No. ________

In The
Supreme Court of the United States

NETSCOUT SYSTEMS, INC., NETSCOUT SYSTEMS TEXAS, LLC, fka TEKTRONIX TEXAS, LLC dba TEKTRONIX COMMUNICATIONS,

Petitioners,

v.

PACKET INTELLIGENCE LLC,

Respondent.

On Petition For A Writ Of Certiorari To The United States Court Of Appeals For The Federal Circuit

SUPPLEMENTAL APPENDIX

MICHAEL J. LYONS
AHREN C. HSU-HOFFMAN
THOMAS Y. NOLAN
MORGAN, LEWIS & BOCKIUS LLP
1400 Page Mill Road
Palo Alto, California 94304

ERIC KRAEUTLER
JULIE GOLDEMBERG
MORGAN, LEWIS & BOCKIUS LLP
1701 Market Street
Philadelphia, Pennsylvania 19103

WILLIAM R. PETERSON
Counsel of Record
MORGAN, LEWIS & BOCKIUS LLP
1000 Louisiana Street, Suite 4000
Houston, Texas 77002
(713) 890-5188
william.peterson@morganlewis.com

JASON D. FRANK
MORGAN, LEWIS & BOCKIUS LLP
One Federal Street
Boston, Massachusetts 02110

Counsel for Petitioners

COCKLE LEGAL BRIEFS (800) 225-6964
WWW.COCKLELEGALBRIEFS.COM

VOLUME II
TABLE OF CONTENTS

Page

Patent 6,665,725, December 16, 2003 .... App. II-1

Certificate of Correction, June 29, 2004 .... App. II-72

Certificate of Correction, October 8, 2013 .... App. II-74

Patent 6,839,751, August 3, 2004 .... App. II-75

Certificate of Correction, March 8, 2005..........................App. II-120

Patent 6,954,789, August 3, 2004..App. II-121

Certificate of Correction, March 7, 2006..........................App. II-161

Certificate of Correction, October 1, 2013 ....App. II-162

US006665725B1

(12) **United States Patent**
Dietz et al.

(10) **Patent No.: US 6,665,725 B1**
(45) **Date of Patent: Dec. 16, 2003**

(54) **PROCESSING PROTOCOL SPECIFIC INFORMATION IN PACKETS SPECIFIED BY A PROTOCOL DESCRIPTION LANGUAGE**

(75) Inventors: **Russell S. Dietz**, San Jose, CA (US); **Andrew A. Koppenhaver**, Littleton, CO (US); **James F. Torgerson**, Andover, MN (US)

(73) Assignee: **Hi/fn, Inc.**, Los Gatos, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 537 days.

(21) Appl. No.: **09/609,179**

(22) Filed: **Jun. 30, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/141,903, filed on Jun. 30, 1999.

(51) **Int. Cl.**[7] **G06F 13/00**

(52) **U.S. Cl.** **709/230**; 709/246; 709/228; 370/389

(58) **Field of Search** 709/203, 206, 709/216, 217, 222, 246, 225, 228, 230, 232; 703/26; 370/489, 13, 17

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,736,320 A	4/1988	Bristol	364/300
4,891,639 A	1/1990	Nakamura	340/825.5
5,101,402 A	3/1992	Chui et al.	370/17
5,247,517 A	9/1993	Ross et al.	370/85.5
5,247,693 A	9/1993	Bristol	709/203
5,315,580 A	5/1994	Phaal	370/13
5,339,268 A	8/1994	Machida	365/49
5,351,243 A	9/1994	Kalkunte et al.	370/92
5,365,514 A	11/1994	Hershey et al.	370/17
5,375,070 A	12/1994	Hershey et al.	364/550
5,394,394 A	2/1995	Crowther et al.	370/60
5,414,650 A	5/1995	Hekhuis	364/715.02
5,414,704 A	5/1995	Spinney	370/60

(List continued on next page.)

OTHER PUBLICATIONS

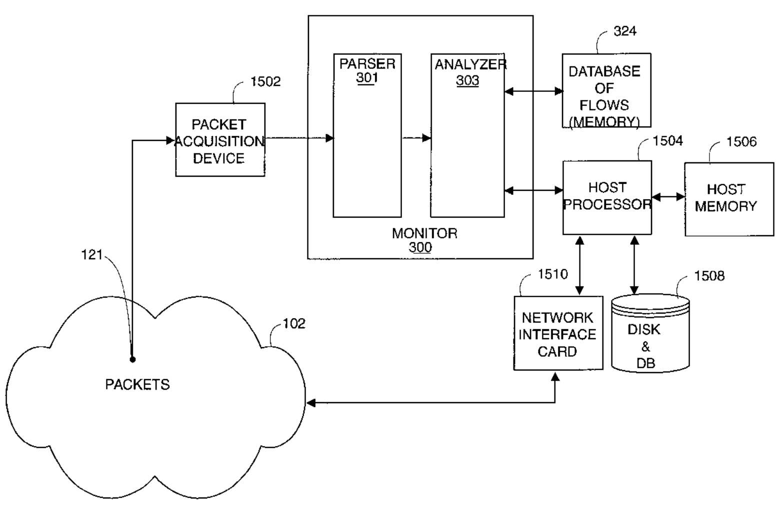
"Technical Note: the Narus System," Downloaded Apr. 29, 1999 from www.narus.com, Narus Corporation, Redwood City California.

Primary Examiner—Hosain T. Alam
Assistant Examiner—Khanh Quang Dinh
(74) *Attorney, Agent, or Firm*—Dov Rosenfeld; Inventek

(57) **ABSTRACT**

A method of performing protocol specific operations on a packet passing through a connection point on a computer network. The packet contents conform to protocols of a layered model wherein the protocol at a at a particular layer level may include one or a set of child protocols defined for that level. The method includes receiving the packet and receiving a set of protocol descriptions for protocols may be used in the packet. A protocol description for a particular protocol at a particular layer level includes any child protocols of the particular protocol, and for any child protocol, where in the packet information related to the particular child protocol may be found. A protocol description also includes any protocol specific operations to be performed on the packet for the particular protocol at the particular layer level. The method includes performing the protocol specific operations on the packet specified by the set of protocol descriptions based on the base protocol of the packet and the children of the protocols used in the packet. A particular embodiment includes providing the protocol descriptions in a high-level protocol description language, and compiling to the descriptions into a data structure. The compiling may further include compressing the data structure into a compressed data structure. The protocol specific operations may include parsing and extraction operations to extract identifying information. The protocol specific operations may also include state processing operations defined for a particular state of a conversational flow of the packet.

17 Claims, 20 Drawing Sheets



U.S. PATENT DOCUMENTS

5,430,709	A		7/1995	Galloway	370/13
5,432,776	A		7/1995	Harper	370/17
5,493,689	A		2/1996	Waclawsky et al.	709/206
5,500,855	A		3/1996	Hershey et al.	370/17
5,511,215	A		4/1996	Terasaka et al.	709/246
5,568,471	A		10/1996	Hershey et al.	370/17
5,574,875	A		11/1996	Stansfield et al.	395/403
5,586,266	A		12/1996	Hershey et al.	709/216
5,606,668	A		2/1997	Shwed	709/216
5,608,662	A		3/1997	Large et al.	364/724.01
5,634,009	A		5/1997	Iddon et al.	709/206
5,651,002	A		7/1997	Van Seters et al.	370/392
5,680,585	A	*	10/1997	Bruell	703/26
5,684,954	A		11/1997	Kaiserswerth et al.	709/203
5,703,877	A		12/1997	Nuber et al.	370/395
5,721,827	A	*	2/1998	Logan et al.	709/217
5,732,213	A		3/1998	Gessel et al.	709/216
5,740,355	A		4/1998	Watanabe et al.	395/183.21
5,761,424	A		6/1998	Adams et al.	709/232
5,764,638	A		6/1998	Ketchum	370/401
5,781,735	A		7/1998	Southard	709/238
5,784,298	A		7/1998	Hershey et al.	364/557
5,787,253	A		7/1998	McCreery et al.	709/227
5,805,808	A		9/1998	Hansani et al.	709/203
5,812,529	A		9/1998	Czarnik et al.	370/245
5,819,028	A		10/1998	Manghirmalani et al.	709/203
5,825,774	A		10/1998	Ready et al.	370/401
5,826,017	A		10/1998	Holzmann	709/206
5,835,726	A		11/1998	Shwed et al.	709/228
5,838,919	A		11/1998	Schwaller et al.	709/208
5,841,895	A		11/1998	Huffman	382/155
5,850,386	A		12/1998	Anderson et al.	370/241
5,850,388	A		12/1998	Anderson et al.	370/252
5,862,335	A		1/1999	Welch, Jr. et al.	709/232
5,878,420	A		3/1999	de la Salle	707/10
5,893,155	A		4/1999	Cheriton	711/144
5,903,754	A		5/1999	Pearson	709/238
5,917,821	A		6/1999	Gobuyan et al.	370/392
6,014,380	A		1/2000	Hendel et al.	370/392
6,272,151	B1	*	8/2001	Gupta et al.	370/489
6,430,409	B1	*	8/2002	Rossmann	455/422.1
6,516,337	B1	*	2/2003	Tripp et al.	709/202
6,519,568	B1	*	2/2003	Harvey et al.	705/1

* cited by examiner

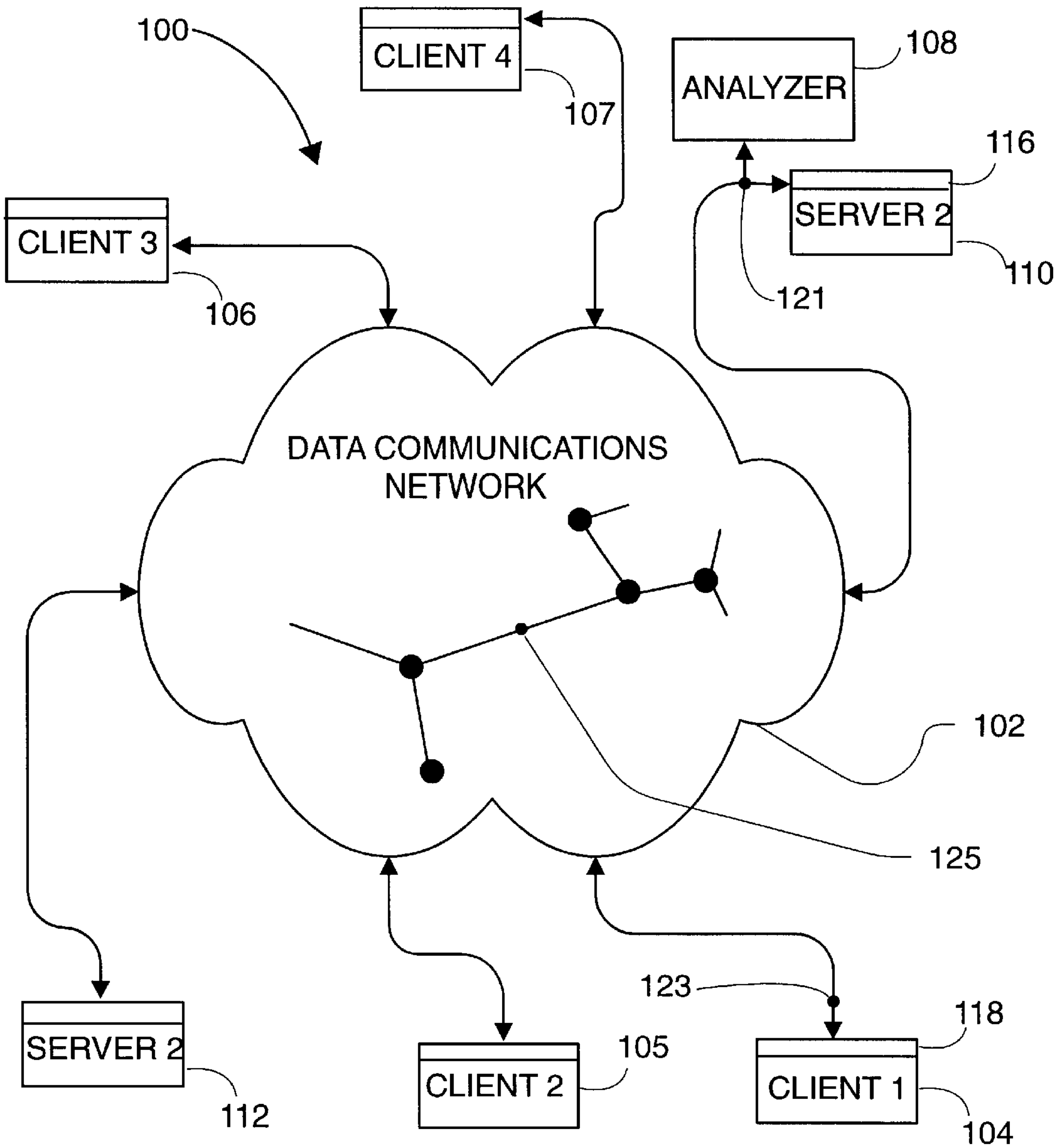

100
CLIENT 4
107
ANALYZER
108
116
SERVER 2
110
121
CLIENT 3
106
DATA COMMUNICATIONS
NETWORK
102
125
123
118
SERVER 2
112
CLIENT 2
105
CLIENT 1
104

FIG. 1

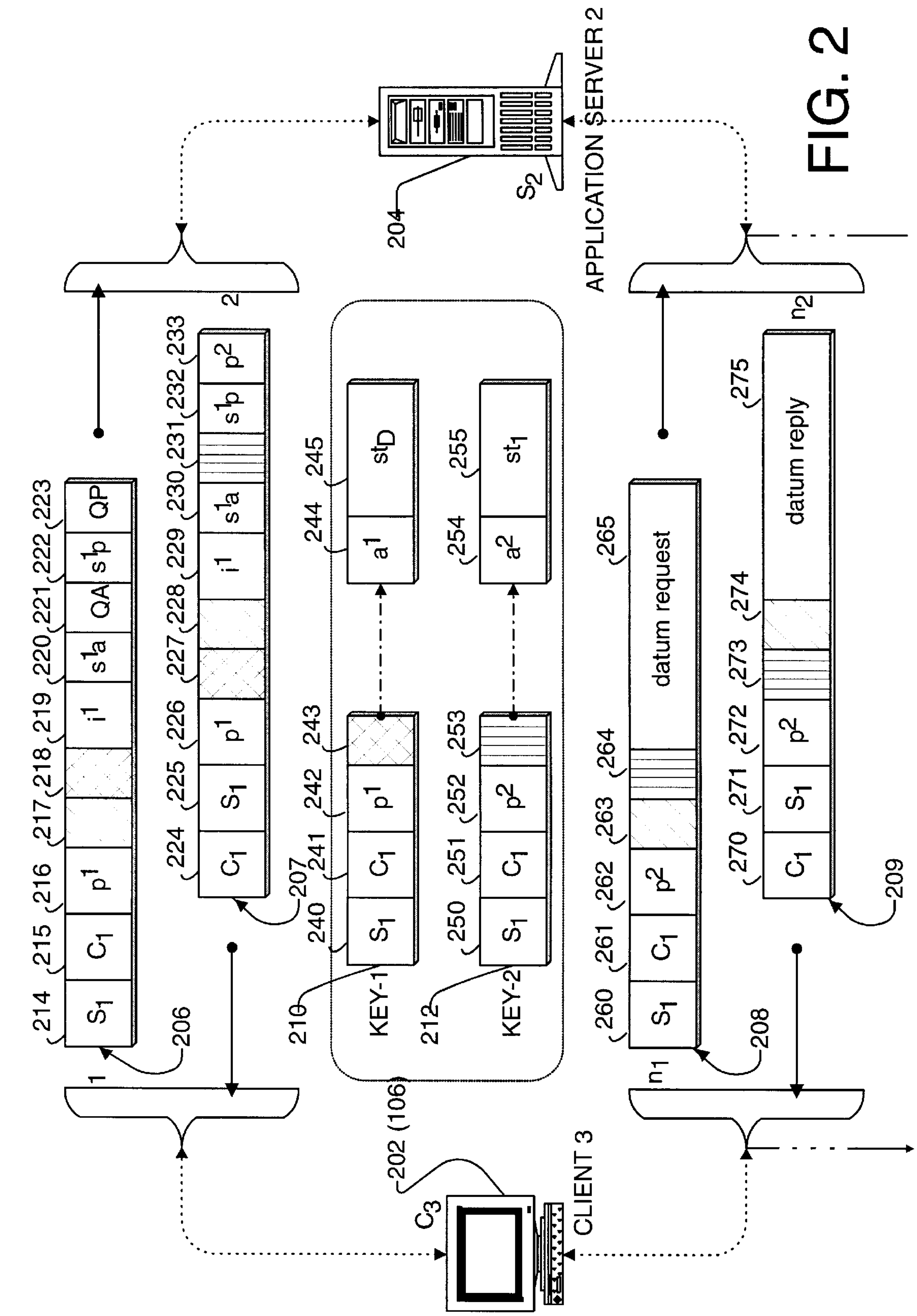
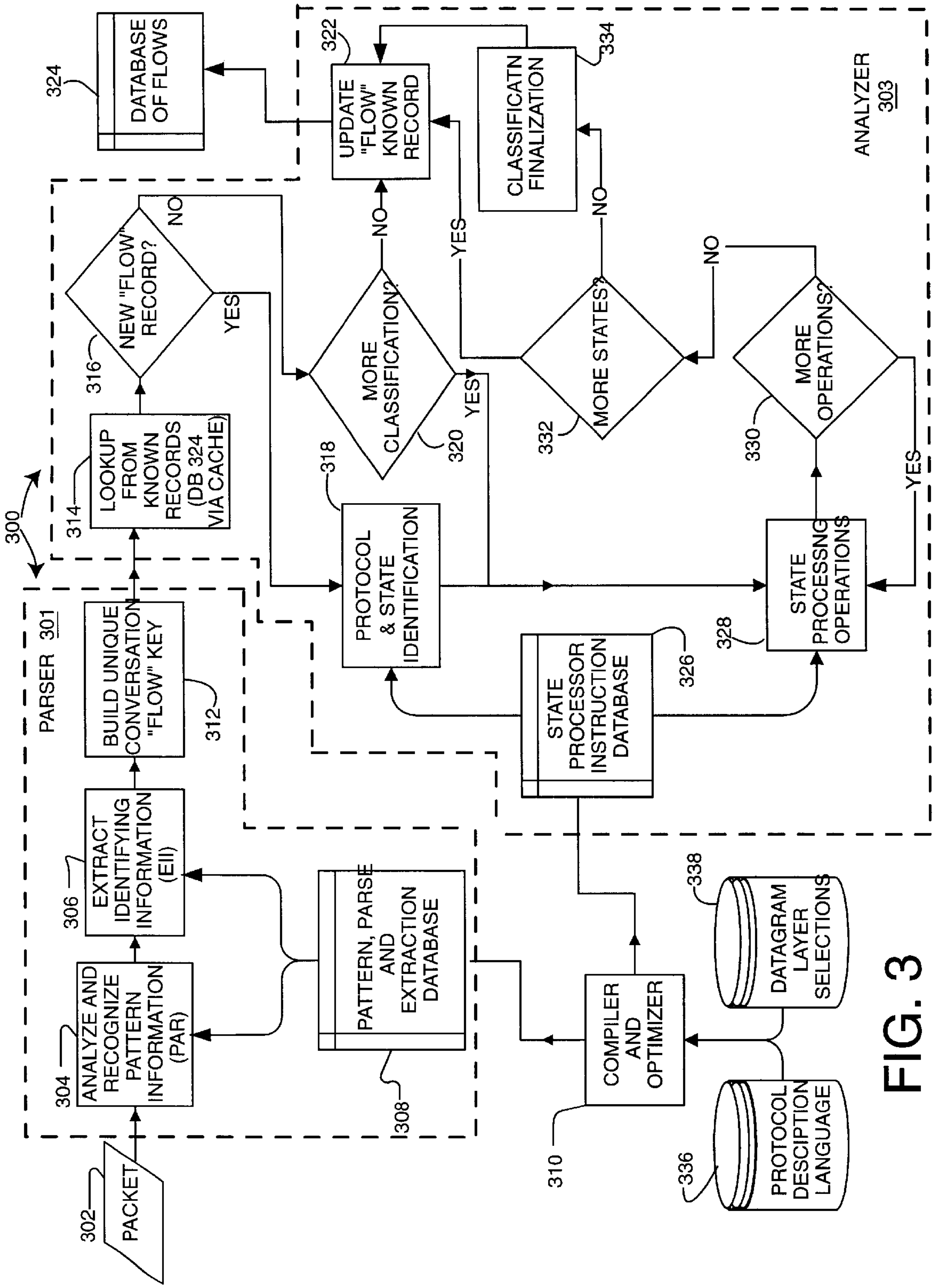

APPLICATION SERVER 2
S_2
204
CLIENT 3
C_3
202 (106)
KEY-1
KEY-2
210
212
datum request
datum reply
206
207
208
209
1
2
n_1
n_2
S_1
C_1
p^1
i^1
s^1a
QA
s^1p
QP
p^2
a^1
st_D
a^2
st_1
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
240
241
242
243
244
245
250
251
252
253
254
255
260
261
262
263
264
265
270
271
272
273
274
275

