a synchronize bit (SYN), and a no more data from sender bit (FIN). There is also a window size field (WINDOW) for specifying the size of the window being used.

The Concept of a Dialog:

The concept of a dialog is used throughout the following description. As will become apparent, it is a concept which provides a useful way of conceptualizing, organizing and displaying information about the performance of a network—for any protocol and for any layer of the multi-level protocol stack.

As noted above, the basic unit of information in communication is a packet. A packet conveys meaning between the sender and the receiver and is part of a larger framework of packet exchanges. The larger exchange is called a dialog within the context of this document. That is, a dialog is a communication between a sender and a receiver, which is composed of one or more packets being transmitted between the two. There can be multiple senders and receivers which can change roles. In fact, most dialogs involve exchanges in both directions.

Stated another way, a dialog is the exchange of messages and the associated meaning and state that is inherent in any particular exchange at any layer. It refers to the exchange between the peer entities (hardware or software) in any communication. In those situations where there is a layering of protocols, any particular message exchange could be viewed as belonging to multiple dialogs. For example, in FIG. 4 Nodes A and B are exchanging packets and are engaged in multiple dialogs. Layer 1 in Node A has a dialog with Layer 1 in Node B. For this example, one could state that this is the data link layer and the nature of the dialog deals with the message length, number of messages, errors and perhaps the guarantee of the delivery. Simultaneously, Layer n of Node A is having a dialog with Layer n of node B. For the sake of the example, one could state that this is an application layer dialog which deals with virtual terminal connections and response rates. One can also assume that all of the other layers (2 through n-1) are also having simultaneous dialogs.

In some protocols there are explicit primitives that deal with the dialog and they are generally referred to as connections or virtual circuits. However, dialogs exist even in stateless and connectionless protocols. Two more examples will be described to help clarify the concept further, one dealing with a connection oriented protocol and the other dealing with a connectionless protocol.

In a typical connection oriented protocol, Node A sends a connection request (CR) message to Node B. The CR is an explicit request to form a connection. This is the start of a particular dialog, which is no different from the start of the connection. Nodes A and B could have other dialogs active simultaneously with this particular dialog. Each dialog is seen as unique. A connection is a particular type of dialog.

In a typical connectionless protocol, Node A sends Node B a message that is a datagram which has no connection paradigm, in fact, neither do the protocol(s) at higher layers. The application protocol designates this as a request to initiate some action. For example, a file server protocol such as Sun Microsystems' Network File System (NFS) could make a mount request. A dialog comes into existence once the communication between Nodes A and B has begun. It is possible to determine that communication has occurred and to determine the actions being requested. If in fact there exists more than one communication thread between Nodes A and B, then these would represent separate, different dialogs.

Inside the Network Monitor:

Monitor **10** includes a MIPS R3000 general purpose microprocessor (from MIPS Computer Systems, Inc.) running at 25 MHz. It is capable of providing 20 mips processing power. Monitor **10** also includes a 64Kbyte instruction cache and a 64Kbyte data cache, implemented by SRAM.

The major software modules of Monitor **10** are implemented as a mixture of tasks and subroutine libraries as shown in FIG. **5**. It is organized this way so as to minimize the context switching overhead incurred during critical processing sequences. There is NO PREEMPTION of any module in the monitor subsystem. Each module is cognizant of the fact that it should return control to the kernel in order to let other tasks run. Since the monitor subsystem is a closed environment, the software is aware of real time constraints.

Among the major modules which make up Monitor **10** is a real time kernel **20**, a boot/load module **22**, a driver **24**, a test module **26**, an SNMP Agent **28**, a Timer module **30**, a real time parser (RTP) **32**, a Message Transport Module (MTM) **34**, a statistics database (STATS) **36**, an Event Manager (EM) **38**, an Event Timing Module (ETM) **40** and a control module **42**. Each of these will now be described in greater detail.

Real Time Kernel **20** takes care of the general housekeeping activities in Monitor **10**. It is responsible for scheduling, handling intertask communications via queues, managing a potentially large number of timers, manipulating linked lists, and handling simple memory management.

Boot/Load Module **22**, which is FProm based, enables Monitor **10** to start itself when the power is turned on in the box. It initializes functions such as diagnostics, and environmental initialization and it initiates down loading of the Network Monitor Software including program and configuration files from the Management Workstation. Boot/load module **22** is also responsible for reloading program and/or configuration data following internal error detection or on command from the Management Workstation. To accomplish down loading, boot/load module **22** uses the Trivial File Transfer Protocol (TFTP). The protocol stack used for loading is TFTP/UDP/IP/ethernet over the LAN and TFTP/UDP/IP/SLIP over the serial line.

Device Driver **24** manages the network controller hardware so that Monitor **10** is able to read and write packets from the network and it manages the serial interface. It does so both for the purposes of monitoring traffic (promiscuous mode) and for the purposes of communicating with the Management Workstation and other devices on the network. The communication occurs through the network controller hardware of the physical network (e.g. Ethernet). The drivers for the LAN controller and serial line interface are used by the boot load module and the MTM. They provide access to the chips and isolate higher layers from the hardware specifics.

Test module **26** performs and reports results of physical layer tests (TDR, connectivity, . . .) under control of the Management Workstation. It provides traffic load information in response to user requests identifying the particular traffic data of interest. The load information is reported either as a percent of available bandwidth or as frame size(s) plus rate.

SNMP Agent **28** translates requests and information into the network management protocol being used to communicate with the Management Workstation, e.g., the Simple Network Management Protocol (SNMP).

Control Module **42** coordinates access to monitor control variables and performs actions necessary when these are altered. Among the monitor control variables which it handles are the following:

set reset monitor—transfer control to reset logic;

set time of day—modify monitor hardware clock and generate response to Management Workstation;

get time of day—read monitor hardware clock and generate response to Workstation;

set trap permit—send trap control ITM to EM and generate response to Workstation;

get trap permit—generate response to Workstation;

Control module **42** also updates parse control records within STATS when invoked by the RTP (to be described) or during overload conditions so that higher layers of parsing are dropped until the overload situation is resolved. When overload is over it restores full parsing.

Timer **30** is invoked periodically to perform general housekeeping functions. It pulses the watchdog timer at appropriate intervals. It also takes care of internal time stamping and kicking off routines like the EM routine which periodically recalculates certain numbers within the statistical database (i.e., STATS).

Real Time Parser (RTP) **32** sees all frames on the network and it determines which protocols are being used and interprets the frames. The RTP includes a protocol parser and a state machine. The protocol parser parses a received frame in the "classical" manner, layer-by-layer, lowest layer first. The parsing is performed such that the statistical objects in STATS (i.e., the network parameters for which performance data is kept) are maintained. Which layers are to have statistics stored for them is determined by a parse control record that is stored in STATS (to be described later). As each layer is parsed, the RTP invokes the appropriate functions in the statistics module (STATS) to update those statistical objects which must be changed.

The state machine within RTP **32** is responsible for tracking state as appropriate to protocols and connections. It is responsible for maintaining and updating the connection oriented statistical elements in STATS. In order to track connection states and events, the RTP invokes a routine within the state machine. This routine determines the state of a connection based on past observed frames and keeps track of sequence numbers. It is the routine that determines if a connection is in data transfer state and if a retransmission has occurred. The objectives of the state machine are to keep a brief history of events, state transitions, and sequence numbers per connection; to detect data transfer state so that sequence tracking can begin; and to count inconsistencies but still maintain tracking while falling into an appropriate state (e.g. unknown).

RTP **32** also performs overload control by determining the number of frames awaiting processing and invoking control module **42** to update the parse control records so as to reduce the parsing depth when the number becomes too large.

Statistics Module (STATS) **36** is where Monitor **10** keeps information about the statistical objects it is charged with monitoring. A statistical object represents a network parameter for which performance information is gathered. This information is contained in an extended MIB (Management Information Base), which is updated by RTP **32** and EM **38**.

STATS updates statistical objects in response to RTP invocation. There are at least four statistical object classes, namely, counters, timers, percentages (%), and meters. Each statistical object is implemented as appropriate to the object class to which it belongs. That is, each statistical object behaves such that when invoked by RTP **32** it updates and then generates an alarm if its value meets a preset threshold. (Meets means that for a high threshold the value is equal to or greater than the threshold and for a low threshold the value is equal to or less than the threshold. Note that a single object may have both high and low thresholds.)

STATS **36** is responsible for the maintenance and initial analysis of the database. This includes coordinating access to the database variables, ensuring appropriate interlocks are applied and generating alarms when thresholds are crossed. Only STATS **36** is aware of the internal structure of the database, the rest of the system is not.

STATS **36** is also responsible for tracking events of interest in the form of various statistical reductions. Examples are counters, rate meters, and rate of change of rate meters. It initiates events based on particular statistics reaching configured limits, i.e., thresholds. The events are passed to the EM which sends a trap (i.e., an alarm) to the Management Workstation. The statistics within STATS **36** are readable from the Management Workstation on request.

STATS performs lockup on all addressing fields. It assigns new data structures to address field values not currently present. It performs any hashing for fast access to the database. More details will be presented later in this document.

Event Manager (EM) **38** extracts statistics from STATS and formats it in ways that allow the Workstation to understand it. It also examines the various statistics to see if their behavior warrants a notification to the Management Workstation. If so, it uses the SNMP Agent software to initiate such notifications.

If the Workstation asks for data, EM **38** gets the data from STATS and sends it to the Workstation. It also performs some level of analysis for statistical, accounting and alarm filtering and decides on further action (e.g. delivery to the Management Workstation). EM **38** is also responsible for controlling the delivery of events to the Management Workstation, e.g., it performs event filtering. The action to be taken on receipt of an event (e.g. threshold exceeded in STATS) is specified by the event action associated with the threshold. The event is used as an index to select the defined action (e.g. report to Workstation, run local routine xxxx, ignore). The action can be modified by commands from the Management Workstation (e.g., turn off an alarm) or by the control module in an overload situation. An update to the event action, however, does not affect events previously processed even if they are still waiting for transmission to the Management Workstation. Discarded events are counted as such by EM **38**.

EM **38** also implements a throttle mechanism to limit the rate of delivery of alarms to the console based on configured limits. This prevents the rapid generation of multiple alarms. In essence, Monitor **10** is given a maximum frequency at which alarms may be sent to the Workstation. Although alarms in excess of the maximum frequency are discarded, a count is kept of the number of alarms that were discarded.

EM **38** invokes routines from the statistics module (STATS) to perform periodic updates such as rate calculations and threshold checks. It calculates time averages, e.g., average traffic by source stations, destination stations. EM **38** requests for access to monitor control variables are passed to the control module.

EM **38** checks whether asynchronous traps (i.e., alarms) to the Workstation are permitted before generating any.

EM **38** receives database update requests from the Management Workstation and invokes the statistics module (STATS) to process these.

Message Transport Module (MTM) **34**, which is DRAM based, has two distinct but closely related functions. First, it is responsible for the conversion of Workstation commands and responses from the internal format used within Monitor **10** to the format used to communicate over the network. It isolates the rest of the system from the protocol used to communicate within Management Workstation. It translates between the internal representation of data and ASN.1 used for SNMP. It performs initial decoding of Workstation requests and directs the requests to appropriate modules for processing. It implements SNMP/UDP/IP/LLC or ETHERNET protocols for LAN and SNMP/UDP/IP/SLIP protocols for serial line. It receives network management commands from the Management Workstation and delivers these to the appropriate module for action. Alarms and responses destined for the Workstation are also directed via this module.

Second, MTM **34** is responsible for the delivery and reception of data to and from the Management Workstation using the protocol appropriate to the network. Primary and backup communication paths are provided transparently to the rest of the monitor modules (e.g. LAN and dial up link). It is capable of full duplex delivery of messages between the console and monitoring module. The messages carry event, configuration, test and statistics data.

Event Timing Module (ETM) **40** keeps track of the start time and end times of user specified transactions over the network. In essence, this module monitors the responsiveness of the network at any protocol or layer specified by the user.

Address Tracking Module **42** keeps track of the node name to node address bindings on networks which implement dynamic node addressing protocols.

Memory management for Monitor **10** is handled in accordance with following guidelines. The available memory is divided into four blocks during system initialization. One block includes receive frame buffers. They are used for receiving LAN traffic and for receiving secondary link traffic. These are organized as linked lists of fixed sized buffers. A second block includes system control message blocks. They are used for intertask messages within Monitor and are organized as a linked list of free blocks and multiple linked lists of in process intertask messages. A third block includes transmit buffers. They are used for creation and transmission of workstation alarms and responses and are organized as a linked list of fixed sized buffers. A fourth block is the statistics. This is allocated as a fixed size area at system initialization and managed by the statistics module during system operation.

Task Structure of Monitor;

The structure of the Monitor in terms of tasks and intertask messages is shown in FIG. **6**. The rectangular blocks represent interrupt service routines, the ovals represent tasks and the circles represent input queues.

Each task in the system has a single input queue which it uses to receive all input. All inter-process communications take place via messages placed onto the input queue of the destination task. Each task waits on a (well known) input queue and processes events or inter-task messages (i.e., ITM's) as they are received. Each task returns to the kernel within an appropriate time period defined for each task (e.g. after processing a fixed number of events).

Interrupt service routines (ISR's) run on receipt of hardware generated interrupts. They invoke task level processing by sending an ITM to the input queue of the appropriate task.

The kernel scheduler acts as the base loop of the system and calls any runnable tasks as subroutines. The determination of whether a task is runnable is made from the input queue, i.e., if this has an entry the task has work to perform. The scheduler scans the input queues for each task in a round robin fashion and invokes a task with input pending. Each task processes items from its input queue and returns to the scheduler within a defined period. The scheduler then continues the scan cycle of the input queues. This avoids any task locking out others by processing a continuously busy input queue. A task may be given an effectively higher priority by providing it with multiple entries in the scan table.

Database accesses are generally performed using access routines. This hides the internal structure of the database from other modules and also ensures that appropriate interlocks are applied to shared data.

The EM processes a single event from the input queue and then returns to the scheduler.

The MTM Xmit task processes a single event from its input queue and then returns control to the scheduler. The MTM Recv task processes events from the input queue until it is empty or a defined number (e.g. 10) events have been processed and then returns control to the scheduler.

The timer task processes a single event from the input queue and then returns control to the scheduler.

RTP continues to process frames until the input queue is empty or it has processed a defined number (e.g. 10) frames. It then returns to the scheduler.

The following sections contain a more detailed description of some of the above-identified software modules.

The Statistics Module (STATS):

The functions of the statistics module are:

- to define statistics records;
- to allocate and initialize statistics records;
- to provide routines to lookup statistics records, e.g. lookup_id_addr;
- to provide routines to manipulate the statistics within the records, e.g. stats_age, stats_incr and stats_rate;
- to provide routines to free statistics records, e.g. stats_allocate and stats_deallocate

It provides these services to the Real Time Parser (RTP) module and to the Event Manager (EM) module.

STATS defines the database and it contains subroutines for updating the statistics which it keeps.

STATS contains the type definitions for all statistics records (e.g. DLL, IP, TCP statistics). It provides an initialization routine whose major function is to allocate statistics records at startup from cacheable memory. It provides lookup routines in order to get at the statistics. Each type of statistics record has its own lookup routine (e.g. lookup_ip_address) which returns a pointer to a statistics record of the appropriate type or NULL.

As a received frame is being parsed, statistics within statistics records need to be manipulated (e.g. incremented) to record relevant information about the frame. STATS provides the routines to manipulate those statistics. For example, there is a routine to update counters. After the counter is incremented/decremented and if there is a non-zero threshold associated with the counter, the internal routine compares its value to the threshold. If the threshold has been exceeded, the Event Manager is signaled in order to send a trap to the Workstation. Besides manipulating statistics, these routines, if necessary, signal the Event Manager via an Intertask Message (ITM) to send a trap to the Management Workstation.

The following is an example of some of the statistics records that are kept in STATS.

- o monitor statistics
- o mac statistics for segment
- o llc statistics for segment
- o statistics per ethernet/lsap type for segment
- o ip statistics for segment
- o icmp statistics for segment
- o tcp statistics for segment
- o udp statistics for segment
- o nfs statistics for segment
- o ftp control statistics for segment
- o ftp data statistics for segment
- o telnet statistics for segment
- o smtp statistics for segment
- o arp statistics for segment
- o statistics per mac address
- o statistics per ethernet type/lasp per mac address
- o statistics per ip address (includes icmp)
- o statistics per tcp socket
- o statistics per udp socket
- o statistics per nfs socket
- o statistics per ftp control socket
- o statistics per ftp data socket
- o statistics per telnet socket
- o statistics per smtp socket
- o arp statistics per ip address
- o statistics per mac address pair
- o statistics per ip pair (includes icmp)
- o statistics per tcp connection
- o statistics per udp pair
- o statistics per nfs pair
- o statistics per ftp control connection
- o statistics per ftp data connection
- o statistics per telnet connection
- o statistics per smtp connection
- o connection histories per udp and tcp socket

All statistics are organized similarly across protocol types. The details of the data structures for the DLL level are presented later.

As noted earlier, there are four statistical object classes (i.e., variables), namely, counts, rates, percentages (%), and meters. They are defined and implemented as follows.

A count is a continuously incrementing variable which rolls around to 0 on overflow. It may be reset on command from the user (or from software). A threshold may be applied to the count and will cause an alarm when the threshold count is reached. The threshold count fires each time the counter increments past the threshold value. For example, if the threshold is set to 5, alarms are generated when the count is 5, 10, 15, ...

A rate is essentially a first derivative of a count variable. The rate is calculated at a period appropriate to the variable. For each rate variable, a minimum, maximum and average value is maintained. Thresholds may be set on high values of the rate. The maximums and minimums may be reset on command. The threshold event is triggered each time the rate calculated is in the threshold region.

As commonly used, the % is calculated at a period appropriate to the variable. For each % variable a minimum, maximum and average value is maintained. A threshold may be set on high values of the %. The threshold event is triggered each time the % calculated is in the threshold region.

Finally, a meter is a variable which may take any discrete value within a defined range. The current value has no correlation to past or future values. A threshold may be set on a maximum and/or minimum value for a meter.

The rate and % fields of network event variables are updated differently than counter or meter fields in that they are calculated at fixed intervals rather than on receipt of data from the network.

Structures for statistics kept on a per address or per address pair basis are allocated at initialization time. There are several sizes for these structures. Structures of the same size are linked together in a free pool. As a new structure is needed, it is obtained from a free queue, initialized, and linked into an active list. Active lists are kept on a per statistics type basis.

As an address or address pair (e.g. mac, ip, tcp . . .) is seen, RTP code calls an appropriate lookup routine. The lookup routine scans active statistics structures to see if a structure has already been allocated for the statistics. Hashing algorithms are used in order to provide for efficient lookup. If no structure has been allocated, the lookup routine examines the appropriate parse control records to determine whether statistics should be kept, and, if so, it allocates a structure of the appropriate size, initializes it and links it into an active list.

Either the address of a structure or a NULL is returned by these routines. If NULL is returned, the RTP does not stop parsing, but it will not be allowed to store the statistics for which the structure was requested.

The RTP updates statistics within the data base as it runs. This is done via macros defined for the RTP. The macros call on internal routines which know how to manipulate the relevant statistic. If the pointer to the statistics structure is NULL, the internal routine will not be invoked.

The EM causes rates to be calculated. The STATS module supplies routines (e.g. stats_rate) which must be called by the EM in order to perform the rate calculations. It also calls subroutines to reformat the data in the database in order to present it to the Workstation (i.e., in response to a get from the Workstation).

The calculation algorithms for the rate and % fields of network event variables are as follows.

The following rates are calculated in units per second, at the indicated (approximate) intervals:

1. 10 second intervals:
   e.g. DLL frame, byte, ethernet, 802.3, broadcast, multicast rates
2. 60 second intervals
   e.g., all DLL error, ethertype/dsap rates all IP rates.
   TCP packets, bytes, errors, retransmitted packets, retransmitted bytes, acks, rsts UDP packet, error, byte rates
   FTP file transfer, byte transfer, error rates

For these rates, the new average replaces the previous value directly. Maximum and minimum values are retained until reset by the user.

The following rates are calculated in units per hour at the indicated time intervals:

1. 15 minute interval.
   e.g., TCP—connection rate
   Telnet connection rate
   FTP session rate

The hourly rate is calculated from a sum of the last twelve 5 minute readings, as obtained from the buckets for the pertinent parameter. Each new reading replaces the oldest of the twelve values maintained. Maximum and minimum values are retained until reset by the user.

There are a number of other internal routines in STATS. For example, all statistical data collected by the Monitor is subject to age out. Thus, if no activity is seen for an address (or address pair) in the time period defined for age out, then the data is discarded and the space reclaimed so that it may be recycled. In this manner, the Monitor is able to use the memory for active elements rather than stale data. The user can select the age out times for the different components. The EM periodically kicks off the aging mechanism to perform this recycling of resources. STATS provides the routines which the EM calls, e.g. stats_age.

There are also routines in STATS to allocate and deallocate Statistics, e.g., stats_allocate and stats_deallocate. The allocate routine is called when stations and dialogs are picked up by the Network Monitor. The deallocate routine is called by the aging routines when a structure is to be recycled.

The Data Structures in STATS

The general structure of the database within STATS is illustrated by FIGS. 7*a–c*, which shows information that is maintained for the Data Link Layer (DLL) and its organization. A set of data structures is kept for each address associated with the layer. In this case there are three relevant addresses, namely a segment address, indicating which segment the node is on, a MAC address for the node on the segment, and an address which identifies the dialog occurring over that layer. The dialog address is the combination of the MAC addresses for the two nodes which make up the dialog. Thus, the overall data structure has three identifiable components: a segment address data structure (see FIG. 7*a*), a MAC address data structure (see FIG. 7*b*) and a dialog data structure (see FIG. 7*c*).

The segment address structure includes a doubly linked list **102** of segment address records **104**, each one for a different segment address. Each segment address record **104** contains a forward and backward link (field **106**) for forward and backward pointers to neighboring records and a hash link (field **108**). In other words, the segment address records are accessed by either walking down the doubly linked list or by using a hashing mechanism to generate a pointer into the doubly linked list to the first record of a smaller hash linked list. Each record also contains the address of the segment (field **110**) and a set of fields for other information. Among these are a flags field **112**, a type field **114**, a parse_control field **116**, and an EM_control field **118**. Flags field **112** contains a bit which indicates whether the identified address corresponds to the address of another Network Monitor. This field only has meaning in the MAC address record and not in the segment or dialog address record. Type field **114** identifies the MIB group which applies to this address. Parse control field **116** is a bit mask which indicates what subgroups of statistics from the identified MIB group are maintained, if any. Flags field **112**, type field **114** and parse control field **116** make up what is referred to as the parse control record for this MAC address. The Network Monitor uses a default value for parse control field **116** upon initialization or whenever a new node is detected. The default value turns off all statistics gathering. The statistics gathering for any particular address may subsequently be turned on by the Workstation through a Network Monitor control command that sets the appropriate bits of the parse control field to one.

EM_control field **118** identifies the subgroups of statistics within the MIB group that have changed since the EM last serviced the database to update rates and other variables. This field is used by the EM to identify those parts of STATS which must be updated or for which recalculations must be performed when the EM next services STAT.

Each segment address record **104** also contains three fields for time related information. There is a start_time field **120** for the time that is used to perform some of the rate calculations for the underlying statistics; a first_seen field **122** for the time at which the Network Monitor first saw the communication; and a last_seen field **124** for the time at which the last communication was seen. The last_seen time is used to age out the data structure if no activity is seen on the segment after a preselected period of time elapses. The first_seen time is a statistic which may be of interest to the network manager and is thus retrievable by the Management Workstation for display.

Finally, each segment address record includes a stats_pointer field **126** for a pointer to a DLL segment statistics data structure **130** which contains all of the statistics that are maintained for the segment address. If the bits in parse_control field **116** are all set to off, indicating that no statistics are to be maintained for the address, then the pointer in stats_pointer field **126** is a null pointer.

The list of events shown in data structure **130** of FIG. 7*a* illustrates the type of data that is collected for this address when the parse control field bits are set to on. Some of the entries in DLL segment statistics data structure **130** are pointers to buckets for historical data. In the case where buckets are maintained, there are twelve buckets each of which represents a time period of five minutes duration and each of which generally contains two items of information, namely, a count for the corresponding five minute time period and a MAX rate for that time period. MAX rate records any spikes which have occurred during the period and which the user may not have observed because he was not viewing that particular statistic at the time.

At the end of DLL segment statistics data structure **130**, there is a protocol_Q pointer **132** to a linked list **134** of protocol statistics records **136** identifying all of the protocols which have been detected running on top of the DLL layer for the segment. Each record **136** includes a link **138** to the next record in the list, the identity of the protocol (field **140**), a frames count for the number of frames detected for the identified protocol (field **142**); and a frame rate (field **144**).

The MAC address data structure is organized in a similar manner to that of the segment data structure (see FIG. 7*b*). There is a doubly linked list **146** of MAC address records **148**, each of which contains the same type of information as is stored in DLL segment address records **104**. A pointer **150** at the end of each MAC address record **148** points to a DLL address statistics data structure **152**, which like the DLL segment address data structure **130**, contains fields for all of the statistics that are gathered for that DLL MAC address. Examples of the particular statistics are shown in FIG. 7*b*.

At the end of DLL address statistics data structure **152**, there are two pointer fields **152** and **154**, one for a pointer to a record **158** in a dialog link queue **160**, and the other for a pointer to a linked list **162** of protocol statistics records **164**. Each dialog link queue entry **158** contains a pointer to the next entry (field **168**) in the queue and it contains a dialog_addr pointer **170** which points to an entry in the DLL dialog queue which involves the MAC address. (see FIG. 7*c*). Protocol statistics records **164** have the same structure and contain the same categories of information as their counterparts hanging off of DLL segment statistics data structure **130**.

The above-described design is repeated in the DLL dialog data structures. That is, dialog record **172** includes the same categories of information as its counterpart in the DLL segment address data structure and the MAC address data structure. The address field **174** contains the addresses of

both ends of the dialog concatenated together to form a single address. The first and second addresses within the single address are arbitrarily designated nodes **1** and **2**, respectively. In the stats_pointer field **176** there is a pointer to a dialog statistics data structure **178** containing the relevant statistics for the dialog. The entries in the first two fields in this data structure (i.e., fields **180** and **182**) are designated protocol entries and protocols. Protocol entries is the number of different protocols which have been seen between the two MAC addresses. The protocols that have been seen are enumerated in the protocols field **182**.

DLL dialog statistics data structure **178**, illustrated by FIG. **7***c*, includes several additional fields of information which only appear in these structures for dialogs for which state information can be kept (e.g. TCP connection). The additional fields identify the transport protocol (e.g., TCP) (field **184**) and the application which is running on top of that protocol (field **186**). They also include the identity of the initiator of the connection (field **188**), the state of the connection (field **190**) and the reason that the connection was closed, when it is closed (field **192**). Finally, they also include a state_pointer (field **194**) which points to a history data structure that will be described in greater detail later. Suffice it to say, that the history data structure contains a short history of events and states for each end of the dialog. The state machine uses the information contained in the history data structure to loosely determine what the state of each of the end nodes is throughout the course of the connection. The qualifier "loosely" is used because the state machine does not closely shadow the state of the connection and thus is capable of recovering from loss of state due to lost packets or missed communications.

The above-described structures and organization are used for all layers and all protocols within STATS.

Real Time Parser (RTP)

The RTP runs as an application task. It is scheduled by the Real Time Kernel scheduler when received frames are detected. The RTP parses the frames and causes statistics, state tracking, and tracing operations to be performed.

The functions of the RTP are:

- obtain frames from the RTP Input Queue;
- parse the frames;
- maintain statistics using routines supplied by the STATS module;
- maintain protocol state information;
- notify the MTM via an ITM if a frame has been received with the Network Monitor's address as the destination address; and
- notify the EM via an ITM if a frame has been received with any Network Monitor's address as the source address.

The design of the RTP is straightforward. It is a collection of routines which perform protocol parsing. The RTP interfaces to the Real Time Kernel in order to perform RTP initialization, to be scheduled in order to parse frames, to free frames, to obtain and send an ITM to another task; and to report fatal errors. The RTP is invoked by the scheduler when there is at least one frame to parse. The appropriate parse routines are executed per frame. Each parse routine invokes the next level parse routine or decides that parsing is done. Termination of the parse occurs on an error or when the frame has been completely parsed.

Each parse routine is a separately compilable module. In general, parse routines share very little data. Each knows where to begin parsing in the frame and the length of the data remaining in the frame.

The following is a list of the parse routines that are available within RTP for parsing the different protocols at the various layers.

Data Link Layer Parse—rtp_dll_parse:

This routine handles Ethernet, IEEE 802.3, IEEE 802.2, and SNAP. See RFC 1010, Assigned Numbers for a description of SNAP (Subnetwork Access Protocol).

Address Resolution Protocol Parse—rtp_arp_parse

ARP is parsed as specified in RFC 826.

Internet Protocol Parse—rtp_ip_parse

IP Version 4 is parsed as specified in RFC 791 as amended by RFC 950, RFC 919, and RFC 922.

Internet Control Message Protocol Parse—rtp_icmp_parse

ICMP is parsed as specified in RFC 792.

Unit Data Protocol Parse—rtp_udp_parse

UDP is parsed as specified in RFC 768.

Transmission Control Protocol Parse—rtp_tcp_parse

TCP is parsed as specified in RFC 793.

Simple Mail Transfer Protocol Parse—rtp_smtp_parse

SMTP is parsed as specified in RFC 821.

File Transfer Protocol Parse—rtp_ftp_parse

FTP is parsed as specified in RFC 959.

Telnet Protocol Parse—rtp_telnet_parse

The Telnet protocol is parsed as specified in RFC 854.

Network File System Protocol Parse—rpt_nfs_parse

The NFS protocol is parsed as specified in RFC 1094.

The RTP calls routines supplied by STATS to look up data structures. By calling these lookup routines, global pointers to data structures are set up. Following are examples of the pointers to statistics data structures that are set up when parse routines call Statistics module lookup routines.

mac_segment, mac_dst_segment, mac_this_segment, mac_src, mac_dst, mac dialog

ip_src_segment, ip_dst_segment, ip_this_segment, ip_src, ip_dst, ip_dialog

tcp_src_segment, tcp_dst_segment, tcp_this_segment,

tcp_src, tcp_dst, tcp_src_socket, tcp_dst_socket, tcp_connection

The mac_src and mac_dst routines return pointers to the data structures within STATS for the source MAC address and the destination MAC address, respectively. The lookup_mac_dialog routine returns a pointer to the data structure within STATS for the dialog between the two nodes on the MAC layer. The other STATS routines supply similar pointers for data structures relevant to other protocols.

The RTP routines are aware of the names of the statistics that must be manipulated within the data base (e.g. frames, bytes) but are not aware of the structure of the data. When a statistic is to be manipulated, the RTP routine invokes a macro which manipulates the appropriate statistics in data structures. The macros use the global pointers which were set up during the lookup process described above.

After a frame has been parsed (whether the parse was successful or not), the RTP routine examines the destination mac and ip addresses. If either of the addresses is that of the Network Monitor, RTP obtains a low priority ITM, initializes it, and sends the ITM to the MTM task. One of the fields of the ITM contains the address of the buffer containing the frame.

The RTP must hand some received frames to the EM in order to accomplish the autotopology function (described later). After a frame has been parsed (whether the parse was successful or not), the RTP routine examines the source mac

ınd ip addresses. If either of the addresses is that of another Network Monitor, RTP obtains a low priority ITM, initializes it and sends the ITM to the EM task. The address data structure (in particular, the flags field of the parse control record) within STATS for the MAC or the IP address indicates whether the source address is that of another Network Monitor. One of the fields of the ITM contains the address of the buffer containing the frame.

The RTP receives traffic frames from the network for analysis. RTP operation may be modified by sending control messages to the Monitor. RTP first parses these messages, then detects that the messages are destined for the Monitor and passes them to the MTM task. Parameters which affect RTP operation may be changed by such control messages.

The general operation of the RTP upon receipt of a traffic frame is as follows:

```
Get next frame from input queue
get address records for these stations
For each level of active parsing
{
get pointer to start of protocol header
call layer parse routine
determine protocol at next level
set pointer to start of next layer protocol
}end of frame parsing
if this is a monitor command add to MTM input queue
if this frame is from another monitor, pass to EM
check for overload—if yes tell control
```

The State Machine:

In the described embodiment, the state machine determines and keeps state for both addresses of all TCP connections. TCP is a connection oriented transport protocol, and TCP clearly defines the connection in terms of states of the connection. There are other protocols which do not explicitly define the communication in terms of state, e.g. connectionless protocols such as NFS. Nevertheless, even in the connectionless protocols there is implicitly the concept of state because there is an expected order to the events which will occur during the course of the communication. That is, at the very least, one can identify a beginning and an end of the communication, and usually some sequence of events which will occur during the course of the communication. Thus, even though the described embodiment involves a connection oriented protocol, the principles are applicable to many connectionless protocols or for that matter any protocol for which one can identify a beginning and an end to the communication under that protocol.

Whenever a TCP packet is detected, the RTP parses the information for that layer to identify the event associated with that packet. It then passes the identified event along with the dialog identifier to the state machine. For each address of the two parties to the communication, the state machine determines what the current state of the node is. The code within the state machine determines the state of a connection based upon a set of rules that are illustrated by the event/state table shown in FIG. 8.

The interpretation of the event/state table is as follows. The top row of the table identifies the six possible states of a TCP connection. These states are not the states defined in the TCP protocol specification. The left most column identifies the eight events which may occur during the course of a connection. Within the table is an array of boxes, each of which sits at the intersection of a particular event/state combination. Each box specifies the actions taken by the state machine if the identified event occurs while the connection is in the identified state. When the state machine receives a new event, it may perform three types of action. It may change the recorded state for the node. The state to which the node is changed is specified by the S="STATE" entry located at the top of the box. It may increment or decrement the appropriate counters to record the information relevant to that event's occurrence. (In the table, incrementing and decrementing are signified by the ++ and the -- symbols, respectively, located after the identity of the variable being updated.) or the state machine may take other actions such as those specified in the table as start close timer, Look_for_Data_State, or Look_at_History (to be described shortly). The particular actions which the state machine takes are specified in each box. An empty box indicates that no action is taken for that particular event/state combination. Note, however, that the occurrence of an event is also likely to have caused the update of statistics within STATS, if not by the state machine, then by some other part of the RTP. Also note that it may be desirable to have the state machine record other events, in which case the state table would be modified to identify those other actions.

Two events appearing on the table deserve further explanation, namely, close timer expires and inactivity timer expires. The close timer, which is specified by TCP, is started at the end of a connection and it establishes a period during which any old packets for the connection which are received are thrown away (i.e., ignored). The inactivity timer is not specified by TCP but rather is part of the Network Monitor's resource management functions. Since keeping statistics for dialogs (especially old dialogs) consumes resources, it is desirable to recycle resources for a dialog if no activity has been seen for some period of time. The inactivity timer provides the mechanism for accomplishing this. It is restarted each time an event for the connection is received. If the inactivity timer expires (i.e., if no event is received before the timer period ends), the connection is assumed to have gone inactive and all of the resources associated with the dialog are recycled. This involves freeing them up for use by other dialogs.

The other states and events within the table differ from but are consistent with the definitions provided by TCP and should be self evident in view of that protocol specification.

The event/state table can be read as follows. Assume, for example, that node 1 is in DATA state and the RTP receives another packet from node 1 which it determines to be a TCP FIN packet. According to the entry in the table at the intersection of FIN/DATA (i.e., event/state), the state machine sets the state of the connection for node 1 to CLOSING, it decrements the active connections counter and it starts the close timer. When the close timer expires, assuming no other events over that connection have occurred, the state machine sets node 1's state to CLOSED and it starts the inactivity timer. If the RTP sends another SYN packet to reinitiate a new connection before the inactive timer expires, the state machine sets node 1's state to CONNECTING (see the SYN/CLOSED entry) and it increments an after close counter.

When a connection is first seen, the Network Monitor sets the state of both ends of the connection to UNKNOWN state. If some number of data and acknowledgment frames are seen from both connection ends, the states of the connection ends may be promoted to DATA state. The connection history is searched to make this determination as will be described shortly.

Referring to FIGS. 9*a–b*, within STATS there is a history data structure **200** which the state machine uses to remember the current state of the connection, the state of each of the

nodes participating in the connection and a short history of state related information. History data structure **200** is identified by a state_pointer found at the end of the associated dialog statistics data structure in STATS (see FIG. 7*c*). Within history data structure **200**, the state machine records the current state of node **1** (field **202**), the current state of node **2** (field **206**) and other data relating to the corresponding node (fields **204** and **208**). The other data includes, for example, the window size for the receive and transmit communications, the last detected sequence numbers for the data and acknowledgment frames, and other data transfer information.

History data structure **200** also includes a history table (field **212**) for storing a short history of events which have occurred over the connection and it includes an index to the next entry within the history table for storing the information about the next received event (field **210**). The history table is implemented as a circular buffer which includes sufficient memory to store, for example, **16** records. Each record, shown in FIG. 9*b*, stores the state of the node when the event was detected (field **218**), the event which was detected (i.e., received) (field **220**), the data field length (field **222**), the sequence number (field **224**), the acknowledgment sequence number (field **226**) and the identity of the initiator of the event, i.e., either node **1** or node **2** or 0 if neither (field **228**).

Though the Network Monitor operates in a promiscuous mode, it may occasionally fail to detect or it may, due to overload, lose a packet within a communication. If this occurs the state machine may not be able to accurately determine the state of the connection upon receipt of the next event. The problem is evidenced by the fact that the next event is not what was expected. When this occurs, the state machine tries to recover state by relying on state history information stored in the history table in field **212** to deduce what the state is. To deduce the current state from historical information, the state machine uses one of the two previously mentioned routines, namely, Look_for_Data_State and Look_at_History.

Referring to FIG. **10**, Look_for_Data_State routine **230** searches back through the history one record at a time until it finds evidence that the current state is DATA state or until it reaches the end of the circular buffer (step **232**). Routine **230** detects the existence of DATA state by determining whether node **1** and node **2** each have had at least two data events or two acknowledgment combinations with no intervening connect, disconnect or abort events (step **234**). If such a sequence of events is found within the history, routine **230** enters both node **1** and node **2** into DATA state (step **236**), it increments the active connections counter (step **238**) and then it calls a Look_for_Initiator routine to look for the initiator of the connection (step **240**). If such a pattern of events is not found within the history, routine **230** returns without changing the state for the node (step **242**).

As shown in FIG. **11**, Look_for_Initiator routine **240** also searches back through the history to detect a telltale event pattern which identifies the actual initiator of the connection (step **244**). More specifically, routine **240** determines whether nodes **1** and **2** each sent connect-related packets. If they did, routine **240** identifies the initiator as the first node to send a connect-related packet (step **246**). If the search is not successful, the identity of the connection initiator remains unknown (step **248**).

The Look_at_History routine is called to check back through the history to determine whether data transmissions have been repeated. In the case of retransmissions, the routine calls a Look_for_Retransmission routine **250**, the operation of which is shown in FIG. **12**. Routine **250** searches back through the history (step **252**) and checks whether the same initiator node has sent data twice (step **254**). It detects this by comparing the current sequence number of the packet as provided by the RTP with the sequence numbers of data packets that were previously sent as reported in the history table. If a retransmission is spotted, the retransmission counter in the dialog statistics data structure of STATS is incremented (step **256**). If the sequence number is not found within the history table, indicating that the received packet does not represent a retransmission, the retransmission counter is not incremented (step **258**).

Other statistics such as Window probes and keep alives may also be detected by looking at the received frame, data transfer variables, and, if necessary, the history.

Even if frames are missed by the Network Monitor, because it is not directly "shadowing" the connection, the Network Monitor still keeps useful statistics about the connection. If inconsistencies are detected the Network Monitor counts them and, where appropriate, drops back to UNKNOWN state. Then, the Network Monitor waits for the connection to stabilize or deteriorate so that it can again determine the appropriate state based upon the history table.

Principal Transactions of Network Monitor Modules:

The transactions which represent the major portion of the processing load within the Monitor, include monitoring, actions on threshold alarms, processing database get/set requests from the Management Workstation, and processing monitor control requests from the Management Workstation. Each of these mechanisms will now be briefly described.

Monitoring involves the message sequence shown in FIG. **13**. In that figure, as in the other figures involving message sequences, the numbers under the heading SEQ. identify the major steps in the sequence. The following steps occur:

1. ISR puts Received traffic frame ITM on RTP input queue
2. request address of pertinent data structure from STATS (get parse control record for this station)
3. pass pointer to RTP
4. update statistical objects by call to statistical update routine in STATS using pointer to pertinent data structure
5. parse completed—release buffers

The major steps which follow a statistics threshold event (i.e., an alarm event) are shown in FIG. **14**. The steps are as follows:

1. statistical object update causes threshold alarm
2. STATS generates threshold event ITM to event manager (EM)
3. look up appropriate action for this event
4. perform local event processing
5. generate network alarm ITM to MTM Xmit (if required)
6. format network alarm trap for Workstation from event manager data
7. send alarm to Workstation

The major steps in processing of a database update request (i.e., a get/set request) from the Management Workstation are shown in FIG. **15**. The steps are as follows:

1. LAN ISR receives frame from network and passes it to RTP for parsing
2. RTP parses frame as for any other traffic on segment.
3. RTP detects frame is for monitor and sends received Workstation message over LAN ITM to MTM Recv.
4. MTM Recv processes protocol stack.

5. MTM Recv sends database update request ITM to EM.
6. EM calls STATS to do database read or database write with appropriate IMPB
7. STATS performs database access and returns response to EM.
8. EM encodes response to Workstation and sends database update response ITM to MTM Xmit
9. MTM Xmit transmits.

The major steps in processing of a monitor control request from the Management Workstation are shown in FIG. 16. The steps are as follows:

1. Lan ISR receives frame from network and passes received frame ITM to RTP for parsing.
2. RTP parses frame as for any other traffic on segment.
3. RTP detects frame is for monitor and sends received workstation message over LAN ITM to MTM Recv.
4. MTM Recv processes protocol stack and decodes workstation command.
5. MTM Recv sends request ITM to EM.
6. EM calls Control with monitor control IMPB.
7. Control performs requested operation and generates response to EM.
8. EM sends database update response ITM to MTM Xmit.
9. MTM Xmit encodes response to Workstation and transmits.

The Monitor/Workstation Interface:

The interface between the Monitor and the Management Workstation is based on the SNMP definition (RFC 1089 SNMP; RFC 1065 SMI; RFC 1066 SNMP MIB—Note: RFC means Request for Comments). All five SNMP PDU types are supported:

get-request
get-next-request
get-response
set-request
trap

The SNMP MIB extensions are designed such that where possible a user request for data maps to a single complex MIB object. In this manner, the get-request is simple and concise to create, and the response should contain all the data necessary to build the screen. Thus, if the user requests the IP statistics for a segment this maps to an IP Segment Group.

The data in the Monitor is keyed by addresses (MAC, IP) and port numbers (telnet, FTP). The user may wish to relate his data to physical nodes entered into the network map. The mapping of addresses to physical nodes is controlled by the user (with support from the Management Workstation system where possible) and the Workstation retains this information so that when a user requests data for node 'Joe' the Workstation asks the Monitor for the data for the appropriate address(es). The node to address mapping need not be one to one.

Loading and dumping of monitors uses TFTP (Trivial File Transfer Protocol). This operates over UDP as does SNMP. The Monitor to Workstation interface follows the SNMP philosophy of operating primarily in a polled mode. The Workstation acts as the master and polls the Monitor slaves for data on a regular (configurable) basis.

The information communicated by the SNMP is represented according to that subset of ASN.1 (ISO 8824 Specification of ASN.1) defined in the Internet standard Structure of Management Information (SMI—RFC 1065). The subset of the standard Management Information Base (MIB) (RFC 1066 SNMP MIB) which is supported by the Workstation is defined in Appendix III. The added value provided by the Workstation is encoded as enterprise specific extensions to the MIB as defined in Appendix IV. The format for these extensions follows the SMI recommendations for object identifiers so that the Workstation extensions fall in the subtree 1.3.6.1.4.1.x.1. where x is an enterprise specific node identifier assigned by the IAB.

Appendix V is a summary of the network variables for which data is collected by the Monitor for the extended MIB and which can be retrieved by the Workstation. The summary includes short descriptions of the meaning and significance of the variables, where appropriate.

The Management Workstation:

The Management Workstation is a SUN Sparcstation (also referred to as a Sun) available from Sun Microsystems, Inc. It is running the Sun flavor of Unix and uses the Open Look Graphical User Interface (GUI) and the SunNet Manager as the base system. The options required are those to run SunNet Manager with some additional disk storage requirement.

The network is represented by a logical map illustrating the network components and the relationships between them, as shown in FIG. 17. A hierarchical network map is supported with navigation through the layers of the hierarchy, as provided by SNM. The Management Workstation determines the topology of the network and informs the user of the network objects and their connectivity so that he can create a network map. To assist with the map creation process, the Management Workstation attempts to determine the stations connected to each LAN segment to which a Monitor is attached. Automatic determination of segment topology by detecting stations is performed using the autotopology algorithms as described in copending U.S. patent application Ser. No. 07/641,156, entitled "Automatic Topology Monitor for Multi-Segment Local Area Network" filed on Jan. 14, 1991 now U.S. Pat. No. 5,546,540 (Attorney Docket No. 13283-NE.APP), incorporated herein by reference.

In normal operation, each station in the network is monitored by a single Monitor that is located on its local segment. The initial determination of the Monitor responsible for a station is based on the results of the autotopology mechanism. The user may override this initial default if required.

The user is informed of new stations appearing on any segment in the network via the alarm mechanism. As for other alarms, the user may select whether stations appearing on and disappearing from the network segment generate alarms and may modify the times used in the aging algorithms. When a new node alarm occurs, the user must add the new alarm to the map using the SNM tools. In this manner, the SNM system becomes aware of the nodes.

The sequence of events following the detection of a new node is:

1. the location of the node is determined automatically for the user.
2. the Monitor generates an alarm for the user indicating the new node and providing some or all of the following information:
   mac address of node
   ip address of node
   segment that the node is believed to be located on
   Monitor to be responsible for the node
3. the user must select the segment and add the node manually using the SNM editor
4. The update to the SNM database will be detected and the file reread. The Workstation database is recon-

structed and the parse control records for the Monitors updated if required.

5. The Monitor responsible for the new node has its parse control record updated via SNMP set request(s).

An internal record of new nodes is required for the autotopology. When a new node is reported by a Network Monitor, the Management Workstation needs to have the previous location information in order to know which Network Monitors to involve in autotopology. For example, two nodes with the same IP address may exist in separate segments of the network. The history makes possible the correlation of the addresses and it makes possible duplicate address detection.

Before a new Monitor can communicate with the Management Workstation via SNMP it needs to be added to the SNM system files. As the SNM files are cached in the database, the file must be updated and the SNM system forced to reread it.

Thus, on the detection of a new Monitor the following events need to occur in order to add the Monitor to the Workstation:

1. The Monitor issues, a trap to the Management Workstation software and requests code to be loaded from the Sun Microsystems boot/load server.
2. The code load fails as the Monitor is not known to the unix networking software at this time.
3. The Workstation confirms that the new Monitor does not exceed the configured system limits (e.g. 5 Monitors per Workstation) and terminates the initialization sequence if limits are exceeded. An alarm is issued to the user indicating the presence of the new Monitor and whether it can be supported.
4. The user adds the Monitor to the SNMP.HOSTS file of the SNM system, to the etc/hosts file of the Unix networking system and to the SNM map.
5. When the files have been updated the user resets the Monitor using the set tool (described later).
6. The Monitor again issues a trap to the Management Workstation software and requests code to be loaded from the Sun boot/load server.
7. The code load takes place and the Monitor issues a trap requesting data from the Management Workstation.
8. The Monitor data is issued using SNMP set requests.

Note that on receiving the set request, the SNMP proxy rereads in the (updated) SNMP.HOSTS file which now includes the new Monitor. Also note that the SNMP hosts file need only contain the Monitors, not the entire list of nodes in the system.

9. On completion of the set request(s) the Monitor run command is issued by the Workstation to bring the Monitor on line.

The user is responsible for entering data into the SNM database manually. During operation, the Workstation monitors the file write date for the SNM database. When this is different from the last date read, the SNM database is reread and the Workstation database reconstructed. In this manner, user updates to the SNM database are incorporated into the Workstation database as quickly as possible without need for the user to take any action.

When the Workstation is loaded, the database is created from the data in the SNM file system (which the user has possibly updated). This data is checked for consistency and for conformance to the limits imposed by the Workstation at this time and a warning is generated to the user if any problems are seen. If the data errors are minor the system continues operation; if they are fatal the user is asked to correct them and Workstation operation terminates.

The monitoring functions of the Management Workstation are provided as an extension to the SNM system. They consist of additional display tools (i.e., summary tool, values tool, and set tool) which the user invokes to access the Monitor options and a Workstation event log in which all alarms are recorded.

As a result of the monitoring process, the Monitor makes a large number of statistics available to the operator. These are available for examination via the Workstation tools that are provided. In addition, the Monitor statistics (or a selected subset thereof) can be made visible to any SNMP manager by providing it with knowledge of the extended MIB. A description of the statistics maintained are described elsewhere.

Network event statistics are maintained on a per network, per segment and per node basis. Within a node, statistics are maintained on a per address (as appropriate to the protocol layer—IP address, port number, . . .) and per connection basis. Per network statistics are always derived by the Workstation from the per segment variables maintained by the Monitors. Subsets of the basic statistics are maintained on a node to node and segment to segment basis.

If the user requests displays of segment to segment traffic, the Workstation calculates this data as follows. The inter segment traffic is derived from the node to node statistics for the intersecting set of nodes. Thus, if segment A has nodes **1, 2,** and **3** and segment B has nodes **20, 21,** and **22,** then summing the node to node traffic for

1→20,21,22

2→20,21,22

3→20,21,22

produces the required result. On-LAN/off-LAN traffic for segments is calculated by a simply summing node to node traffic for all stations on the LAN and then subtracting this from total segment counts.

Alarms are reported to the user in the following ways:

1. Alarms received are logged in a Workstation log.
2. The node which the alarm relates to is highlighted on the map.
3. The node status change is propagated up through the (map) hierarchy to support the case where the node is not visible on the screen. This is as provided by SNM.

Summary Tool

After the user has selected an object from the map and invokes the display tools, the summary tool generates the user's initial screen at the Management Workstation. It presents a set of statistical data selected to give an overview of the operational status of the object (e.g., a selected node or segment). The Workstation polls the Monitor for the data required by the Summary Tool display screens.

The Summary Tool displays a basic summary tool screen such as is shown in FIG. **18**. The summary tool screen has three panels, namely, a control panel **602**, a values panel **604**, and a dialogs panel **606**. The control panel includes the indicated mouse activated buttons. The functions of each of the buttons is as follows. The file button invokes a traditional file menu. The view button invokes a view menu which allows the user to modify or tailor the visual properties of the tool. The properties button invokes a properties menu containing choices for viewing and sometimes modifying the properties of objects. The tools button invokes a tools menu which provides access to the other Workstation tools, e.g. Values Tool.

The Update Interval field allows the user to specify the frequency at which the displayed statistics are updated by

polling the Monitor. The Update Once button enables the user to retrieve a single screen update. When the Update Once button is invoked not only is the screen updated but the update interval is automatically set to "none".

The type field enables the user to specify the type of network objects on which to operate, i.e., segment or node.

The name button invokes a pop up menu containing an alphabetical list of all network objects of the type selected and apply and reset buttons. The required name can then be selected from the (scrolling) list and it will be entered in the name field of the summary tool when the apply button is invoked. Alternatively, the user may enter the name directly in the summary tool name field.

The protocol button invokes a pop up menu which provides an exclusive set of protocol layers which the user may select. Selection of a layer copies the layer name into the displayed field of the summary tool when the apply operation is invoked. An example of a protocol selection menu is shown in FIG. **19**. It displays the available protocols in the form of a protocol tree with multiple protocol families. The protocol selection is two dimensional. That is, the user first selects the protocol family and then the particular layer within that family.

As indicated by the protocol trees shown in FIG. **19**, the capabilities of the Monitor can be readily extended to handle other protocol families. The particular ones which are implemented depend upon the needs of the particular network environment in which the Monitor will operate.

The user invokes the apply button to indicate that the selection process is complete and the type, name, protocol, etc. should be applied. This then updates the screen using the new parameter set that the user selected. The reset button is used to undo the selections and restore them to their values at the last apply operation.

The set of statistics for the selected parameter set is displayed in values panel **604**. The members of the sets differ depending upon, for example, what protocol was selected. FIGS. **20***a–g* present examples of the types of statistical variables which are displayed for the DLL, IP, UDP, TCP, ICMP, NFS, and ARP/RARP protocols, respectively. The meaning of the values display fields are described in Appendix I, attached hereto.

Dialogs panel **606** contains a display of the connection statistics for all protocols for a selected node. Within the Management Workstation, connection lists are maintained per node, per supported protocol. When connections are displayed, they are sorted on "Last Seen" with the most current displayed first. A single list returned from the Monitor contains all current connection. For TCP, however, each connection also contains a state and TCP connections are displayed as Past and Present based upon the returned state of the connection. For certain dialogs, such as TCP and NFS over UDP, there is an associated direction to the dialog, i.e., from the initiator (source) to the receiver (sink). For these dialogs, the direction is identified in a DIR. field. A sample of information that is displayed in dialogs panel **606** is presented in FIG. **21** for current connections.