FIG. 2



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

FIG. 3

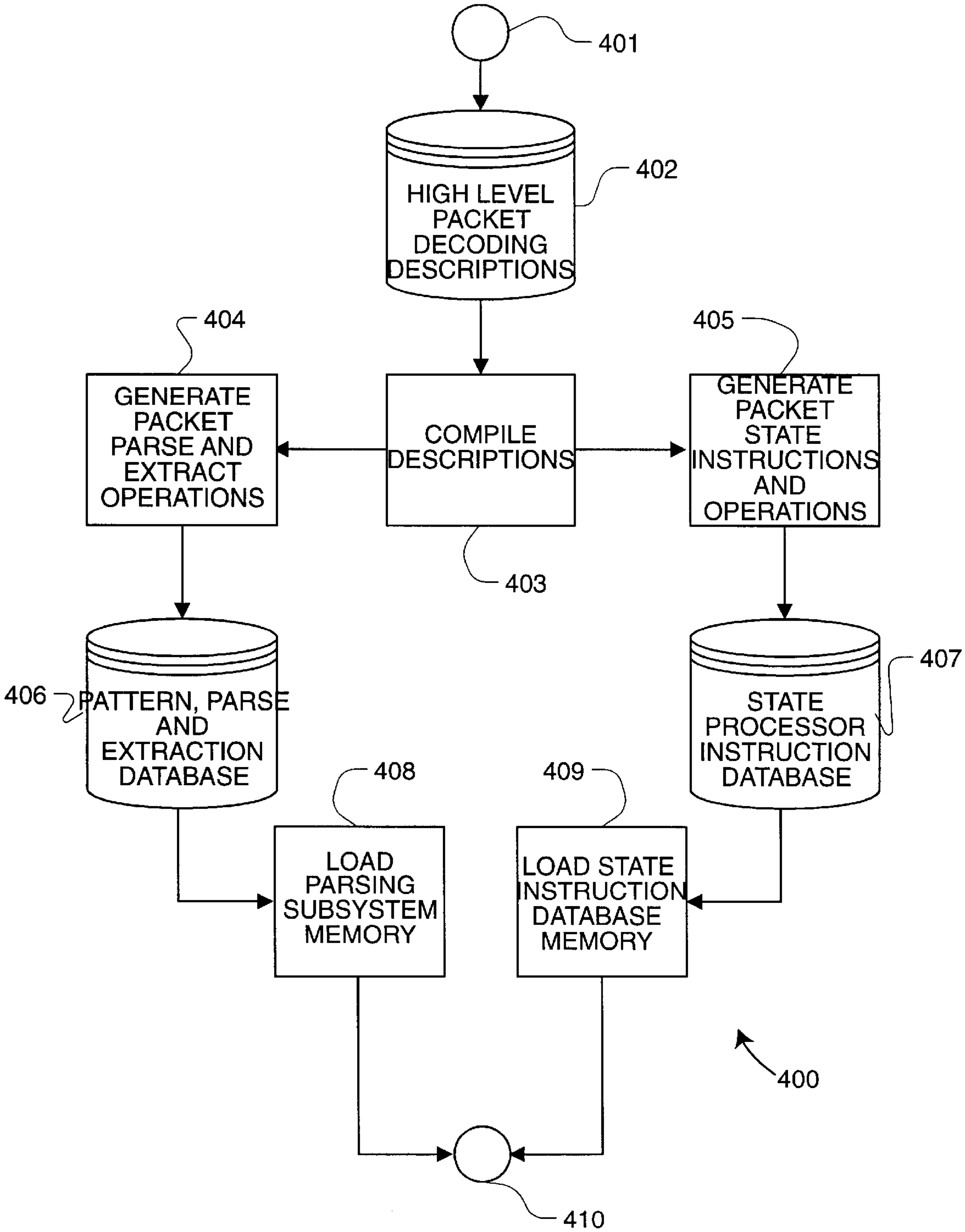

401
HIGH LEVEL PACKET DECODING DESCRIPTIONS
402
404
405
GENERATE PACKET PARSE AND EXTRACT OPERATIONS
COMPILE DESCRIPTIONS
GENERATE PACKET STATE INSTRUCTIONS AND OPERATIONS
403
407
406
PATTERN, PARSE AND EXTRACTION DATABASE
STATE PROCESSOR INSTRUCTION DATABASE
408
409
LOAD PARSING SUBSYSTEM MEMORY
LOAD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

FIG. 4

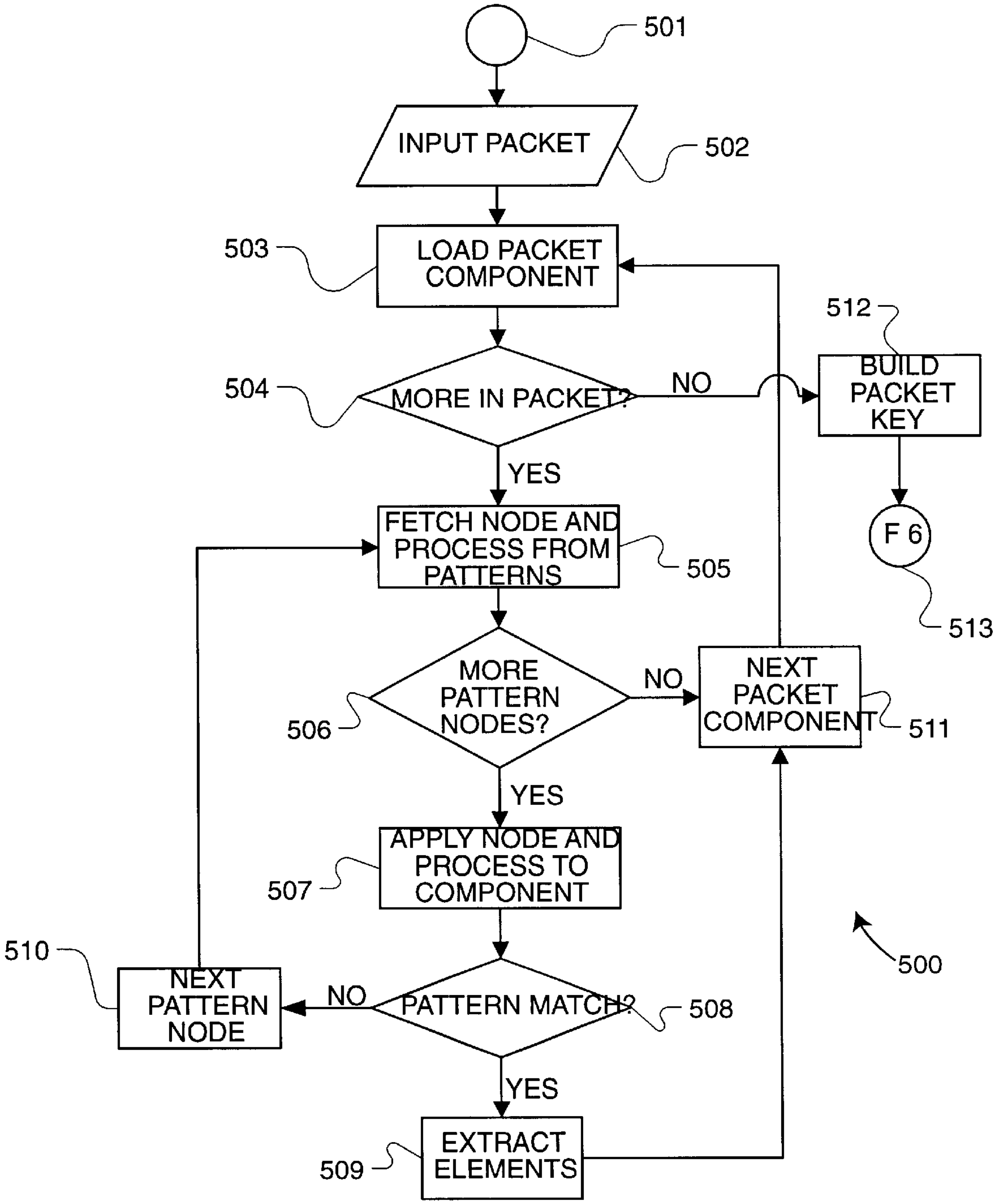

501
INPUT PACKET
502
503
LOAD PACKET COMPONENT
504
MORE IN PACKET?
NO
512
BUILD PACKET KEY
YES
FETCH NODE AND PROCESS FROM PATTERNS
505
F 6
513
MORE PATTERN NODES?
NO
NEXT PACKET COMPONENT
506
511
YES
APPLY NODE AND PROCESS TO COMPONENT
507
500
510
NEXT PATTERN NODE
NO
PATTERN MATCH?
508
YES
EXTRACT ELEMENTS
509

FIG. 5

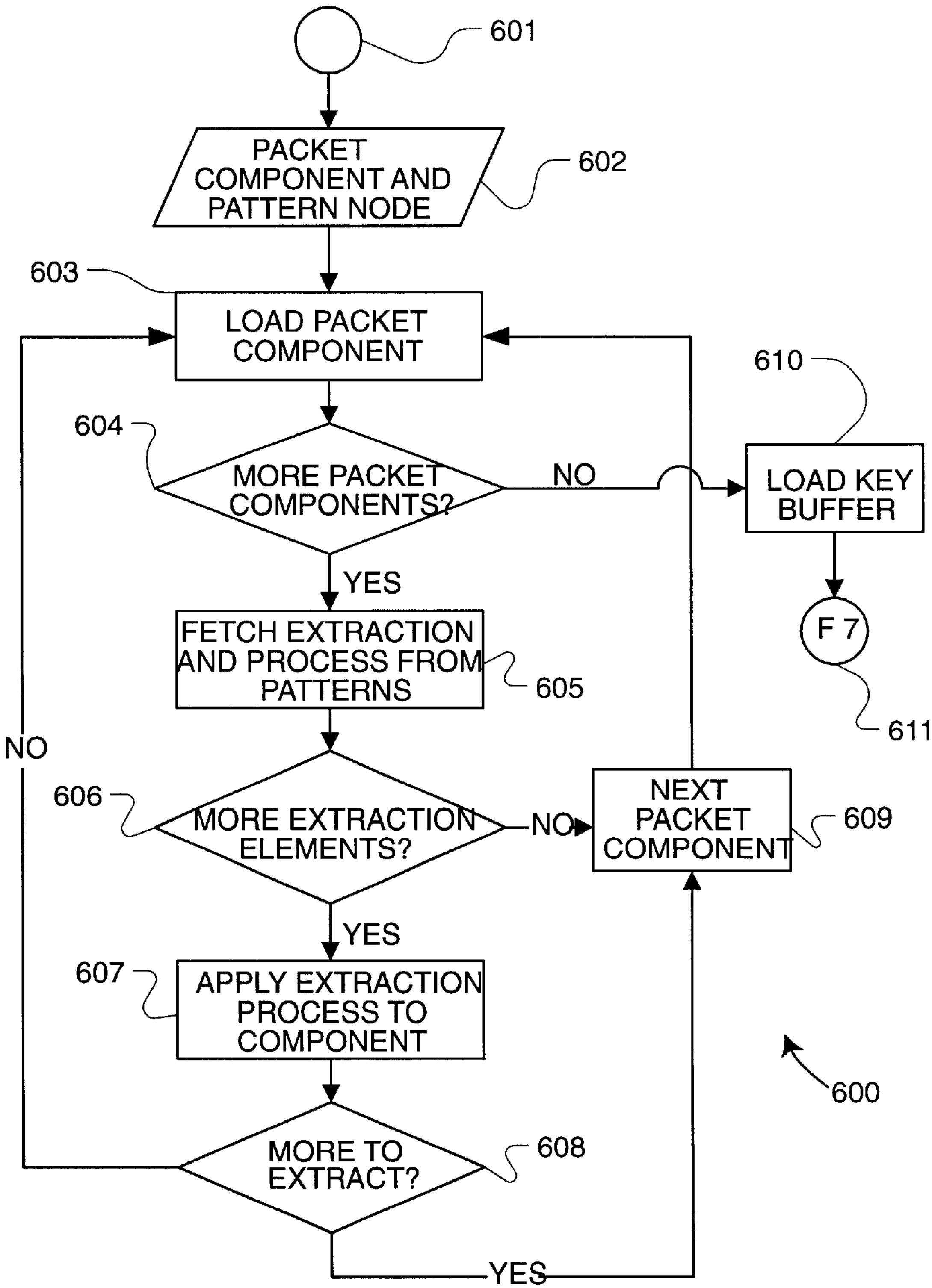

601
PACKET COMPONENT AND PATTERN NODE
602
603
LOAD PACKET COMPONENT
610
604
MORE PACKET COMPONENTS?
NO
LOAD KEY BUFFER
YES
FETCH EXTRACTION AND PROCESS FROM PATTERNS
605
F 7
611
NO
606
MORE EXTRACTION ELEMENTS?
NO
NEXT PACKET COMPONENT
609
YES
607
APPLY EXTRACTION PROCESS TO COMPONENT
600
MORE TO EXTRACT?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

FIG. 6

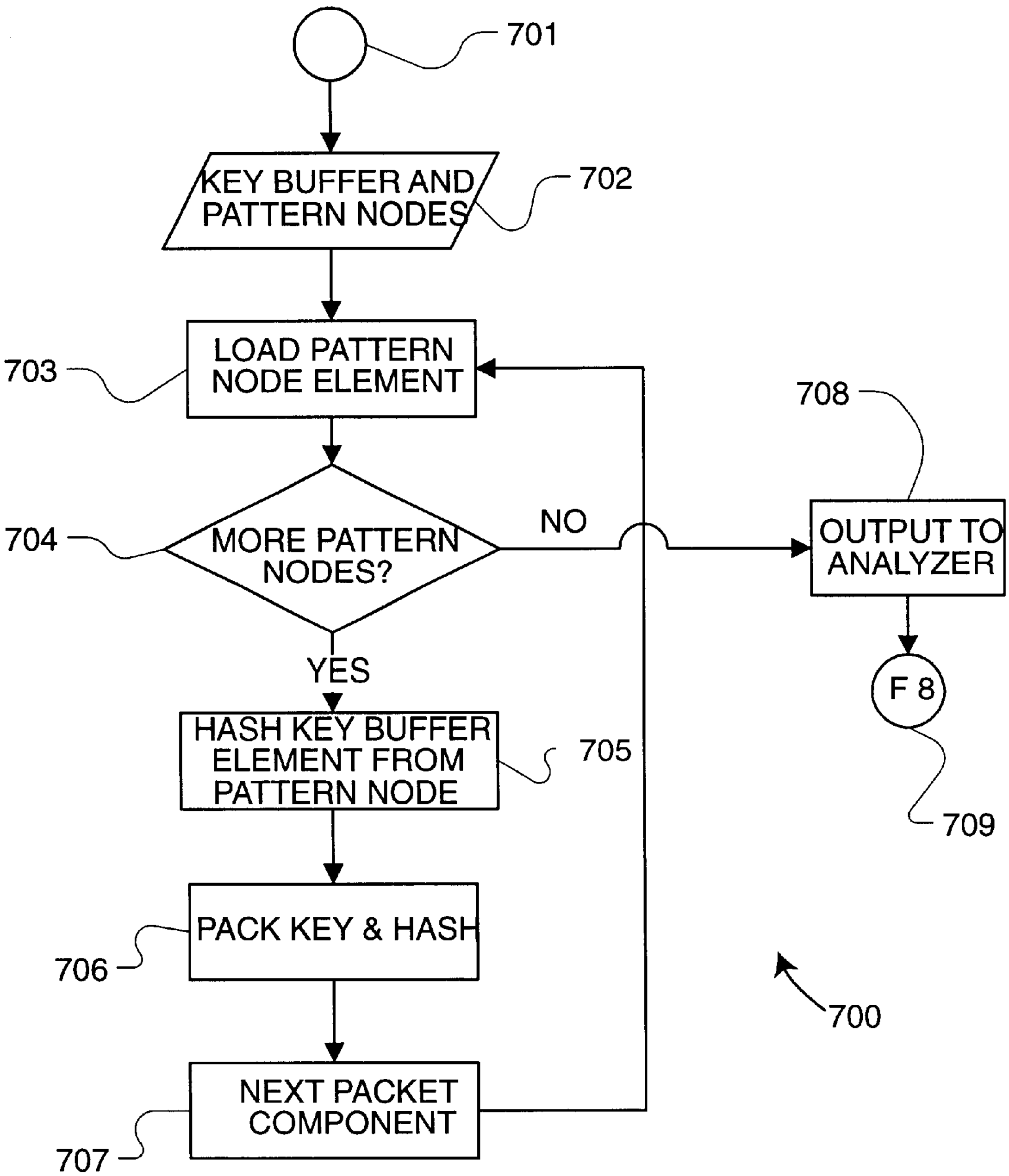

701
KEY BUFFER AND PATTERN NODES
702
LOAD PATTERN NODE ELEMENT
703
708
MORE PATTERN NODES?
NO
OUTPUT TO ANALYZER
704
YES
F 8
HASH KEY BUFFER ELEMENT FROM PATTERN NODE
705
709
PACK KEY & HASH
706
700
NEXT PACKET COMPONENT
707

FIG. 7

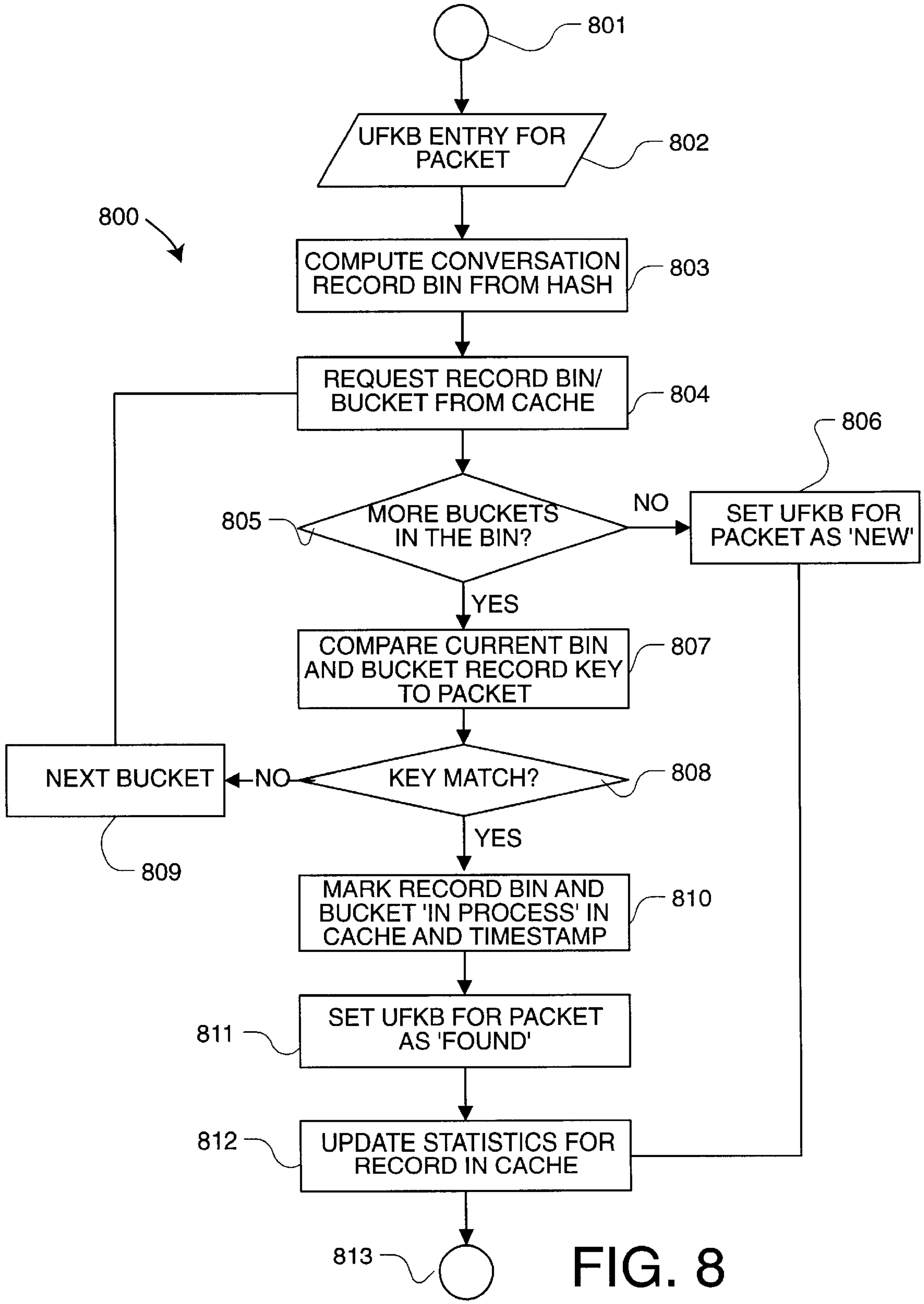

801
UFKB ENTRY FOR PACKET
802
800
COMPUTE CONVERSATION RECORD BIN FROM HASH
803
REQUEST RECORD BIN/ BUCKET FROM CACHE
804
806
805
MORE BUCKETS IN THE BIN?
NO
SET UFKB FOR PACKET AS 'NEW'
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
807
NEXT BUCKET
NO
KEY MATCH?
808
YES
809
MARK RECORD BIN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

FIG. 8

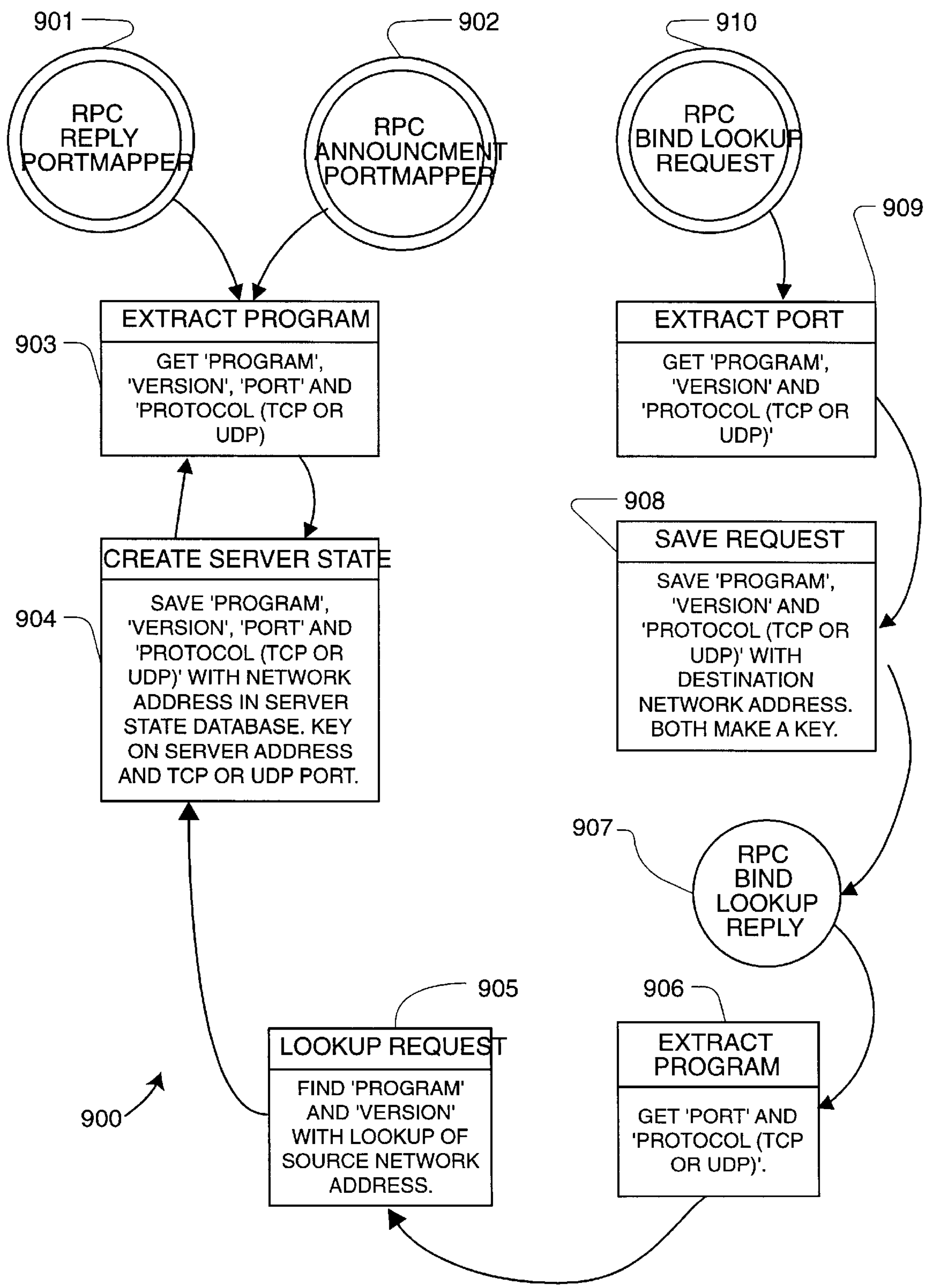

901
RPC REPLY PORTMAPPER
902
RPC ANNOUNCMENT PORTMAPPER
910
RPC BIND LOOKUP REQUEST
909
903
EXTRACT PROGRAM
GET 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)
EXTRACT PORT
GET 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'
908
SAVE REQUEST
SAVE 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'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