Values Tool

The values tool provides the user with the ability to look at the statistical database for a network object in detail. When the user invokes this tool, he may select a basic data screen containing a rate values panel **620**, a count values panel **622** and a protocols seen panel **626**, as shown in FIG. **22**, or he may select a traffic matrix screen **628**, as illustrated in FIG. **23**.

In rate values and count values panels **620** and **622**, value tools presents the monitored rate and count statistics, respectively, for a selected protocol. The parameters which are displayed for the different protocols (i.e., different groups) are listed in Appendix II. In general, a data element that is being displayed for a node shows up in three rows, namely, a total for the data element, the number into the data element, and the number out of the data element. Any exceptions to this are identified in Appendix II. Data elements that are displayed for segments, are presented as totals only, with no distinction between Rx and Tx.

When invoked the Values Tool displays a primary screen to the user. The primary screen contains what is considered to be the most significant information for the selected object. The user can view other information for the object (i.e., the statistics for the other parameters) by scrolling down.

The displayed information for the count values and rate values panels **620** and **622** includes the following. An alarm field reports whether an alarm is currently active for this item. It displays as "*" if active alarm is present. A Current Value/Rate field reports the current rate or the value of the counter used to generate threshold alarms for this item. This is reset following each threshold trigger and thus gives an idea of how close to an alarm threshold the variable is. A Typical Value field reports what this item could be expected to read in a "normal" operating situation. This field is filled in for those items where this is predictable and useful. It is maintained in the Workstation database and is modifiable by the user using the set tool. An Accumulated Count field reports the current accumulated value of the item or the current rate. A Max Value field reports the highest value recently seen for the item. This value is reset at intervals defined by a user adjustable parameter (default 30 minutes). This is not a rolling cycle but rather represents the highest value since it was reset which may be from 1 to 30 minutes ago (for a rest period of 30 minutes). It is used only for rates. A Min Value field reports the lowest value recently seen for the item. This operates in the same manner as Max Value field and is used only for rates.

A Percent (%) field reports only for the following variables:

```
off seg counts:
    100 (in count / total off seg count)
    100 (out count / total off seg count)
    100 (transit count / total off seg count)
    100 (local count / total off seg count)
off seg rates
    100 (transit rate / total off seg rate), etc.
protocols
    100 (frame rate this protocol / total frame
rate)
```

On the right half of the basic display, there the following additional fields: a High Threshold field and a Sample period for rates field.

Set Tool

The set tool provides the user with the ability to modify the parameters controlling the operation of the Monitors and the Management Workstation. These parameters affect both user interface displays and the actual operation of the Monitors. The parameters which can be operated on by the set tool can be divided into the following categories: alarm thresholds, monitoring control, segment Monitor administration, and typical values.

The monitoring control variables specify the actions of the segment Monitors and each Monitor can have a distinct set of control variables (e.g., the parse control records that are described elsewhere). The user is able to define those

nodes, segments, dialogs and protocols in which he is interested so as to make the best use of memory space available for data storage. This mechanism allows for load sharing, where multiple Monitors on the same segment can divide up the total number of network objects which are to be monitored so that no duplication of effort between them takes place.

The monitor administration variables allow the user to modify the operation of the segment Monitor in a more direct manner than the monitoring control variables. Using the set tool, the user can perform those operations such as reset, time changes etc. which are normally the prerogative of a system administrator.

Note that the above descriptions of the tools available through the Management Workstation are not meant to imply that other choices may not be made regarding the particular information which is displayed and the manner in which it is displayed.

Adaptively Setting Network Monitor Thresholds:

The Workstation sets the thresholds in the Network Monitor based upon the performance of the system as observed over an extended period of time. That is, the Workstation periodically samples the output of the Network Monitors and assembles a model of a normally functioning network. Then, the Workstation sets the thresholds in the Network Monitors based upon that model. If the observation period is chosen to be long enough and since the model represents the "average" of the network performance over the observation period, temporary undesired deviations from normal behavior are smoothed out over time and model tends to accurately reflect normal network behavior.

Referring the FIG. **24**, the details of the training procedure for adaptively setting the Network Monitor thresholds are as follows. To begin training, the Workstation sends a start learning command to the Network Monitors from which performance data is desired (step **302**). The start learning command disables the thresholds within the Network Monitor and causes the Network Monitor to periodically send data for a predefined set of network parameters to the Management Workstation. (Disabling the thresholds, however, is not necessary. One could have the learning mode operational in parallel with monitoring using existing thresholds.) The set of parameters may be any or all of the previously mentioned parameters for which thresholds are or may be defined.

Throughout the learning period, the Network Monitor sends "snapshots" of the network's performance to the Workstation which, in turn, stores the data in a performance history database **306** (step **304**). The network manager sets the length of the learning period. Typically, it should be long enough to include the full range of load conditions that the network experiences so that a representative performance history is generated. It should also be long enough so that short periods of overload or faulty behavior do not distort the resulting averages.

After the learning period has expired, the network manager, through the Management Workstation, sends a stop learning command to the Monitor (step **308**). The Monitor ceases automatically sending further performance data updates to the Workstation and the Workstation processes the data in its performance history database (step **310**). The processing may involve simply computing averages for the parameters of interest or it may involve more sophisticated statistical analysis of the data, such as computing means, standard deviations, maximum and minimum values, or using curve fitting to compute rates and other pertinent parameter values.

After the Workstation has statistically analyzed the performance data, it computes a new set of thresholds for the relevant performance parameters (step **312**). To do this, it uses formulas which are appropriate to the particular parameter for which a threshold is being computed. That is, if the parameter is one for which one would expect to see wide variations in its value during network monitoring, then the threshold should be set high enough so that the normal expected variations do not trigger alarms. On the other hand, if the parameter is of a type for which only small variations are expected and larger variations indicate a problem, then the threshold should be set to a value that is close to the average observed value. Examples of formulae which may be used to compute thresholds are:

*	Highest value seen during learning period;
*	Highest value seen during learning period + 10%;
*	Highest value seen during learning period + 50%;
*	Highest value seen during learning period + user-defined percent;
*	Any value of the parameter other than zero;
*	Average value seen during learning period + 50%; and
*	Average value seen during learning period + user-defined percent

As should be evident from these examples, there is a broad range of possibilities regarding how to compute a particular threshold. The choice, however, should reflect the parameter's importance in signaling serious network problems and its normal expected behavior (as may be evidenced from the performance history acquired for the parameter during the learning mode).

After the thresholds are computed, the Workstation loads them into the Monitor and instructs the Monitor to revert to normal monitoring using the new thresholds (step **314**).

This procedure provides a mechanism enabling the network manager to adaptively reset thresholds in response to changing conditions on the network, shifting usage patterns and evolving network topology. As the network changes over time, the network manager merely invokes the adaptive threshold setting feature and updates the thresholds to reflect those changes.

The Diagnostic Analyzer Module:

The Management Workstation includes a diagnostic analyzer module which automatically detects and diagnoses the existence and cause of certain types of network problems. The functions of the diagnostic module may actually be distributed among the Workstation and the Network Monitors which are active on the network. In principle, the diagnostic analyzer module includes the following elements for performing its fault detection and analysis functions.

The Management Workstation contains a reference model of a normally operating network. The reference model is generated by observing the performance of the network over an extended period of time and computing averages of the performance statistics that were observed during the observation period. The reference model provides a reference against which future network performance can be compared so as to diagnose and analyze potential problems. The Network Monitor (in particular, the STATS module) includes alarm thresholds on a selected set of the parameters which it monitors. Some of those thresholds are set on parameters which tend to be indicative of the onset or the presence of particular network problems.

During monitoring, when a Monitor threshold is exceeded, thereby indicating a potential problem (e.g. in a

TCP connection), the Network Monitor alerts the Workstation by sending an alarm. The Workstation notifies the user and presents the user with the option of either ignoring the alarm or invoking a diagnostic algorithm to analyze the problem. If the user invokes the diagnostic algorithm, the Workstation compares the current performance statistics to its reference model to analyze the problem and report its results. (Of course, this may also be handled automatically so as to not require user intervention.) The Workstation obtains the data on current performance of the network by retrieving the relevant performance statistics from all of the segment Network Monitors that may have information useful to diagnosing the problem.

The details of a specific example involving poor TCP connection performance will now be described. This example refers to a typical network on which the diagnostic analyzer resides, such as the network illustrated in FIG. **25**. It includes three segments labelled S1, S2, and S3, a router R1 connecting S1 to S2, a router R2 connecting S2 to S3, and at least two nodes, node A on S1 which communicates with node B on S3. On each segment there is also a Network Monitor **324** to observe the performance of its segment in the manner described earlier. A Management Workstation **320** is also located on S1 and it includes a diagnostic analyzer module **322**. For this example, the symptom of the network problem is degraded performance of a TCP connection between Nodes A and B.

A TCP connection problem may manifest itself in a number of ways, including, for example, excessively high numbers for any of the following:

errors
packets with bad sequence numbers
packets retransmitted
bytes retransmitted
out of order packets
out of order bytes
packets after window closed
bytes after window closed
average and maximum round trip times

or by an unusually low value for the current window size. By setting the appropriate thresholds, the Monitor is programmed to recognize any one or more of these symptons. If any one of the thresholds is exceeded, the Monitor sends an alarm to the Workstation. The Workstation is programmed to recognize the particular alarm as related to an event which can be further analyzed by its diagnostic analyzer module **322**. Thus, the Workstation presents the user with the option of invoking its diagnostic capabilities (or automatically invokes the diagnostic capabilities).

In general terms, when the diagnostic analyzer is invoked, it looks at the performance data that the segment Monitors produce for the two nodes, for the dialogs between them and for the links that interconnect them and compares that data to the reference model for the network. If a significant divergence from the reference model is identified, the diagnostic analyzer informs the Workstation (and the user) about the nature of the divergence and the likely cause of the problem. In conducting the comparison to "normal" network performance, the network circuit involved in communications between nodes A and B is decomposed into its individual components and diagnostic analysis is performed on each link individually in the effort to isolate the problem further.

The overall structure of the diagnostic algorithm **400** is shown in FIG. **26**. When invoked for analyzing a possible TCP problem between nodes A and B, diagnostic analyzer **322** checks for a TCP problem at node A when it is acting as a source node (step **402**). To perform this check, diagnostic algorithm **400** invokes a source node analyzer algorithm **450** shown in FIG. **27**. If a problem is identified, the Workstation reports that there is a high probability that node A is causing a TCP problem when operating as a source node and it reports the results of the investigation performed by algorithm **450** (step **404**).

If node A does not appear to be experiencing a TCP problem when acting as a source node, diagnostic analyzer **322** checks for evidence of a TCP problem at node B when it is acting as a sink node (step **406**). To perform this check, diagnostic algorithm **400** invokes a sink node analyzer algorithm **470** shown in FIG. **28**. If a problem is identified, the Workstation reports that there is a high probability that node B is causing a TCP problem when operating as a sink node and it reports the results of the investigation performed by algorithm **470** (step **408**).

Note that source and sink nodes are concepts which apply to those dialogs for which a direction of the communication can be defined. For example, the source node may be the one which initiated the dialog for the purpose of sending data to the other node, i.e., the sink node.

If node B does not appear to be experiencing a TCP problem when acting as a sink node, diagnostic analyzer **322** checks for evidence of a TCP problem on the link between Node A and Node B (step **410**). To perform this check, diagnostic algorithm **400** invokes a link analysis algorithm **550** shown in FIG. **29**. If a problem is identified, the Workstation reports that there is a high probability that a TCP problem exists on the link and it reports the results of the investigation performed by link analysis algorithm **550** (step **412**).

If the link does not appear to be experiencing a TCP problem, diagnostic analyzer **322** checks for evidence of a TCP problem at node B when it is acting as a source node (step **414**). To perform this check, diagnostic algorithm **400** invokes the previously mentioned source algorithm **450** for Node B. If a problem is identified, the Workstation reports that there is a medium probability that node B is causing a TCP problem when operating as a source node and it reports the results of the investigation performed by algorithm **450** (step **416**).

If node B does not appear to be experiencing a TCP problem when acting as a source node, diagnostic analyzer **322** checks for a TCP problem at node A when it is acting as a sink node (step **418**). To perform this check, diagnostic algorithm **400** invokes sink node analyzer algorithm **470** for Node A. If a problem is identified, the Network Monitor reports that there is a medium probability that node A is causing a TCP problem when operating as a sink node and it reports the results of the investigation performed by algorithm **470** (step **420**).

Finally, if node A does not appear to be experiencing a TCP problem when acting as a sink node, diagnostic analyzer **322** reports that it was not able to isolate the cause of a TCP problem (step **422**).

The algorithms which are called from within the above-described diagnostic algorithm will now be described.

Referring to FIG. **27**, source node analyzer algorithm **450** checks whether a particular node is causing a TCP problem when operating as a source node. The strategy is as follows. To determine whether a TCP problem exists at this node which is the source node for the TCP connection, look at other connections for which this node is a source. If other TCP connections are okay, then there is probably not a problem with this node. This is an easy check with a high

probability of being correct. If no other good connections exist, then look at the lower layers for possible reasons. Start at DLL and work up as problems at lower layers are more fundamental, i.e., they cause problems at higher layers whereas the reverse is not true.

In accordance with this approach, algorithm **450** first determines whether the node is acting as a source node in any other TCP connection and, if so, whether the other connection is okay (step **452**). If the node is performing satisfactorily as a source node in another TCP connection, algorithm **450** reports that there is no problem at the source node and returns to diagnostic algorithm **400** (step **454**). If algorithm **450** cannot identify any other TCP connections involving this node that are okay, it moves up through the protocol stack checking each level for a problem. In this case, it then checks for DLL problems at the node when it is acting as a source node by calling an DLL problem checking routine **510** (see FIG. **30**) (step **456**). If a DLL problem is found, that fact is reported (step **458**). If no DLL problems are found, algorithm **450** checks for an IP problem at the node when it is acting as a source by calling an IP problem checking routine **490** (see FIG. **31**) (step **460**). If an IP problem is found, that fact is reported (step **462**). If no IP problems are found, algorithm **450** checks whether any other TCP connection in which the node participates as a source is not okay (step **464**). If another TCP connection involving the node exists and it is not okay, algorithm **450** reports a TCP problem at the node (step **466**). If no other TCP connections where the node is acting as a source node can be found, algorithm **450** exits.

Referring to FIG. **28**, sink node analyzer algorithm **470** checks whether a particular node is causing a TCP problem when operating as a sink node. It first determines whether the node is acting as a sink node in any other TCP connection and, if so, whether the other connection is okay (step **472**). If the node is performing satisfactorily as a sink node in another TCP connection, algorithm **470** reports that there is no problem at the source node and returns to diagnostic algorithm **400** (step **474**). If algorithm **470** cannot identify any other TCP connections involving this node that are okay, it then checks for DLL problems at the node when it is acting as a sink node by calling DLL problem checking routine **510** (step **476**). If a DLL problem is found, that fact is reported (step **478**). If no DLL problems are found, algorithm **470** checks for an IP problem at the node when it is acting as a sink by calling IP problem checking routine **490** (step **480**). If an IP problem is found, that fact is reported (step **482**). If no IP problems are found, algorithm **470** checks whether any other TCP connection in which the node participates as a sink is not okay (step **484**). If another TCP connection involving the node as a sink exists and it is not okay, algorithm **470** reports a TCP problem at the node (step **486**). If no other TCP connections where the node is acting as a sink node can be found, algorithm **470** exits.

Referring to FIG. **31**, IP problem checking routine **490** checks for IP problems at a node. It does this by comparing the IP performance statistics for the node to the reference model (steps **492** and **494**). If it detects any significant deviations from the reference model, it reports that there is an IP problem at the node (step **496**). If no significant deviations are noted, it reports that there is no IP problem at the node (step **498**).

As revealed by examining FIG. **30**, DLL problem checking routine **510** operates in a similar manner to IP problem checking routine **490**, with the exception that it examines a different set of parameters (i.e., DLL parameters) for significant deviations.

Referring the FIG. **29**, link analysis logic **550** first determines whether any other TCP connection for the link is operating properly (step **552**). If a properly operating TCP connection exists on the link, indicating that there is no link problem, link analysis logic **550** reports that the link is okay (step **554**). If a properly operating TCP connection cannot be found, the link is decomposed into its constituent components and an IP link component problem checking routine **570** (see FIG. **32**) is invoked for each of the link components (step **556**). IP link component problem routine **570** evaluates the link component by checking the IP layer statistics for the relevant link component.

The decomposition of the link into its components arranges them in order of their distance from the source node and the analysis of the components proceeds in that order. Thus, for example, the link components which make up the link between nodes A and B include in order: segment S1, router R1, segment S2, router R2, and segment S3. The IP data for these various components are analyzed in the following order:

IP data for segment S1
IP data for address R1
IP data for source node to R1
IP data for S1 to S2
IP data for S2
IP data for address R2
IP data for S3
IP data for S2 to S3
IP data for S1 to S3

As shown in FIG. **32**, IP link component problem checking routine **570** compares IP statistics for the link component to the reference model (step **572**) to determine whether network performance deviates significantly from that specified by the model (step **574**). If significant deviations are detected, routine **570** reports that there is an IP problem at the link component (step **576**). Otherwise, it reports that it found no IP problem (step **578**).

Referring back to FIG. **29**, after completing the IP problem analysis for all of the link components, logic **550** then invokes a DLL link component problem checking routine **580** (see FIG. **33**) for each link component to check its DLL statistics (step **558**).

DLL link problem routine **580** is similar to IP link problem routine **570**. As shown in FIG. **33**, DLL link problem checking routine **580** compares DLL statistics for the link to the reference model (step **582**) to determine whether network performance at the DLL deviates significantly from that specified by the model (step **584**). If significant deviations are detected, routine **580** reports that there is a DLL problem at the link component (step **586**). Otherwise, it reports that no DLL problems were found (step **588**).

Referring back to FIG. **29**, after completing the DLL problem analysis for all of the link components, logic **550** checks whether there is any other TCP on the link (step **560**). If another TCP exists on the link (which implies that the other TCP is also not operating properly), logic **550** reports that there is a TCP problem on the link (step **562**). Otherwise, logic **550** reports that there was not enough information from the existing packet traffic to determine whether there was a link problem (step **564**)

If the analysis of the link components does not isolate the source of the problem and if there were components for which sufficient information was not available (due possibly to lack of traffic over through that component), the user may send test messages to those components to generate the information needed to evaluate its performance.

The reference model against which comparisons are made to detect and isolate malfunctions may be generated by examining the behavior of the network over an extended period of operation or over multiple periods of operation. During those periods of operation, average values and maximum excursions (or standard deviations) for observed statistics are computed. These values provide an initial estimate of a model of a properly functioning system. As more experience with the network is obtained and as more historical data on the various statistics is accumulated the thresholds for detecting actual malfunctions or imminent malfunctions and the reference model can be revised to reflect the new experience.

What constitutes at significant deviation from the reference model depends upon the particular parameter involved. Some parameters will not deviate from the expected norm and thus any deviation would be considered to be significant, for example, consider ICMP messages of type "destination unreachable," IP errors, TCP errors. Other parameters will normally vary within a wide range of acceptable values, and only if they move outside of that range should the deviation be considered significant. The acceptable ranges of variation can be determined by watching network performance over a sustained period of operation.

The parameters which tend to provide useful information for identifying and isolating problems at the node level for the different protocols and layers include the following.

TCP
error rate
header byte rate
packets retransmitted
bytes retransmitted
packets after window closed
bytes after window closed
UDP
error rate
header byte rate
IP
error rate
header byte rate
fragmentation rate
all ICMP messages of type destination unreachable, parameter problem, redirection
DLL
error rate
runts

For diagnosing network segment problems, the above-identified parameters are also useful with the addition of the alignment rate and the collision rate at the DLL. All or some subset of these parameters may be included among the set of parameters which are examined during the diagnostic procedure to detect and isolate network problems.

The above-described technique can be applied to a wide range of problems on the network, including among others, the following:

TCP Connection fails to establish
UDP Connection performs poorly
UDP not working at all
IP poor performance/high error rate
IP not working at all
DLL poor performance/high error rate
DLL not working at all

For each of these problems, the diagnostic approach would be similar to that described above, using, of course, different parameters to identify the potential problem and isolate its cause.

The Event Timing Module

Referring again to FIG. **5**, the RTP is programmed to detect the occurrence of certain transactions for which timing information is desired. The transactions typically occur within a dialog at a particular layer of the protocol stack and they involve a first event (i.e., an initiating event) and a subsequent partner event or response. The events are protocol messages that arrive at the Network Monitor, are parsed by the RTP and then passed to Event Timing Module (ETM) for processing. A transaction of interest might be, for example, a read of a file on a server. In that case, the initiating event is the read request and the partner event is the read response. The time of interest is the time required to receive a response to the read request (i.e., the transaction time). The transaction time provides a useful measure of network performance and if measured at various times throughout the day under different load conditions gives a measure of how different loads affect network response times. The layer of the communication protocol at which the relevant dialog takes place will of course depend upon the nature of the event.

In general, when the RTP detects an event, it transfers control to the ETM which records an arrival time for the event. If the event is an initiating event, the ETM stores the arrival time in an event timing database **300** (see FIG. **34**) for future use. If the event is a partner event, the ETM computes a difference between that arrival time and an earlier stored time for the initiating event to determine the complete transaction time.

Event timing database **300** is an array of records **302**. Each record **302** includes a dialog field **304** for identifying the dialog over which the transactions of interest are occurring and it includes an entry type field **306** for identifying the event type of interest. Each record **302** also includes a start time field **308** for storing the arrival time of the initiating event and an average delay time field **310** for storing the computed average delay for the transactions. A more detailed description of the operation of the ETM follows.

Referring to FIG. **35**, when the RTP detects the arrival of a packet of the type for which timing information is being kept, it passes control to the ETM along with relevant information from the packet, such as the dialog identifier and the event type (step **320**). The ETM then determines whether it is to keep timing information for that particular event by checking the event timing database (step **322**). Since each event type can have multiple occurrences (i.e., there can be multiple dialogs at a given layer), the dialog identifier is used to distinguish between events of the same type for different dialogs and to identify those for which information has been requested. All of the dialog/events of interest are identified in the event timing database. If the current dialog and event appear in the event timing database, indicating that the event should be timed, the ETM determines whether the event is a starting event or an ending event so that it may be processed properly (step **324**). For certain events, the absence of a start time in the entry field of the appropriate record **302** in event timing database **300** is one indicator that the event represents a start time; otherwise, it is an end time event. For other events, the ETM determines if the start time is to be set by the event type as specified in the packet being parsed. For example, if the event is a file read a start time is stored. If the event is the read completion it represents an end time. In general, each protocol event will have its own intrinsic meaning for how to determine start and end times.

Note that the arrival time is only an estimate of the actual arrival time due to possible queuing and other processing delays. Nevertheless, the delays are generally so small in comparison to the transaction times being measured that they are of little consequence.

In step **324**, if the event represents a start time, the ETM gets the current time from the kernal and stores it in start time field **308** of the appropriate record in event timing database **300** (step **326**). If the event represents an end time event, the ETM obtains the current time from the kernel and computes a difference between that time and the corresponding start time found in event timing database **300** (step **328**). This represents the total time for the transaction of interest. It is combined with the stored average transaction time to compute a new running average transaction time for that event (step **330**).

Any one of many different methods can be used to compute the running average transaction time. For example, the following formula can be used:

New Avg.=[(5*stored Avg.)+Transaction Time]/6. After six transaction have been timed, the computed new average becomes a running average for the transaction times. The ETM stores this computed average in the appropriate record of event timing database **300**, replacing the previous average transaction time stored in that record, and it clears start time entry field **308** for that record in preparation for timing the next transaction.

After processing the event in steps **322**, **326**, and **330**, the ETM checks the age of all of the start time entries in the event timing database **300** to determine if any of them are too "old" (step **332**). If the difference between the current time and any of the start times exceeds a preselected threshold, indicating that a partner event has not occurred within a reasonable period of time, the ETM deletes the old start time entry for that dialog/event (step **334**). This insures that a missed packet for a partner event does not result in an erroneously large transaction time which throws off the running average for that event.

If the average transaction time increases beyond a preselected threshold set for timing events, an alarm is sent to the Workstation.

Two examples will now be described to illustrate the operation of the ETM for specific event types. In the first example, Node A of FIG. **25** is communicating with Node B using the NFS protocol. Node A is the client while Node B is the server. The Network Monitor resides on the same segment as node A, but this is not a requirement. When Node A issues a read request to Node B, the Network Monitor sees the request and the RTP within the Network Monitor transfers control to the ETM. Since it is a read, the ETM stores a start time in the Event Timing Database. Thus, the start time is the time at which the read was initiated.

After some delay, caused by the transmission delays of getting the read message to node B, node B performs the read and sends a response back to node A. After some further transmission delays in returning the read response, the Network Monitor receives the second packet for the event. At the time, the ETM recognizes that the event is an end time event and updates the average transaction time entry in the appropriate record with a new computed running average. The ETM then compares the average transaction time with the threshold for this event and if it has been exceeded, issues an alarm to the Workstation.

In the second example, node A is communicating with Node B using the Telnet protocol. Telnet is a virtual terminal protocol. The events of interest take place long after the initial connection has been established. Node A is typing at a standard ASCII (VT100 class) terminal which is logically (through the network) connected to Node B. Node B has an application which is receiving the characters being typed on Node A and, at appropriate times, indicated by the logic of the applications, sends characters back to the terminal located on Node A. Thus, every time node A sends characters to B, the Network Monitor sees the transmission.

In this case, there are several transaction times which could provide useful network performance information. They include, for example, the amount of time it takes to echo characters typed at the keyboard through the network and back to the display screen, the delay between typing an end of line command and seeing the completion of the application event come back or the network delays incurred in sending a packet and receiving acknowledgment for when it was received.

In this example, the particular time being measured is the time it takes for the network to send a packet and receive an acknowledgement that the packet has arrived. Since Telnet runs on top of TCP, which in turn runs on top of IP, the Network Monitor monitors the TCP acknowledge end-to-end time delays.

Note that this is a design choice of the implementation and that all events visible to the Network Monitor by virtue of the fact that information is in the packet could be measured.

When Node A transmits a data packet to Node B, the Network Monitor receives the packet. The RTP recognizes the packet as being part of a timed transaction and passes control to the ETM. The ETM recognizes it as a start time event, stores the start time in the event timing database and returns control to the RTP after checking for aging.

When Node B receives the data packet from Node A, it sends back an acknowledgment packet. When the Network Monitor sees that packet, it delivers the event to the ETM, which recognizes it as an end time event. The ETM calculates the delay time for the complete transaction and uses that to update the average transaction time. The ETM then compares the new average transaction time with the threshold for this event. If it has been exceeded, the ETM issues an alarm to the Workstation.

Note that this example is measuring something very different than the previous example. The first example measures the time it takes to traverse the network, perform an action and return that result to the requesting node. It measures performance as seen by the user and it includes delay times from the network as well as delay times from the File Server.

The second example is measuring network delays without looking at the service delays. That is, the ETM is measuring the amount of time it takes to send a packet to a node and receive the acknowledgement of the receipt of the message. In this example, the ETM is measuring transmissions delays as well as processing delays associated with network traffic, but not anything having to do with non-network processing.

As can be seen from the above examples, the ETM can measure a broad range of events. Each of these events can be measured passively and without the cooperation of the nodes that are actually participating in the transmission.

The Address Tracker Module (ATM)

Address tracker module (ATM) **43**, one of the software modules in the Network Monitor (see FIG. **5**), operates on networks on which the node addresses for particular node to node connections are assigned dynamically. An Appletalk® Network, developed by Apple Computer Company, is an example of a network which uses dynamic node addressing. In such networks, the dynamic change in the address of a particular service causes difficulty troubleshooting the net-

work because the network manager may not know where the various nodes are and what they are called. In addition, foreign network addresses (e.g., the IP addresses used by that node for communication over an IP network to which if is connected) can not be relied upon to point to a particular node. ATM **43** solves this problem by passively monitoring the network traffic and collecting a table showing the node address to node name mappings.

In the following description, the network on which the Monitor is located is assumed to be an Appletalk® Network. Thus, as background for the following discussion, the manner in which the dynamic node addressing mechanism operates on that network will first be described.

When a node is activated on the Appletalk® Network, it establishes its own node address in accordance with protocol referred to as the Local Link Access Protocol (LLAP). That is, the node guesses its own node address and then verifies that no other node on the network is using that address. The node verifies the uniqueness of its guess by sending an LLAP Enquiry control packet informing all other nodes on the network that it is going to assign itself a particular address unless another node responds that the address has already been assigned. If no other node claims that address as its own by sending an LLAP acknowledgment control packet, the first node uses the address which it has selected. If another node claims the address as its own, the first node tries another address. This continues until, the node finds an unused address.

When the first node wants to communicate with a second node, it must determine the dynamically assigned node address of the second node. It does this in accordance with another protocol referred to as the Name Binding Protocol (NBP). The Name Binding Protocol is used to map or bind human understandable node names with machine understandable node addresses. The NBP allows nodes to dynamically translate a string of characters (i.e., a node name) into a node address. The node needing to communicate with another node broadcasts an NBP Lookup packet containing the name for which a node address is being requested. The node having the name being requested responds with its address and returns a Lookup Reply packet containing its address to the original requesting node. The first node then uses that address for its current communications with the second node.

Referring to FIG. **36**, the network includes an Appletalk® Network segment **702** and a TCP/IP segment **704**, each of which are connected to a larger network **706** through their respective gateways **708**. A Monitor **710**, including a Real Time Parser (RTP) **712** and an Address Tracking Module (ATM) **714**, is located on Appletalk network segment **702** along with other nodes **711**. A Management Workstation **716** is located on segment **704**. It is assumed that Monitor **710** has the features and capabilities previously described; therefore, those features not specifically related to the dynamic node addressing capability will not be repeated here but rather the reader is referred to the earlier discussion. Suffice it to say that Monitor **710** is, of course, adapted to operate on Appletalk Network segment **702**, to parse and analyze the packets which are transmitted over that segment according to the Appletalk® family of protocols and to communicate the information which it extracts from the network to Management Workstation **716** located on segment **704**.

Within Monitor **710**, ATM **714** maintains a name table data structure **720** such as is shown in FIG. **37**. Name Table **720** includes records **722**, each of which has a node name field **724**, a node address field **726**, an IP address field **728**, and a time field **729**. ATM **714** uses Name Table **720** to keep track of the mappings of node names to node address and to IP address. The relevance of each of the fields of records **722** in Name Table **720** are explained in the following description of how ATM **714** operates.

In general, Monitor **710** operates as previously described. That is, it passively monitors all packet traffic over segment **702** and sends all packets to RTP **712** for parsing. When RTP **712** recognizes an Appletalk packet, it transfers control to ATM **714** which analyzes the packet for the presence of address mapping information.

The operation of ATM **714** is shown in greater detail in the flow diagram of FIG. **38**. When ATM **714** receives control from RTP **712**, it takes the packet (step **730** and strips off the lower layers of the protocol until it determines whether there is a Name Binding Protocol message inside the packet (step **732**). If it is a NBP message, ATM **714** then determines whether it is new name Lookup message (step **734**). If it is a new name Lookup message, ATM **714** extracts the name from the message (i.e., the name for which a node address is being requested) and adds the name to the node name field **724** of a record **722** in Name Table **720** (step **736**).

If the message is an NBP message but it is not a new name Lookup message, ATM **714** determines whether it is a Lookup Reply (step **738**). If it is a Lookup Reply, signifying that it contains a node name/node address binding, ATM **714** extracts the name and the assigned node address from the message and adds this information to Name Table **720** (step **740**). ATM **714** does this by searching the name fields of records **722** in Name Table **720** until it locates the name. Then, it updates the node address field of the identified record to contain the node address which was extracted from the received NBP packet. ATM **714** also updates time field **729** to record the time at which the message was processed.

After ATM **714** has updated the address field of the appropriate record, it determines whether any records **722** in Name Table **720** should be aged out (step **742**). ATM **714** compares the current time to the times recorded in the time fields. If the elapsed time is greater than a preselected time period (e.g. 48 hours), ATM **714** clears the record of all information (step **744**). After that, it awaits the next packet from RTP **712** (step **745**).

As ATM **714** is processing a packet and it determines either that it does not contain an NBP message (step **732**) or it does not contain a Lookup Reply message (step **738**), ATM **714** branches to step **742** to perform the age out check before going on to the next packet from RTP **712**.

The Appletalk to IP gateways provide services that allow an Appletalk Node to dynamically connect to an IP address for communicating with IP nodes. This service extends the dynamic node address mechanism to the IP world for all Appletalk nodes. While the flexibility provided is helpful to the users, the network manager is faced with the problem of not knowing which Appletalk Nodes are currently using a particular IP address and thus, they can not easily track down problems created by the particular node.

ATM **714** can use passive monitoring of the IP address assignment mechanisms to provide the network manager a Name-to-IP address mapping.

If ATM **714** is also keeping IP address information, it implements the additional steps shown in FIG. **39** after completing the node name to node address mapping steps. ATM **714** again checks whether it is an NBP message (step **748**). If it is an NBP message, ATM **714** checks whether it is a response to an IP address request (step **750**). IP address requests are typically implied by an NBP Lookup request for an IP gateway. The gateway responds by supplying the

gateway address as well as an IP address that is assigned to the requesting node. If the NBP message is an IP address response, ATM **714** looks up the requesting node in Name Table **720** (step **752**) and stores the IP address assignment in the IP address field of the appropriate record **722** (step **754**).

After storing the IP address assignment information, ATM **714** locates all other records **722** in Name Table **720** which contain that IP address. Since the IP address has been assigned to a new node name, those old entries are no longer valid and must be eliminated. Therefore, ATM **714** purges the IP address fields of those records (step **756**). After doing this cleanup step, ATM **714** returns control to RTP **712**.

Other embodiments are within the following claims. For example, the Network Monitor can be adapted to identify node types by analyzing the type of packet traffic to or from the node. If the node being monitored is receiving mount requests, the Monitor would report that the node is behaving like node a file server. If the node is issuing routing requests, the Monitor would report that the node is behaving like a router. En either case, the network manager can check a table of what nodes are permitted to provide what functions to determine whether the node is authorized to function as either a file server or a router, and if not, can take appropriate action to correct the problem.

Appendix VI contains microfiche of the source code for an embodiment of the invention. The source code is presented in **32** files which may be grouped as follows:

Group 1:	R_DLL.C; R_ICMP.C; R_IP.C; R_NFS.C; R_PMAP.C; R_RPC.C; R_TCP.C; R_UDP.C; RTP.C
Group 2:	S_DLL.H; S.H; S_ICMP.H; S_IP.H; S_NFS.H; S_PMAP.H; S_RPC.H; S_TCP.H; S_UDP.H
Group 3:	S_DLL_A.C; S_DLL_P.C; S_ICMP_A.C; S_ICMP_P.C; S_IP_A.C; S_IP_P.C; S_NFS_A.C; S_NFS_P.C; S_PMAP_P.C; S_TCP_A.C; S_TCP_P.C; S_UDP_A.C; S_UDP_P.C; STATS_P.C

The nine files in Group 1 relate to the real time parser code and contain source code for modules that do the parsing and state machine processing. Macros for maintaining statistics also appear among these source code files. The nine files in Group 2 contain the source code that defines the structures which hold the information that is determined during parsing. Among these files, the S.H file contains the base macros for maintaining the statistics. Finally, the remaining 14 files in Group 3 contain code that locates, allocates and deallocates the structures defined by the files found in Group 2. The source code in this group also contains the code that calculates the rates and ages out the data structures that have not been used within a timeout period.

The source code is written in C language. It may be compiled by a MIPS R3000 C compiler (Ver. 2.2) and run on a MIPS 3230 workstation which has a RISC-os operating system (MIPS products are available from MIPS Computer Systems, Inc. of Sunnyvale, Calif.).

We claim:

1. A method for monitoring a plurality of communication dialogs occurring in a network of nodes, each dialog of said plurality of dialogs being effected by a transmission of one or more packets among two or more communicating nodes, each dialog of said plurality of dialogs complying with a different predefined communication protocol selected from among a plurality of protocols available in said network, said plurality of dialogs representing multiple different protocols from among said plurality of available protocols, said method comprising:

passively, in real time, and on an ongoing basis, detecting the contents of packets;

from the detected contents of said packets, identifying all of the dialogs of said plurality of communication dialogs occurring in said network;

deriving from said detected contents of said packets, information about the identified dialogs; and

for each of the identified dialogs, storing the derived information about that identified dialog.

2. The method of claim **1** wherein the derived information is information about the states of the identified dialogs.

3. The method of claim **2** wherein said step of deriving information about the states of dialogs comprises;

maintaining a current state for each dialog; and

updating the current state in response to the detected contents of packets detected at a later time.

4. The method of claim **2** wherein said step of deriving information about the states of dialogs comprises:

maintaining, for each dialog, a history of events based on information derived from the contents of packets; and

analyzing the history of events to derive information about the dialog.

5. The method of claim **4** wherein said step of analyzing the history includes counting events.

6. The method of claim **4** wherein said step of analyzing the history includes gathering statistics about events.

7. The method of claim **4** further comprising:

monitoring the history of events for dialogs which are inactive; and

purging from the history of events dialogs which have been inactive for a predetermined period of time.

8. The method of claim **3** wherein said step of deriving information about the states of dialogs comprises updating said current state in response to observing the transmission of at least two data related packets between nodes.

9. The method of claim **4** wherein said step of analyzing the history of events comprises:

analyzing sequence numbers of data related packets stored in said history of events; and

detecting retransmissions based on said sequence numbers.

10. The method of claim **3** further comprising:

updating the current state based on each new packet associated with said dialog; and

if an updated current state cannot be determined, consulting information about prior packets associated with said dialog as an aid in updating said state.

11. The method of claim **4** further comprising searching said history of events to identify the initiator of a dialog.

12. The method of claim **4**, further comprising searching the history of events for packets which have been retransmitted.

13. The method of claim **3** wherein the full set of packets associated with a dialog up to a point in time completely define a true state of the dialog at that point in time, said step of updating the current state in response to the detected contents of transmitted packets comprises generating a current state which may not conform to the true state.

14. The method of claim **4** wherein the step of updating the current state comprises updating the current state to indicate that it is unknown.

15. The method of claim **13** further comprising updating the current state to the true state based on information about prior packets transmitted in the dialog.

16. The method of claim **14** further comprising updating the current state to the true state based on information about prior packets transmitted in the dialog.

17. The method of claim 2 wherein said step of deriving information about the states of dialogs occurring in said network comprises parsing said packets in accordance with more than one but fewer than all layers of a corresponding communication protocol.

18. The method of claim 1 is wherein each said communication protocol includes multiple layers, and each dialog complies with one of said layers.

19. The method of claim 2 wherein said multiple different protocols include a connectionless-type protocol in which the state of a dialog is implicit in transmitted packets, and said step of deriving information about the states of dialogs includes inferring the states of said dialogs from said packets.

20. The method of claim 3 further comprising:

parsing said packets in accordance with a corresponding communication protocol; and

temporarily suspending parsing of some layers of said protocol when parsing is not rapid enough to match the rate of packets to be parsed.

21. The method of claim 1 further comprising storing the derived communication information in a database.

22. The method of claim 21 further comprising, in response to an inquiry from a remotely located entity, retrieving from the database data regarding communications about which communication information had previously been detected and stored and sending the retrieved data to said remotely located entity.

23. The method of claim 1 wherein said multiple different protocols include protocols for different layers of a protocol stack as well as protocols for different protocol stacks.

24. Apparatus for monitoring a plurality of communication dialogs which occur in a network of nodes, each dialog of said plurality of dialogs being effected by a transmission of one or more packets among two or more communicating nodes, each dialog of said plurality of dialogs complying with a different predefined communication protocol selected from among a plurality of protocols available in said network, said plurality of dialogs representing multiple different protocols from among said plurality of available protocols, said apparatus comprising:

a monitor connected to the network medium, said monitor programmed to perform the tasks of passively, in real time, and on an ongoing basis: (1) monitoring transmitted packets; (2) from the monitored packets, identifying all of the dialogs of said plurality of communication dialogs; (3) from the monitored packets, deriving communication information associated with said plurality of communication dialogs; and (4) for each of the identified dialogs, storing the communication information about that identified dialog that is derived from said monitored packets; and

a workstation for receiving said information about dialogs from said monitor and providing an interface through which said communication information about the identified dialogs is displayed to a user.

25. The apparatus of claim 24 wherein said workstation further comprises means for enabling a user to observe events of active dialogs.

* * * * *

United States Patent [19]

Daniel, III et al.

[11] **Patent Number: 4,972,453**

[45] **Date of Patent: Nov. 20, 1990**

[54] **AUTONOMOUS EXPERT SYSTEM FOR DIRECTLY MAINTAINING REMOTE TELEPHONE SWITCHING SYSTEMS**

[75] Inventors: **William F. Daniel, III**, Louisville; **Karen C. Loeb**, Englewood; **Charles S. Roush**, Boulder, all of Colo.

[73] Assignee: **AT&T Bell Laboratories**, Murray Hill, N.J.

[21] Appl. No.: **317,232**

[22] Filed: **Feb. 28, 1989**

[51] Int. Cl.[5] **H04M 3/28**

[52] U.S. Cl. **379/10**; 379/15; 371/15.1; 371/18

[58] Field of Search 379/10, 15, 14, 32; 371/15.1, 18; 364/513

[56] **References Cited**

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"Expert Systems for AT&T Switched Network Maintenance", *AT&T Technical Journal*, vol. 67, Issue 1, pp. 93–103, Paul H. Callahan.

"Operations Systems Technology for New AT&T Network and Service Capabilities", *AT&T Technical Journal*, vol. 66, Issue 3, pp. 64–72.

Expert Systems in Central Office Switch Maintenance, Macleish, Thiedke, Vennergrund, IEEE Communications Magazine, Sep. 1986 vol. 24, No. 9 pp. 26–33.

Primary Examiner—Stafford D. Schreyer

Attorney, Agent, or Firm—John C. Moran

[57] **ABSTRACT**

An autonomous expert system for directly maintaining remote computer systems by directly accessing the remote computer systems, diagnosing, and clearing fault conditions on those computer systems. The expert system performs those functions by first accessing a fault report from a centralized service reporting center, establishing a data connection to the computer system reporting the fault, invoking diagnostic routines on the computer system to gather data about the reported fault, analyzing the data, and, if appropriate, clearing the reported fault from the computer system. If the fault cannot be cleared, the expert system recommends maintenance procedures and replacement parts for a technician who the expert system dispatches to the remote computer. The recommendations are based on field experience stored in rules and databases maintained by the expert system. When the remote computer system is controlling a customr switching system (PBX), the expert system only invokes testing procedures in the computer system which do not disrupt stable telephone calls. The expert system access the PBX via the public telephone network.

15 Claims, 24 Drawing Sheets

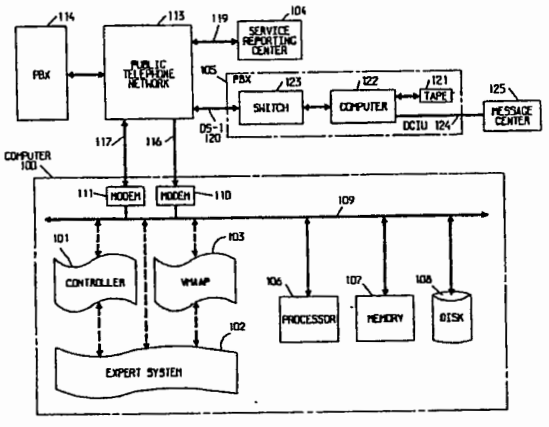

FIG. 1

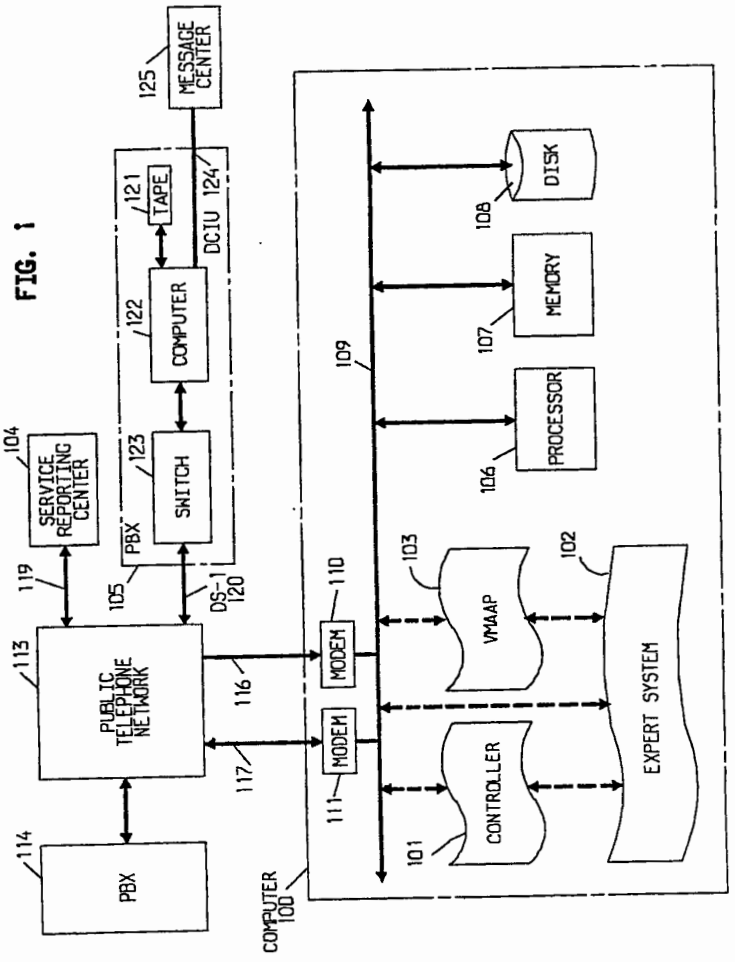
MESSAGE CENTER
125
TAPE
121
DCTU
124
COMPUTER
122
SWITCH
123
PBX
105
SERVICE REPORTING CENTER
104
119
DS-1
120
PUBLIC TELEPHONE NETWORK
113
116
117
PBX
114
MODEM
110
MODEM
111
COMPUTER
100
109
DISK
108
MEMORY
107
PROCESSOR
106
VMAAP
103
CONTROLLER
101
EXPERT SYSTEM
102

FIG. 2

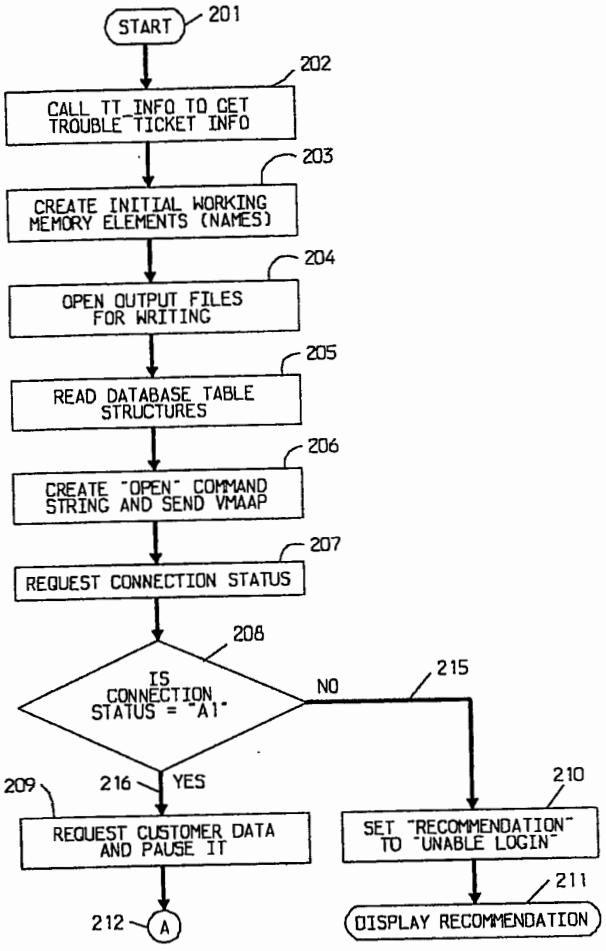
START
201
CALL TT_INFO TO GET TROUBLE TICKET INFO
202
CREATE INITIAL WORKING MEMORY ELEMENTS (NAMES)
203
OPEN OUTPUT FILES FOR WRITING
204
READ DATABASE TABLE STRUCTURES
205
CREATE "OPEN" COMMAND STRING AND SEND VMAAP
206
REQUEST CONNECTION STATUS
207
IS CONNECTION STATUS = "A1"
208
NO
215
YES
216
REQUEST CUSTOMER DATA AND PAUSE IT
209
SET "RECOMMENDATION" TO "UNABLE LOGIN"
210
DISPLAY RECOMMENDATION
211
A
212

FIG. 3

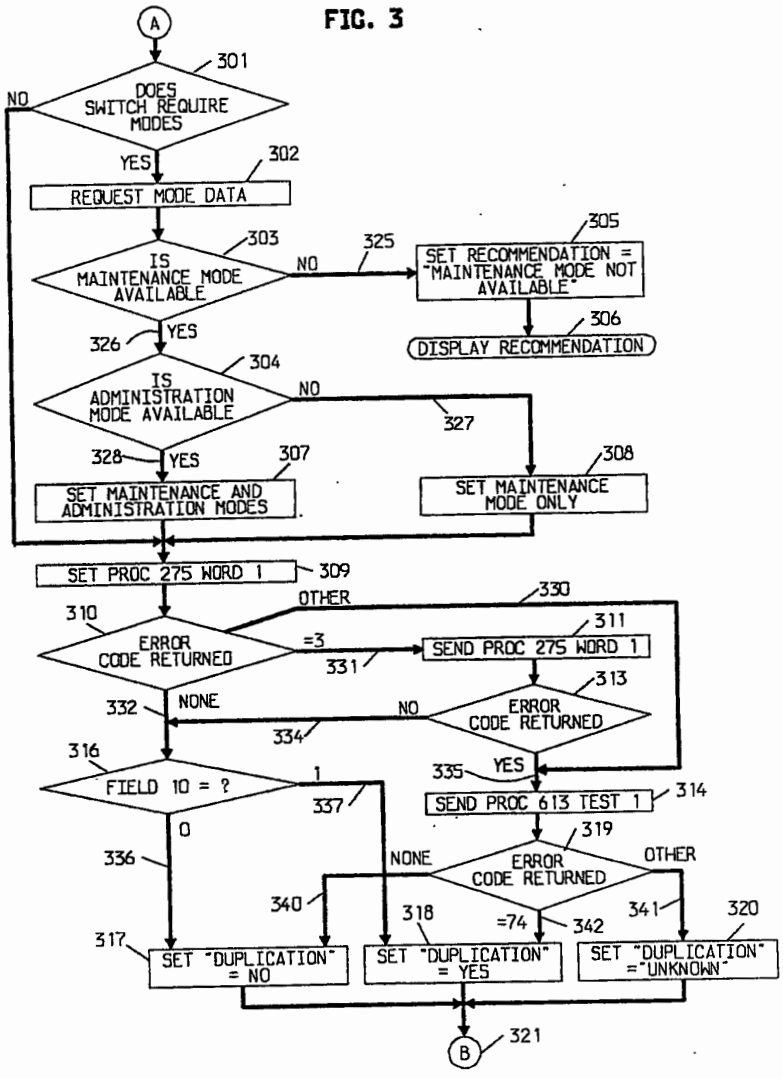
A
301
DOES SWITCH REQUIRE MODES
NO
YES
302
REQUEST MODE DATA
303
IS MAINTENANCE MODE AVAILABLE
NO
325
305
SET RECOMMENDATION = "MAINTENANCE MODE NOT AVAILABLE"
306
DISPLAY RECOMMENDATION
326
YES
304
IS ADMINISTRATION MODE AVAILABLE
NO
327
328
YES
307
SET MAINTENANCE AND ADMINISTRATION MODES
308
SET MAINTENANCE MODE ONLY
SET PROC 275 WORD 1
309
310
ERROR CODE RETURNED
OTHER
330
=3
331
311
SEND PROC 275 WORD 1
313
ERROR CODE RETURNED
NO
334
332
NONE
316
FIELD 10 = ?
1
337
335
YES
SEND PROC 613 TEST 1
314
0
336
319
ERROR CODE RETURNED
NONE
OTHER
340
318
=74
342
341
320
317
SET "DUPLICATION" = NO
SET "DUPLICATION" = YES
SET "DUPLICATION" = "UNKNOWN"
B
321