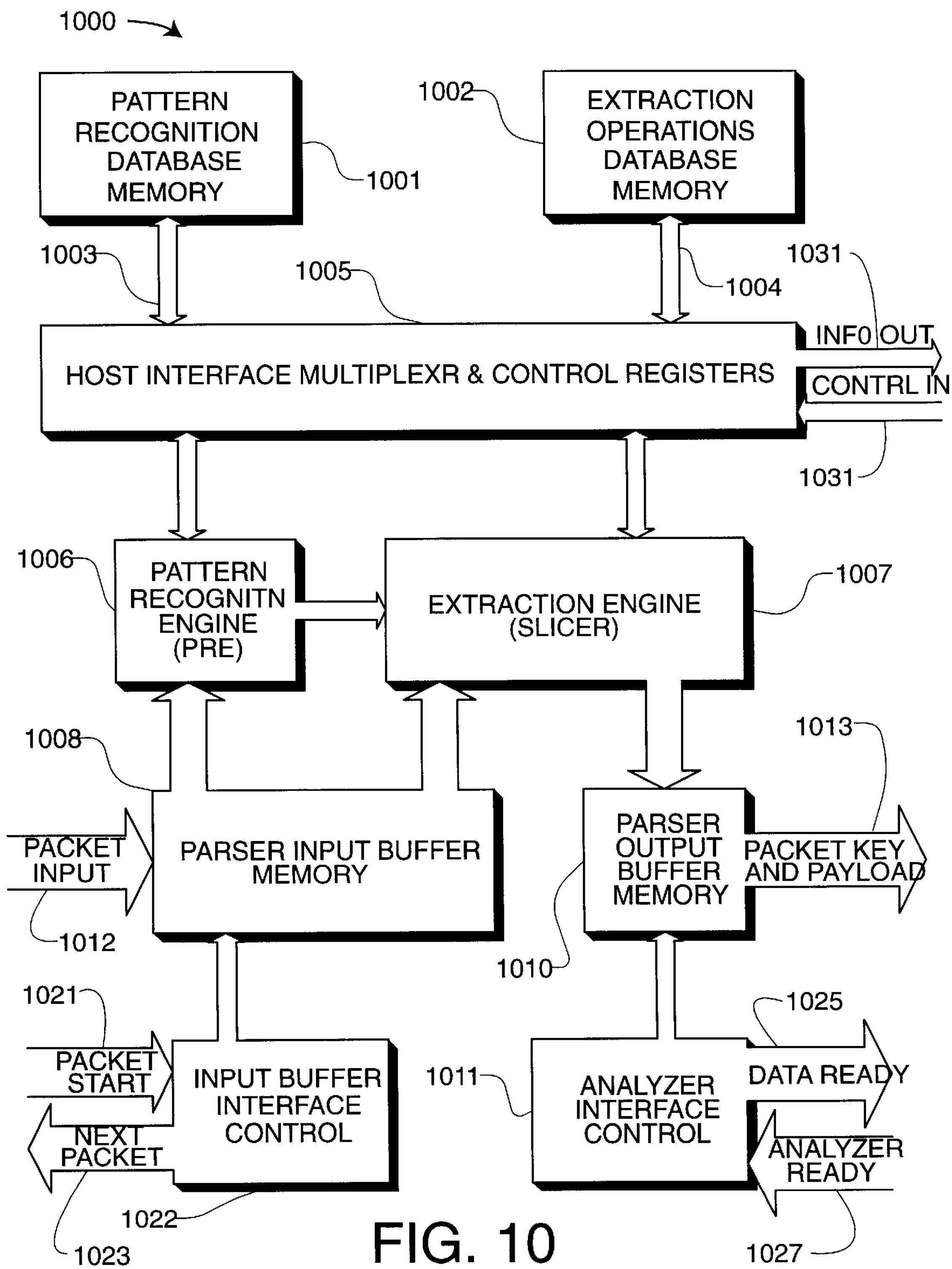

1000
PATTERN RECOGNITION DATABASE MEMORY
1001
1002
EXTRACTION OPERATIONS DATABASE MEMORY
1003
1005
1004
1031
HOST INTERFACE MULTIPLEXR & CONTROL REGISTERS
INF0 OUT
CONTRL IN
1031
1006
PATTERN RECOGNITN ENGINE (PRE)
EXTRACTION ENGINE (SLICER)
1007
1008
1013
PACKET INPUT
PARSER INPUT BUFFER MEMORY
PARSER 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

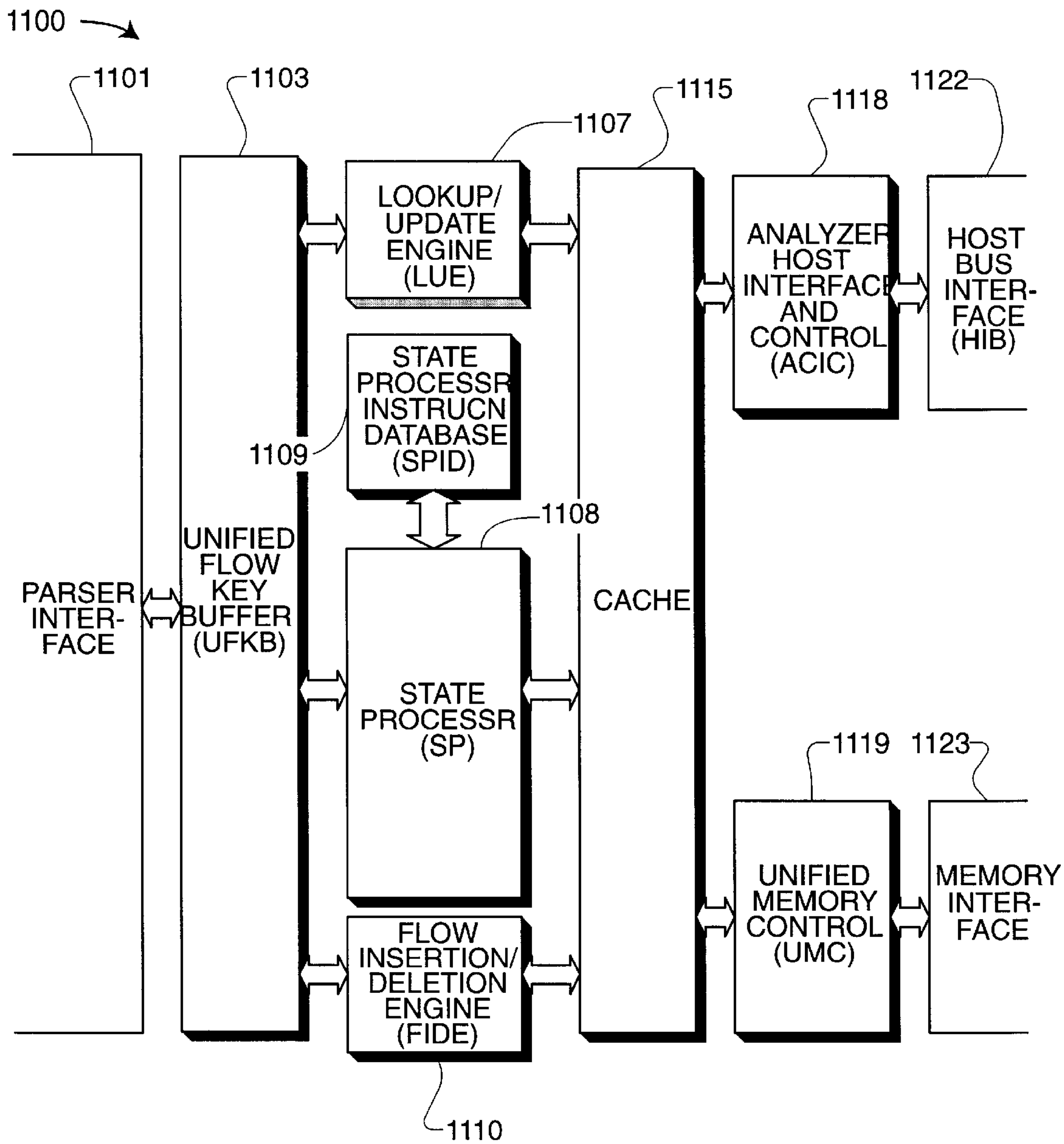

1100
1101
1103
1107
1115
1118
1122
LOOKUP/
UPDATE
ENGINE
(LUE)
ANALYZER
HOST
INTERFACE
AND
CONTROL
(ACIC)
HOST
BUS
INTER-
FACE
(HIB)
STATE
PROCESSR
INSTRUCN
DATABASE
(SPID)
1109
1108
UNIFIED
FLOW
KEY
BUFFER
(UFKB)
PARSER
INTER-
FACE
CACHE
STATE
PROCESSR
(SP)
1119
1123
UNIFIED
MEMORY
CONTROL
(UMC)
MEMORY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

FIG. 11

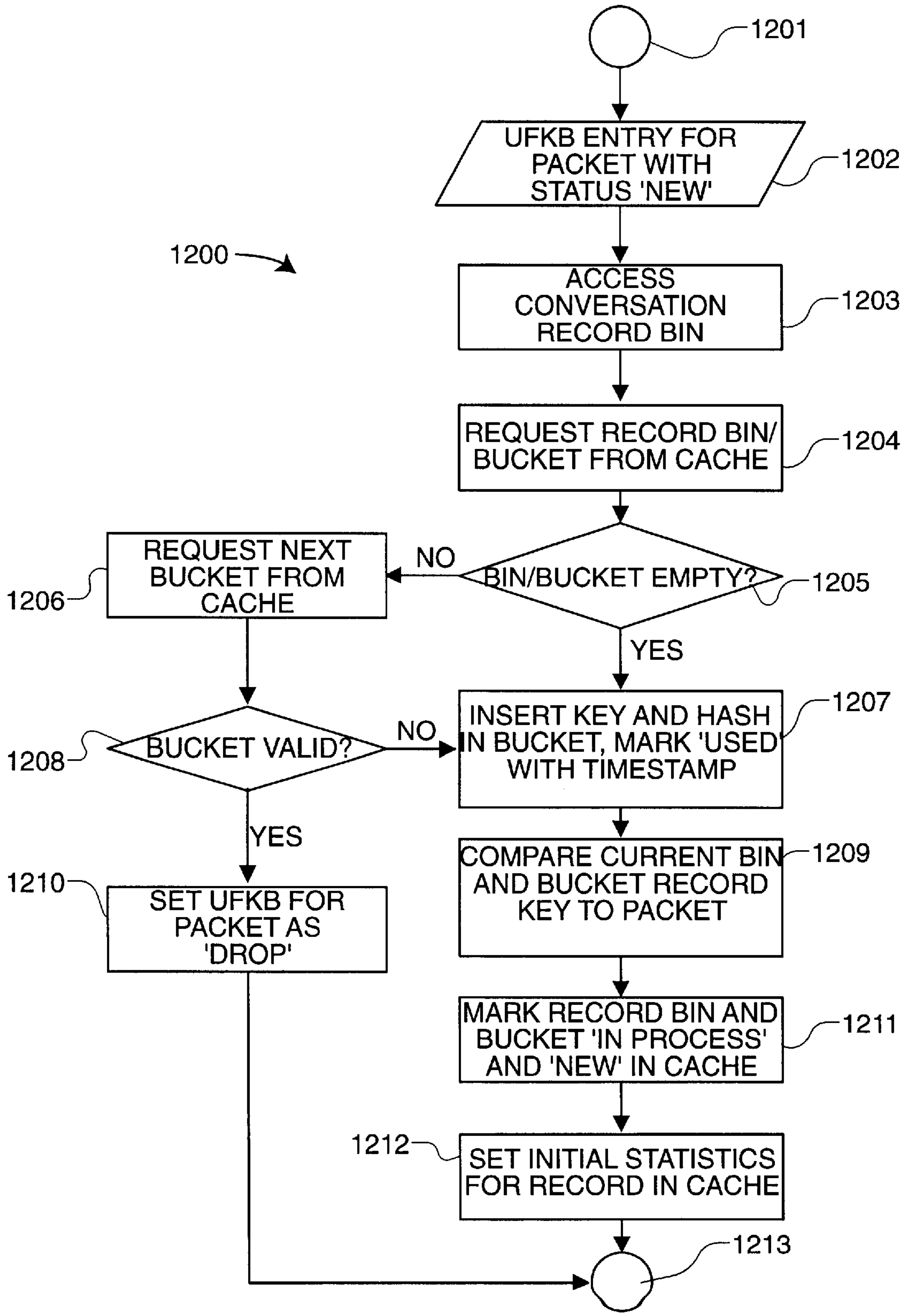

1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
REQUEST NEXT BUCKET FROM CACHE
1206
NO
BIN/BUCKET EMPTY?
1205
YES
BUCKET VALID?
1208
NO
INSERT KEY AND HASH IN BUCKET, MARK 'USED' WITH TIMESTAMP
1207
YES
COMPARE CURRENT 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

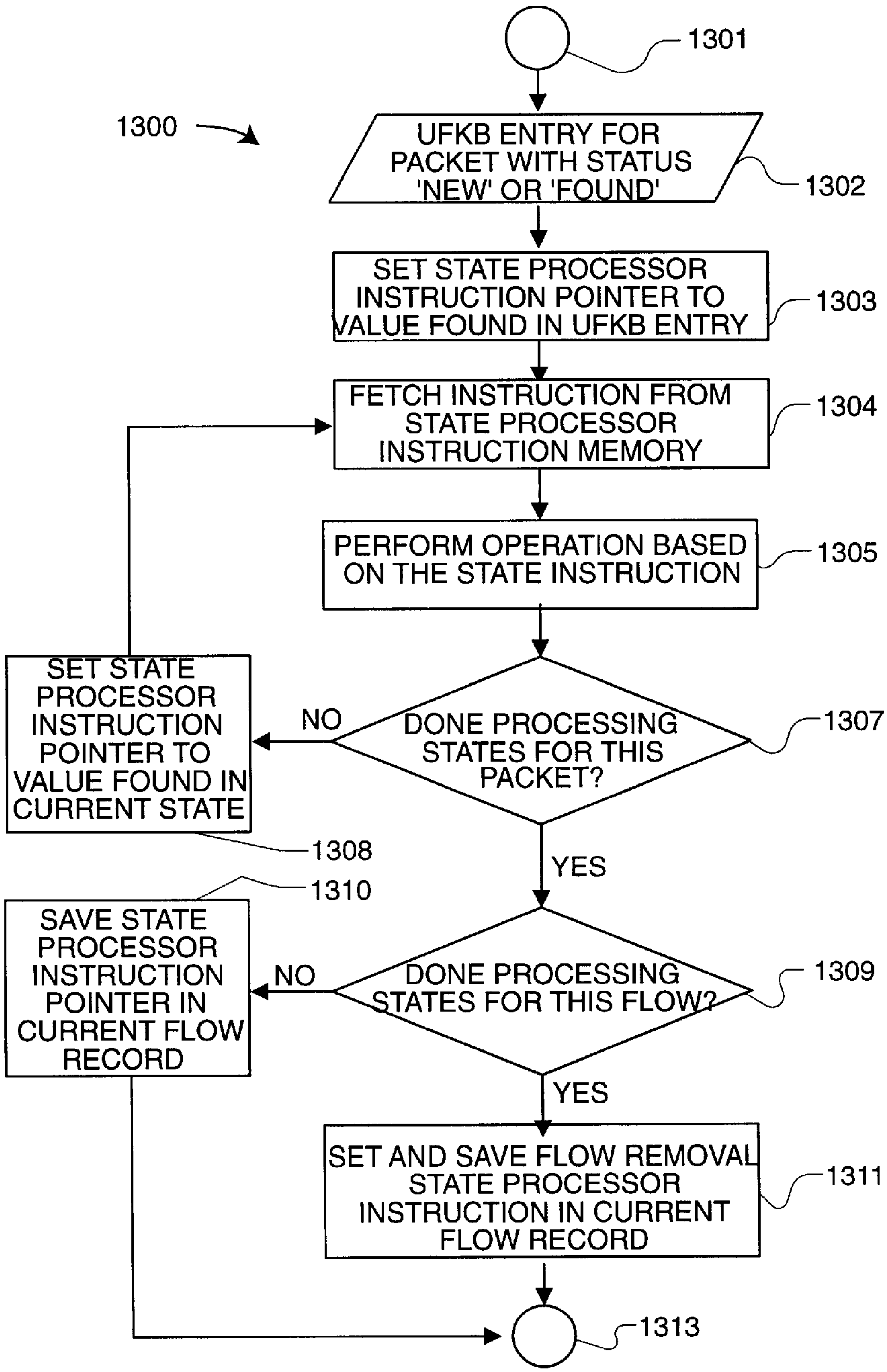

1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
DONE PROCESSING STATES FOR THIS PACKET?
1307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

FIG. 13

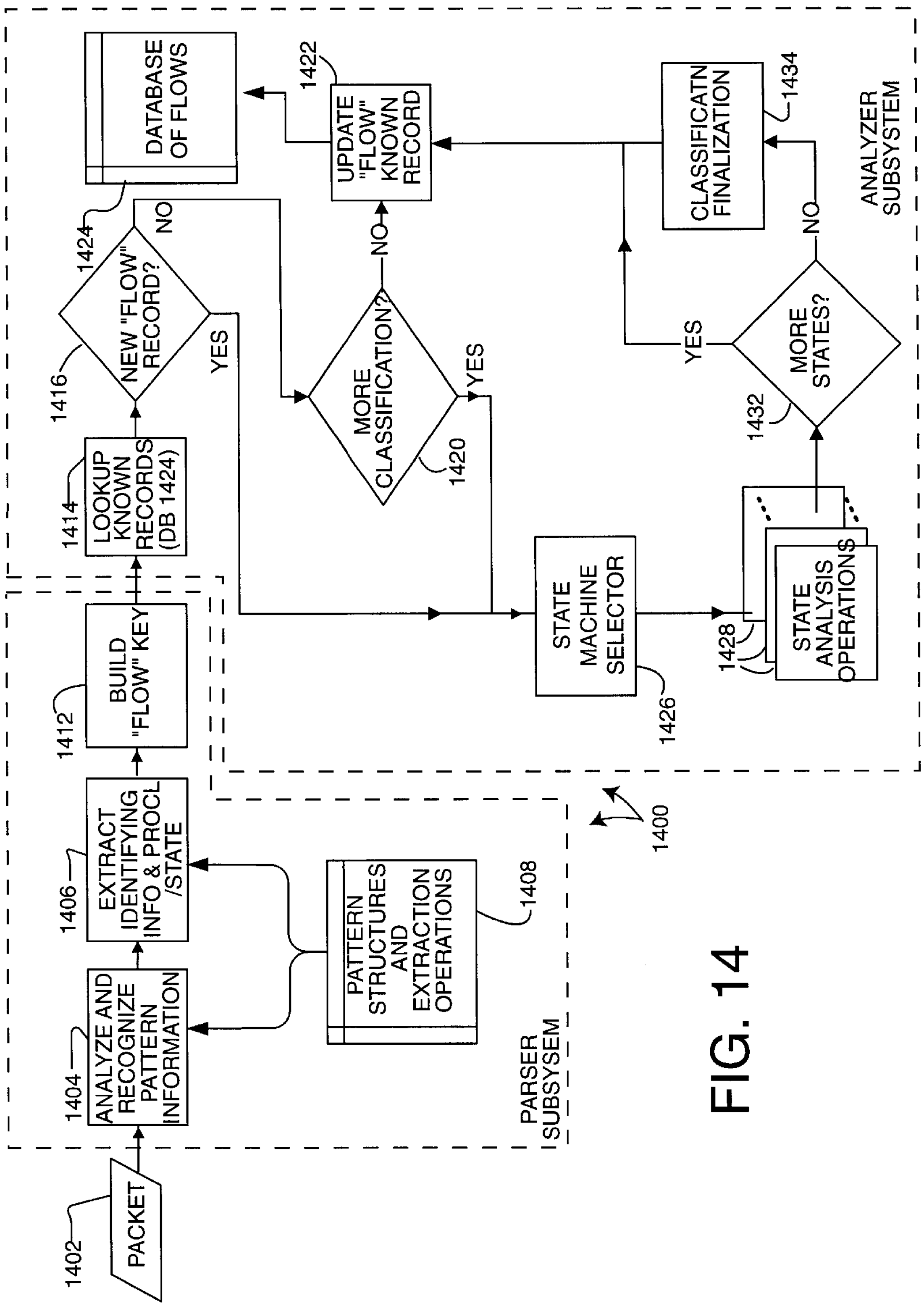

PACKET
1402
ANALYZE AND RECOGNIZE PATTERN INFORMATION
1404
EXTRACT IDENTIFYING INFO & PROCL /STATE
1406
PATTERN STRUCTURES AND EXTRACTION OPERATIONS
1408
PARSER SUBSYSEM
BUILD "FLOW" KEY
1412
LOOKUP KNOWN RECORDS (DB 1424)
1414
NEW "FLOW" RECORD?
1416
YES
NO
DATABASE OF FLOWS
1424
MORE CLASSIFICATION?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