FIG. 4

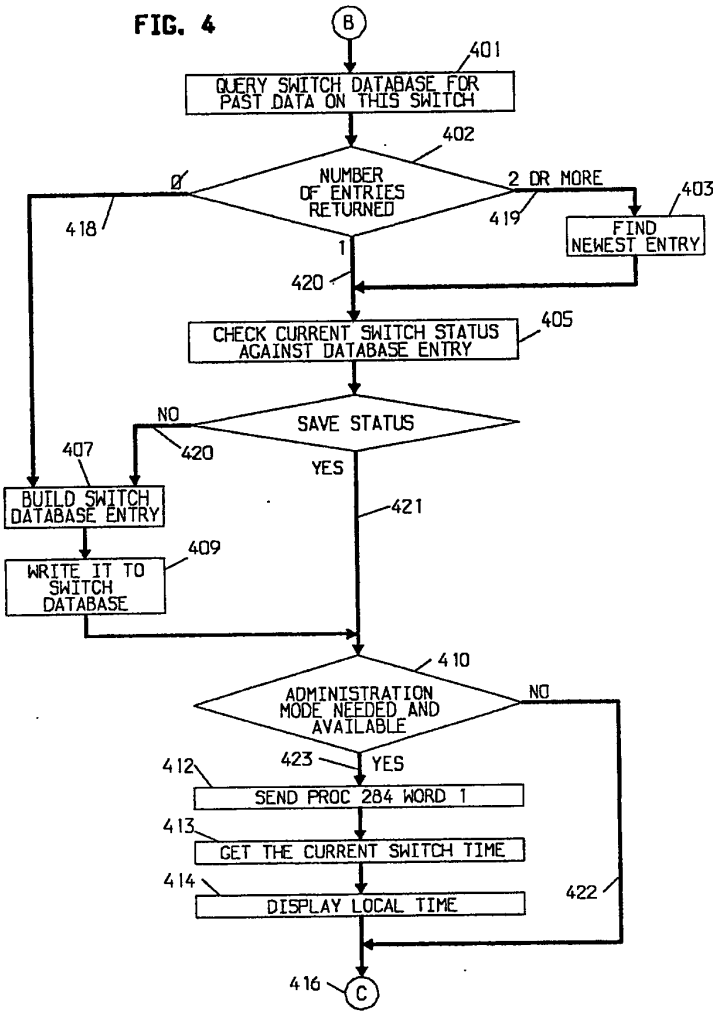
B
401
QUERY SWITCH DATABASE FOR PAST DATA ON THIS SWITCH
402
NUMBER OF ENTRIES RETURNED
Ø
2 OR MORE
418
419
403
FIND NEWEST ENTRY
1
420
CHECK CURRENT SWITCH STATUS AGAINST DATABASE ENTRY
405
SAVE STATUS
NO
420
YES
407
BUILD SWITCH DATABASE ENTRY
421
409
WRITE IT TO SWITCH DATABASE
410
ADMINISTRATION MODE NEEDED AND AVAILABLE
NO
423
YES
412
SEND PROC 284 WORD 1
413
GET THE CURRENT SWITCH TIME
414
DISPLAY LOCAL TIME
422
416
C

FIG. 5

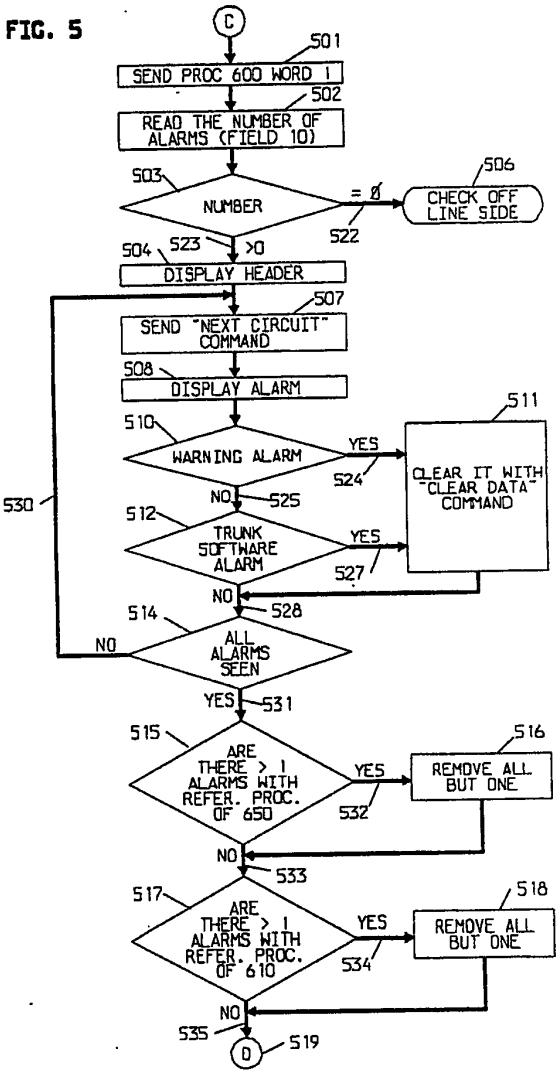
C
501
SEND PROC 600 WORD 1
502
READ THE NUMBER OF ALARMS (FIELD 10)
503
NUMBER
= Ø
506
CHECK OFF LINE SIDE
522
523
>0
504
DISPLAY HEADER
507
SEND "NEXT CIRCUIT" COMMAND
508
DISPLAY ALARM
511
510
WARNING ALARM
YES
524
CLEAR IT WITH "CLEAR DATA" COMMAND
NO
525
530
512
TRUNK SOFTWARE ALARM
YES
527
NO
528
514
ALL ALARMS SEEN
NO
YES
531
515
ARE THERE > 1 ALARMS WITH REFER. PROC. OF 650
YES
516
REMOVE ALL BUT ONE
532
NO
533
517
ARE THERE > 1 ALARMS WITH REFER. PROC. OF 610
YES
518
REMOVE ALL BUT ONE
534
NO
535
D
519

FIG. 6

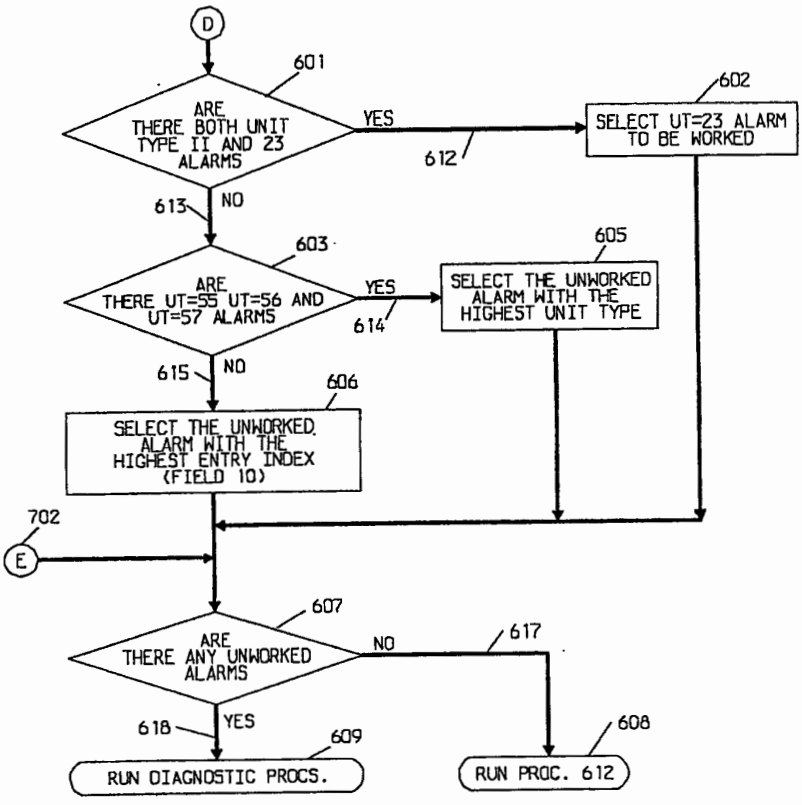
D
601
ARE THERE BOTH UNIT TYPE II AND 23 ALARMS
YES
602
SELECT UT=23 ALARM TO BE WORKED
612
613
NO
603
ARE THERE UT=55 UT=56 AND UT=57 ALARMS
YES
605
SELECT THE UNWORKED ALARM WITH THE HIGHEST UNIT TYPE
614
615
NO
606
SELECT THE UNWORKED ALARM WITH THE HIGHEST ENTRY INDEX (FIELD 10)
702
E
607
ARE THERE ANY UNWORKED ALARMS
NO
617
618
YES
609
RUN DIAGNOSTIC PROCS.
608
RUN PROC. 612

FIG. 7

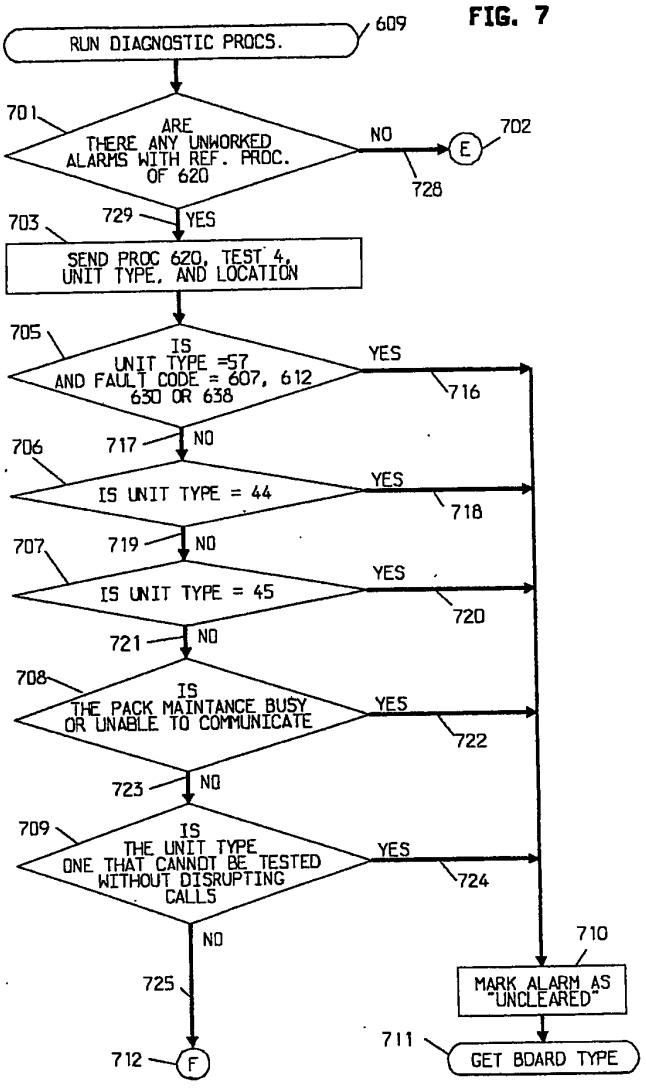
RUN DIAGNOSTIC PROCS.
609
701
ARE THERE ANY UNWORKED ALARMS WITH REF. PROC. OF 620
NO
E
702
728
729
YES
703
SEND PROC 620, TEST 4, UNIT TYPE, AND LOCATION
705
IS UNIT TYPE =57 AND FAULT CODE = 607, 612 630 OR 638
YES
716
717
NO
706
IS UNIT TYPE = 44
YES
718
719
NO
707
IS UNIT TYPE = 45
YES
720
721
NO
708
IS THE PACK MAINTANCE BUSY OR UNABLE TO COMMUNICATE
YES
722
723
NO
709
IS THE UNIT TYPE ONE THAT CANNOT BE TESTED WITHOUT DISRUPTING CALLS
YES
724
NO
725
712
F
710
MARK ALARM AS "UNCLEARED"
711
GET BOARD TYPE

FIG. 8

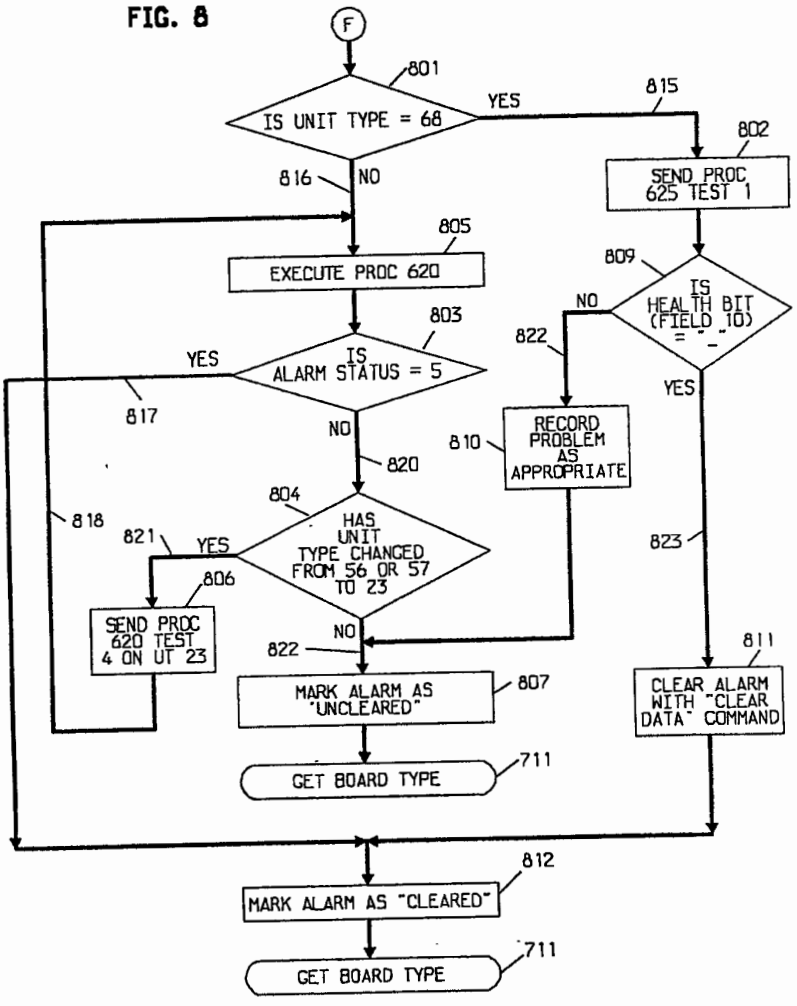
F
801
IS UNIT TYPE = 68
YES
815
802
SEND PROC 625 TEST 1
816
NO
805
EXECUTE PROC 620
809
IS HEALTH BIT (FIELD 10) = "-"
NO
822
YES
803
IS ALARM STATUS = 5
YES
817
NO
820
810
RECORD PROBLEM AS APPROPRIATE
804
HAS UNIT TYPE CHANGED FROM 56 OR 57 TO 23
818
821
YES
806
SEND PROC 620 TEST 4 ON UT 23
NO
822
823
811
CLEAR ALARM WITH "CLEAR DATA" COMMAND
MARK ALARM AS "UNCLEARED"
807
GET BOARD TYPE
711
812
MARK ALARM AS "CLEARED"
GET BOARD TYPE
711

FIG. 9

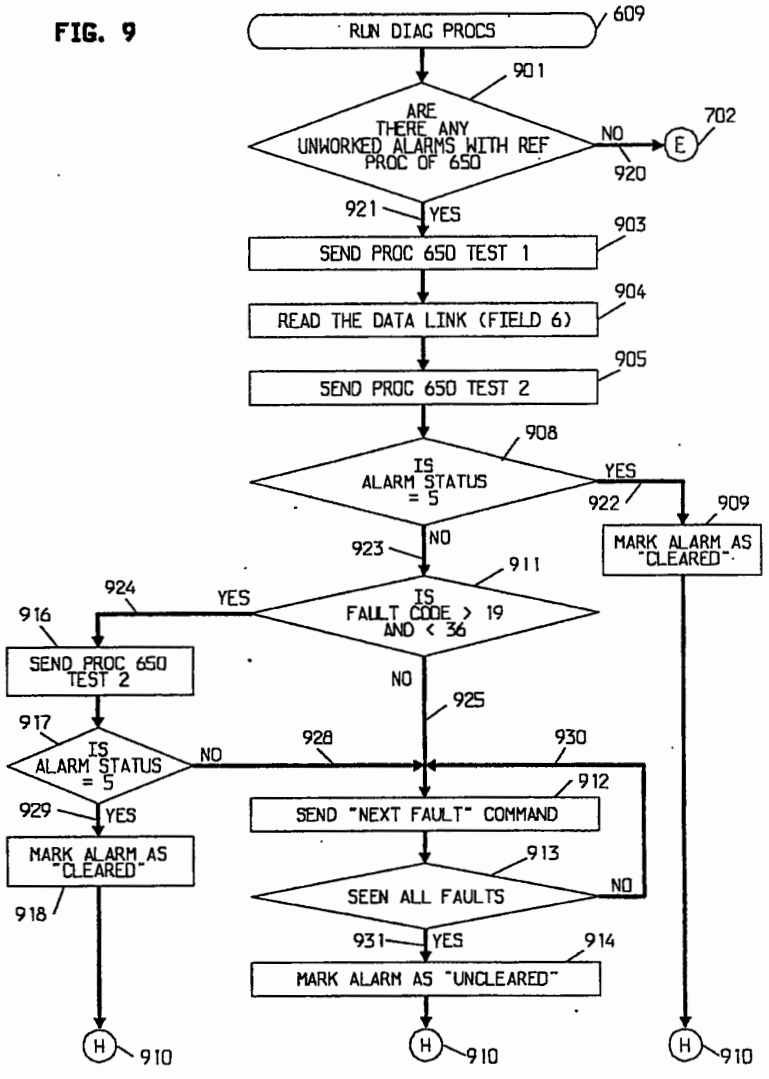
RUN DIAG PROCS
609
901
ARE THERE ANY UNWORKED ALARMS WITH REF PROC OF 650
NO
702
E
920
921
YES
SEND PROC 650 TEST 1
903
READ THE DATA LINK (FIELD 6)
904
SEND PROC 650 TEST 2
905
908
IS ALARM STATUS = 5
YES
922
909
MARK ALARM AS "CLEARED"
923
NO
911
924
YES
IS FAULT CODE > 19 AND < 36
916
SEND PROC 650 TEST 2
NO
925
917
IS ALARM STATUS = 5
NO
928
930
912
929
YES
SEND "NEXT FAULT" COMMAND
MARK ALARM AS "CLEARED"
913
SEEN ALL FAULTS
NO
918
931
YES
914
MARK ALARM AS "UNCLEARED"
H
910
H
910
H
910

FIG. 10

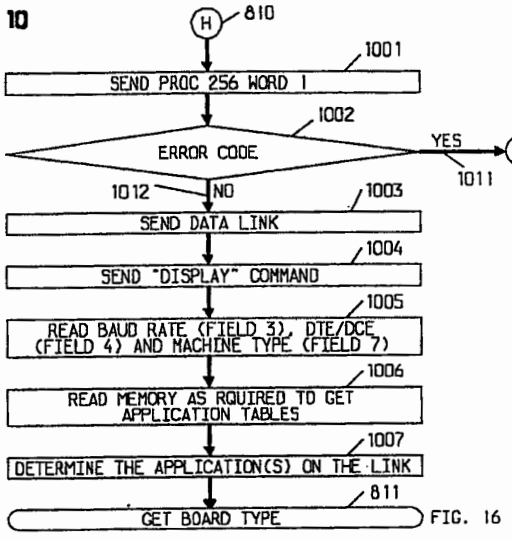

FIG. 16

FIG. 11

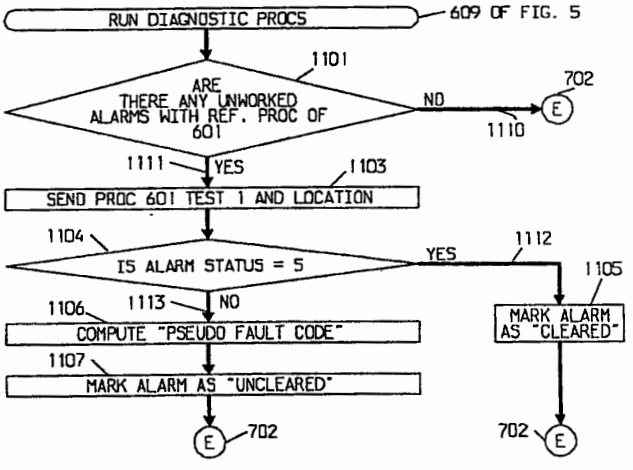

FIG. 12

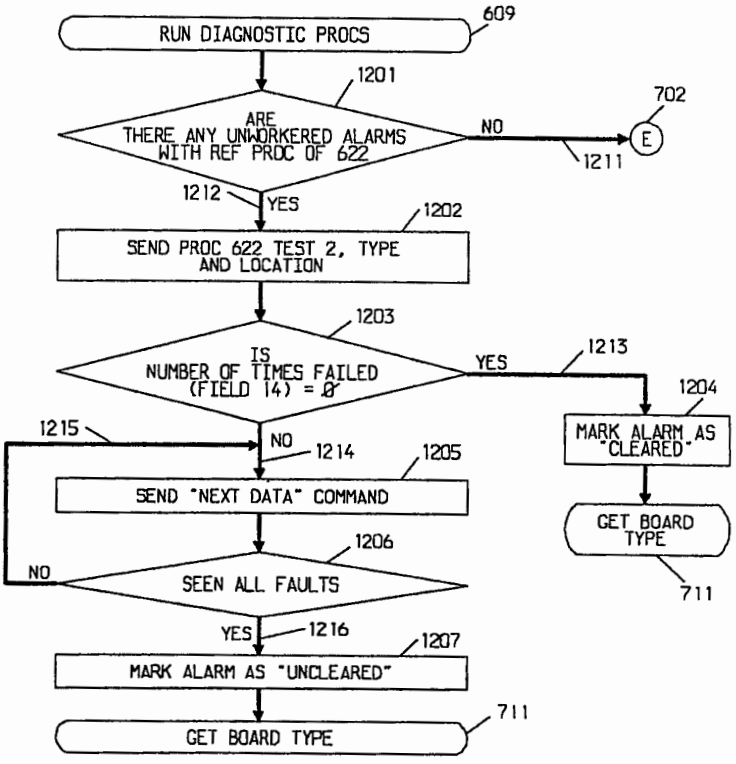
609
RUN DIAGNOSTIC PROCS
1201
ARE THERE ANY UNWORKERED ALARMS WITH REF PROC OF 622
NO
702
E
1211
1212
YES
1202
SEND PROC 622 TEST 2, TYPE AND LOCATION
1203
IS NUMBER OF TIMES FAILED (FIELD 14) = 0
YES
1213
1204
MARK ALARM AS "CLEARED"
GET BOARD TYPE
711
1215
NO
1214
1205
SEND "NEXT DATA" COMMAND
1206
NO
SEEN ALL FAULTS
YES
1216
1207
MARK ALARM AS "UNCLEARED"
711
GET BOARD TYPE

FIG. 13

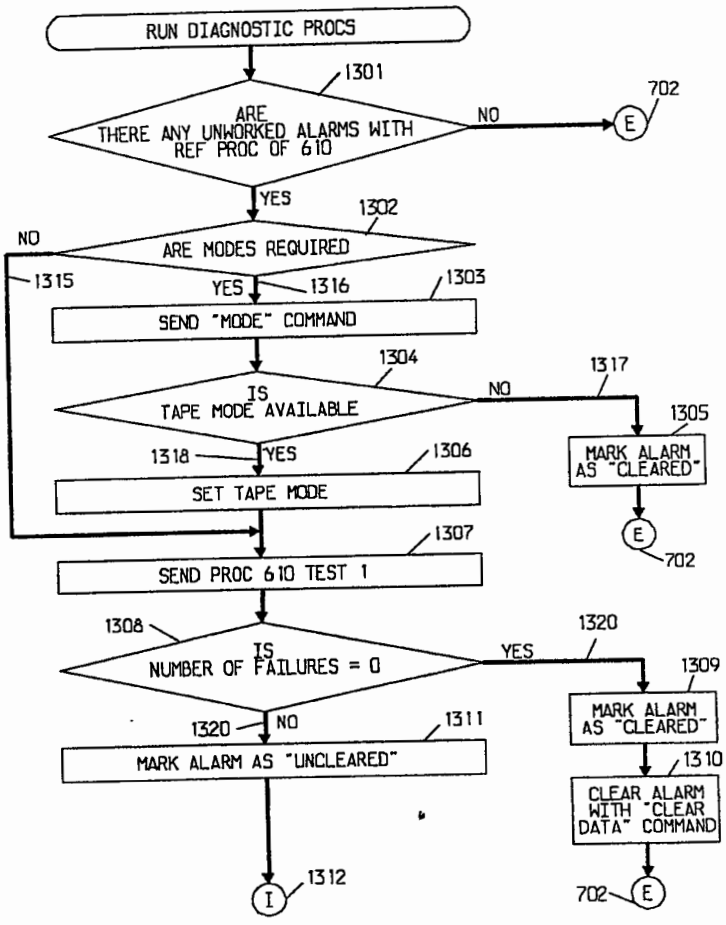
RUN DIAGNOSTIC PROCS
1301
ARE THERE ANY UNWORKED ALARMS WITH REF PROC OF 610
NO
702
E
YES
1302
ARE MODES REQUIRED
NO
1315
YES
1316
1303
SEND "MODE" COMMAND
1304
IS TAPE MODE AVAILABLE
NO
1317
1305
MARK ALARM AS "CLEARED"
E
702
1318
YES
1306
SET TAPE MODE
1307
SEND PROC 610 TEST 1
1308
IS NUMBER OF FAILURES = 0
YES
1320
1309
MARK ALARM AS "CLEARED"
1320
NO
1311
MARK ALARM AS "UNCLEARED"
1310
CLEAR ALARM WITH "CLEAR DATA" COMMAND
I
1312
702
E

FIG. 14

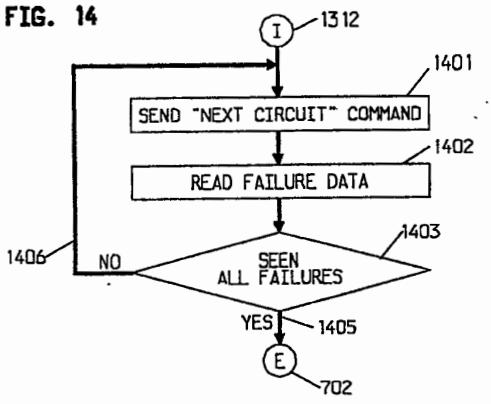
I
1312
1401
SEND "NEXT CIRCUIT" COMMAND
1402
READ FAILURE DATA
1403
1406
NO
SEEN ALL FAILURES
YES
1405
E
702

FIG. 15

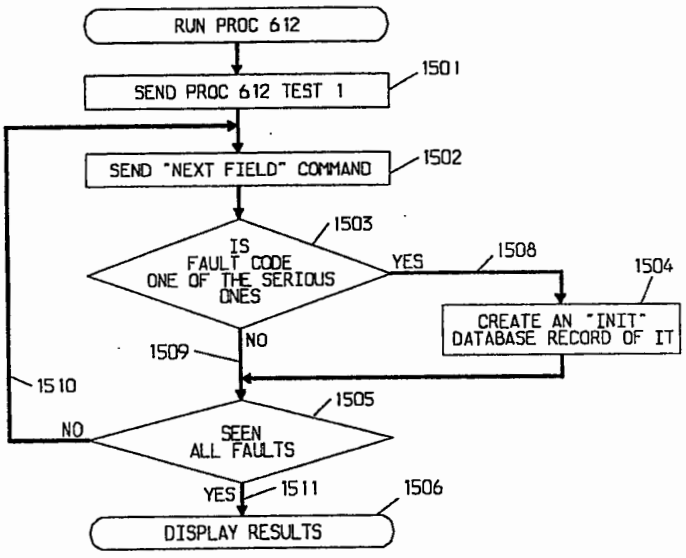
RUN PROC 612
SEND PROC 612 TEST 1
1501
SEND "NEXT FIELD" COMMAND
1502
1503
IS FAULT CODE ONE OF THE SERIOUS ONES
YES
1508
1504
CREATE AN "INIT" DATABASE RECORD OF IT
NO
1509
1510
1505
NO
SEEN ALL FAULTS
YES
1511
1506
DISPLAY RESULTS