FIG. 14

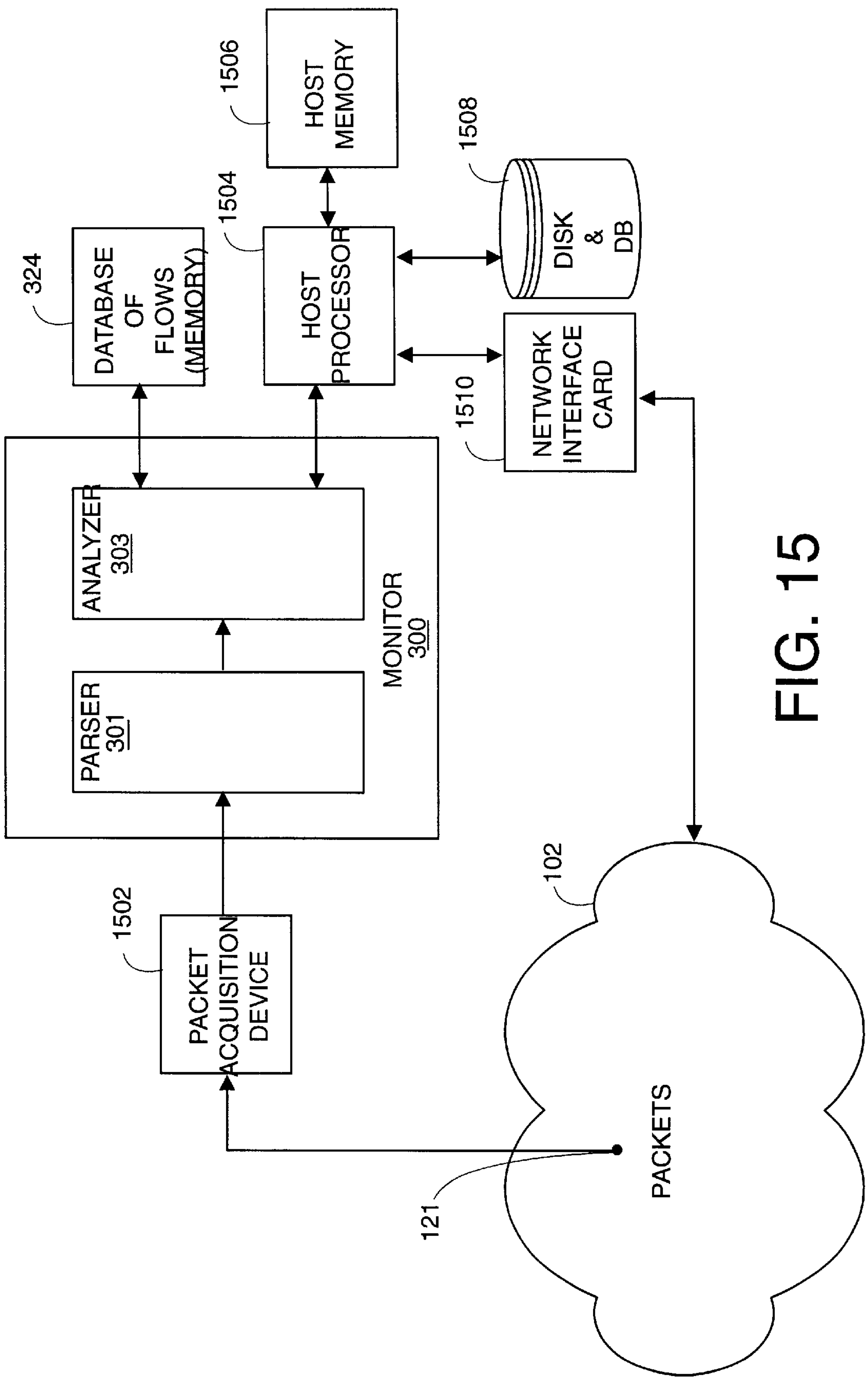

HOST MEMORY
1506
1508
DISK & DB
1504
HOST PROCESSOR
324
DATABASE OF FLOWS (MEMORY)
NETWORK INTERFACE CARD
1510
ANALYZER
303
MONITOR
300
PARSER
301
1502
PACKET ACQUISITION DEVICE
102
PACKETS
121

FIG. 15

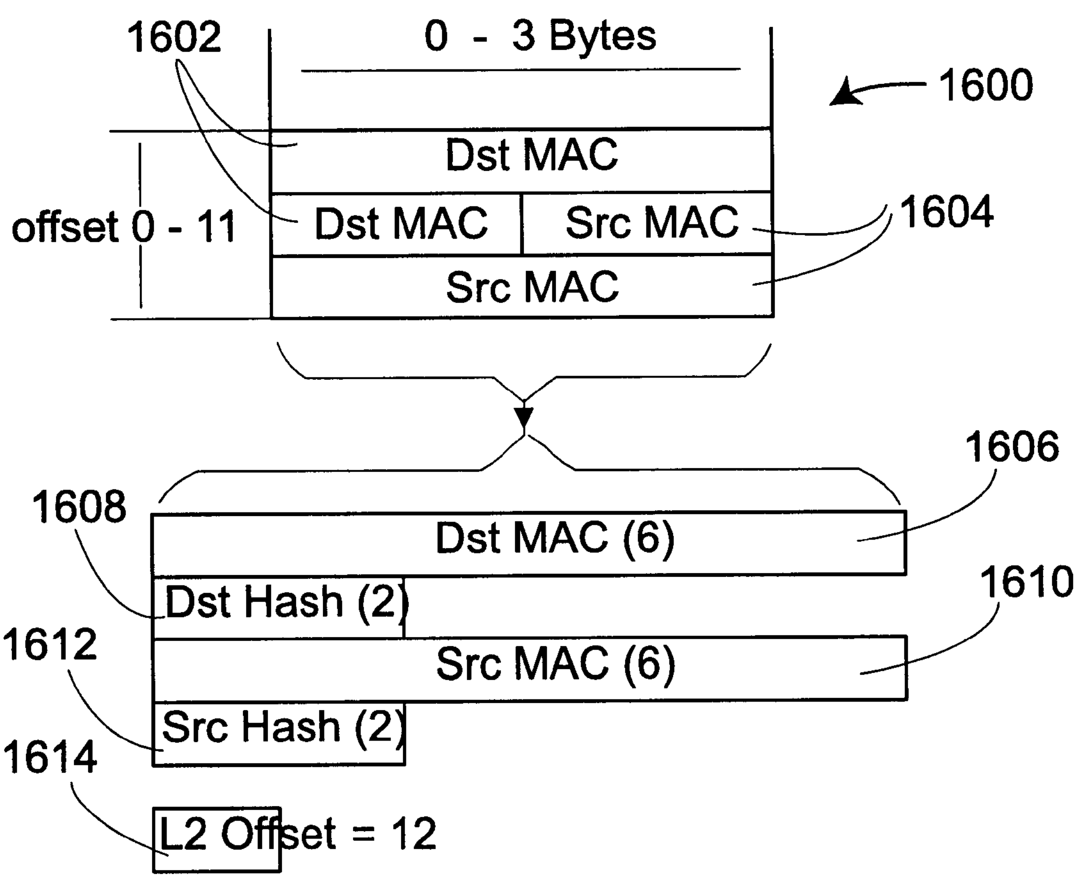

1602
0 - 3 Bytes
1600
Dst MAC
offset 0 - 11
Dst MAC
Src MAC
1604
Src MAC
1606
1608
Dst MAC (6)
Dst Hash (2)
1610
1612
Src MAC (6)
Src Hash (2)
1614
L2 Offset = 12

FIG. 16

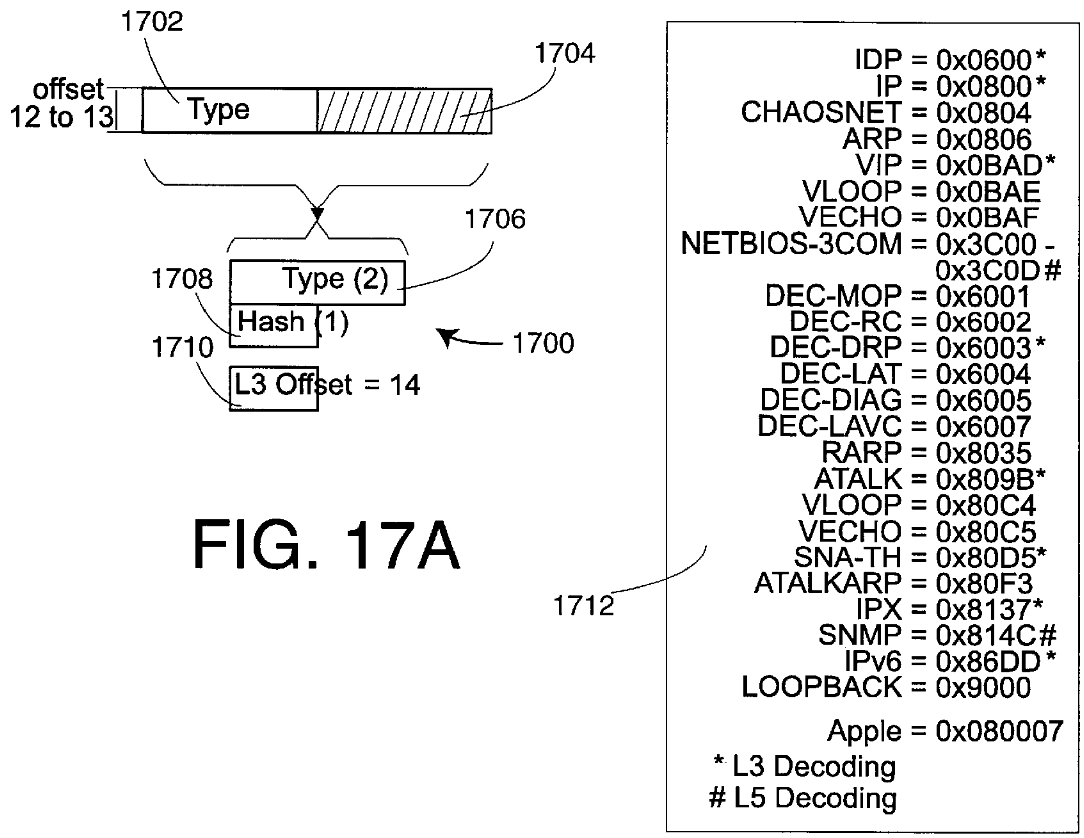


FIG. 17A

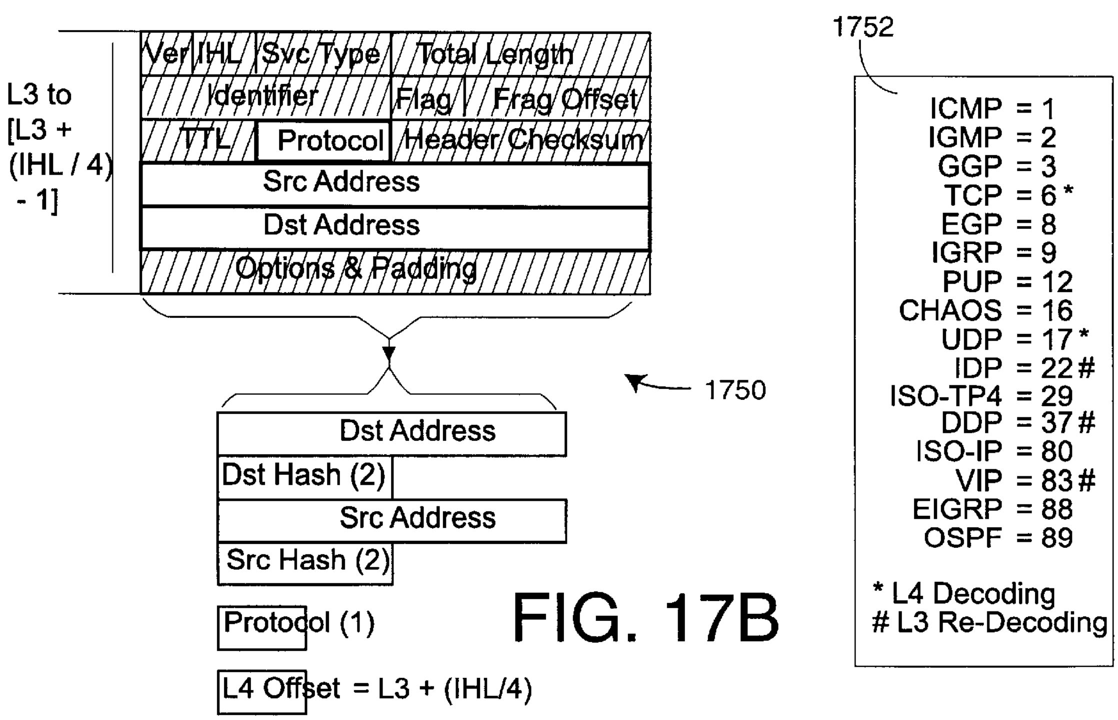


FIG. 17B

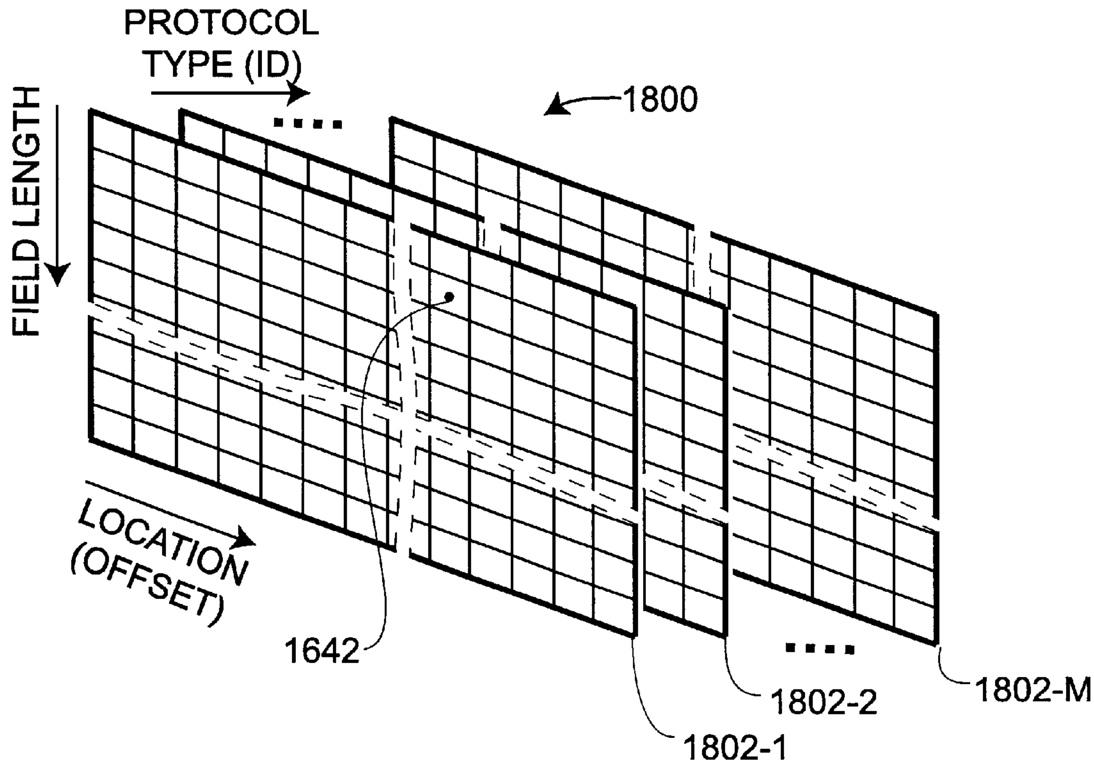


FIG. 18A

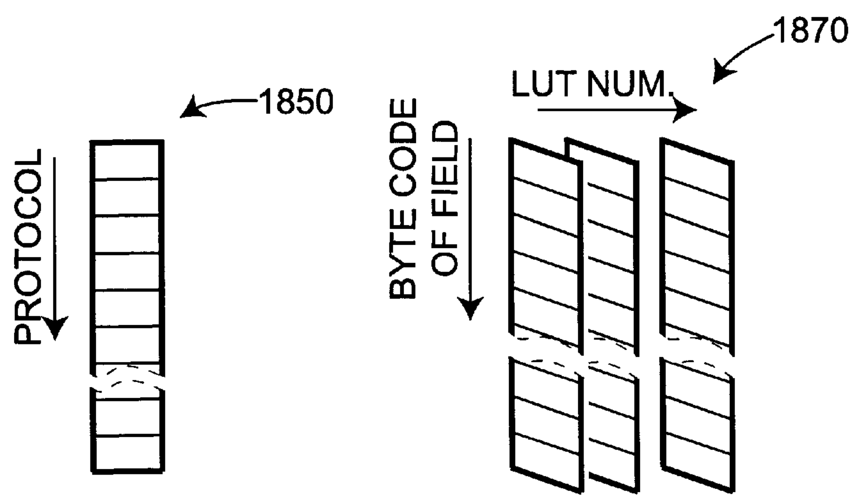


FIG. 18B

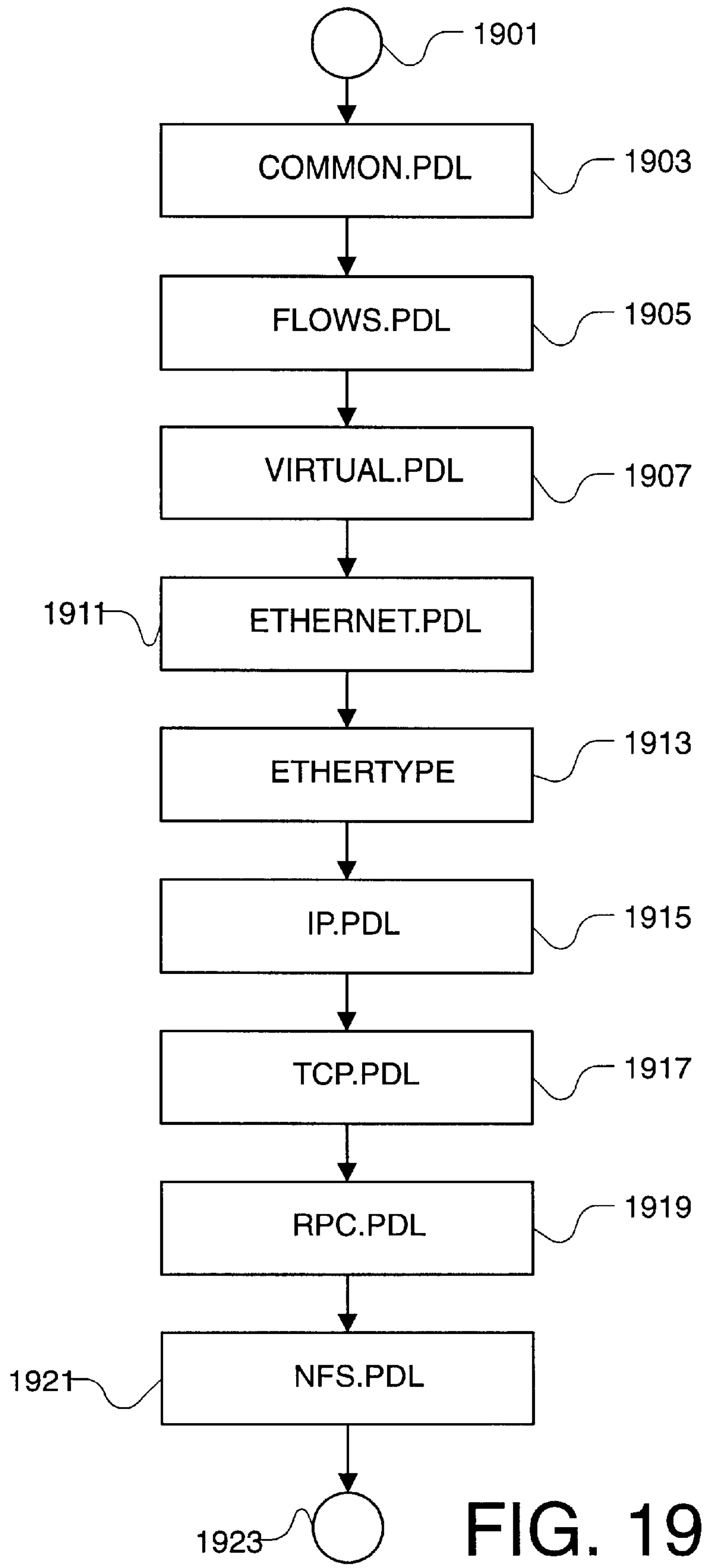

1901
COMMON.PDL
1903
FLOWS.PDL
1905
VIRTUAL.PDL
1907
1911
ETHERNET.PDL
ETHERTYPE
1913
IP.PDL
1915
TCP.PDL
1917
RPC.PDL
1919
1921
NFS.PDL
1923

FIG. 19

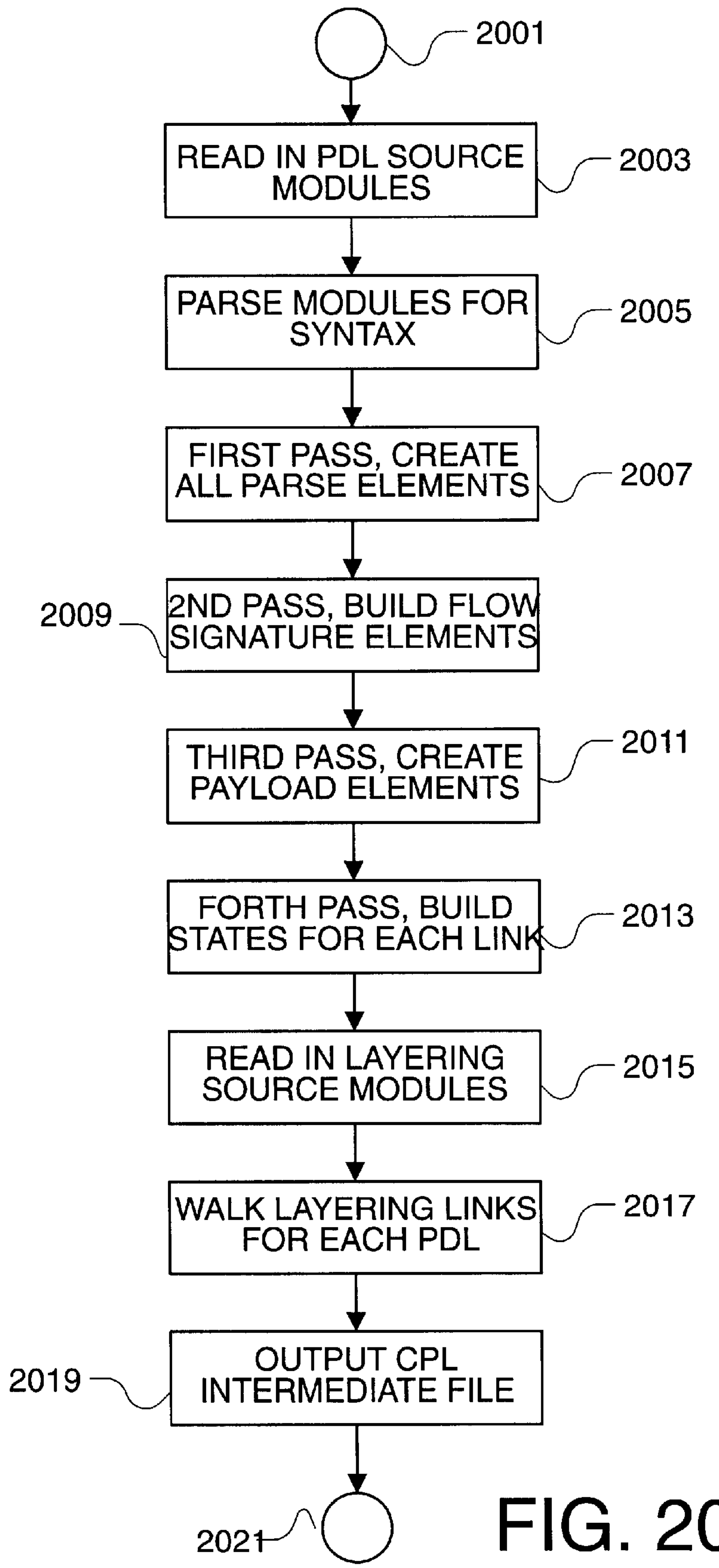

2001
READ IN PDL SOURCE MODULES
2003
PARSE MODULES FOR SYNTAX
2005
FIRST PASS, CREATE ALL PARSE ELEMENTS
2007
2ND PASS, BUILD FLOW SIGNATURE ELEMENTS
2009
THIRD PASS, CREATE PAYLOAD ELEMENTS
2011
FORTH PASS, BUILD STATES FOR EACH LINK
2013
READ IN LAYERING SOURCE MODULES
2015
WALK LAYERING LINKS FOR EACH PDL
2017
OUTPUT CPL INTERMEDIATE FILE
2019
2021

FIG. 20

PROCESSING PROTOCOL SPECIFIC INFORMATION IN PACKETS SPECIFIED BY A PROTOCOL DESCRIPTION LANGUAGE

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 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. 09/608,237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK, to inventors Dietz, et al., filed Jun. 30, 2000, 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, 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, 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, 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.

COPYRIGHT NOTICE

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.

The recognizing and classifying in such a network monitor should be at all protocol layer levels in conversational flows that pass in either direction at a point in a network. Furthermore, the monitor should provide for properly analyzing each of the packets exchanged between a client and a server, maintaining information relevant to the current state of each of these conversational flows.

Related and incorporated by reference U.S. patent application Ser. No. 09/608,237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK, to inventors Dietz, et al, 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.

A network analyzer should be able to analyze many different protocols. At a base level, there are a number of standards used in digital telecommunications, including Ethernet, HDLC, ISDN, Lap B, ATM, X.25, Frame Relay, Digital Data Service, FDDI (Fiber Distributed Data Interface), T1, and others. Many of these standards employ different packet and/or frame formats. For example, data is transmitted in ATM and frame-relay systems in the form of fixed length packets (called "cells") that are 53 octets (i.e., bytes) long. Several such cells may be needed to make up the information that might be included in the packet employed by some other protocol for the same payload information—for example in a conversational flow that uses the frame-relay standard or the Ethernet protocol.

In order for a network monitor to be able to analyze different packet or frame formats, the monitor needs to be able to perform protocol specific operations on each packet with each packet carrying information conforming to different protocols and related to different applications. For example, the monitor needs to be able to parse packets of different formats into fields to understand the data encapsulated in the different fields. As the number of possible packet formats or types increases, the amount of logic required to parse these different packet formats also increases.

Prior art network monitors exist that parse individual packets and look for information at different fields to use for building a signature for identifying packets. 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." In this patent, there are fixed locations specified for particular types of packets. For example, if a DECnet packet appears, the Chiu system 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 locations are examined. The system looks only at the lowest levels up to the protocol layer. There are fixed locations for each of the fields that specified the next level. 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.

It is desirable to be able to adaptively determine the locations and the information extracted from any packet for the particular type of packet. In this way, an optimal signature may be defined using a protocol-dependent and packet-content-dependent definition of what to look for and where to look for it in order to form a signature.

There thus is also a need for a network monitor that can be tailored or adapted for different protocols and for different application programs. There thus is also a need for a network monitor that can accommodate new protocols and for new application programs. There also is a need for means for specifying new protocols and new levels, including new applications. There also is a need for a mechanism to describe protocol specific operations, including, for example, what information is relevant to packets and packets that need to be decoded, and to include specifying parsing operations and extraction operations. There also is a need for a mechanism to describe state operations to perform on packets that are at a particular state of recognition of a flow in order to further recognize the flow.

SUMMARY

One embodiment of the invention is a method of performing protocol specific operations on a packet passing through a connection point on a computer network. The packet contents conform to protocols of a layered model wherein the protocol at a particular layer level may include one or a set of child protocols defined for that level. The method includes receiving the packet and receiving a set of protocol descriptions for protocols may be used in the packet. A protocol description for a particular protocol at a particular layer level includes any child protocols of the particular protocol, and for any child protocol, where in the packet information related to the particular child protocol may be found. A protocol description also includes any protocol specific operations to be performed on the packet for the particular protocol at the particular layer level. The method includes performing the protocol specific operations on the packet specified by the set of protocol descriptions based on the base protocol of the packet and the children of the protocols used in the packet. A particular embodiment includes providing the protocol descriptions in a high-level protocol description language, and compiling to the descriptions into a data structure. The compiling may further include compressing the data structure into a compressed data structure. The protocol specific operations may include parsing and extraction operations to extract identifying information. The protocol specific operations may also include state processing operations defined for a particular state of a conversational flow of the packet.

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. **17**A 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. **17**B is an example of an IP packet, for example, of the Ethertype packet shown in FIGS. **16** and **17**A, and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. **18**A 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. **18**B 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.

FIG. **19** shows various PDL file modules to be compiled together by the compiling process illustrated in FIG. **20** as an example, in accordance with a compiling aspect of the invention.

FIG. **20** is a flowchart of the process of compiling high-level language files according to an aspect 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 from 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, NBTBIOS, 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)

Diferent communications 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. **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 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 updatelookup 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 **110** 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, 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, 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.

The Pattern Parse and Extraction Database Format

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 base level). Each protocol is either a parent node of some other protocol at the next later 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.

As an example of the tree structure, consider an Ethernet 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. Another child of the IP may be the UDP protocol.

A packet includes at least one header for each protocol used. The child protocol of a particular protocol used in a packet is indicated by the contents at a location within the header of the particular protocol. The contents of the packet that specify the child are in the form of a child recognition pattern.

A network analyzer preferably can analyze many different protocols. At a base level, there are a number of packet types used in digital telecommunications, including Ethernet, HDLC, ISDN, Lap B, ATM, X.25, Frame Relay, Digital Data Service, FDDI (Fiber Distributed Data Interface), and T1, among others. Many of these packet types use different packet and/or frame formats. For example, data is transmitted in ATM and frame-relay systems in the form of fixed length packets (called "cells") that are 53 octets (i.e., bytes) long; several such cells may be needed to make up the information that might be included in a single packet of some other type.

Note that the term packet herein 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," "frame format" and "cell format" are generally synonymous.

The packet monitor **300** can analyze different protocols, and thus can perform different protocol specific operations on a packet wherein the protocol headers of any protocol are located at different locations depending on the parent protocol or protocols used in the packet. Thus, the packet monitor adapts to different protocols according to the contents of the packet. The locations and the information extracted from any packet are adaptively determined for the particular type of packet. For example, there is no fixed definition of what to look for or where to look in order to form the flow signature. In some prior art systems, such as that described in U.S. Pat. No. 5,101,402 to Chiu, et al., there are fixed locations specified for particular types of packets. With the proliferation of protocols, 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 number of levels is variable for any protocol and is whatever number is sufficient to uniquely identify as high up the level system as we wish to go, all the way to the application level (in the OSI model).

Even the same protocol may have different variants. Ethernet packets for example, have several known variants, each having a basic format that remains substantially the same. 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 Ethernet (IEEE 803.x) packet. A monitor should be able to handle all types of Ethernet protocols. With the Ethertype protocol, the contents that indicate the child protocol is in one location, while with an IEEE type, the child protocol is specified in a different location. The child protocol is indicated by a child recognition pattern.

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. Such information is also to be specified in the parsing structures and extraction operations database **308**. This includes all of the header information at this level in the form of 6 bytes of Dst MAC information **1606** and 6 bytes of Src MAC information **1610**. Also specified are the source and destination address components, respectively, of the hash. These are shown as 2 byte Dst Hash **1608** from the Dst MAC address and the 2 byte Src Hash **1612** from the Src MAC address. Finally, information is included (**1614**) on where to the header starts for information related to the next layer level. In this case the next layer level (level **2**) information starts at packet offset **12**.

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**.

Also shown is some of the extracted part used for the parser record and to locate the next header information. The signature part of the parser record includes extracted part **1702**. Also included is the 1-byte Hash component **1710** from this information.

An offset field **1710** provides the offset to go to the next level information, i.e., to locate the start of the next layer level header. For the Ethertype packet, the start of the next layer header 14 bytes from the start of the frame.

Other packet types are arranged differently. For example, in an ATM system, each ATM packet comprises a five-octet "header" segment followed by a forty-eight octet "payload" segment. The header segment of an ATM cell contains information relating to the routing of the data contained in the payload segment. The header segment also contains traffic control information. Eight or twelve bits of the header segment contain the Virtual Path Identifier (VPI), and sixteen bits of the header segment contain the Virtual Channel Identifier (VCI). Each ATM exchange translates the abstract routing information represented by the VPI and VCI bits into the addresses of physical or logical network links and routes each ATM cell appropriately.

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 header starts at a different location (**L3**) depending on the parent protocol. Also included in FIG. **17**B are some of the fields to be extracted for the signature, and an indication of where the next level's header would start in the packet.

Note that the information shown in FIGS. **16**, **17**A, and **17**B would be specified to the monitor in the form of PDL files and compiled into the database **308** of pattern structures and extraction operations.

The parsing subsystem **301** performs operations on the packet header data based on information stored in the database **308**. Because data related to protocols can be considered as organized in the form of a tree, it is required in the parsing subsystem to search through data that is originally organized in the form of a tree. Since real time operation is preferable, it is required to carry out such searches rapidly.

Data structures are known for efficiently storing information organized as trees. Such storage-efficient means typically require arithmetic computations to determine pointers to the data nodes. Searching using such storage-efficient data structures may therefore be too time consuming for the present application. It is therefore desirable to store the protocol data in some form that enables rapid searches.

In accordance with another aspect of the invention, the database **308** is stored in a memory and includes a data structure used to store the protocol specific operations that are to be performed on a packet. In particular, a compressed representation is used to store information in the pattern parse and extraction database **308** used by the pattern recognition process **304** and the extraction process **306** in the parser subsystem **301**. The data structure is organized for rapidly locating the child protocol related information by using a set of one or more indices to index the contents of the data structure. A data structure entry includes an indication of validity. Locating and identifying the child protocol includes indexing the data structure until a valid entry is found. Using the data structure to store the protocol information used by the pattern recognition engine (PRE) **1006** enables the parser subsystem **301** to perform rapid searches.

In one embodiment, the data structure is in the form of a three-dimensional structure. Note that this three dimensional structure in turn is typically stored in memory as a set of two-dimensional structures whereby one of the three dimensions of the 3-D structure is used as an index to a particular 2-D array. This forms a first index to the data structure.

FIG. **18**A shows such a 3-D representation **1800** (which may be considered as an indexed set of 2-D representations). The three dimensions of this data structure are:

1. Type identifier [1:M]. This is the identifier that identifies a type of protocol at a particular level. For example, 01 indicates an Ethernet frame. 64 indicates IP, 16 indicates an IEEE type Ethernet packet, etc. Depending on how many protocols the packet parser can handle, M may be a large number; M may grow over time as the capability of analyzing more protocols is added to monitor **300**. When the 3-D structure is considered a set of 2-D structures, the type ID is an index to a particular 2-D structure.
2. Size [1:64]. The size of the field of interest within the packet.
3. Location [1:512]. This is the offset location within the packet, expressed as a number of octets (bytes).

At any one of these locations there may or may not be valid data. Typically, there will not be valid data in most locations. The size of the 3-D array is M by 64 by 512, which can be large; M for example may be 10,000. This is a sparse 3-D matrix with most entries empty (i.e., invalid).

Each array entry includes a "node code" that indicates the nature of the contents. This node code has one of four values: (1) a "protocol" node code indicating to the pattern recognition process **304** that a known protocol has been recognized as the next (i.e., child) protocol; (2) a "terminal" node code indicating that there are no children for the protocol presently being searched, i.e., the node is a final node in the protocol tree; (3) a "null" (also called "flush") node code indicating that there is no valid entry.

In the preferred embodiment, the possible children and other information are loaded into the data structure by an initialization that includes compilation process **310** based on the PDL files **336** and the layering selections **338**. The following information is included for any entry in the data structure that represents a protocol.

(a) A list of children (as type IDs) to search next. For example, for an Ethernet type 2, the children are Ethertype (IP, IPX, etc, as shown in **1712** of FIG. **17**). These children are compiled into the type codes. The code for IP is 64, that for IPX is 83, etc.

(b) For each of the IDs in the list, a list of the child recognition patterns that need to be compared. For example, $64{:}0800_{16}$ in the list indicates that the value to look for is 0800 (hex) for the child to be type ID 64 (which is the IP protocol). $83{:}8137_{16}$ in the list indicates that the value to look for is 8137 (hex) for the child to be type ID **83** (which is the IPX protocol), etc.

(c) The extraction operations to perform to build the identifying signature for the flow. The format used is (offset, length, flow_signature_value_identifier), the flow_signature_value_identifier indicating where the extracted entry goes in the signature, including what operations (AND, ORs, etc.) may need to be carried out. If there is also a hash key component, for instance, then information on that is included. For example, for an Ethertype packet, the 2-byte type (**1706** in FIG. **17**) is used in the signature. Furthermore, a 1-byte hash (**1708** in FIG. **17**A) of the type is included. . Note furthermore, the child protocol starts at offset **14**.

An additional item may be the "fold." Folding is used to reduce the storage requirements for the 3-D structure. Since each 2-D array for each protocol ID may be sparsely populated, multiple arrays may be combined into a single 2-D array as long as the individual entries do not conflict with each other. A fold number is then used to associate each element. For a given lookup, the fold number of the lookup must match the fold number entry. Folding is described in more detail below.

In the case of the Ethernet, the next protocol field may indicate a length, which tells the parser that this is a IEEE type packet, and that the next protocol is elsewhere. Normally, the next protocol field contains a value which identifies the next, i.e., child protocol.

The entry point for the parser subsystem is called the virtual base layer and contains the possible first children, i.e., the packet types. An example set of protocols written in a high level protocol description language (PDL) is included herein. The set includes PDL files, and the file describing all the possible entry points (i.e., the virtual base) is called virtual.pdl. There is only one child, 01, indicating the Ethernet, in this file. Thus, the particular example can only handle Ethernet packets. In practice, there can be multiple entry points.

In one embodiment, the packet acquisition device provides a header for every packet acquired and input into monitor **300** indicating the type of packet. This header is used to determine the virtual base layer entry point to the parser subsystem. Thus, even at the base layer, the parser subsystem can identify the type of packet.

Initially, the search starts at the child of the virtual base, as obtained in the header supplied by the acquisition device. In the case of the example, this has ID value 01, which is the 2-D array in the overall 3-D structure for Ethernet packets.

Thus hardware implementing pattern analysis process **304** (e.g., pattern recognition engine (PRE) **1006** of FIG. **10**) searches to determine the children (if any) for the 2-D array that has protocol ID 01. In the preferred embodiment that uses the 3-D data structure, the hardware PRE **1006** searches up to four lengths (i.e., sizes) simultaneously. Thus, the process **304** searches in groups of four lengths. Starting at protocol ID 01, the first two sets of 3-D locations searched are

(1, 1, 1)	(1, 1, 2)	. . .
(1, 2, 1)	(1, 2, 2)	
(1, 3, 1)	(1, 3, 2)	
(1, 4, 1)	(1, 4, 2)	

At each stage of a search, the analysis process **304** examines the packet and the 3-D data structure to see if there is a match (by looking at the node code). If no valid data is found, e.g., using the node code, the size is incremented (to maximum of 4) and the offset is then incremented as well.

Continuing with the example, suppose the pattern analysis process **304** finds something at 1, 2, 12. By this, we mean that the process **304** has found that for protocol ID value 01 (Ethernet) at packet offset **12**, there is information in the packet having a length of 2 bytes (octets) that may relate to the next (child) protocol. The information, for example, may be about a child for this protocol expressed as a child recognition pattern. The list of possible child recognition patterns that may be in that part of the packet is obtained from the data structure.

The Ethernet packet structure comes in two flavors, the Ethertype packet and newer IEEE types, and the packet location that indicates the child is different for both. The location that for the Ethertype packet indicates the child is a "length" for the IEEE type, so a determination is made for the Ethernet packet whether the "next protocol" location contains a value or a length (this is called a "LENGTH" operation). A successful LENGTH operation is indicated by contents less than or equal to $05DC_{16}$, then this is an IEEE type Ethernet frame. In such a case, the child recognition pattern is looked for elsewhere. Otherwise, the location contains a value that indicates the child.

Note that while this capability of the entry being a value (e.g., for a child protocol ID) or a length (indicating further analysis to determine the child protocol) is only used for Ethernet packets, in the future, other packets may end up being modified. Accordingly, this capability in the form of a macro in the PDL files still enables such future packets to be decoded.

Continuing with the example, suppose that the LENGTH operation fails. In that case, we have an Ethertype packet, and the next protocol field (containing the child recognition pattern) is 2 bytes long starting at offset **12** as shown as packet field **1702** in FIG. **17**A. This will be one of the children of the Ethertype shown in table **1712** in FIG. **17**A. The PRE uses the information in the data structure to check what the ID code is for the found 2-byte child recognition pattern. For example, if the child recognition pattern is 0800

(Hex), then the protocol is IP. If the child recognition pattern is 0BAD (Hex) the protocol is VIP (VINES).

Note that an alternate embodiment may keep a separate table that includes all the child recognition patterns and their corresponding protocol ID's

To follow the example, suppose the child recognition pattern at **1, 2, 12** is 0800_{16}, indicating IP. The ID code for the IP protocol is 64_{10}). To continue with the Ethertype example, once the parser matches one of the possible children for the protocl—in the example, the protocol type is IP with an ID of 64—then the parser continues the search for the next level. The ID is 64, the length is unknown, and offset is known to be equal or larger than 14 bytes (**12** offset for type, plus 2, the length of type), so the search of the 3-D structure commences from location **(64, 1)** at packet offset **14**. A populated node is found at **(64, 2)** at packet offset **14**. Heading details are shown as **1750** in FIG. **17**B. The possible children are shown in table **1752**.

Alternatively, suppose that at **(1, 2, 12)** there was a length $\mathbf{1211}_{10}$. This indicates that this is an IEEE type Ethernet frame, which stores its type elsewhere. The PRE now continues its search at the same level, but for a new ID, that of an IEEE type Ethernet frame. An IEEE Ethernet packet has protocol ID 16, so the PRE continues its search of the three-dimensional space with ID 16starting at packet offset **14**.

In our example, suppose there is a "protocol" node code found at **(16, 2)** at packet offset **14**, and the next protocol is specified by child recognition pattern 0800_{16}. This indicates that the child is the IP protocol, which has type ID 64. Thus the search continues, starting at **(64, 1)** at packet offset **16**.

Compression.

As noted above, the 3-D data structure is very large, and sparsely populated. For example, if 32 bytes are stored at each location, then the length is M by 64 by 512 by 32 bytes, which is M megabytes. If M=10,000, then this is about 10 gigabytes. It is not practical to include 10 Gbyte of memory in the parser subsystem for storing the database **308**. Thus a compressed form of storing the data is used in the preferred embodiment. The compression is preferably carried out by an optimizer component of the compilation process **310**.

Recall that the data structure is sparse. Different embodiments may use different compression schemes that take advantage of the sparseness of the data structure. One embodiment uses a modification of multi-dimensional run length encoding.

Another embodiment uses a smaller number two-dimensional structures to store the information that otherwise would be in one large three-dimensional structure. The second scheme is used in the preferred embodiment.

FIG. **18**A illustrated how the 3-D array **1800** can be considered a set of 2-D arrays, one 2-D array for each protocol (i.e., each value of the protocol ID). The 2-D structures are shown as **1802-1**, **1802-2**, . . . , **1802**-M for up to M protocol ID's. One table entry is shown as **1804**. Note that the gaps in table are used to illustrate that each 2-D structure table is typically large.