FIG. 17

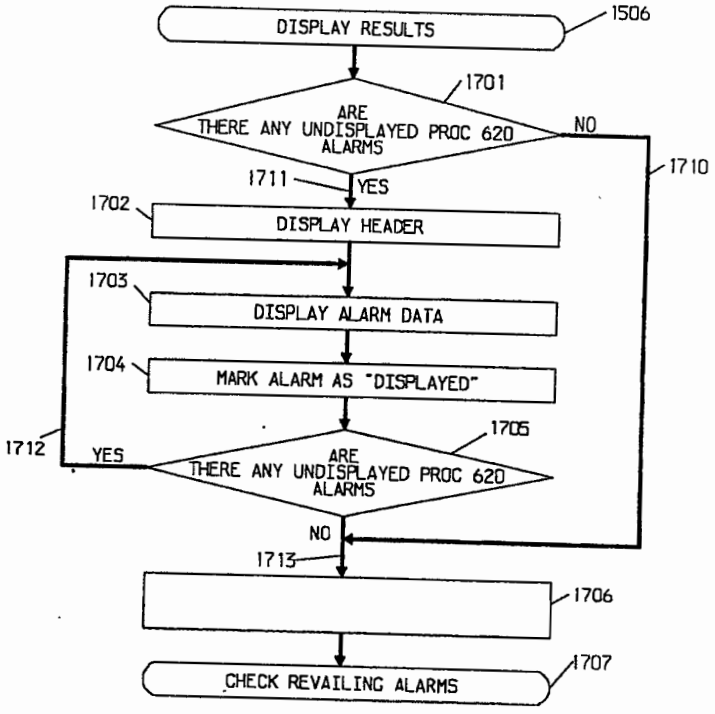
DISPLAY RESULTS
1506
1701
ARE THERE ANY UNDISPLAYED PROC 620 ALARMS
NO
1710
1711
YES
1702
DISPLAY HEADER
1703
DISPLAY ALARM DATA
1704
MARK ALARM AS "DISPLAYED"
1705
1712
YES
ARE THERE ANY UNDISPLAYED PROC 620 ALARMS
NO
1713
1706
CHECK REVAILING ALARMS
1707

FIG. 18

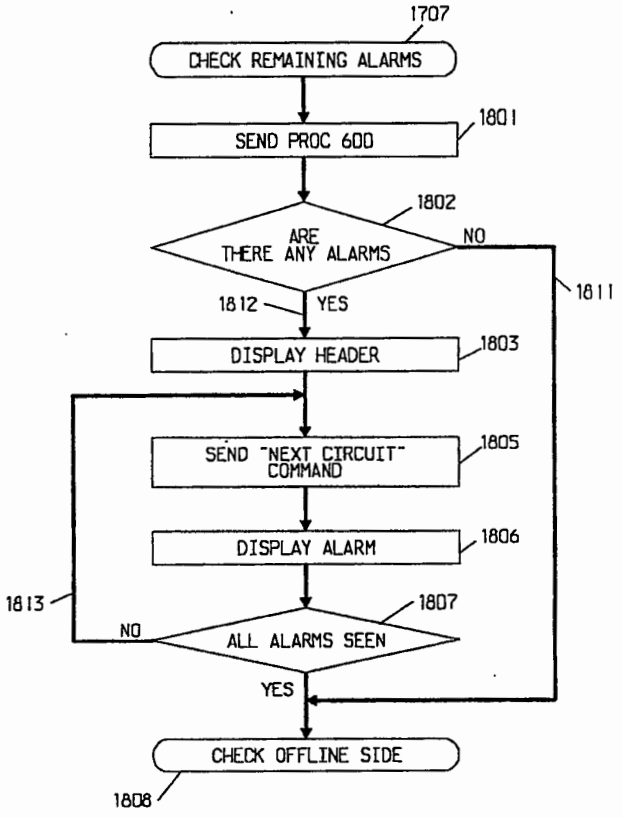
1707
CHECK REMAINING ALARMS
1801
SEND PROC 600
1802
ARE THERE ANY ALARMS
NO
1811
1812
YES
1803
DISPLAY HEADER
1805
SEND "NEXT CIRCUIT" COMMAND
1806
DISPLAY ALARM
1813
1807
NO
ALL ALARMS SEEN
YES
CHECK OFFLINE SIDE
1808

FIG. 19

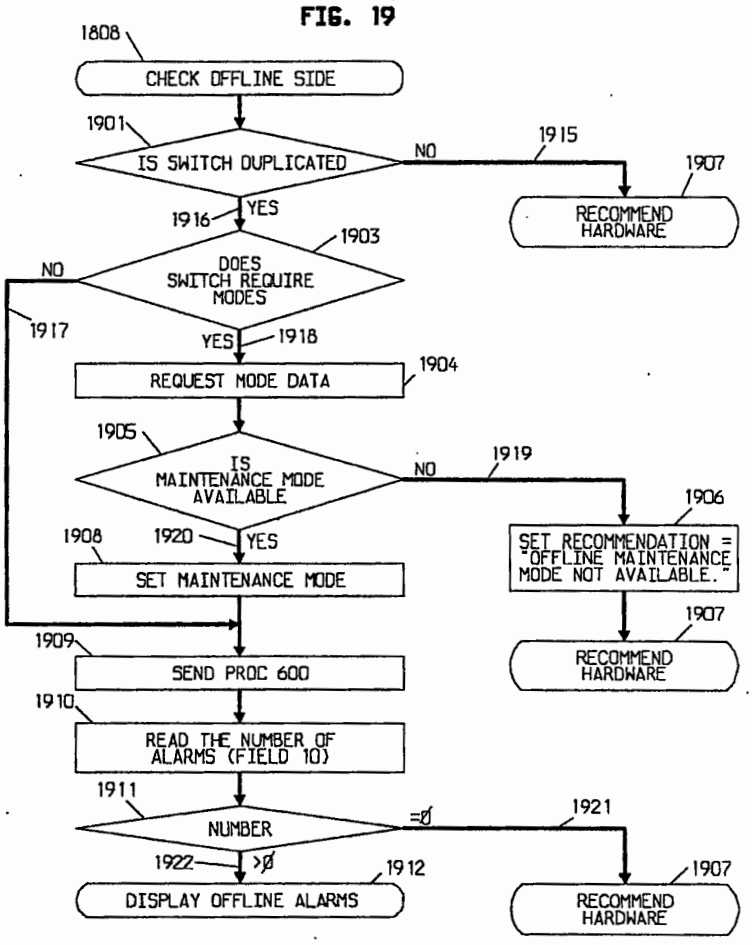
1808
CHECK OFFLINE SIDE
1901
IS SWITCH DUPLICATED
NO
1915
1907
RECOMMEND HARDWARE
YES
1916
1903
DOES SWITCH REQUIRE MODES
NO
1917
YES
1918
1904
REQUEST MODE DATA
1905
IS MAINTENANCE MODE AVAILABLE
NO
1919
1906
SET RECOMMENDATION = "OFFLINE MAINTENANCE MODE NOT AVAILABLE."
1907
RECOMMEND HARDWARE
1908
1920
YES
SET MAINTENANCE MODE
1909
SEND PROC 600
1910
READ THE NUMBER OF ALARMS (FIELD 10)
1911
NUMBER
=Ø
1921
1922
>Ø
1912
DISPLAY OFFLINE ALARMS
1907
RECOMMEND HARDWARE

FIG. 20

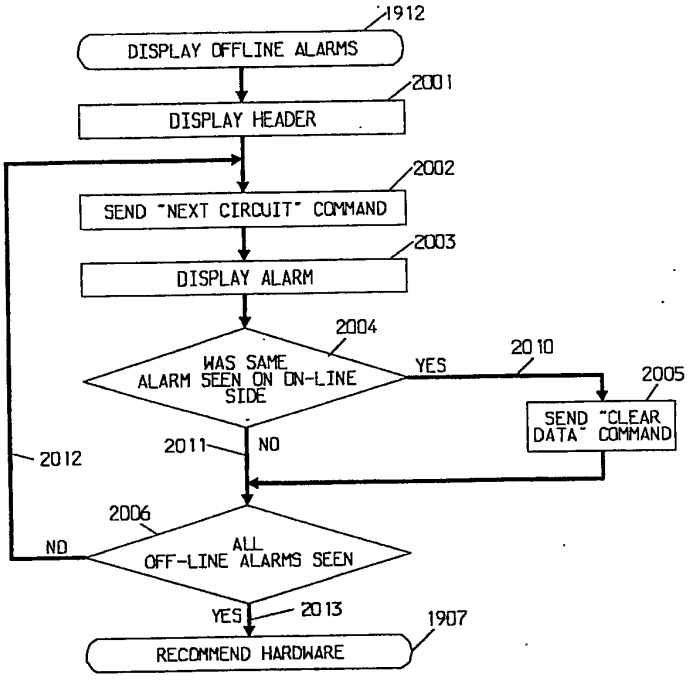
1912
DISPLAY OFFLINE ALARMS
2001
DISPLAY HEADER
2002
SEND "NEXT CIRCUIT" COMMAND
2003
DISPLAY ALARM
2004
WAS SAME ALARM SEEN ON ON-LINE SIDE
YES
2010
2005
SEND "CLEAR DATA" COMMAND
2011
NO
2012
2006
ALL OFF-LINE ALARMS SEEN
NO
YES
2013
1907
RECOMMEND HARDWARE

FIG. 21

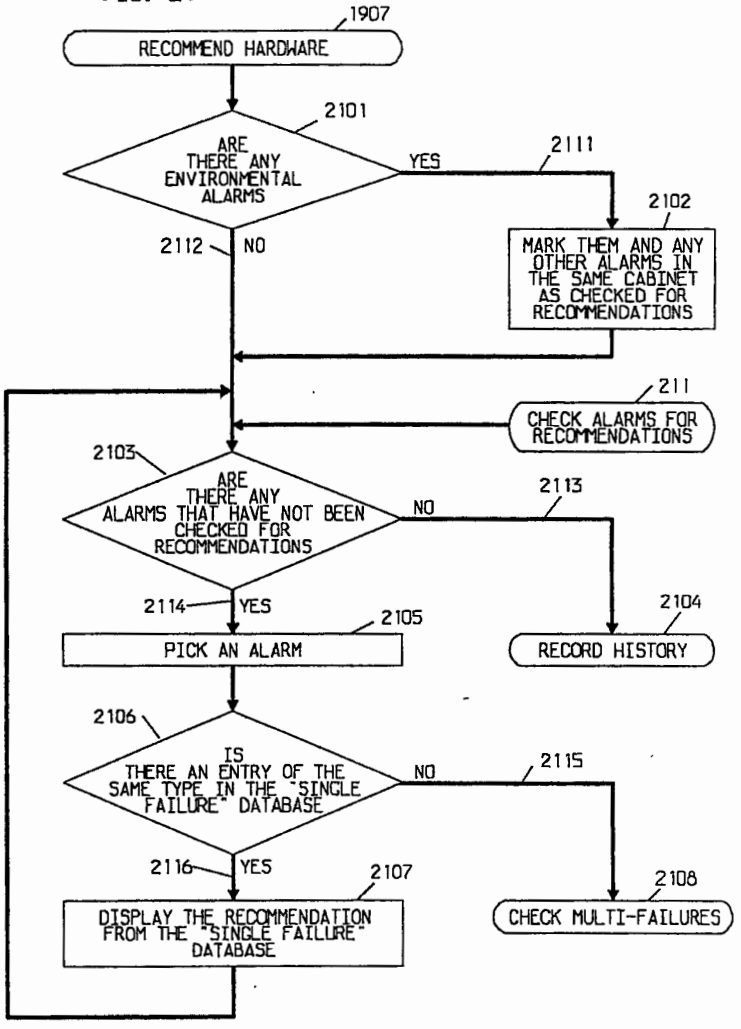
1907
RECOMMEND HARDWARE
2101
ARE THERE ANY ENVIRONMENTAL ALARMS
YES
2111
2102
MARK THEM AND ANY OTHER ALARMS IN THE SAME CABINET AS CHECKED FOR RECOMMENDATIONS
2112
NO
211
CHECK ALARMS FOR RECOMMENDATIONS
2103
ARE THERE ANY ALARMS THAT HAVE NOT BEEN CHECKED FOR RECOMMENDATIONS
NO
2113
2114
YES
2105
PICK AN ALARM
2104
RECORD HISTORY
2106
IS THERE AN ENTRY OF THE SAME TYPE IN THE "SINGLE FAILURE" DATABASE
NO
2115
2116
YES
2107
DISPLAY THE RECOMMENDATION FROM THE "SINGLE FAILURE" DATABASE
2108
CHECK MULTI-FAILURES

FIG. 22

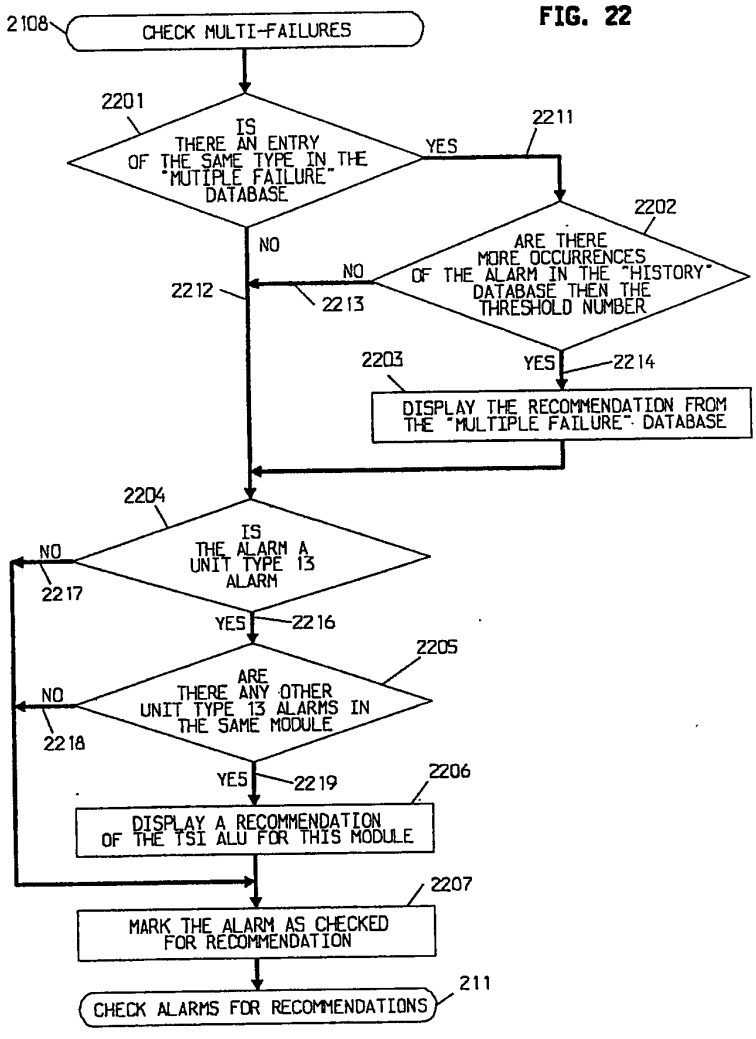
2108
CHECK MULTI-FAILURES
2201
IS THERE AN ENTRY OF THE SAME TYPE IN THE "MUTIPLE FAILURE" DATABASE
YES
2211
NO
2202
ARE THERE MORE OCCURRENCES OF THE ALARM IN THE "HISTORY" DATABASE THEN THE THRESHOLD NUMBER
NO
2212
2213
2203
YES
2214
DISPLAY THE RECOMMENDATION FROM THE "MULTIPLE FAILURE" DATABASE
2204
IS THE ALARM A UNIT TYPE 13 ALARM
NO
2217
YES
2216
2205
ARE THERE ANY OTHER UNIT TYPE 13 ALARMS IN THE SAME MODULE
NO
2218
YES
2219
2206
DISPLAY A RECOMMENDATION OF THE TSI ALU FOR THIS MODULE
2207
MARK THE ALARM AS CHECKED FOR RECOMMENDATION
CHECK ALARMS FOR RECOMMENDATIONS
211

FIG. 23

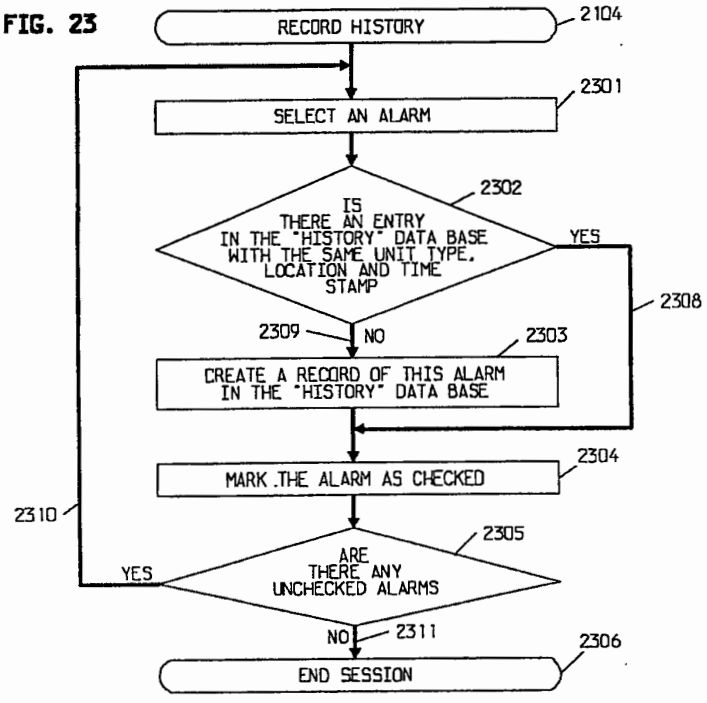
RECORD HISTORY
2104
SELECT AN ALARM
2301
IS THERE AN ENTRY IN THE "HISTORY" DATA BASE WITH THE SAME UNIT TYPE, LOCATION AND TIME STAMP
2302
YES
2308
2309
NO
2303
CREATE A RECORD OF THIS ALARM IN THE "HISTORY" DATA BASE
MARK THE ALARM AS CHECKED
2304
2310
ARE THERE ANY UNCHECKED ALARMS
2305
YES
NO
2311
END SESSION
2306

FIG. 24

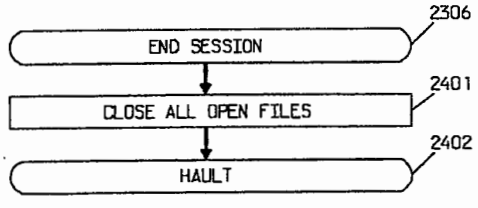
2306
END SESSION
2401
CLOSE ALL OPEN FILES
2402
HAULT

FIG. 25

SWITCH DATA

CUSTOMER : XYZ COMPANY
RELEASE : R2V3
VINTAGE : 1.2
DUPLICATED: YES
LOCAL TIME: 6:44 AM WEDNESDAY, JANUARY 18, 1989

2501
2502
2503

FIG. 26

ON-LINE PROCESSOR

ON-LINE PROCESSOR HAS 3 ALARM(S). 2604

FIG. 27

PROC 600 - ALARM CAUSES/ERROR LOG

UNIT TYPE	MOD	CAB	CAR	SLOT	CKT	ALARM STA	TOTAL FAIL	ENTRY INDEX	STAMP INDEX	DAY	HR	MIN	PROC REF	
2	0	0	0	20	1	2	3	1	3	18	6	16	10	2701
68	0	0	3	5	-	2	1	2	3	18	3	44	20	2702
13	2	0	0	7	-	2	60	3	3	18	2	49	20	

FIG. 28

PROC 610 - TAPE TESTS

EQUIPMENT TI	CN	DA	XP	SV	PW	CT	ALM STA	NBR FAIL	IDX	FAULT CODE	DAY	HR	MIN	RUN TAPE	BRD TYPE	BRD VINT	RESOLUTION	
-	-	-	-	-	-	-	4	1	1	949	18	6	16	29			UNCLEARED	2801
1	-	-	-	-	-	-	4	2	1	803	26	9	4	29			UNCLEARED	
-	1	-	-	-	-	-	2	3	1	925	18	6	12	29			UNCLEARED	

FIG. 29

PROC 620 - NETWORK PROCEDURE

UNIT TYPE	MOD	CAB	CAR	SLOT	CKT	RMA STA	ALARM STA	CKT STA	INIT FL CD	FINAL FL CD	BRD TYPE	BRD VINT	RESOLUTION	
68	0	0	3	5	-	-	2	1	1856	-	ANN11E	2	UNCLEARED	2901
THIS DS-1 CIRCUIT REPORTS EXCESSIVE SLIPS.														2902
13	2	0	0	7	-	-	2	1	407	-	TN440B	2	CLEARED	2903

FIG. 30

PROC 612 - INITIALIZATION CAUSES

UNIT TYPE	FAULT CODE	MEMORY BLOCK	ADDRESS BLOCK	DAY	HOUR	MINUTE	RELOAD COUNT	PROCESSOR HEALTH
3	8	0	771015	18	6	46	1	0

FIG. 31

REMAINING ON-LINE ALARMS

ON-LINE PROCESSOR HAS 2 ALARM(S) REMAINING.

PROC 600 - ALARM CAUSES/ERROR LOG

UNIT TYPE	MOD	CAB	CAR	SLOT	CKT	ALARM STA	TOTAL FAIL	ENTRY INDEX	STAMP INDEX	DAY	HR	MIN	PROC REF
2	0	0	0	20	1	2	3	1	3	18	6	16	10
68	0	0	3	5	-	2	1	2	3	18	3	44	20

FIG. 32

OFF-LINE PROCESSOR

OFF-LINE PROCESSOR HAS NO ALARMS.

FIG. 33

HARDWARE REPLACEMENTS

REPLACE TAPE CARTRIDGE.

FIG. 34

```
2:793::TAPE CARTRIDGE::
10:407:EXIST:::
14:521:::IF BOARD REPLACEMENTS FAIL, TRY REPLACING THE IOBI-UPCI CABLE:
27:353.1:EXIST:70G (3/4 AMP) FUSE::
```

FIG. 35

```
2:940:::2:10000:!UPGRADE TO LATEST SOFTWARE DOT ISSUE.!:!ALARM DISABLED.!
13:407-1:LOCATION:!EXISTING BOARD WITH TN440B V31:2:10000::!EXCESSIVE PARITY ERRORS.!
13:407-2:EXIST::2:10000::! EXCESSIVE PARITY ERRORS.!
16:219:EXIST::5:10000::!IGNORE IF COINCIDES WITH MODULE PROCESSOR FAILURE.!
24:286-1:LOCATION:!EXISTING BOARD WITH SN252 V31:3:10000::
24:286-2:EXIST::3:10000::
```

FIG. 36

```
555-555-5555,PBX.592,69,0,0,3,8,1,ON,2,573948,2/2/1989,12:9,283,-,-,ANN17B,5,CLEARED,-
555-555-5555,PBX.592,69,0,1,1,18,1,OFF,2,613440,2/2/1989,0:24,-,-,-,-,-,UNCLEARED,-
555-555-5555,PBX.592,69,0,1,0,16,4,OFF,2,615671,2/2/1989,23:37,-,-,-,-,-,UNCLEARED,-
555-555-5555,PBX.1103,11,0,0,0,13,-,ON,1,574404,2/2/1989,12:47,84,-,-,TN445,1,CLEARED,-
555-555-5554,PBX.1296,32,0,2,1,20,1,ON,2,574020,2/2/1989,15,140,140,-,SN230B,1,UNCLEARED,-
555-555-5553,pbx.1310,56,4,0,0,3,-,ON,1,569393,1/29/1989,19:47,639,-,-,TN441,5,UNCLEARED,-
```

AUTONOMOUS EXPERT SYSTEM FOR DIRECTLY MAINTAINING REMOTE TELEPHONE SWITCHING SYSTEMS

REFERENCE TO A MICROFICHE APPENDIX

This application contains a microfiche appendix, designated A, which lists program instructions incorporated in the disclosed expert system. The total number of microfiche is 2 sheets and the total number of frames is 135.

TECHNICAL FIELD

This invention relates to maintaining computer systems and in particular to maintaining such systems using an expert system.

BACKGROUND OF THE INVENTION

Modern private branch exchanges (PBX) use a computer to control a switching network. PBXs are also referred to as customer switching systems or private automatic branch exchanges (PABX). In addition to controlling the PBX, the computer is continuously running basic diagnostic tests not only on itself but also on the switching network and communication facilities interconnecting the PBX to other PBXs and other types of computer systems. In addition to permanent faults/alarms, these diagnostic tests find many transitory faults within the PBX. The transitory faults may indicate that a component of the PBX is marginally faulty or that the PBX's environmental conditions have induced a failure in the PBX. Such environmental conditions result from a variety of sources ranging from error conditions on the communication facilities to electrical noise in the AC power supplied to the PBX at its site. Each fault occurring on a PBX must be investigated by a service technician to determine the severity of the fault. When a PBX manufacturer has thousands of PBXs to maintain in the field, the cost of making such investigations becomes enormous.

Some manufacturers have equipped their PBXs to report all faults to a centralized service reporting center. A technician at the service reporting center reviews the faults reports and then remotely accesses the PBX to determine the cause of the faults. Whereas the ability of a technician to remotely maintain PBXs is an improvement, the manufacturer still incurs considerable costs in maintaining PBXs in the field because of the labor cost of technicians.

Expert systems have been extensively used to assist in the maintenance of remote systems by directly supporting maintenance technicians. U.S. Pat. No. 4,697,243 discloses an expert system which assists technicians in the maintenance of elevators. In that system, an expert system running on a central computer leads an on-site technician through a diagnostic session with menus, questions, and directions displayed to the technician on a remote terminal. The technician communicates fault and test data to the expert system via the terminal. The expert system then diagnoses the elevator fault and sends the diagnosis back to the technician who then repairs the elevator.

U.S. Pat. No. 4,517,468 discloses an expert system executing on a central computer for collecting data from remote steam turbine generator power plants. After collecting the data from a plant, the expert system determines if a fault condition exists in that plant by using field knowledge incorporated into the expert system. Upon detection of a fault condition, the expert system communicates the information to the plant operator with suggested actions to be taken. However, the expert system does not directly run any tests on the plant or alter the state of data within the plant. Further, the system requires an unique mechanism for accessing the data from the plant since the system cannot use the same means to gather data as used by technicians.