Consider the set of trees that represent the possible protocols. Each node represents a protocol, and a protocol may have a child or be a terminal protocol. The base (root) of the tree has all packet types as children. The other nodes form the nodes in the tree at various levels from level **1** to the final terminal nodes of the tree. Thus, one element in the base node may reference node ID **1**, another element in the base node may reference node ID **2** and so on. As the tree is traversed from the root, there may be points in the tree where the same node is referenced next. This would occur, for example, when an application protocol like Telnet can run on several transport connections like TCP or UDP. Rather than repeating the Telnet node, only one node is represented in the patterns database **308** which can have several parents. This eliminates considerable space explosion.

Each 2-D structure in FIG. **18**A represents 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.

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.

Assume two 2-D arrays are being considered for folding. Call the first 2-D arrays A and the second 2-D array B. Since both 2-D arrays are partially populated, 2-D array B can be combined with 2-D arrays A if and only if none of the individual elements of these two 2-D arrays that have the same 2-D location conflict. If the result is foldable, then the valid entries of 2-D array B are combined with the valid entries of 2-D array A yielding one physical 2-D array. However, it is necessary to be able to distinguish the original 2-D array A entries from those of 2-D array B. For example, if a parent protocol of the protocol represented by 2-D array B wants to reference the protocol ID of 2-D array B, it must now reference 2-D array A instead. However, only the entries that were in the original 2-D array B are valid entries for that lookup. To accomplish this, each element in any given 2-D array is tagged with a fold number. When the original tree is created, all elements in all the 2-D arrays are initialized with a fold value of zero. Subsequently, if 2-D array B is folded into 2-D array A, all valid elements of 2-D array B are copied to the corresponding locations in 2-D array A and are given different fold numbers than any of the elements in 2-D array A. For example, if both 2-D array A and 2-D array B were original 2-D arrays in the tree (i.e., not previously folded) then, after folding, all the 2-D array A entries would still have fold **0** and the 2-D array B entries would now all have a fold value of 1. After 2-D array B is folded into 2-D array A, the parents of 2-D array B need to be notified of the change in the 2-D array physical location of their children and the associated change in the expected fold value.

This folding process can also occur between two 2-D arrays that have already been folded, as long as none of the individual elements of the two 2-D arrays conflict for the same 2-D array location. As before, each of the valid elements in 2-D array B must have fold numbers assigned to them that are unique from those of 2-D array A. This is accomplished by adding a fixed value to all the 2-D array B fold numbers as they are merged into 2-D array A. This fixed value is one larger than the largest fold value in the original 2-D array A. It is important to note that the fold number for any given 2-D array is relative to that 2-D array only and does not span across the entire tree of 2-D arrays.

This process of folding can now be attempted between all combinations of two 2-D arrays until there are no more candidates that qualify for folding. By doing this, the total number of 2-D arrays can be significantly reduced.

Whenever a fold occurs, the 3-D structure (i.e., all 2-D arrays) must be searched for the parents of the 2-D array being folded into another array. The matching pattern which previously was mapped to a protocol ID identifying a single 2-D array must now be replaced with the 2-D array ID and the next fold number (i.e., expected fold).

Thus, in the compressed data structure, each entry valid entry includes the fold number for that entry, and additionally, the expected fold for the child.

An alternate embodiment of the data structure used in database **308** is illustrated in FIG. **18**B. Thus, like the 3-D structure described above, it permits rapid searches to be performed by the pattern recognition process **304** by indexing locations in a memory rather than performing address link computations. The structure, like that of FIG. **18**A, is suitable for implementation in hardware, for example, for implementation to work with the pattern recognition engine (PRE) **1006** of FIG. **10**.

A table **1850**, called the protocol table (PT) has an entry for each protocol known by the monitor **300**, and includes some of the characteristics of each protocol, including a description of where the field that specifies next protocol (the child recognition pattern) can be found in the header, the length of the next protocol field, flags to indicate the header length and type, and one or more slicer commands, the slicer can build the key components and hash components for the packet at this protocol at this layer level.

For any protocol, there also are one or more lookup tables (LUTs). Thus database **308** for this embodiment also includes a set of LUTs **1870**. Each LUT has 256 entries indexed by one byte of the child recognition pattern that is extracted from the next protocol field in the packet. Such a protocol specification may be several bytes long, and so several of LUTs **1870** may need to be looked up for any protocol.

Each LUT's entry includes a 2-bit "node code" that indicates the nature of the contents, including its validity. This node code has one of four values: (1) a "protocol" node code indicating to the pattern recognition engine **1006** that a known protocol has been recognized; (2) an "intermediate" node code, indicating that a multi-byte protocol code has been partially recognized, thus permitting chaining a series of LUTs together before; (3) a "terminal" node code indicating that there are no children for the protocol presently being searched, i.e., the node is a final node in the protocol tree; (4) a "null" (also called "flush" and "invalid") node code indicating that there is no valid entry.

In addition to the node code, each LUT entry may include the next LUT number, the next protocol number (for looking up the protocol table **1850**), the fold of the LUT entry, and the next fold to expect. Like in the embodiment implementing a compressed form of the 3-D representation, folding is used to reduce the storage requirements for the set of LUTs. Since the LUTs **1870** may be sparsely populated, multiple LUTs may be combined into a single LUT 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 LUT.

For a given lookup, the fold number of the lookup must match the fold number in the lookup table. The expected fold is obtained from the previous table lookup (the "next fold to expect" field). The present implementation uses 5-bits to describe the fold and thus allows up to 32 tables to be folded into one table.

When using the data structure of FIG. **18**B, when a packet arrives at the parser, the virtual base has been pre-pended or is known. The virtual base entry tells the packet recognition engine where to find the first child recognition pattern in the packet. The pattern recognition engine then extracts the child recognition pattern bytes from the packet and uses them as an address into the virtual base table (the first LUT). If the entry looked up in the specified next LUT by this method matches the expected next fold value specified in the virtual base entry, the lookup is deemed valid. The node code is then examined. If it is an intermediate node then the next table field obtained from the LUT lookup is used as the most significant bits of the address. The next expected fold is also extracted from the entry. The pattern recognition engine **1006** then uses the next byte from the child recognition pattern as the for the next LUT lookup.

Thus, the operation of the PRE continues until a terminal code is found. The next (initially base layer) protocol is looked up in the protocol table **1850** to provide the PRE **1006** with information on what field in the packet (in input buffer memory **1008** of parser subsystem **1000**) to use for obtaining the child recognition pattern of the next protocol, including the size of the field. The child recognition pattern bytes are fetched from the input buffer memory **1008**. The number of bytes making up the child recognition pattern is also now known.

The first byte of the protocol code bytes is used as the lookup in the next LUT. If a LUT lookup results in a node code indicating a protocol node or a terminal node, the Next LUT and next expected fold is set, and the "next protocol" from LUT lookup is used as an index into the protocol table **1850**. This provides the instructions to the slicer **1007**, and where in the packet to obtain the field for the next protocol. Thus, the PRE **1006** continues until it is done processing all the fields (i.e., the protocols), as indicated by the terminal node code reached.

Note that when a child recognition pattern is checked against a table there is always an expected fold. If the expected fold matches the fold information in the table, it is used to decide what to do next. If the fold does not match, the optimizer is finished.

Note also that an alternate embodiment may use different size LUTs, and then index a LUT by a different amount of the child recognition pattern.

The present implementation of this embodiment allows for child recognition patterns of up to four bytes. Child recognition patterns of more than 4 bytes are regarded as special cases.

In the preferred embodiment, the database is generated by the compiler process **310**. The compiler process first builds a single protocol table of all the links between protocols. Links consist of the connection between parent and child protocols. Each protocol can have zero or more children. If a protocol has children, a link is created that consists of the parent protocol, the child protocol, the child recognition pattern, and the child recognition pattern size. The compiler first extracts child recognition patterns that are greater than two bytes long. Since there are only a few of these, they are handled separately. Next sub links are created for each link that has a child recognition pattern size of two.

All the links are then formed into the LUTs of 256 entries.

Optimization is then carried out. The first step in the optimization is checking all the tables against all the other tables to find out which ones can share a table. This process proceeds the same way as described above for two-dimensional arrays, but now for the sparse lookup tables.

Part of the initialization process (e.g., compiler process **310**) loads a slicer instruction database with data items including of instruction, source address, destination address, and length. The PRE **1006** when it sends a slicer instruction sends this instruction as an offset into the slicer instruction database. The instruction or Op code tells the slicer what to extract from the incoming packet and where to put it in the flow signature. Writing into certain fields of the flow signature automatically generates a hash. The instruction can also tell the slicer how to determine the connection status of certain protocols.

Note that alternate embodiments may generate the pattern, parse and extraction database other than by compiling PDL files.

The Compilation Process

The compilation process **310** is now described in more detail. This process **310** includes creating the parsing patterns and extractions database **308** that provides the parsing subsystem **301** with the information needed to parse packets and extract identifying information, and the state processing instructions database **326** that provides the state processes that need to be performed in the state processing operation **328**.

Input to the compiler includes a set of files that describe each of the protocols that can occur. These files are in a convenient protocol description language (PDL) which is a high level language. PDL is used for specifying new protocols and new levels, including new applications. The PDL is independent of the different types of packets and protocols that may be used in the computer network. A set of PDL files is used to describe what information is relevant to packets and packets that need to be decoded. The PDL is further used to specify state analysis operations. Thus, the parser subsystem and the analyzer subsystems can adapt and be adapted to a variety of different kinds of headers, layers, and components and need to be extracted or evaluated, for example, in order to build up a unique signature.

There is one file for each packet type and each protocol. Thus there is a PDL file for Ethernet packets and there is a PDL file for frame relay packets. The PDL files are compiled to form one or more databases that enable monitor **300** to perform different protocol specific operations on a packet wherein the protocol headers of any protocol are located at different locations depending on the parent protocol or protocols used in the packet. Thus, the packet monitor adapts to different protocols according to the contents of the packet. In particular, the parser subsystem **301** is able to extract different types of data for different types of packets. For example, the monitor can know how to interpret a Ethernet packet, including decoding the header information, and also how to interpret an frame relay packet, including decoding the header information.

The set of PDL files, for example, may include a generic Ethernet packet file. There also is included a PDL file for each variation Ethernet file, for example, an EEE Ethernet file.

The PDL file for a protocol provides the information needed by compilation process **310** to generate the database **308**. That database in turn tells the parser subsystem how to parse and/or extract information, including one or more of what protocol-specific components of the packet to extract for the flow signature, how to use the components to build the flow signature, where in the packet to look for these components, where to look for any child protocols, and what child recognition patterns to look for. For some protocols, the extracted components may include source and destination addresses, and the PDL file may include the order to use these addresses to build the key. For example, Ethernet frames have end-point addresses that are useful in building a better flow signature. Thus the PDL file for an Ethernet packet includes information on how the parsing subsystem is to extract the source and destination addresses, including where the locations and sizes of those addresses are. In a frame-relay base layer, for example, there are no specific end point addresses that help to identify the flow better, so for those type of packets, the PDL file does not include information that will cause the parser subsystem to extract the end-point addresses.

Some protocols also include information on connections. TCP is an example of such a protocol. Such protocol use connection identifiers that exist in every packet. The PDL file for such a protocol includes information about what those connection identifiers are, where they are, and what their length is. In the example of TCP, for example running over IP, these are port numbers. The PDL file also includes information about whether or not there are states that apply to connections and disconnections and what the possible children are states. So, at each of these levels, the packet monitor **300** learns more about the packet. The packet monitor **300** can identify that a particular packet is part of a particular flow using the connection identifier. Once the flow is identified, the system can determine the current state and what states to apply that deal with connections or disconnections that exist in the next layer up to these particular packets.

For the particular PDL used in the preferred embodiment, a PDL file may include none or more FIELD statement each defining a specific string of bits or bytes (i.e., a field) in the packet. A PDL file may further include none or more GROUP statements each used to tie together several defined fields. A set of such tied together fields is called a group. A PDL file may further include none or more PROTOCOL statements each defining the order of the fields and groups within the header of the protocol. A PDL file may further include none or more FLOW statements each defining a flow by describing where the address, protocol type, and port numbers are in a packet. The FLOW statement includes a description of how children flows of this protocol are determined using state operations. States associated may have state operations that may be used for managing and maintaining new states learned as more packets of a flow are analyzed.

FIG. **19** shows a set of PDL files for a layering structure for an Ethernet packet that runs TCP on top of IP. The contents of these PDL files are attached as an APPENDIX hereto. Common.pdl **(1903)** is a file containing the common protocol definitions, i.e., some field definitions for commonly used fields in various network protocols. Flows.pdl **(1905)** is a file containing general flow definitions. Virtual.pdl **(1907)** is a PDL file containing the definition for the VirtualBase layer used. Ethernet.pdl **(1911)** is the PDL file containing the definition for the Ethernet packet. The decision on Ethertype vs. IEEE type Ethernet file is described herein. If this is Ethertype, the selection is made from the file Ethertype.pdl **(1913)**. In an alternate embodiment, the Ethertype selection definition may be in the same Ethernet file **1911**. In a typical implementation, PDL files for other Ethernet types would be included. IP.pdl **(1915)** is a PDL file containing the packet definitions for the Internet Protocol. TCP.pdl **(1917)** is the PDL file containing the packet definitions for the Transmission Control Protocol, which in this case is a transport service for the IP protocol. In addition to extracting the protocol information the TCP protocol definition file assists in the process of identification of connections for the processing of states. In a typical set of files, there also would be a file UDP.pdl for the User Datagram Protocol (UDP) definitions. RPC.pdl (**1919**) is a PDL file file containing the packet definitions for Remote Procedure Calls.

NFS.pdl (**1921**) is a PDL file containing the packet definitions for the Network File System. Other PDL files would typically be included for all the protocols that might be encountered by monitor **300**.

Input to the compilation process **310** is the set of PDL files (e.g., the files of FIG. **19**) for all protocols of interest. Input to process **310** may also include layering information shown in FIG. **3** as datagram layer selections **338**. The layer selections information describes the layering of the protocols—what protocol(s) may be on top of any particular protocols. For example, IP may run over Ethernet, and also over many other types of packets. TCP may run on top of IP. UDP also may run on top of IP. When no layering information is explicitly included, it is inherent; the PDL files include the children protocols, and this provides the layering information.

The compiling process **310** is illustrated in FIG. **20**. The compiler loads the PDL source files into a scratch pad memory (step **2003**) and reviews the files for the correct syntax (parse step **2005**). Once completed, the compiler creates an intermediate file containing all the parse elements (step **2007**). The intermediate file in a format called "Compiled Protocol Language" (CPL). CPL instructions have a fixed layer format, and include all of the patterns, extractions, and states required for each layer and for the entire tree for a layer. The CPL file includes the number of protocols and the protocol definitions. A protocol definition for each protocol can include one or more of the protocol name, the protocol ID, a header section, a group identification section, sections for any particular layers, announcement sections, a payload section, a children section, and a states section. The CPL file is then run by the optimizer to create the final databases that will be used by monitor **300**. It would be clear to those in the art that alternate implementations of the compilation process **310** may include a different form of intermediate output, or no intermediate output at all, directly generating the final database(s).

After the parse elements have been created, the compiler builds the flow signature elements (step **2009**). This creates the extraction operations in CPL that are required at each level for each PDL module for the building of the flow signature (and hash key) and for links between layers (**2009**).

With the flow signature operations complete, the PDL compiler creates (step **2011**) the operations required to extract the payload elements from each PDL module. These payload elements are used by states in other PDL modules at higher layers in the processing.

The last pass is to create the state operations required by each PDL module. The state operations are complied from the PDL files and created in CPL form for later use (**2013**).

The CPL file is now run through an optimizer that generates the final databases used by monitor **300**.

PROTOCOL DEFINITION LANGUAGE (PDL) REFERENCE GUIDE (VERSION A0.02)

Included herein is this reference guide (the "guide") for the page description language (PDL) which, in one aspect of the invention, permits the automatic generation of the databases used by the parser and analyzer sub-systems, and also allows for including new and modified protocols and applications to the capability of the monitor.

COPYRIGHT NOTICE

1. INTRODUCTION

The inventive protocol Definition Language (PDL) is a special purpose language used to describe network protocols and all the fields within the protocol headers. Within this guide, protocol descriptions (PDL files) are referred to as PDL or rules when there in no risk of confusion with other types of descriptions.

PDL uses both form and organization similar to the data structure definition part of the C programming language and the PERL scripting language. Since PDL was derived from a language used to decode network packet contact, the authors have mixed the language format with the requirements of packet decoding. This results in an expressive language that is very familiar and comfortable for describing packet content and the details required representing a flow.

1.1 Summary

The PDL is a non-procedural Forth Generation language (4GL). This means is describes what needs to be done without describing how to do it. The details of how are hidden in the compiler and the Compiled Protocol Layout (CPL) optimization utility.

In addition, it is used to describe network flows by defining which fields are the address fields, which are the protocol type fields, etc.

Once a PDL file is written, it is compiled using the Netscope compiler (nsc), which produces the MeterFlow database (MeterFlow.db) and the Netscope database (Netscope.db). The MeterFlow database contains the flow definitions and the Netscope database contains the protocol header definitions.

These databases are used by programs like: mfkeys, which produces flow keys (also called flow signatures); mfcpl, which produces flow definitions in CPL format; mfpkts which produces sample packets of all known protocols; and netscope, which decodes Sniffer™ and tcpdump files.

1.2 Guide Conventions

The following conventions will be used throughout this guide:

Small courier typeface indicates C code examples or function names. Functions are written with parentheses after them [function ()], variables are written just as their names [variables], and structure names are written prefixed with "struct" [struct packet].

Italics indicate a filename (for instance, mworks/base/h/base.h). Filenames will usually be written relative to the root directory of the distribution.

Constants are expressed in decimal, unless written "0x . . . ", the C language notation for hexadecimal numbers.

Note that any contents on any line in a PDL file following two hyphen (--) are ignored by the compiler. That is, they are comments.

2. PROGRAM STRUCTURE

A MeterFlow PDL decodes and flow set is a non-empty sequence of statements.

There are four basic types of statements or definitions available in MeterFlow PDL:

FIELD,

GROUP,

PROTOCOL and

FLOW.

2.1 Field Definitions

The FIELD definition is used to define a specific string of bits or bytes in the packet. The FIELD definition has the following format:

Name FIELD
SYNTAX Type [{Enums }]
DISPLAY-HINT "FormatString"
LENGTH "Expression"
FLAGS FieldFlags
ENCAP FieldName [, FieldName2]
LOOKUP LookupType [Filename]
ENCODING EncodingType
DEFAULT "value"
DESCRIPTION "Description"

Where only the FIELD and SYNTAX lines are required. All the other lines are attribute lines, which define special characteristics about the FIELD. Attribute lines are optional and may appear in any order. Each of the attribute lines are described in detail below:

2.1.1 SYNTAX Type [{Enums}]

This attribute defines the type and, if the type is an INT, BYTESTRING, BITSTRING, or SNMPSEQUENCE type, the enumerated values for the FIELD. The currently defined types are:

INT(numBits)	Integer that is numBits bits long.
UNSIGNED INT(numBits)	Unsigned integer that is numBits bits long.
BYTESTRING(numBytes)	String that is numBytes bytes long.
BYTESTRING(R1 . . . R2)	String that ranges in size from R1 to R2 bytes.
BITSTRING(numBits)	String that is numBits bits long.
LSTRING(lenBytes)	String with lenBytes header.
NSTRING	Null terminated string.
DNSSTRING	DNS encoded string.
SNMPOID	SNMP Object Identifier.
SNMPSEQUENCE	SNMP Sequence.
SNMPTIMETICKS	SNMP TimeTicks.
COMBO field1 field2	Combination pseudo field.

2.1.2 DISPLAY-HINT "FormatString"

This attribute is for specifying how the value of the FIELD is displayed. The currently supported formats are:

Numx	Print as a num byte hexidecimal number.
Numd	Print as a num byte decimal number.
Numo	Print as a num byte octal number.
Numb	Print as a num byte binary number.
Numa	Print num bytes in ASCII format.
Text	Print as ASCII text.
HexDump	Print in hexdump format.

2.1.3 LENGTH "Expression"

This attribute defines an expression for determining the FIELD's length. Expressions are arithmetic and can refer to the value of other FIELD's in the packet by adding a $ to the referenced field's name. For example, "($tcpHeaderLen*4)–20" is a valid expression if tcpHeaderLen is another field defined for the current packet.

2.1.4 FLAGS FieldFlags

The attribute defines some special flags for a FIELD. The currently supported FieldFlags are:

SAMELAYER	Display field on the same layer as the previous field.
NOLABEL	Don't display the field name with the value.
NOSHOW	Decode the field but don't display it.
SWAPPED	The integer value is swapped.

2.1.5 ENCAP FieldName [, FieldName2]

This attribute defines how one packet is encapsulated inside another. Which packet is determined by the value of the FieldName field. If no packet is found using FieldName then FieldName2 is tried.

2.1.6 LOOKUP LookupType [Filename]

This attribute defines how to lookup the name for a particular FIELD value. The currently supported Lookup-Types are:

SERVICE	Use getservbyport( ).
HOSTNAME	Use gethostbyaddr( ).
MACADDRESS	Use $METERFLOW/conf/mac2ip.cf.
FILE file	Use file to lookup value.

2.1.7 ENCODING EncodingType

This attribute defines how a FIELD is encoded. Currently, the only supported EncodingType is BER (for Basic Encoding Rules defined by ASN.1).

2.1.8 DEFAULT "value"

This attribute defines the default value to be used for this field when generating sample packets of this protocol.

2.1.9 DESCRIPTION "Description"

This attribute defines the description of the FIELD. It is used for informational purposes only.

2.2 Group Definitions

The GROUP definition is used to tie several related FIELDs together. The GROUP definition has the following format:

Name GROUP
LENGTH "Expression"
OPTIONAL "Condition"
SUMMARIZE "Condition":"FormatString" ["Condition": "FormatString" . . .]
DESCRIPTION "Description"
::={Name=FieldOrGroup [, Name=FieldorGroup . . .]}

Where only the GROUP and ::=lines are required. All the other lines are attribute lines, which define special characteristics for the GROUP. Attribute lines are optional and may appear in any order. Each attribute line is described in detail below:

2.2.1 LENGTH "Expression"

This attribute defines an expression for determining the GROUP's length. Expressions are arithmetic and can refer to the value of other FIELD's in the packet by adding a $ to the referenced field's name. For example,

"($tcpHeaderLen*4)–20" is a valid expression if tcpHeaderLen is another field defined for the current packet.

2.2.2 OPTIONAL "Condition"

This attribute defines a condition for determining whether a GROUP is present or not. Valid conditions are defined in the Conditions section below.

2.2.3 SUMMARIZE "Condition":"FormatString" ["Condition":"FormatString" . . .]

This attribute defines how a GROUP will be displayed in Detail mode. A different format (FormatString) can be specified for each condition (Condition). Valid conditions are defined in the Conditions section below. Any FIELD's value can be referenced within the FormatString by proceeding the FIELD's name with a $. In addition to FIELD names there are several other special $ keywords:

$LAYER	Displays the current protocol layer.
$GROUP	Displays the entire GROUP as a table.
$LABEL	Displays the GROUP label.
$field	Displays the field value (use enumerated name if available).
$:field	Displays the field value (in raw format).

2.2.4 DESCRIPITION "Description"

This attribute defines the description of the GROUP. It is used for informational purposes only.

2.2.5 ::={Name=FieldOrGroup [, Name=FieldOrGroup . . .]}

This defines the order of the fields and subgroups within the GROUP.

2.3 PROTOCOL Definitions

The PROTOCOL definition is used to define the order of the FIELDs and GROUPs within the protocol header. The PROTOCOL definition has the following format:

Name PROTOCOL

SUMMARIZE "Condition":"FormatString"] "Condition":"FormatString" . . .]

DESCRIPTION "Description"

REFERENCE "Reference"

::={Name=FieldOrGroup [, Name=FieldOrGroup . . .]}

Where only the PROTOCOL and ::=lines are required. All the other lines are attribute lines, which define special characteristics for the PROTOCOL. Attribute lines are optional and may appear in any order. Each attribute line is described in detail below:

2.3.1 SUMMARIZE "Condition":"FormatString" ["Condition":"FormatString". . .]

This attribute defines how a PROTOCOL will be displayed in Summary mode. A different format (FormatString) can be specified for each condition (Condition). Valid conditions are defined in the Conditions section below. Any FIELD's value can be referenced within the FormatString by proceeding the FIELD's name with a $. In addition to FIELD names there are several other special $ keywords:

$LAYER	Displays the current protocol layer.
$VARBIND	Displays the entire SNMP VarBind list.
$field	Displays the field value (use enumerated name if available).

-continued

$:field	Displays the field value (in raw format).
$#field	Counts all occurrences of field.
$*field	Lists all occurrences of field.

2.3.2 DESCRIPTION "Description"

This attribute defines the description of the PROTOCOL. It is used for informational purposes only.

2.3.3 REFERENCE "Reference"

This attribute defines the reference material used to determine the protocol format. It is used for informational purposes only.

2.3.4 ::={Name=FieldOrGroup [, Name=FieldOrGroup . . .]}

This defines the order of the FIELDs and GROUPs within the PROTOCOL.

2.4 FLOW Definitions

The FLOW definition is used to define a network flow by describing where the address, protocol type, and port numbers are in a packet. The FLOW definition has the following format:

Name FLOW

HEADER {Option [, Option . . .]}

DLC-LAYER {Option [, Option . . .]}

NET-LAYER {Option [, Option . . .]}

CONNECTION {Option [, Option . . .]}

PAYLOAD {Option [, Option . . .]}

CHILDREN {Option [, Option . . .]}

STATE-BASED

STATES "Definitions"

Where only the FLOW line is required. All the other lines are attribute lines, which define special characteristics for the FLOW. Attribute lines are optional and may appear in any order. However, at least one attribute line must be present. Each attribute line is described in detail below:

2.4.1 HEADER {Option [, Option . . .]}

This attribute is used to describe the length of the protocol header. The currently supported Options are:

LENGTH = number	Header is a fixed length of size number.
LENGTH = field	Header is variable length determined by value of field.
IN-WORDS	The units of the header length are in 32-bit words rather than bytes.

2.4.2 DLC-LAYER {Option [, Option . . .]}

If the protocol is a data link layer protocol, this attribute describes it. The currently supported Options are:

DESTINATION = field	Indicates which field is the DLC destination address.
SOURCE = field	Indicates which field is the DLC source address.
PROTOCOL	Indicates this is a data link layer protocol.
TUNNELING	Indicates this is a tunneling protocol.

2.4.3 NET-LAYER {Option [, Option . . .]}

If the protocol is a network layer protocol, then this attribute describes it. The currently supported Options are:

DESTINATION = field	Indicates which field is the network destination address.
SOURCE = field	Indicates which field is the network source address.
TUNNELING	Indicates this is a tunneling protocol.
FRAGMENTATION = type	Indicates this protocol supports fragmentation. There are currently two fragmentation types: IPV4 and IPV6.

2.4.4 CONNECTION {Option [, Option . . .]}

If the protocol is a connection-oriented protocol, then this attribute describes how connections are established and torn down. The currently supported Options are:

IDENTIFIER = field	Indicates the connection identifier field.
CONNECT-START = "flag"	Indicates when a connection is being initiated.
CONNECT-COMPLETE = "flag"	Indicates when a connection has been established.
DISCONNECT-START = "flag"	Indicates when a connection is being torn down.
DISCONNECT-COMPLETE = "flag"	Indicates when a connection has been torn down.
INHERITED	Indicates this is a connection-oriented protocol but the parent protocol is where the connection is established.

2.4.5 PAYLOAD {Option [, Option . . .]}

This attribute describes how much of the payload from a packet of this type should be stored for later use during analysis. The currently supported Options are:

INCLUDE-HEADER	Indicates that the protocol header should be included.
LENGTH = number	Indicates how many bytes of the payload should be stored.
DATA = field	Indicates which field contains the payload.

2.4.6 CHILDREN {Option [, Option . . .]}

This attribute describes how children protocols are determined. The currently supported Options are:

DESTINATION = field	Indicates which field is the destination port.
SOURCE = field	Indicates which field is the source port.
LLCCHECK = flow	Indicates that if the DESTINATION field is less than 0 × 05DC then use flow instead of the current flow definition.

2.4.7 STATE-BASED

This attribute indicates that the flow is a state-based flow.

2.4.8 STATES "Definitions"

This attribute describes how children flows of this protocol are determined using states. See the State Definitions section below for how these states are defined.

2.5 CONDITIONS

Conditions are used with the OPTIONAL and SUMMARIZE attributes and may consist of the following:

Value1 == Value2	Value1 equals Value2. Works with string values.
Value1 != Value2	Value1 does not equal Value2. Works with string values.
Value1 <= Value2	Value1 is less than or equal to Value2.
Value1 >= Value2	Value1 is greater than or equal to Value2.
Value1 < Value2	Value1 is less than Value2.
Value1 > Value2	Value1 is greater than Value2.
Field m/regex/	Field matches the regular expression regex.

Where Valuel and Value2 can be either FIELD references (field names preceded by a $) or constant values. Note that compound conditional statements (using AND and OR) are not currently supported.

2.6 STATE DEFINITIONS

Many applications running over data networks utilize complex methods of classifying traffic through the use of multiple states. State definitions are used for managing and maintaining learned states from traffic derived from the network.

The basic format of a state definition is:

StateName: Operand Parameters [Operand Parameters . . .]

The various states of a particular flow are described using the following operands:

2.6.1 CHECKCONNECT, Operand

Checks for connection. Once connected executes operand.

2.6.2 GOTO State

Goes to state, using the current packet.

2.6.3 NEXT State

Goes to state, using the next packet.

2.6.4 DEFAULT Operand

Executes operand when all other operands fail.

2.6.5 CHILD Protocol

Jump to child protocol and perform state-based processing (if any) in the child.

2.6.6 WAIT Numpackets, Operand**1**, Operand**2**

Waits the specified number of packets. Executes operand**1** when the specified number of packets have been received. Executes operand**2** when a packet is received but it is less than the number of specified packets.

2.6.7 MATCH 'String' Weight Offset LF-offset Range LF-range, Operand

Searches for a string in the packet, executes operand if found.

2.6.8 CONSTANT Number Offset Range, Operand

Checks for a constant in a packet, executes operand if found.

2.6.9 EXTRACTIP Offset Destination, Operand

Extracts an IP address from the packet and then executes operand.

2.6.10 EXTRACTPORT Offset Destination, Operand

Extracts a port number from the packet and then executes operand.

2.6.11 CREATEREDIRECTEDFLOW, Operand

Creates a redirected flow and then executes operand.

3. EXAMPLE PDL RULES

The following section contains several examples of PDL Rule files.

3.1 Ethernet

The following is an example of the PDL for Ethernet:

```
MacAddress      FIELD
                SYNTAX          BYTESTRING (6)
                DISPLAY-HINT    "1x:"
                LOOKUP          MACADDRESS
                DESCRIPTION
                        "MAC layer physical address"
etherType       FIELD
                SYNTAX          INT(16)
                DISPLAY-HINT    "1x:"
                LOOKUP          FILE "EtherType.cf"
                DESCRIPTION
                        "Ethernet type field"
etherData       FIELD
                SYNTAX          BYTESTRING(46..1500)
                ENCAP             etherType
                DISPLAY-HINT    "HexDump"
                DESCRIPTION
                        "Ethernet data"
ethernet        PROTOCOL
                DESCRIPTION
                  "Protocol format for an Ethernet frame"
                REFERENCE       "RFC 894"
::= { MacDest=macAddress, MacSrc=macAddress, EtherType=etherType,
  Data=etherData }
ethernet        FLOW
                HEADER { LENGTH=14 }
                DLC-LAYER {
                  SOURCE=MacSrc,
                  DESTINATION=MacDest,
                  TUNNELING,
                  PROTOCOL
                }
                CHILDREN { DESTINATION=EtherType,
                LLC-CHECK=llc }
```

3.2 IP Version 4

Here is an example of the PDL for the IP protocol:

```
ipAddress       FIELD
                SYNTAX          BYTESTRING(4)
                DISPLAY-HINT    "1d."
                LOOKUP          HOSTNAME
                DESCRIPTION
  "IP address"
ipversion       FIELD
                SYNTAX          INT(4)
                DEFAULT         "4"
ipHeaderLength      FIELD
                    SYNTAX INT(4)
ipTypeOfService     FIELD
                    SYNTAX          BITSTRING(8) { minCost(1),
                                    maxReliability(2),
                                    maxThruput(3),
                                    minDelay(4) }
ipLength        FIELD
                SYNTAX UNSIGNED INT(16)
ipFlags         FIELD
                SYNTAX          BITSTRING(3) { moreFrags(0),
                                dontFrag(1) }
IpFragmentOffset    FIELD
                    SYNTAX          INT(13)
ipProtocol      FIELD
                SYNTAX INT(8)
                LOOKUP FILE "IpProtocol.cf"
```

-continued

```
ipData FIELD
                SYNTAX          BYTESTRING(0..1500)
                ENCAP           ipProtocol
                DISPLAY-HINT    "HexDump"
ip          PROTOCOL
            SUMMARIZE
            "$FragmentOffset != 0"
              "IpFragment ID=$Identification Offset=$Fragmentoffset"
            *"Default" :
              "IP Protocol=$Protocol"
            DESCRIPTION
              "Protocol format for the Internet Protocol"
            REFERENCE   "RFC 791"
::= { Version=ipVersion, HeaderLength=ipHeaderLength,
            TypeOfService=ipTypeOfService, Length=ipLength,
            Identification=UInt16, IpFlags=ipFlags,
            FragmentOffset=ipFragmentOffset, TimeToLive=Int8,
            Protocol=ipProtocol, Checksum=ByteStr2,
            IpSrc=ipAddress, IpDest=ipAddress, Options=ipOptions,
            Fragment=ipFragment, Data=ipData }
ip          FLOW
            HEADER { LENGTH=HeaderLength, IN-WORDS }
            NET-LAYER {
                SOURCE=IpSrc,
                DESTINATION=IpDest,
                FRAGMENTATION=IPV4,
                TUNNELING
            }
            CHILDREN { DESTINATION=Protocol }
ipFragData      FIELD
                SYNTAX          BYTESTRING(1..1500)
                LENGTH          "ipLength - ipHeaderLength * 4"
                DISPLAY-HINT    "HexDump"
ipFragment      GROUP
                OPTIONAL        "$FragmentOffset != 0"
::= { Data=ipFragData }
ipOptionCode    FIELD
                SYNTAX INT(8) { ipRR(0x07), ipTimestamp(0x44),
                                ipLSRR(0x83),
                                ipSSRR(0x89) }
                DESCRIPTION
                  "IP option code"
ipOptionLength      FIELD
                    SYNTAX UNSIGNED INT(8)
                    DESCRIPTION
                      "Length of IP option"
ipOptionData    FIELD
                    SYNTAX          BYTESTRING(0..1500)
                    ENCAP             ipOptionCode
                    DISPLAY-HINT    "HexDump"
ipOptions       GROUP
                LENGTH          "(ipHeaderLength * 4) - 20"
::= { Code=ipOptionCode, Length=ipOptionLength, Pointer=UInt8,
            Data=ipOptionData }
```

3.3 TCP

Here is an example of the PDL for the TCP protocol:

```
tcpPort FIELD
        SYNTAX UNSIGNED INT(16)
        LOOKUP FILE "TcpPort.cf"
tcpHeaderLen FIELD
        SYNTAX INT(4)
tcpFlags FIELD
        SYNTAX BITSTRING(12) { fin(0), syn(1), rst(2), psh(3),
                        ack(4), urg(5) }
tcpData FIELD
        SYNTAX BYTESTRING(0..1564)
        LENGTH " ($ipLength- ($jpHeaderLength*4)) -
        ($tcpHeaderLen*4) "
        ENCAP           tcpport
        DISPLAY-HINT    "HexDump"
tcp     PROTOCOL
```

-continued

```
        SUMMARIZE
          "Default"
            "TCP ACK=$Ack WIN=$WindowSize"
        DESCRIPTION
          "Protocol format for the Transmission Control Protocol"
        REFERENCE        "RFC 793"
::= { SrcPort=tcpPort, DestPort=tcpPort, SequenceNum=UInt32,
        Ack=UInt32, HeaderLength=tcpHeaderLen, TcpFlags=tcpFlags,
        WindowSize=UInt16, Checksum=ByteStr2,
        UrgentPointer=UInt16, Options=tcpOptions, Data=tcpData }
tcp     FLOW
        HEADER { LENGTH=HeaderLength, IN-WORDS }
        CONNECTION {
              IDENTIFIER=SequenceNum,
              CONNECT-START="TcpFlags:1",
              CONNECT-COMPLETE="TcpFlags:4",
              DISCONNECT-START="TcpFlags:0",
              DISCONNECT-COMPLETE="TcpFlags:4"
         }
        PAYLOAD { INCLUDE-HEADER }
        CHILDREN { DESTINATION=DestPort, SOURCE=SrcPort }
tcpOptionKind FIELD
                SYNTAX UNSIGNED INT(8) { tcpOptEnd(0),
                tcpNop(1),
tcpMSS(2), tcpWscale(3), tcpTimestamp(4) }
                DESCRIPTION
                    "Type of TCP option"
tcpOptionDataFIELD
                SYNTAX          BYTESTRING(0..1500)
                ENCAP           tcpOptionKind
                FLAGS           SAMELAYER
                DISPLAY-HINT    "HexDump"
tcpOptions      GROUP
                LENGTH          "($tcpHeaderLen * 4) - 20"
::= { Option=tcpOptionKind, OptionLength=UInt8,
        OptionData=tcpOptionData }
tcpMSS PROTOCOL
::= { MaxSegmentSize=UInt16 }
```

3.4 HTTP (With State)

Here is an example of the PDL for the HTTP protocol:

```
httpData FIELD
    SYNTAX   BYTESTRING(1..1500)
    LENGTH      "($ipLength - ($ipHeaderLength * 4)) -
                ($tcpHeaderLen * 4) "
DISPLAY-HINT    "Text"
FLAGS           NOLABEL
http          PROTOCOL
              SUMMARIZE
                "$httpData m/^GET|^HTTP|^HEAD|^POST/" :
                    "HTTP $httpData"
                "$httpData m/^[Dd]ate|^[Ss]erver|^[Ll]ast-
                [Mm]odified/" :
                    "HTTP $httpData"
                "$httpData m/^[Cc]ontent-/" :
                    "HTTP $httpData"
                $httpData m/^<HTML>/" :
                    "HTTP [HTML document]"
                $httpData m/^GIF/" :
                    "HTTP [GIF image]"
                "Default" :
                    "HTTP [Data]"
              DESCRIPTION
                "Protocol format for HTTP."
::= { Data=httpData }
http   FLOW
HEADER { LENGTH=0 }
CONNECTION { INHERITED }
PAYLOAD { INCLUDE-HEADER, DATA=Data, LENGTH=256 }
STATES
                "S0: CHECKCONNECT, GOTO S1
                    DEFAULT NEXT S0
```

-continued

```
                S1: WAIT 2, GOTO S2, NEXT S1
                    DEFAULT NEXT S0
                S2: MATCH
                        '\n\r\n'             900 0 0 255 0, NEXT S3
                        '\n\n'               900 0 0 255 0, NEXT S3
                        'POST /tds?'          50 0 0 127 1,
                                             CHILD sybaseWebsql
                        '.hts HTTP/1.0'       50 4 0 127 1,
                                             CHILD sybaseJdbc
                        'jdbc:sybase:Tds'     50 4 0 127 1,
                                             CHILD sybaseTds
                        'PCN-The Poin'       500 4 1 255 0,
                                             CHILD pointcast
                        't: BW-C-'           100 4 1 255 0,
                                             CHILD backweb
                        DEFAULT NEXT S3
                s3: MATCH
                        '\n\r\n'              50 0 0    0 0, NEXT S3
                        '\n\n'                50 0 0    0 0, NEXT S3
                        'Content-Type:'      800 0 0 255 0,
                                             CHILD mime
                        'PCN-The Poin'       500 4 1 255 0,
                                             CHILD pointcast
                        't: BW-C-'           100 4 1 255 0,
                                             CHILD backweb
                        DEFAULT NEXT S0"
sybaseWebsql        FLOW
                    STATE-BASED
sybaseJdbc          FLOW
                    STATE-BASED
sybaseTds           FLOW
                    STATE-BASED
pointcast           FLOW
                    STATE-BASED
backweb             FLOW
                    STATE-BASED
mime                FLOW
                    STATE-BASED
                    STATES
"   S0:   MATCH
'application'       900 0 0    1 0,
                    CHILD mimeApplication
'audio'             900 0 0    1 0,
                    CHILD mimeAudio
'image'              50 0 0    1 0,
                    CHILD mimeImage
'text'               50 0 0    1 0,
                    CHILD mimeText
'video'              50 0 0    1 0,
                    CHILD mimeVideo
'x-world'           500 4 1 255 0,
                    CHILD mimeXworld
DEFAULT GOTO S0"
mimApplication      FLOW
                    STATE-BASED
mimeAudio       FLOW
                STATE-BASED
                STATES
                  "S0: MATCH
                        'basic'              100 0 0 1 0,
                                             CHILD pdBasicAudio
                        'midi'               100 0 0 1 0,
                                             CHILD pdMidi
                        'mpeg'               100 0 0 1 0,
                                             CHILD pdMpeg2Audio
                        'vnd.rn-realaudio'   100 0 0 1 0,
                                             CHILD pdRealAudio
                        'wav'                100 0 0 1 0,
                                             CHILD pdWav
                        'x-aiff'             100 0 0 1 0,
                                             CHILD pdAiff
                        'x-midi'             100 0 0 1 0,
                                             CHILD pdMidi
                        'x-mpeg'             100 0 0 1 0,
                                             CHILD pdMpeg2Audio
                        'x-mpgurl'           100 0 0 1 0,
                                             CHILD pdMpeg3Audio
```

-continued

```
                         'x-pn-realaudio'    100 0 0 1 0,
                                             CHILD pdRealAudio
                         'x-wav'             100 0 0 1 0,
                                             CHILD pdWav
                       DEFAULT GOTO S0"
mimeImage        FLOW
                 STATE-BASED
mimeText         FLOW
                 STATE-BASED
mimeVideo        FLOW
                 STATE-BASED
mimeXworld       FLOW
                 STATE-BASED
pdBasicAudio       FLOW
                 STATE-BASED
pdMidi             FLOW
                 STATE-BASED
pdMpeg2Audio       FLOW
                 STATE-BASED
pdMpeg3Audio       FLOW
                 STATE-BASED
pdRealAudio        FLOW
                 STATE-BASED
pdWav              FLOW
                 STATE-BASED
pdAiff             FLOW
                 STATE-BASED
```

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.