The problem with prior expert systems that diagnose fault conditions in remote computer systems, is that they require a human technician to determine the fault condition or to test and retire fault alarms in those systems. Also those expert systems require special mechanisms for gaining access to remote system data which add to the operating costs.

SUMMARY OF THE INVENTION

A technical advancement is achieved by an expert system that maintains remote computer systems by directly accessing the remote computer systems, diagnosing, and clearing fault conditions on those computer systems. The expert system performs those functions by first accessing a fault report from a centralized service reporting center, establishing a data connection to the computer system reporting the fault, invoking diagnostic routines on the computer system to gather data about the reported fault, analyzing the data, and, if appropriate, clearing the reported fault from the computer system. Advantageously, if the fault cannot be cleared, the expert system recommends maintenance procedures and replacement parts for a technician who the expert system dispatches to the remote computer. The recommendations are based on field experience stored in rules and databases maintained by the expert system. The centralized service reporting center receives faults or alarms directly from the computer systems, and the expert system accesses the reporting center via a digital link.

The expert system accesses the remote computer system in the same manner as a technician by placing a data call through the public telephone switching network. After gaining access to the remote computer system, the expert system invokes test procedures to obtain further data from the computer system and retires alarms representing transitory faults. When the remote computer system is controlling a customer switching system (PBX), the expert system only invokes testing procedures in the computer system which do not disrupt stable telephone calls. In addition, the expert system is capable of maintaining different vintages of the same PBX and identifies the vintage by interrogating each PBX.

In addition, the expert system maintains databases in which the results of previous accesses to any individual PBX are recorded. That information is continuously reused for each access to an individual PBX to diagnose alarms on that system and identify recurrent problems.

These and other features and advantages of the invention will become more apparent from the following description of an illustrative embodiment of the invention considered together with the drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a plurality of systems including a computer that executes an expert system embodying the principles of the invention for maintaining the illustrated PBXs;

FIGS. 2 through 24 illustrate, in flow diagram form, the logical flow of the expert system of Microfiche Appendix A;

FIGS. 25 through 33 provide an example of information displayed by the expert system;

FIG. 34 illustrates a portion of the SINGLE FAILURE database;

FIG. 35 illustrates a portion of the MULTI-FAILURE database; and

FIG. 36 illustrates a portion of the HISTORY database.

DETAILED DESCRIPTION

FIG. 1 illustrates expert system 102 which embodies the principles of the invention for performing maintenance on a plurality of PBXs (105 and 114) via public telephone network 113. Expert system 102 is executing on computer 100 which advantageously may be of the AT&T 6300 family of personal computers. PBX 114 and 105 (also referred to as customer switching systems) are telephone switching systems whose telephone switching network is controlled by a stored program computer. Within each PBX, the computer is constantly executing diagnostic routines checking for fault conditions. For example, within PBX 105, computer 122 is periodically running diagnostic routines to verify not only the state of switch 123 but also the state of the central office trunks such as DS-1 120, digital transmission facility (DCIU) 124 and tape unit 121. If a fault is detected with one of these units, PBX 105 records that fault. Such a fault is commonly referred to as an alarm or an alarm condition and results in a call being placed by PBX 105 via the public telephone network 113 to the service reporting center 104. Upon completion of the call, computer 122 transmits the alarm information to service reporting center 104 where it is recorded. The process of recording alarms by service reporting center 104 is referred to as generating a trouble report or trouble ticket.

Once service reporting center 104 has recorded the trouble ticket in its internal database, then either a human technician or expert system 102 accesses service reporting center 104 to obtain the trouble ticket. Either the technician or expert system 102 accesses PBX 105 via public telephone network 113 to run diagnostic procedures (PROCs) on computer 122 to perform a complete diagnosis of the state of PBX 105. The accessing of PBX 105 for this purpose is referred to as a session. For the AT&T System 85, detailed information on the operation of the PROCs is set forth in the manual entitled, "AT&T System 85, Release 2, Version 4, Maintenance."

After either the technician or expert system 102 has initiated a session with PBX 105, a listing of the alarms found by computer 122 is obtained and then PROCs are run to perform diagnostic tests and gather additional information concerning the nature of the alarms. Many alarms can be resolved through the execution of PROCs and do not require the replacement of any parts within PBX 105. After finishing the session with PBX 105, both the technician and expert system 102 generate a report indicating what alarms, if any, still exist on the system and a recommendation about the desirability of sending a technician to the site. Expert system 102 also recommends what spare parts may be needed to resolve the remaining alarms.

Consider now in greater detail the operations of expert system 102 in maintaining PBX 105. As illustrated in FIG. 1, PBX 105 consists of switch 123, computer 122, tape unit 121, and DCIU 124 which interconnects PBX 105 to message center 125. The remainder of this description uses the following example to illustrate the operation of expert system 102. The example assumes that computer 122 has determined the existence of alarms with respect to computer 122, tape unit 121, and a data transmission facility such as DS-1 120 which are unit-type alarms 13, 2, and 68, respectively. These alarms are illustrated in FIG. 27.

Expert system 102 is constructed using a rule-based methodology. Such a methodology allows expert system 102 to represent units of knowledge in the form of rules which allows easy change of the knowledge represented in each rule without disturbing the rest of the system. A rule-based system consists of three components: working memory, rule memory, and an inference mechanism. The working memory describes the current state of the rule-based system, and moderates all communication between rules. If a rule needs to pass values to another rule, then it must do so through the working memory. The programmer declares items in working memory using a format that is similar to type-declaration information in standard programming languages.

The rule memory is a collection of rules. Each rule consists of a set of conditions and a set of actions. The programmer constructs the rules so that each represents a functionally independent and meaningful portion of the problem solution. In addition, the rule base has access to databases where additional knowledge and PBX specific history information is stored. An example of such databases is in expert system 102, the SINGLE FAILURE and MULTI-FAILURE databases.

In procedural languages, the sequence of program statements and explicit control statements determine execution order. In rule-based programming, the inference mechanism regulates the matching, selection and execution of rules. The inference mechanism is similar to an interpreter executing the following four-step loop:

(1) In the match phase, the inference mechanism collects all rules whose conditions match the current state in working memory.

(2) During the select stage, the inference mechanism selects the rule to be executed. If there is more than one rule that matches the current state, a process called conflict resolution specifies how rule priority is determined.

(3) In the act stage, the actions specified by the selected rule are executed. This results in modifications to the state of working memory.

(4) After the rules actions are executed, the inference mechanism again begins the match stage. This loop continues until no more rules match working memory, or until an explicit halt is encountered.

Expert system 102 is based on the C5 programming language which is similar to OPS5 programming language designed and built by Carnegie-Mellon University. Further details concerning C5 can be found in the article entitled, "Rule-Based Programming in the Unix® System," G. T. Vesonder, AT&T Technical Journal, Jan.-Feb. 1988, Volume 67, Issue 1. Expert system 105 is illustrated in C5 source language in Microfiche Appendix A.

Expert system 102 not only incorporates engineering and field experience within the rules of the program, but also in databases. In particular, the SINGLE FAILURE and MULTI-FAILURE databases are used to store recommendations on whether to replace parts

which have caused alarms within PBX 105. In addition, expert system 102 maintains ADMINISTRATION, HISTORY, and SWITCH databases. The ADMINISTRATION database contains information detailing how the different components are utilized within a PBX. The SWITCH database records information about configuration reported to expert system 102 by each particular PBX with which it has communicated. Finally, the HISTORY database contains a history of the alarms found and action taken for each PBX session. The HISTORY database is used to anticipate serious problems within a particular PBX and to gather additional field experience for later incorporation into the rules (see Microfiche Appendix A) and into the SINGLE FAILURE and MULTI-FAILURE databases.

Expert system 102 is executed by processor 106 in computer 100 as illustrated in FIG. 1. Programs are stored in memory 107 whereas the databases are stored in disk 108. Initially, controller 101 accesses service reporting center 104 via modem 111 and public telephone network 113. From service reporting center 104, controller 101 obtains the trouble ticket information for PBX 105. Expert system 102 then obtains the trouble ticket from controller 101. Expert system 102 then opens a session with PBX 105 by accessing PBX 105 via VMAAP 103, modem 110, and public telephone network 113. As described in greater detail with respect to FIG. 2, expert system 102 now obtains customer data and data concerning the functions of PBX 105. After obtaining this information, expert system 102 requests and obtains from PBX 105 the number of alarms presently existing on the PBX and detailed information about the unit-type and location of each alarm.

For the present example, this information is illustrated in FIG. 27. A unit-type 2 alarm indicates that there is a tape unit problem. A unit-type 68 alarm indicates that there has been an error on a data transmission facility such as DS-1 120, and a unit-type 13 alarm indicates a failure on a port data section of the memory of computer 122. As will be described in greater detail with respect to FIGS. 13 and 14, expert system 102 performs the appropriate PROCs with respect to tape unit 121 and determines that the unit-type 2 alarm cannot be cleared since the trouble/fault still exists on tape unit 121. Then by utilizing the data within SINGLE FAILURE database, expert system 102 recommends that a service technician be dispatched to PBX 105 with a new tape cartridge to replace the existing one. Expert system 102 next analyzes the unit-type 13 and 68 alarms by executing the appropriate PROCs and utilizing the SINGLE FAILURE and MULTI-FAILURE databases. Expert system 102 will successfully cause PBX 105 to recover from these two alarms.

In addition, during each session, expert system 102 performs preventive maintenance with respect to PBX 105 by determining whether computer 122 has undergone any initializations. Based on a examination of these initializations using the HISTORY database, expert system 102 will recommend whether a service technician should be dispatched to PBX 105 to perform specified service procedures which can include the part replacement.

FIG. 2 illustrates the initial setup and logging on to PBX 105 by expert system 102 via VMAAP 103. Initially, expert system 102 obtains information concerning the trouble ticket from controller 101. Upon obtaining this information, expert system 102 creates initial working memory elements using block 203 and opens the necessary output files via block 204. An example of such a working memory element is the switch memory element which contains the information illustrated in FIG. 25 in lines 2501 and 2502. An example of an output file opened by block 204 is one used to store information such as illustrated in FIGS. 25 through 33. Block 205 initiates database table structures.

Using block 206, the expert system 102 instructs VMAAP 103 to place a call to PBX 105 in order to open the session with PBX 105. Block 206 transmits a command to VMAAP 103 which contains the necessary information to identify PBX 105. Expert system 102 waits in block 206 until it receives information back from VMAAP 103 indicating that the connection has been made. Expert system 102 then requests the status of the connection via block 207. Based on the status determined by block 207, decision block 208 determines if a connection has been made. If the connection status is "A1" indicating a successful login to PBX 105, then path 216 is followed to block 209. However, if the status is not "A1", block 210 is executed via path 215. Execution of block 210 indicates that expert system 102 was unable to log on to PBX 105 via VMAAP 103. This information then is displayed via block 211 (see FIG. 22).

If it was possible to log on to PBX 105, expert system 102 requests, in block 209, the customer data from PBX 105 via VMAAP 103. Upon receiving the customer data, block 209 parses this data so that it is in a usable form.

Next, expert system 105 determines the available modes of operation and switch parameters of PBX 105. This is accomplished in FIG. 3. Blocks 301 through 307 determine what modes are implemented and available. The modes include the administration, maintenance, and tape modes. The modes are required in order to avoid interaction problems with other entities that may also be doing work on the PBX, such as an on-site craftsperson. The administration mode allows administration of the different characteristics of the PBX such as which telephone numbers are assigned to which physical ports. The maintenance mode allows the different maintenance procedures to be executed. The tape mode allows the administration data stored on-line in the PBX's memory to be transferred to tape unit 121.

The first decision that must be made is whether the PBX 105 is of a version that requires the modes. This is done by block 301. Certain earlier versions of PBX 105 did not have modes since only one entity at a time could access the PBX. If the decision is made in decision block 301 that the PBX under test does have modes, block 302 requests the data on which modes are available. Next, block 303 checks if the maintenance mode is available. If the maintenance mode is not available, path 325 is followed to block 305 where the recommendation is set so that the message "maintenance mode not available" is displayed during the display recommendation portion of the session by block 211. If the maintenance mode is not available, expert system 102 must stop the session with PBX 105 at this point since it cannot proceed without itself setting the maintenance mode. If the maintenance mode is available, decision block 303 via path 326 checks whether the administration mode is available. If the administration mode is available, then block 307 via path 328 sets both the administration and maintenance modes. If the administration mode is not available, path 327 is followed from decision block 304 to block 308 which sets the maintenance mode only. If

the administration mode is not available, the session does not stop since expert system 102 can perform limited maintenance functions without the administration mode.

Blocks 310 through 321 determine whether computer 105 in PBX 105 is duplicated, e.g., has two processors. One processor is online and the other one is offline waiting to be brought online if the current online processor fails. If PBX 105 has duplicated processors, it is necessary to test both of them. Two Procedures (PROCs) perform the duplication testing. These PROCs are detailed in the aforementioned AT&T Maintenance Manual. First, PROC 275 is executed by block 309. Decision block 310 checks the information returned by PBX 105 in response to PROC 275. If no error code is returned by PBX 105, path 332 is followed to decision block 316. If an error code of "3" is returned, expert system 102 determines that an error may have occurred, and block 311 once again executes PROC 275 in PBX 105. Decision block 313 checks the results of the execution of block 311; and if no error code is returned, path 334 is followed to decision block 316. If decision block 310 finds an error code other than "3" or if decision block 313 finds any error code, paths 330 or 335, respectively, are followed from these decision blocks to block 314. Block 314 executes PROC 613. The results of the execution of PROC 613 are checked by decision block 319. If no error code is returned, path 340 is followed to block 318 since this indicates that PROC 613 has determined that computer 122 is duplicated. If error code 74 is returned, path 342 is followed to block 317 since this indicates that PROC 613 has determined that computer 122 is not duplicated. If any other error code is returned, path 341 is followed to block 320 which indicates that the state of duplication is unknown.

If no error code was returned from the execution of PROC 275 in block 309, then path 332 is followed from decision block 310. Decision block 316 examines field 10 of the information returned by PBX 105 in response to PROC 275. This field indicates whether computer 122 is duplicated. If computer 122 is not duplicated, then block 317 marks it as such. If PROC 275 indicates that the processor is duplicated, block 318 marks the system as having a duplicated processor.

The information displayed in lines 2501 of FIG. 25 was obtained in block 209. Blocks 309 through 321 obtained line 2502.

FIG. 4 illustrates the additional administrative tasks that are performed before the testing of PBX 105 can commence. Blocks 401 through 409 check the SWITCH database to determine whether PBX 105 has had maintenance performed on it in the past by expert system 102. First, block 401 queries the SWITCH database to determine if it contains any data with respect to the PBX under test. Decision block 402 then determines the number of entries. If the PBX has not previously been encountered before, path 418 is followed to blocks 407 and 409 which build an entry in the SWITCH database for this PBX. If paths 419 or 420 are followed, the switch has previously had maintenance performed on it. However, what must still be determined is whether the PBX's configuration has changed; and if it has changed what the newest configuration is.

Path 420 is taken if the PBX has only one recorded configuration. If path 419 is followed indicating the existence of more than one past configurations, then it is necessary to determine the newest entry which defines the latest configuration that expert system 102 has encountered with respect to PBX 105. After this has been determined, block 405 is executed which determines (on the basis of the information received and, as shown in FIG. 25 in lines 2501 and 2502) whether the present configuration of PBX 105 represents a change from its last recorded configuration. If there has been a change, block 407 via path 420 creates a new database entry for this PBX. If there has not been a change, path 421 is followed to decision block 410.

Blocks 410 to 413 are concerned with obtaining the local time maintained by PBX 105. The local time is important since PBX 105 may be located anywhere in the world, and the PBX alarms which will be discussed later are time-stamped relative to this local time. If decision block 410 determines that the administration mode has been set by expert system 102, path 423 is followed to blocks 412 and 413 which obtain the local time from PBX 105. Block 414 then displays the local time as indicated in line 2503 of FIG. 25. If the administration mode is not available, path 422 is followed to connector 416.

Having obtained the information defining the system parameters of PBX 105, expert system 102 now obtains an overall view of the maintenance condition of PBX 105 by execution of PROC 600. Execution of PROC 600 on PBX 105 obtains the number of alarms on the PBX and then requests are made for detailed information about each alarm. Block 501 transmits the PROC 600 request to PBX 105 via VMAAP 103. PBX 105 responds to this request with the number of alarms which are outstanding within the PBX. This number is read by block 502, and decision block 503 makes a determination of whether any alarms exist on PBX 105. If no alarms exist, path 522 is followed to block 506 which proceeds to check the off line processor, if any, for alarms.

If alarms exist, then path 523 is followed to block 504 which displays lines 2701 of FIG. 27. Expert system 102 obtains information concerning each of these alarms by the repetitive transmission of the "next circuit" command of PROC 600 by block 507. As information about each alarm is received, it is displayed by block 508 to create each line in lines 2702 of FIG. 27. Warning alarms and the trunk software alarms identified by decision blocks 510 and 512, respectively, are immediately cleared by block 511 via paths 524 and 527, respectively. The sequence of block 504 through 512 is terminated by decision block 514 after information on all the alarms has been obtained. As long as there is still an outstanding alarm, path 530 is followed back to block 507. After information about all alarms has been obtained from PBX 105, path 531 is followed to decision block 515. Blocks 515 through 518 account for the fact that DCIU 124 and tape unit 121 within PBX 105 can each have multiple alarms. Since the diagnostic tests performed for these units are complete, it is desirable only to perform each test once per session. Hence, blocks 515 through 518 remove all but at most one alarm for DCIU 124 and tape unit 121.

There are three overall goals that must be achieved in the execution of each of the diagnostic PROCs. First, expert system 102 determines the failures that caused each alarm by executing diagnostic routines on PBX 105. Secondly, expert system 102 generates a report detailing the results of the diagnostic routines and indicating the remaining alarms on the system. Finally, expert system 102 provides recommendations for re-

placing hardware on PBX 105 if necessary. An example of such a recommendation is illustrated in FIG. 33 where it is recommended to replace the tape cartridge of PBX 105.

FIG. 6 is concerned with the order in which the alarms obtained in FIG. 5 should be processed. The aforementioned AT&T Maintenance Manual indicates that the alarms should be processed in the order in which they are received upon execution of PROC 600. This order is given by the entry index number as illustrated in FIG. 27. However, field knowledge obtained and incorporated into expert system 102 indicates that if both unit-type 11 and 23 alarms are encountered, then the alarm with a unit type of 23 should be processed first. Decision block 601 and block 602 accomplish this. Similarly, experience has shown that if unit-type 55, 56 and 57 alarms are present together, then the alarms should be processed in descending order by unit type (i.g. 57 then 56 then 55). This is accomplished by blocks 603 and 605. Otherwise, if none of these special cases are encountered, block 606 simply chooses the unprocessed alarm with the highest index number.

Decision block 607 results in the execution of the diagnostic PROCs detailed in FIGS. 7, 9, 11, 12, 13, and 15. It is important to remember expert system 103, whose overall logical flow is illustrated in FIGS. 2 through 24 is implemented in a rule-based language (see Microfiche Appendix A.) For more complete details on how each diagnostic routine is implemented, the code starting at page 36 and entitled, "Referred PROCs" in Microfiche Appendix A should be examined.

The following is a description of the operation of each of these PROCs. Note that in our present example alarm information received from PBX 105 as illustrated in FIG. 27 indicates the existence of alarms of unit-types 2, 68, and 13. Unit-type 2 alarms indicate a problem with the tape unit. Unit-type 68 alarms indicate that there has been an error on a data transmission facility such as DS-1 120. Unit-type 13 alarms indicate a failure in the port data section of the memory of computer 122. However for unit-type 13 alarms, field experience incorporated into expert system 102 has shown that a variety of different equipment failures within PBX 105 may result in that type of alarm. Those failures will be further detailed during the discussion of unit-type alarm 13.

FIG. 13 shows the logical operations performed by expert system 102 in response to a unit-type 2 alarm. This alarm indicates that an error has been encountered on tape unit 121. Decision block 1301 represents the logical select stage of rule-based expert system 103 for a unit-type alarm 2.

Logical blocks 1302 through 1306 are concerned with versions of PBX 105 which require modes. If PBX 105 is of a non-mode version, then path 1315 is followed to block 1307. If modes are required, then blocks 1303 and 1304 determine whether the tape mode is available to expert system 102. If the tape mode is not available, path 1317 is followed from decision block 1304 to block 1305 which marks the alarm as "uncleared."Marking the alarm as uncleared causes a message indicating that fact to be printed. If the tape mode is available, then block 1306 is executed via path 1318 to set the tape mode.

Because of the nature of tape unit 121, failure status information only is collected from this unit and no diagnostic tests are actually run on it. However, as will be illustrated later, a recommendation may be made to replace the tape cartridge. In response to the execution of PROC 610, decision block 1308 determines whether tape unit failures have occurred. If no tape unit failures are outstanding, blocks 1309 and 1310 are executed via path 1320. These blocks note that the alarm has been cleared, and a command is sent to PBX 105 to clear the indication in the PBX. In FIG. 14, blocks 1401 through 1403 collect all the failures associated with the unit-type alarm 2 on PBX 105.

FIG. 7 illustrates the logical flow performed in utilizing PROC 620 to determine the cause of a network alarm. First, logical decision block 701 ascertains whether there are any such alarms. If there is an outstanding network alarm, then control is passed to block 703 via path 729. Block 703 first obtains the unit-type and location of the failing network unit by execution of PROC 620. Decision blocks 705 through 709 check whether there are special cases which make it undesirable to execute the diagnostic portion of PROC 620. Decision block 705 determines whether there are intermodule calls that could be dropped if the diagnostic portion of PROC 620 is executed. If intermodule calls could be dropped, control is transferred to block 710 via path 716. Decision block 706 checks whether the failing network unit is the attendant console interface (unit-type 44). If the attendant console interface is failing, this test cannot be performed since to properly perform the test, the attendant console headset must be unplugged which requires a craftsperson on site. If the unit failing is unit-type 44, path 718 is followed to block 710; if not, path 719 is followed to decision block 707. The latter decision block checks whether the alarm is of unit-type 45 which indicates an anxiliary trunk circuit pack. In order to test that circuit pack, the DIP switches must be set to a particular setting which is impossible to verify remotely. If the alarm is of unit-type 45, path 720 is followed to block 710, otherwise path 721 is followed to decision block 708.

Decision block 708 determines whether the failing circuit pack has been marked as "maintenance busy" indicating that there is a craftsperson on site performing maintenance tests on this particular circuit pack. If the circuit pack is marked as maintenance busy, path 722 is followed to block 710; otherwise, path 723 is followed to decision block 709. Decision block 709 checks a number of special situations where stable calls could be dropped/disconnected if the diagnostic portion of PROC 620 is executed. If stable calls could be dropped, path 724 is followed to block 710 since it is undesirable to perform a test that could potentially drop calls. If the testing would cause no stable calls to be dropped, path 725 is followed to connector 712. Block 710 marks the alarm as "uncleared," which terminates the session. Connector 711 interconnects to a portion of the program which obtains the board type. This portion is executed so that the board can be checked to insure that it is of the proper vintage and is properly administered.

FIG. 8 illustrates another special case where the diagnostic portion of PROC 620 often cannot be run. Unit-type 68 alarms indicate a failing DS-1 trunk unit such as unit 120 which has 23 separate channels, each capable of carrying a telephone conversation. Since the probability is extremely high that at least one of these channels will be active at any given point in time, a non-invasive PROC (PROC 625) is used to investigate the status of this particular facility. Decision block 801 checks if the failing facility is of unit-type 68; and if it is, path 815 is followed to block 802. Blocks 802 through 811 utilize

PROC 625 to check the status of the failing DS-1 trunk unit. If the failing facility is not of unit-type 68, then path 816 is followed to block 805 which executes the diagnostic portion of PROC 620.

After execution of the diagnostic portion of PROC 620, decision block 803 checks if the alarm status after execution of block 805 indicates that the alarm had been cleared. If the alarm has been cleared, path 817 is followed to block 812. If the alarm has not been cleared, path 820 is followed to decision block 804. Decision block 804 checks whether the alarm after execution of PROC 620 has changed from a unit-type 56 or 57 alarm (intramodule data store or light guide interface fault) to unit-type 23 alarm (duplication channel fault.) If this change has occurred, field experience has found that the unit-type 23 alarm must first be cleared before any other alarms can be processed. The unit-type 23 alarm is cleared by following path 821 to decision block 806 which via path 818 re-executes PROC 620 on the duplication channel via block 805.

If there has not been a change in the unit-type of the alarm, decision block 804 transfers control to block 807 via path 822. Block 807 marks the alarm as "uncleared" and transfers control to connector 711 to obtain the board type. This is done so that a replacement recommendation can be made.

After execution of PROC 625 by block 802, decision block 809 is executed to determine whether the test indicated that the DS-1 trunk facility is failing. If the facility indicates no failures, then block 811 is executed to clear the alarm in PBX 105 via path 823. If the facility indicates a problem, path 822 is followed to block 810 which records the problem. The information recorded in block 810 is utilized to print the information of FIG. 29, line 2902.

In the present example, FIG. 27 illustrates the results of executing PROC 600 to obtain the initial alarms of PBX 105. The third line of block 2702 indicates that there is another failure (unit-type 13 alarm, port data storage unit) which requires the execution of PROC 620. When PROC 620 is executed to investigate this particular alarm at decision block 805, path 816 is followed to block 803 which checks the result. Then, since the port data unit in the present example shows no failures, control follows path 817 to block 812. Block 812 marks this alarm as "cleared" and transfers control to the "get board-type" procedures via connector 711. Therefore, the results of executing PROC 620 as displayed in line 2903 of FIG. 29 indicate that the unit-type 13 alarm has been cleared.

FIG. 9 illustrates the logical flow for PROC 650. This PROC is used to test DCIU 124 of PBX 105. This data transmission facility has eight distinct data links. Each data link interconnects PBX 105 to a computer or communications systems. Examples of such systems are voice mail and message center systems. PBX 105 is connected only to message center 125. First, PROC 650 (test 1) is utilized to determine which of these data links is failing. This information is read from PBX 105 utilizing block 904. Block 905 is then utilized. to execute the diagnostic portion of PROC 650 (test 2) to perform transmission testing on that data link. Decision block 908 then checks if the results of the diagnostic portion of PROC 650 indicate that the transmission test was successful. If so, then blocks 909 and 910 are executed via path 922. If the transmission test failed, path 923 is followed to decision block 911. The latter decision block determines if the fault code returned by the execution of the diagnostic portion of PROC 650 is between 19 and 36. If the returned code is in that range, then field experience has shown that PROC 650 should be re-executed since those alarms may clear themselves. This is performed by following path 924 to block 916. If the returned fault code is not in that range, path 925 is followed to block 912. After re-execution of PROC 650 in block 916, decision block 917 determines whether the alarm has been cleared on the second pass. If the alarm has been cleared, path 929 is followed to block 918 which performs a function similar to that performed by block 909. If the alarm has not been cleared, decision block 917 transfers control via path 928 to block 912. This latter block in conjunction with decision block 913 utilizes the "next fault" command of PROC 650 to obtain all of the outstanding fault information. Once all the fault information has been collected, path 931 is followed to block 914 which marks the alarm as "uncleared" and transfers to connector 910.

FIG. 10 is a continuation of FIG. 9. Blocks 1001 through 1007 obtain information to make up a report similar to FIG. 28. Block 1001 is used to execute PROC 256 to determine additional information about the data link. Decision block 1002 determines whether an error has occurred during the execution of PROC 256. If there is an error, path 1011 is followed to connector 702 which results in error processing as illustrated in FIG. 7. If an error did not occur, path 1012 is followed to block 1003. Block 1003 once again uses PROC 256, but this time specifies the failing data link. Further information about that link is obtained using the display portion of PROC 256 in block 1004. After execution of this block, the specified information is read using block 1005. Then block 1006 reads the translation tables in the memory of PBX 105 to determine the nature of the applications assigned to the logical channels of the indicated data link to PBX 105. For example, the same computer can run applications to function either as a message center or as a telemarketing center. Each application is assigned one or more logical channels on the physical data link between the computer and PBX 105. After executing block 1007, connector 811 transfers control to the procedures that obtain the board type.

FIG. 11 illustrates the logic flow of PROC 601. This PROC obtains information concerning the units in PBX that control the physical environment, e.g., fans, power supplys, battery back-up units, etc. Decision block 1101 first determines whether this PROC is to be run. If so, path 1111 is followed to block 1103 which executes PROC 601. Decision block 1104 checks if the alarm has been marked clearly by PBX 105. If it has, path 1112 is followed to block 1105 and from there to connector 702. If the alarm is not cleared, path 1113 is followed to block 1106. The latter block takes the information returned from PBX 105 as a result of the execution of PROC 601 and computes a pseudo-fault code that summarizes information concerning the failure that was identified. This pseudo-fault code records the possible multiple causes of the alarm in the history database. After execution of block 1106, block 1107 is executed to mark the alarm as uncleared, and control is passed to connector 702.

FIG. 12 illustrates the logical flow of PROC 622. This latter PROC tests peripheral equipment attached to PBX 105, such as telephone stations and data terminals. Block 1202 executes the diagnostic portion of PROC 622 after providing the type and location of the failing peripheral equipment. PROC 622 runs the diag-

nostic portion of the test several times on the failing peripheral unit to fully evaluate the state of the unit. Decision block 1203 determines whether the unit failed under test. If the indicated unit did not fail, path 1213 is followed to block 1204 which marks the alarm as cleared. If the unit failed under test, control is transferred via path 1214 to block 1205. Blocks 1205 and 1206 obtain detailed results of the multiple diagnostic tests performed on the peripheral unit. After all this information has been obtained, path 1216 is followed to block 1207 which marks the alarm as uncleared and control is transferred to connector 711.

FIG. 15 illustrates the logical flow of PROC 612. This latter PROC is executed every time that expert system 102 contacts a PBX such as PBX 105. PROC 612 interrogates the PBX to determine whether the PBX has undergone any software initializations. For example, software initializations occur if the program executed by PBX 105 is repeatedly interrupted by a parity error or programming problem. The information obtained by PROC 612 is utilized to predict in advance whether a particular PBX is approaching a critical point where it may have a severe service outage. If such a situation is detected, a craftsperson may be dispatched to prevent an actual outage from occurring.

Block 1501 executes PROC 612; and block 1502 obtains information about any initialization causes appearing in the PBX's log. Decision block 1503 looks at the resulting fault codes to determine their seriousness. If a serious fault code is detected, then path 1508 is followed to block 1504. This latter block makes a record to track these conditions in the INIT database maintained by expert system 102. An example of a minor fault is an on-site craftsperson who simply stopped the PBX processor to perform maintenance functions. Decision block 1505 insures that all initialization log entries have been checked. After all entries have been checked, decision block 1505 transfers control via path 1511 to connector 1506.

FIG. 16 illustrates the logical flow for obtaining the board or circuit pack type. PROC 600 may provide incomplete information concerning the location of the failing circuit board. Block 1601 determines whether the location of the failing init is completely known. If the location of the failing circuit board is not completely known, control is transferred to connector 702. If the location is known, decision block 1602 is executed to determine whether the administration mode has been set. If the administration mode has not been set, then the board type cannot be determined since this information is stored within PBX 105 and the administration mode is necessary to obtain that information. If the administration mode has been set, then block 1603 is executed. The latter block executes PROC 290 on PBX 105 to obtain the board type and board vintage from the PBX. This information is read by block 1604. Next, the ADMINISTRATION database of expert system 102 is interrogated to ascertain whether the board is correctly administered on PBX 105. The decision of whether the administration is correct is performed in decision block 1607. If the board is incorrectly administered, block 1608 is executed to highlight this fact so that a craftsperson can readminister the board within PBX 105. Lastly, control is passed to connector 702.

FIG. 17 illustrates the logical flow for printing the information gathered by the diagnostic PROCs for this session with PBX 105. See FIGS. 28 through 30 for an example of this printed information. Blocks 1701 through 1705 illustrate the logical flow for printing the information for PROC 620. Block 1701 determines if there is any information to be displayed for PROC 620. If there is no information to be displayed, path 1710 transfers control to block 1706. If there is information to be displayed, control is transferred to block 1702 via path 1711. The latter block prints the display header and then transfers control to blocks 1703 through 1705. These blocks display the data on 2901 through 2903 of FIG. 29. Similar logical flow as used by blocks 1702 through 1705 is utilized in block 1706 for printing information gathered by the execution of PROCs 650, 601, 622, 610, and 612 provide for PROC 620. After execution of block 1706, control is transferred to connector 1707.

FIG. 18 illustrates a check for remaining alarms and the display of alarm information which, for the present example, results in the generation of FIG. 31. The alarm state of the PBX is again checked to ensure that it is consistent with the text results seen by expert system 102. In the present example, unit-type alarm 13 should be cleared; however, unit-type alarms 2 and 68 should still remain on PBX 105. Block 1801 executes PROC 600 to interrogate PBX 105 regarding alarms existing on that PBX. Decision block 1802 checks if there are any remaining alarms. If there are no remaining alarms, control is passed to connector 1808 via path 1811. If there are remaining alarms, block 1803 is executed via path 1812. This latter block displays the header information illustrated in FIG. 31 for the present example. Blocks 1805 through 1807 then determine what alarms are present on PBX 105 and display this information as illustrated in FIG. 31. After all the alarms have been displayed, control is passed via path 1814 to connector 1808.

FIG. 19 illustrates the logical flow of checking the off-line processor of PBX 105. First, decision block 1901 checks if computer 122 is duplicated. If it is not, path 1915 is followed to connector 1907 which executes the program segment which recommends which hardware, if any, should be replaced on PBX 105. If computer 122 is duplicated, decision block 1903 is executed via path 1916. Before maintenance, administration, and tape functions can be accessed in this PBX, decision block 1903 checks whether PBX 105 requires mode permission. If modes are not required, path 1917 is followed to block 1909. If modes are required, block 1904 is executed via 1918. Block 1904 requests the mode data from the off-line processor of PBX 105. Note that the mode data for the on-line processor of PBX 105 was previously obtained in FIG. 3. Decision block 1905 checks whether the off-line maintenance mode is available. If the maintenance mode is not available on the off-line processor of PBX 105, then control is transferred via path 1919 to block 1906. This transfer results in the recommendation being set to display the fact that the off-line maintenance mode is not available. Then, control is passed to connector 1907. If decision block 1905 determines that the maintenance mode is available, control is transferred via path 1920 to block 1908 which sets the maintenance mode in PBX 105. Next, block 1909 executes PROC 600 and block 1910 obtains the number of outstanding alarms on the off-line processor of PBX 105. Decision block 1911 determines whether there are any outstanding alarms on the off-line processor of PBX 105. If there are no outstanding alarms, control is transferred to connector 1907 via path 1921 so that the "recommend hardware" portion of the pro-

gram can be executed. If there are alarms on the off-line processor, then control is transferred via path 1922 to connector 1912 so that these off-line alarms can be displayed and eventually the "recommend hardware" portion of the program is executed.

FIG. 20 illustrates the logical flow for displaying the results of the PBX 105 interrogation performed by the logical flow illustrated in FIG. 19. The logical flow of blocks 2001 through 2003 and block 2006 is similar to that of FIG. 17. The difference between FIGS. 17 and 20 is the actions taken by blocks 2004 and 2005. These two blocks determine if any alarms noted on the off-line processor of PBX 105 had been previously encountered during testing of PBX 105's on-line processor. If an alarm had been previously found during testing of the on-line processor, then that alarm is cleared in the off-line processor by block 2005 since the alarm probably resulted from an unduplicated portion of the system which was reported to both processors. After all of the off-line alarms have been displayed, control is transferred to connector 1907 via path 2013. The present example assumes that the off-line processor of PBX 105 had no alarms and results in the display illustrated in FIG. 32.

FIG. 21 illustrates the logical flow of the portion of the program that determines what replacement parts, if any, should be recommended. A service technician is dispatched to take those parts and to perform the necessary maintenance on PBX 105 to clear the alarms remaining after expert system 102 has finished the session with PBX 105. First, decision block 2101 checks if there are any environmental alarms. If there are environmental alarms, then control is transferred to block 2102 via path 2111. The reason is that an environmental alarm in a cabinet often results in spurious reports of other hardware failures within that cabinet. An example of an environmental condition is an over temperature alarm. When circuit packs are operated outside of their recommended operating temperature range, the packs exhibit error conditions that disappear when normal conditions are restored. Therefore, no hardware recommendations are made for replacement of boards operating under these conditions.

After block 2102 has been performed or if there are no environmental alarms, decision block 2103 is executed. The latter decision block determines whether there are any remaining alarms that are not in a cabinet exhibiting environmental alarms. If there are no such alarms, then control is transferred to connector 2104 via path 2113 and no recommendations will be made. If there are alarms which are not in a cabinet that has an environmental alarm, control is transferred to block 2105 via path 2114. Block 2105 picks a particular alarm. The present example uses the unit-type 2 alarm. Next, decision block 2106 checks if this alarm has an entry in the SINGLE FAILURE database illustrated in FIG. 34 for the present example. Since in the present example the unit-type 2 alarm, indicating tape unit 121, with a fault code of 925 is found within this database, control is passed via path 2116 to block 2107 which displays the recommendation from the SINGLE FAILURE database. In the present example, the recommendation is that the tape cartridge should be replaced (see FIG. 33.) For a unit-type alarm and fault code not found in the SINGLE FAILURE database, control is transferred to connector 2108 via path 2115.

FIG. 22 illustrates the logical flow for checking whether the alarm condition is a transient one that has occurred enough times to warrant a hardware replacement. First, decision block 2201 checks if the unit-type alarm and fault code appears in the MULTI-FAILURE database, a sample entry of which is illustrated in FIG. 35. If there is an entry for the alarm under investigation within the latter database, path 2211 is followed to decision block 2202. The latter decision block first obtains from the HISTORY database the number of occurrences and time period of this particular alarm in PBX 105. This information is compared the MULTI-FAILURE database record to determine if there have been enough identical failures within the specified time interval to exceed the threshold set in the MULTI-FAILURE database. If this threshold is exceeded, then block 2203 is executed via path 2214. Block 2203 displays the replacement equipment recommendations obtained from the MULTI-FAILURE database. Blocks 2204 through 2206 governs a condition which field experience has shown to require special handling. The situation arises when multiple unit-type 13 alarms indicating failure of several port data store units appear within the same module. This condition does not indicate that the circuit packs containing the port stores should be replaced but rather that the time slot interchange arithmetic logic unit in this module is at fault and should be replaced. If decision block 2204 finds that the alarm is a unit-type 13 alarm, then decision block 2205 via path 2216 checks if other unit-type 13 alarms exist in the same module. If multiple alarms of this unit-type exist, then block 2206 is executed via path 2219. The latter block displays the recommendation that the time slot interchange arithmetic logic unit should be replaced. Finally, block 2207 is executed which marks the alarm as having been checked for a recommendation; and control is then transferred to connector 2211.

FIG. 23 illustrates the logical flow for updating the HISTORY database which contains information on the alarms handled by expert system 102 on PBX 105. To be included in the HISTORY database, the new alarm must have a time of occurrence distinct from any other occurrence of the same type and for the same facility already recorded in the HISTORY database. This time of occurrence is determined by the time stamp information received from PBX 105 by PROC 600 and is displayed in FIG. 27 in lines 2702 under the day, hour and minute columns. If decision block 2302 determines that a new entry should not be created, path 2308 is followed to block 2304. If a new entry is required, block 2303 is executed via path 2309. Block 2303 creates a new record for this alarm in the HISTORY database. If a particular component or circuit pack is failing routinely, then there will be multiple entries for that unit within the HISTORY database. Block 2304 marks the alarm as checked and decision block 2305 determines whether there are any remaining unchecked alarms for this session. If there are no remaining alarms, then path 2311 is followed to connector 2306.

FIG. 24 shows the final steps performed to end the current PBX 105 session. Block 2401 indicates that all files are closed and the proper steps taken to exit from this session by expert system 102.

It is to be understood that the above-described embodiment is merely illustrative of the principles of the invention and that other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

We claim:

1. A method for remotely maintaining computer systems by an expert system in conjunction with a central reporting center to which said computer systems report self-detected faults, comprising the steps of:

accessing said central reporting center by said expert system to obtain the identity of one of said computer systems reporting detected faults;

opening a maintenance session with said identified computer system by said expert system via the public telephone network in a similar manner as a human technician;

invoking diagnostic procedures on said identified computer system by said expert system to gather data about said reported faults;

analyzing said data to determine the severity of each of said reported faults by said expert system with respect to said reported faults being transitory and permanent type of faults; and

clearing transitory ones of said reported faults by said expert system upon said transitory ones of said reported faults being determined to be less severity than permanent ones of said reported faults.

2. The method of claim 1 further comprising the step of establishing a plurality of databases containing field experience on components in each of said computer systems concerning replacement of said components;

interrogating said plurality of databases for each of said permanent faults to determine when to replace components in said identified computer system; and

displaying a message defining each of said components to be replaced.

3. The method of claim 2 further comprises the step of interrogating said plurality of databases by said expert system to determine the number of fault occurrences of each component having a transitory fault in said identified computer system;

interrogating said plurality of databases to determine whether said number for each of said components exceeds a predefined threshold; and

recommending replacement of each of said components whose number exceeds said predefined threshold.

4. A method for remotely maintaining telephone switching systems by an expert system in conjunction with a central reporting center to which said switching systems report self-detected faults, comprising the steps of:

accessing said central reporting center by said expert system to obtain the identity of one of said switching systems reporting detected faults;

opening a maintenance session with said identified switching system by said expert system via the public telephone network in a similar manner as a human technician;

invoking diagnostic procedures on said identified switching system by said expert system to gather data about said reported faults;

analyzing said data to determine the severity of each of said reported faults by said expert system with respect to said reported faults being transitory and permanent type of faults; and

clearing transitory ones of said reported faults by said expert system upon said transitory ones of said reported faults being determined to be less severity than permanent ones of said reported faults.

5. The method of claim 4 further comprising the step of establishing a plurality of databases containing field experience on components in each of said switching systems concerning replacement of said components;

interrogating said plurality of databases for each of said permanent faults to determine when to replace components in said identified switching system; and

displaying a message defining each of said components to be replaced.

6. The method of claim 5 further comprises the step of interrogating said plurality of databases by said expert system to determine the number of fault occurrences of each of said components having a transitory fault in said identified switching system;

interrogating said plurality of databases to determine whether said number for each of said components exceeds a predefined threshold; and

recommending replacement of each of said components whose number exceeds said predefined threshold.

7. The method of claim 6 wherein said identified switching system has a control computer including duplicated processors with one of said processors actively controlling said identified switching system and the other of said processors being in a standby condition, the method further comprising the step of testing said other processor in said standby condition.

8. The method of claim 7 wherein said switching systems are of different manufactured vintages and said invoking step comprises the step of requesting from said identified switching system the vintage of said identified switching system thereby being able to utilize the correct diagnostic procedures.

9. A method for remotely determining replacement of components in telephone switching systems by an expert system in conjunction with a central reporting center to which said switching systems report self-detected faults, comprising the steps of:

maintaining a history database of said expert system to record detected faults by component type and component location and time of fault for each of said switching systems;

maintaining a multifault database to store on the basis of field experience recommendations on the replacement of components in said switching systems on the basis of component type and component location and time of fault by said expert system;

accessing said central reporting center by said expert system to obtain the identity of one said switching systems reporting detected faults;

opening a maintenance session with said identified switching system by said expert system in a similar manner as used by a human technician;

invoking diagnostic procedures on said identified switching system by said expert system to gather data about said reported faults and the gathered data including component type and component location and time of fault;

analyzing said data to determine the severity of each of said reported faults by said expert system with respect to being transitory and permanent types of faults;

interrogating said history database with the gathered data by said expert system to determine the number of fault occurrences of each of said components having a transitory fault in said identified switching system; and

recommending replacement of each of said components having said number that exceeds a predefined threshold in said multifault database.

10. The method of claim 9 further comprising the step of maintaining a single fault database to store on the basis of field experience recommendations on the replacement of components for permanent type faults on the basis of component type and component location by said expert system;

interrogating said single fault database by said expert system for each of said components having a permanent fault in said identified switching systems; and

recommending replacement of each of said components found in said single fault database.

11. The method of claim 10 wherein said step of recommending comprises the step of displaying information to dispatch a service technician to replace the recommended components.

12. The method of claim 11 wherein said step of opening comprises the steps of dialing a connection via a public telephone network to said identified switching system; and

logging on to said identified switching system by said expert system.

13. The method of claim 12 wherein said interrogating step of said history database comprises the step of clearing each of said transitory fault not having an occurrence in said history database.

14. The method of claim 13 wherein said identified switching system has a control computer including duplicated processors with one of said processors actively controlling said identified switching system and the other of said processors being in a standby condition, the method further comprising the step of testing said other processor in said standby condition.

15. The method of claim 14 wherein said switching systems are of different manufactured vintages and said invoking step comprises the step of requesting from said identified switching system the vintage of said identified switching system thereby being able to utilize the correct diagnostic procedures.

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[54] **MULTIFUNCTION NETWORK STATION WITH NETWORK ADDRESSES FOR FUNCTIONAL UNITS**

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[52] **U.S. Cl.** **395/200.20**; 395/800; 370/94.3; 364/228.5; 364/241.9; 364/242.95; 364/DIG. 1

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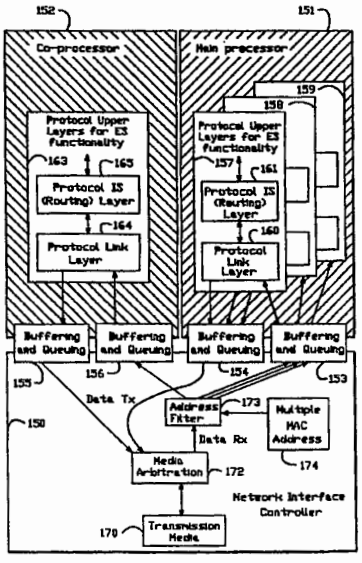
[57] **ABSTRACT**

DLL devices are built with multiple MAC address instead of a single MAC address, and provide a multiple virtual DLL interfaces to the upper layers (3–7) in a computer. This results in a new class of multi-function computers for attachment to a network system which take advantage of the multiple virtual DLL interfaces, to increase performance of the respective functions executed by the computer. Thus, a new network interface control apparatus and a new class of multi-function computer systems for attachments to networks are provided. The memory in the medium access control device stores a plurality of additional network addresses in addition to the assigned network addresses. The address filtering logic includes circuits responsive to the additional network addresses, such as logic for blocking a particular frame on at least one of the plurality of data channels when the source and destination address of a particular frame are found in the additional addresses stored in the memory. The plurality of data channels served by the media access control device may reside on a single physical interface, or in independent physical interfaces as suits the needs of a particular design. A high performance design would include independent buffering and queuing structures for each of the data channels. An alternative design may include shared buffering and queuing structures for a plurality of functional modules in the connected computer which have independent side network addresses.

23 Claims, 16 Drawing Sheets



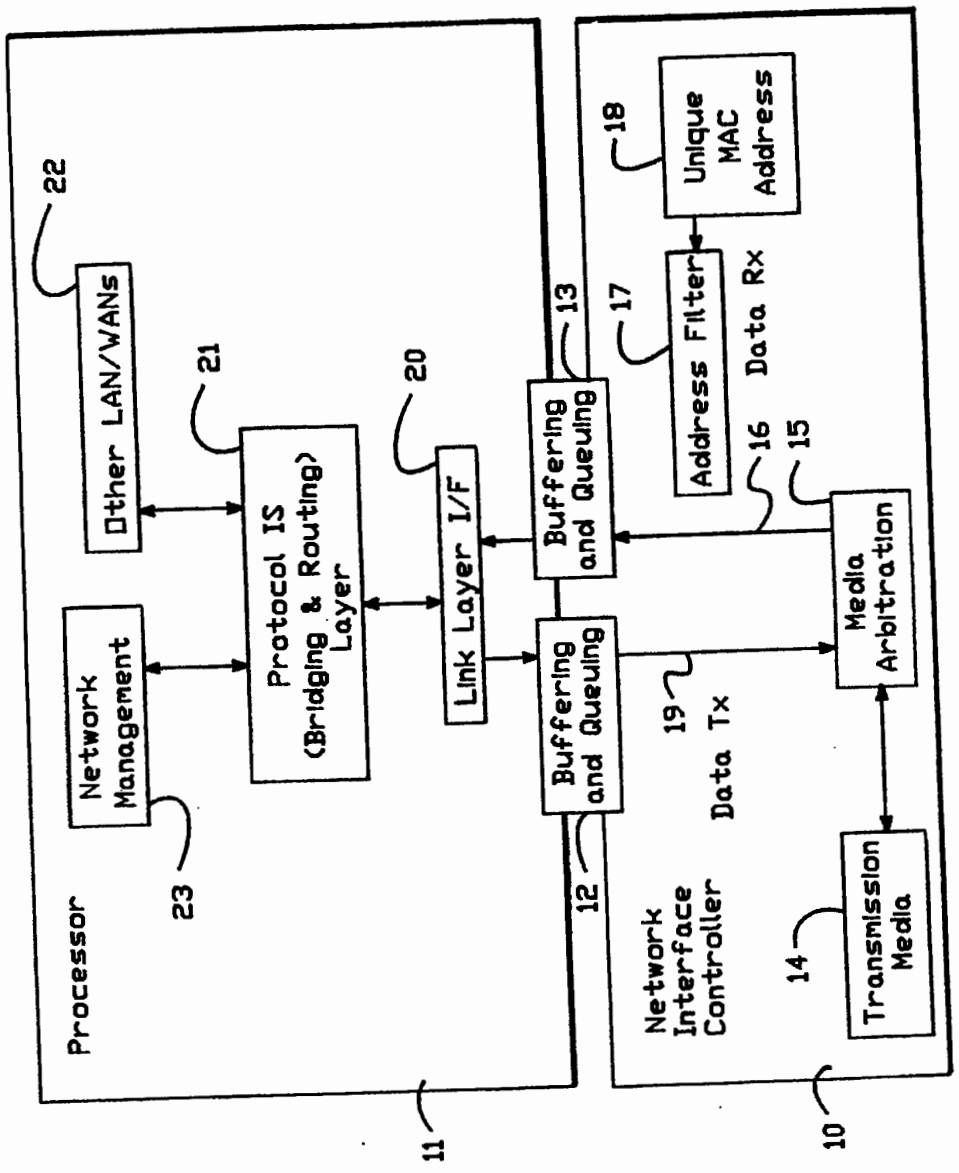


FIG. 1
(PRIOR ART)

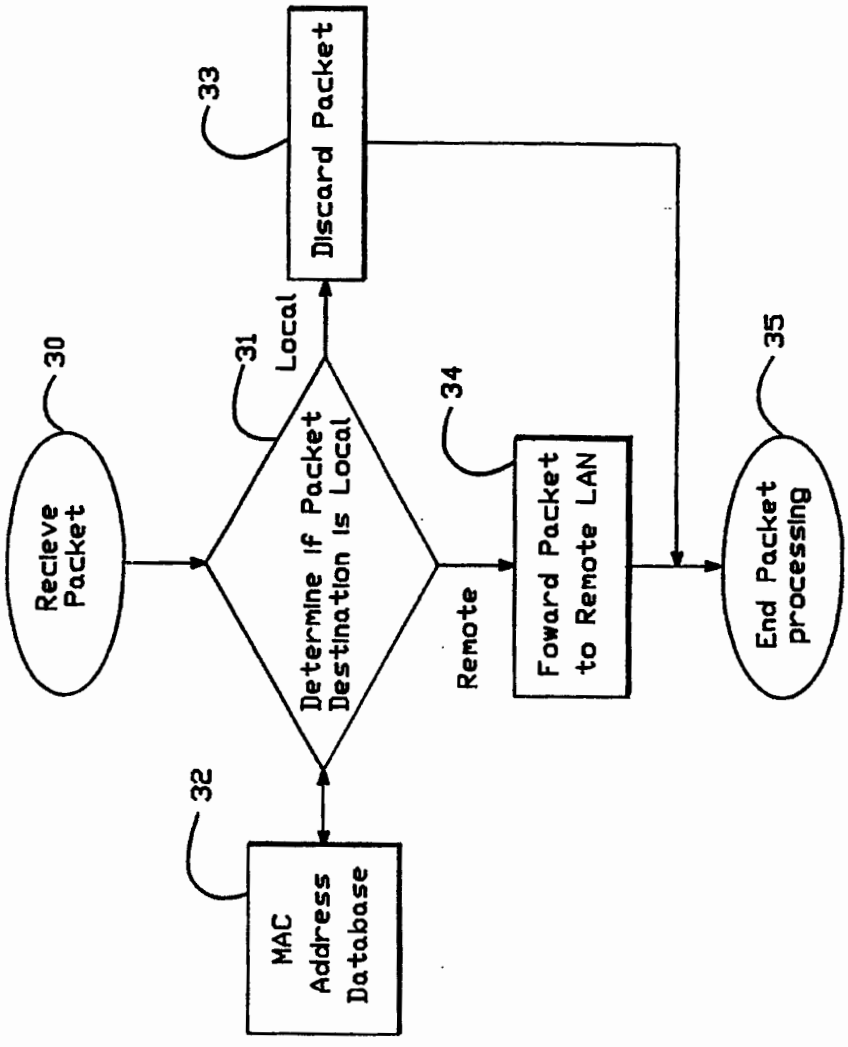


FIG.2
(PRIOR ART)