APPENDIX: SOME PDL FILES

The following pages include some PDL files as examples. Included herein are the PDL contents of the following files. A reference to PDL is also included herein. Note that any contents on any line following two hyphen (--) are ignored by the compiler. That is, they are comments.

common.pdl;
flows.pdl;
virtual.pdl;
ethernet.pdl;
IEEE8032.pdl and IEEE8033.pdl (ethertype files);
IP.pdl;
TCP.pdl and UDP.pdl;
RPC.pdl;
NFS.pdl; and
HTTP.pdl.

```
-----------------------------------------------------------------------------
--
--   Common.pdl - Common protocol definitions
--
--   Description:
--      This file contains some field definitions for commonly used fields
--      in various network protocols.
--
--   Copyright:
--      Copyright (c) 1996–1999 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--   RCS:
--      $Id: Common.pdl,v 1.7 1999/04/13 15:47:56 skip Exp $
-----------------------------------------------------------------------------
Int4      FIELD
          SYNTAX INT(4)
Int8      FIELD
          SYNTAX INT(8)
Int16     FIELD
          SYNTAX INT(16)
Int24     FIELD
          SYNTAX INT(24)
Int32     FIELD
          SYNTAX INT(32)
Int64     FIELD
          SYNTAX INT(64)
UInt8     FIELD
          SYNTAX UNSIGNED INT(8)
UInt16    FIELD
          SYNTAX UNSIGNED INT(16)
UInt24    FIELD
          SYNTAX UNSIGNED INT(24)
UInt32    FIELD
```

-continued

```
        SYNTAX UNSIGNED INT(32)
UInt64  FIELD
        SYNTAX UNSIGNED INT(64)
SInt16  FIELD
        SYNTAX INT(16)
        FLAGS SWAPPED
SUInt16     FIELD
        SYNTAX UNSIGNED INT(16)
        FLAGS SWAPPED
SInt32  FIELD
        SYNTAX INT(32)
        FLAGS SWAPPED
ByteStr1        FIELD
                SYNTAX BYTESTRING(1)
ByteStr2        FIELD
                SYNTAX BYTESTRING(2)
ByteStr4        FIELD
                SYNTAX BYTESTRING(4)
Pad1            FIELD
                SYNTAX BYTESTRING(1)
                FLAGS NOSHOW
Pad2            FIELD
                SYNTAX BYTESTRING(2)
                FLAGS NOSHOW
Pad3            FIELD
                SYNTAX BYTESTRING(3)
                FLAGS NOSHOW
Pad4            FIELD
                SYNTAX BYTESTRING(4)
                FLAGS NOSHOW
Pad5            FIELD
                SYNTAX BYTESTRING(5)
                FLAGS NOSHOW
macAddress      FIELD
    SYNTAX          BYTESTRING(6)
    DISPLAY-HINT    "1x:"
    LOOKUP          MACADDRESS
    DESCRIPTION
        "MAC layer physical address"
ipAddress       FIELD
    SYNTAX          BYTESTRING(4)
    DISPLAY-HINT    "1d."
    LOOKUP          HOSTNAME
    DESCRIPTION
        "IP address"
ipv6Address     FIELD
    SYNTAX          BYTESTRING(16)
    DISPLAY-HINT    "1d."
    DESCRIPTION
        "IPV6 address"
-----------------------------------------------------------------------------
--
--  Flows.pdl - General FLOW definitions
--
--  Description:
--      This file contains general flow definitions.
--
--  Copyright:
--      Copyright (c) 1998-1999 Apptitude, Inc.
--        (fomerly Technically Elite, Inc.)
--      All rights reserved.
--
--  RCS:
--      $Id: Flows.pdl,v 1.12 1999/04/13 15:47:57 skip Exp $
--
-----------------------------------------------------------------------------
chaosnet    FLOW
spanningTree FLOW
sna         FLOW
oracleTNS FLOW
        PAYLOAD { INCLUDE-HEADER, LENGTH=256 }
ciscoOUI FLOW
-----------------------------------------------------------------------------
--  IP Protocols
-----------------------------------------------------------------------------
igmp        FLOW
GGP         FLOW
ST          FLOW
UCL         FLOW
```

-continued

egp	FLOW
igp	FLOW
BBN-RCC-MON	FLOW
NVP2	FLOW
PUP	FLOW
ARGUS	FLOW
EMCON	FLOW
XNET	FLOW
MUX	FLOW
DCN-MEAS	FLOW
HMP	FLOW
PRM	FLOW
TRUNK1	FLOW
TRUNK2	FLOW
LEAF1	FLOW
LEAF2	FLOW
RDP	FLOW
IRTP	FLOW
ISO-TP4	FLOW
NETBLT	FLOW
MFE-NSP	FLOW
MERIT-INP	FLOW
SEP	FLOW
PC3	FLOW
IDPR	FLOW
XTP	FLOW
DDP	FLOW
IDPR-CMTP	FLOW
TPPlus	FLOW
IL	FLOW
SIP	FLOW
SDRP	FLOW
SIP-SR	FLOW
SIP-FRAG	FLOW
IDRP	FLOW
RSVP	FLOW
MHRP	FLOW
BNA	FLOW
SIPP-ESP	FLOW
SIPP-AH	FLOW
INLSP	FLOW
SWIPE	FLOW
NHRP	FLOW
CFTP	FLOW
SAT-EXPAK	FLOW
KRYPTOLAN	FLOW
RVD	FLOW
IPPC	FLOW
SAT-MON	FLOW
VISA	FLOW
IPCV	FLOW
CPNX	FLOW
CPHB	FLOW
WSN	FLOW
PVP	FLOW
BR-SAT-MON	FLOW
SUN-ND	FLOW
WB-MON	FLOW
WB-EXPAK	FLOW
ISO-IP	FLOW
VMTP	FLOW
SECURE-VMTP	FLOW
TTP	FLOW
NSFNET-IGP	FLOW
DGP	FLOW
TCF	FLOW
IGRP	FLOW
OSPFIGP	FLOW
Sprite-RPC	FLOW
LARP	FLOW
MTP	FLOW
AX25	FLOW
IPIP	FLOW
MICP	FLOW
SCC-SP	FLOW
ETHERIP	FLOW
encap	FLOW
GMTP	FLOW

-continued

```
--    UDP Protocols
compressnet   FLOW
rje           FLOW
echo          FLOW
discard       FLOW
systat        FLOW
daytime       FLOW
qotd          FLOW
msp           FLOW
chargen       FLOW
biff          FLOW
who           FLOW
syslog        FLOW
loadav        FLOW
notify        FLOW
acmaint_dbd   FLOW
acmaint_transd   FLOW
puparp        FLOW
applix        FLOW
ock           FLOW
---------------------------------------------------------------------------
--    TCP Protocols
---------------------------------------------------------------------------
tcpmux        FLOW
telnet        FLOW
              CONNECTION { INHERITED }
privMail      FLOW
nsw-fe        FLOW
msg-icp       FLOW
msg-auth      FLOW
dsp           FLOW
privPrint     FLOW
time          FLOW
rap           FLOW
rip           FLOW
graphics      FLOW
nameserver    FLOW
nicname       FLOW
mpm-flags     FLOW
mpm           FLOW
mpm-snd       FLOW
ni-ftp        FLOW
auditd        FLOW
finger        FLOW
re-mail-ck    FLOW
la-maint      FLOW
xns-time      FLOW
xns-ch        FLOW
isi-gl        FLOW
xns-auth      FLOW
privTerm      FLOW
xns-mail      FLOW
privFile      FLOW
ni-mail       FLOW
acas          FLOW
covia         FLOW
tacacs-ds     FLOW
sqlnet        FLOW
gopher        FLOW
netrjs-1      FLOW
netrjs-2      FLOW
netrjs-3      FLOW
netrjs-4      FLOW
privDial      FLOW
deos          FLOW
privRJE       FLOW
vettcp        FLOW
hosts2-ns     FLOW
xfer          FLOW
ctf           FLOW
mit-ml-dev    FLOW
mfcobol       FLOW
kerberos      FLOW
su-mit-tg     FLOW
dnsix         FLOW
mit-dov       FLOW
npp           FLOW
dcp           FLOW
objcall       FLOW
```

-continued

supdup	FLOW
dixie	FLOW
swift-rvf	FLOW
tacnews	FLOW
metagram	FLOW
newacct	FLOW
hostname	FLOW
iso-tsap	FLOW
gppitnp	FLOW
csnet-ns	FLOW
threeCom-tsmux	FLOW
rtelnet	FLOW
snagas	FLOW
mcidas	FLOW
auth	FLOW
audionews	FLOW
sftp	FLOW
ansanotify	FLOW
uucp-path	FLOW
sqlserv	FLOW
cfdptkt	FLOW
erpc	FLOW
smakynet	FLOW
ntp	FLOW
ansatrader	FLOW
locus-map	FLOW
unitary	FLOW
locus-con	FLOW
gss-xlicen	FLOW
pwdgen	FLOW
cisco-fna	FLOW
cisco-tna	FLOW
cisco-sys	FLOW
statsrv	FLOW
ingres-net	FLOW
loc-srv	FLOW
profile	FLOW
emfis-data	FLOW
emfis-cntl	FLOW
bl-idm	FLOW
imap2	FLOW
news	FLOW
uaac	FLOW
iso-tp0	FLOW
iso-ip	FLOW
cronus	FLOW
aed-512	FLOW
sql-net	FLOW
hems	FLOW
bftp	FLOW
sgmp	FLOW
netsc-prod	FLOW
netsc-dev	FLOW
sqlsrv	FLOW
knet-cmp	FLOW
pcmail-srv	FLOW
nss-routing	FLOW
sgmp-traps	FLOW
cmip-man	FLOW
cmip-agent	FLOW
xns-courier	FLOW
s-net	FLOW
namp	FLOW
rsvd	FLOW
send	FLOW
print-srv	FLOW
multiplex	FLOW
cl-1	FLOW
xyplex-mux	FLOW
mailq	FLOW
vmnet	FLOW
genrad-mux	FLOW
xdmcp	FLOW
nextstep	FLOW
bgp	FLOW
ris	FLOW
unify	FLOW
audit	FLOW
ocbinder	FLOW

-continued

ocserver	FLOW
remote-kis	FLOW
kis	FLOW
aci	FLOW
mumps	FLOW
qft	FLOW
gacp	FLOW
prospero	FLOW
osu-nms	FLOW
srmp	FLOW
irc	FLOW
dn6-nlm-aud	FLOW
dn6-smm-red	FLOW
dls	FLOW
dls-mon	FLOW
smux	FLOW
src	FLOW
at-rtmp	FLOW
at-nbp	FLOW
at-3	FLOW
at-echo	FLOW
at-5	FLOW
at-zis	FLOW
at-7	FLOW
at-8	FLOW
tam	FLOW
z39-50	FLOW
anet	FLOW
vmpwscs	FLOW
softpc	FLOW
atls	FLOW
dbase	FLOW
mpp	FLOW
uarps	FLOW
imap3	FLOW
fln-spx	FLOW
rsh-spx	FLOW
cdc	FLOW
sur-meas	FLOW
link	FLOW
dsp3270	FLOW
pdap	FLOW
pawserv	FLOW
zserv	FLOW
fatserv	FLOW
csi-sgwp	FLOW
clearcase	FLOW
ulistserv	FLOW
legent-1	FLOW
legent-2	FLOW
hassle	FLOW
nip	FLOW
tnETOS	FLOW
dsETOS	FLOW
is99c	FLOW
is99s	FLOW
hp-collector	FLOW
hp-managed-node	FLOW
hp-alarm-mgr	FLOW
arns	FLOW
ibm-app	FLOW
asa	FLOW
aurp	FLOW
unidata-ldm	FLOW
ldap	FLOW
uis	FLOW
synotics-relay	FLOW
synotics-broker	FLOW
dis	FLOW
embl-ndt	FLOW
netcp	FLOW
netware-ip	FLOW
mptn	FLOW
kryptolan	FLOW
work-sol	FLOW
ups	FLOW
genie	FLOW
decap	FLOW
nced	FLOW

-continued

ncld	FLOW
imsp	FLOW
timbuktu	FLOW
prm-sm	FLOW
prm-nm	FLOW
decladebug	FLOW
rmt	FLOW
synoptics-trap	FLOW
smsp	FLOW
infoseek	FLOW
bnet	FLOW
silverplatter	FLOW
onmux	FLOW
hyper-g	FLOW
ariell	FLOW
smpte	FLOW
ariel2	FLOW
ariel3	FLOW
opc-job-start	FLOW
opc-job-track	FLOW
icad-el	FLOW
smartsdp	FLOW
svrloc	FLOW
ocs_cmu	FLOW
ocs_amu	FLOW
utmpsd	FLOW
utmpcd	FLOW
iasd	FLOW
nnsp	FLOW
mobileip-agent	FLOW
mobilip-mn	FLOW
dna-cml	FLOW
comscm	FLOW
dsfgw	FLOW
dasp	FLOW
sgcp	FLOW
decvms-sysmgt	FLOW
cvc_hostd	FLOW
https	FLOW
	CONNECTION { INHERITED }
snpp	FLOW
microsoft-ds	FLOW
ddm-rdb	FLOW
ddm-dfm	FLOW
ddm-byte	FLOW
as-servermap	FLOW
tserver	FLOW
exec	FLOW
	CONNECTION { INHERITED }
login	FLOW
	CONNECTION { INHERITED }
cmd	FLOW
	CONNECTION { INHERITED }
printer	FLOW
	CONNECTION { INHERITED }
talk	FLOW
	CONNECTION { INHERITED }
ntalk	FLOW
	CONNECTION { INHERITED }
utime	FLOW
efs	FLOW
timed	FLOW
tempo	FLOW
courier	FLOW
conference	FLOW
netnews	FLOW
netwall	FLOW
apertus-ldp	FLOW
uucp	FLOW
uucp-rlogin	FLOW
klogin	FLOW
kshell	FLOW
new-rwho	FLOW
dsf	FLOW
remotefs	FLOW
rmonitor	FLOW
monitor	FLOW
chshell	FLOW
p9fs	FLOW

-continued

```
whoami      FLOW
meter       FLOW
ipcserver       FLOW
urm         FLOW
nqs         FLOW
sift-uft        FLOW
npmp-trap       FLOW
npmp-local      FLOW
npmp-gui        FLOW
ginad       FLOW
doom        FLOW
mdqs        FLOW
elcsd       FLOW
entrustmanager      FLOW
netviewdm1      FLOW
netviewdm2      FLOW
netviewdm3      FLOW
netgw       FLOW
netrcs      FLOW
flexlm      FLOW
fujitsu-dev     FLOW
ris-cm      FLOW
kerberos-adm    FLOW
rfile       FLOW
pump        FLOW
qrh         FLOW
rrh         FLOW
tell        FLOW
nlogin      FLOW
con         FLOW
ns          FLOW
rxe         FLOW
quotad      FLOW
cycleserv       FLOW
omserv      FLOW
webster         FLOW
phonebook       FLOW
vid         FLOW
cadlock         FLOW
rtip        FLOW
cycleserv2      FLOW
submit      FLOW
rpasswd         FLOW
entomb      FLOW
wpages      FLOW
wpgs        FLOW
concert         FLOW
mdbs_daemon     FLOW
device      FLOW
xtreelic        FLOW
maitrd      FLOW
busboy      FLOW
garcon      FLOW
puprouter       FLOW
socks       FLOW
-----------------------------------------------------------------------------
--
--    Virtual.pdl - Virtual Layer definition
--
--    Description:
--      This file contains the definition for the VirtualBase layer used
--      by the embodiment.
--    Copyright:
--      Copyright (c) 1998–1999 Apptitude,
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--    RCS:
--      $Id: Virtual.pdl,v 1.13 1999/04/13 15:48:03 skip Exp $
-----------------------------------------------------------------------------
--    This includes two things: the flow signature (called FLOWKEY) that the
--    system that is going to use.
--
--    note that not all elements are in the HASH. Reason is that these non-HASHED
--    elements may be varied without the HASH changing, which allows the system
--    to look up multiple buckets with a single HASH. That is, the MeyMatchFlag,
--    StateStatus Flag and MulipacketID may be varied.
--
FLOWKEY {
```

-continued

```
     KeyMatchFlags, -- to tell the system which of the in-HASH elements have to
-- match for the this particular flow record.
                         -- Flows for which complete signatures may not yet have
                         -- been generated may then be stored in the system
--
StateStatusFlags,
     GroupId1               IN-HASH,  -- user defined
     GroupId2               IN-HASH,  -- user defined
     DLCProtocol            IN-HASH, ,   -- data link protocol - lowest level we
                                         -- evaluate. It is the type for the
-- Ethernet V 2
     NetworkProtocol        IN-HASH,     -- IP, etc.
     TunnelProtocol         IN-HASH,     -- IP over IPx, etc.
     TunnelTransport        IN-HASH,
     TransportProtocol      IN-HASH,
     ApplicationProtocol    IN-HASH,
     DLCAddresses(8)        IN-HASH,  -- lowest level address
     NetworkAddresses(16)   IN-HASH,
     TunnelAddresses(16)    IN-HASH,
     ConnectionIds          IN-HASH,
     MultiPacketId                    -- used for fragmentaion purposes
}
--   now define all of the children. In this example, only one virtual
--   child - Ethernet.
virtualChildren      FIELD
               SYNTAX INT(*) { ethernet(1) }
--   now define the base for the children. In this case, it is the same as
--   for the overall system. There may be multiples.
VirtualBase    PROTOCOL
::= { VirtualChildren=virtualChildren }
--
--   The following is the header that every packet has to have and
--   that is placed into the system by the packet acquisition system.
--
VirtualBase    FLOW
               HEADER { LENGTH=8 }
               CHILDREN { DESTINATION=VirtualChildren } -- this will be
--   Ethernet for this example.
--
--   the VirtualBAse will be 01 for these packets.
--------------------------------------------------------------------------
--
--   Ethernet.pdl - Ethernet frame definition
--
--   Description:
--      This file contains the definition for the Ethernet frame. In this
--   PDL file, the decision on EtherType vs. IEEE is made. If this is
--   EtherType, the selection is made from this file. It would be possible
--   to move the EtherType selection to another file, if that would assist
--   in the modularity.
--
--   Copyright:
--      Copyright (c) 1994–1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--   RCS:
--      $Id: Ethernet.pdl,v 1.13 1999/01/26 15:15:57 skip Exp $
--------------------------------------------------------------------------
--
--   Enumerated type of a 16 bit integer that contains all of the
--   possible values of interest in the etherType field of an
--   Ethernet V2 packet.
--
etherType      FIELD
               SYNTAX         INT(16) { xns(0x0600), ip(0x0800),
                              chaosnet(0x0804), arp(0x0806),
                              vines(0xbad),
                              vinesLoop(0x0bae), vinesLoop(0x80c4),
                              vinesEcho(0xbaf), vinesEcho(0x80c5),
                              netbios(0x3c00, netbios(0x3c01),
                              netbios(0x3c02), netbios(0x3c03),
                              netbios(0x3c04), netbios(0x3c05),
                              netbios(0x3c06), netbios(0x3c07)
                              netbios(0x3c08), netbios(0x3c09)
                              netbios(0x3c0a), netbios(0x3c0b),
                              netbios(0x3c0c), netbios(0x3c0d)
                              dec(0x6000), mop(0x6001), mop2(0x6002)
                              drp(0x6003), lat(0x6004), decDiag(0x6005),
```

-continued

```
                        lavc(0x6007), rarp(0x8035), appleTalk(0x809b),
                        sna(0x80d5), aarp(0x80f3), ipx(0x8137)
                        snmp(0x814c), ipv6(0x86dd), loopback(0x9000) }
            DISPLAY-HINT   "1x:"
            LOOKUP         FILE "EtherType.cf"
            DESCRIPTION
                "Ethernet type field"
--
--  The unformatted data field in and Ethernet V2 type frame
--
etherData   FIELD
            SYNTAX         BYTESTRING(46..1500)
            ENCAP          etherType
            DISPLAY-HINT   "HexDump"
            DESCRIPTION
                "Ethernet data"
--
--  The layout and structure of an Ethernet V2 type frame with
--  the address and protocol fields in the correct offset position
ethernet    PROTOCOL
            DESCRIPTION
                "Protocol format for an Ethernet frame"
            REFERENCE      "RFC 894"
::= { MacDest=macAddress, MacSrc=macAddress, EtherType=etherType,
    Data=etherData )
--
--  The elements from this Ethernet frame used to build a flow key
--  to classify and track the traffic. Notice that the total length
--  of the header for this tyoe of packet is fixed and at 14 bytes or
--  octets in length. The special field, LLC-CHECK, is specific to
--  Ethernet frames for the decoding of the base Ethernet type value.
--  If it is NOT LLC, the protocol field in the flow is set to the
--  EtherType value decoded from the packet.
--
ethernet    FLOW
            HEADER { LENGTH=14 }
            DLC-LAYER {
                SOURCE=MacSrc,
                DESTINATION=MacDest,
                TUNNELING,
                PROTOCOL
            }
            CHILDREN { DESTINATION=EtherType, LLC-CHECK=11c }
---------------------------------------------------------------------------
--
--  IEEE8022.pdl - IEEE 802.2 frame definitions
--
--  Description:
--      This file contains the definition for the IEEE 802.2 Link Layer
--      protocols including the SNAP (Sub-network Access Protocol).
--
--  Copyright:
--      Copyright (c) 1994–1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--  RCS:
--      $Id: IEEE8022.pdi,v i.18 1999/01/26 15:15:58 skip Exp $
---------------------------------------------------------------------------
--
--  IEEE 802.2 LLC
--
11cSap  FIELD
        SYNTAX         INT(16) { ipx(0xFFFF), ipx(0xE0E0), isoNet(0xFEFE),
                       netbios(0xF0F0), vsnap(0XAAAA), ip(0x0606),
                       vines(0xBCBC), xns(0x8080), spanningTree(0x4242),
                       sna(0x0c0c), sna(0x0808), sna(0x0404) }
        DISPLAY-HINT   "ix:"
        DESCRIPTION
            "Service Access Point"
11cControl     FIELD
        -- This is a special field. When the decoder encounters this field, it
        -- invokes the hard-coded LLC decoder to decode the rest of the packet.
        -- This is necessary because LLC decoding requires the ability to
        -- handle forward references which the current PDL format does not
        -- support at this time.
        SYNTAX         UNSIGNED INT(8)
        DESCRIPTION
            "Control field"
```

-continued

```
11cPduType      FIELD
          SYNTAX BITSTRING(2) { 11cInformation(0), 11cSupervisory(1),
                 11cInformation(2), 11cUnnumbererd(3) }
11cData         FIELD
          SYNTAX          BYTESTRING(38..1492)
          ENCAP           11cPduType
          FLAGS           SAMELAYER
          DISPLAY-HINT    "HexDump"
11c       PROTOCOL
          SUMMARIZE
               "$11cPduType == 11cUnnumbered" :
                 "LLC ($SAP) $Modifier"
               "$11cPduType == 11cSupervisory" :
                 "LLC ($SAP) $Function N(R)=$NR"
               "$11cPduType == 0|2" :
                 "LLC ($SAP) N(R)=$NR N(S)=$NS"
               "Default"
                 "LLC ($SAP) $11cPduType"
          DESCRIPTION
               "IEEE 802.2 LLC frame format"
::= { SAP=11cSap, Control=11cControl, Data=11cData }
11c        FLOW
          HEADER { LENGTH=3 }
          DLC-LAYER { PROTOCOL }
          CHILDREN { DESTINATION=SAP }
11cUnnumberedData FIELD
          SYNTAX          BYTESTRING(0..1500)
          ENCAP           11cSap
          DISPLAY-HINT    "HexDump"
11cUnnumbered PROTOCOL
          SUMMARIZE
               "Default" :
                 "LLC ($SAP) $Modifier"
::= { Data=11cUnnumberedData }
11cSupervisoryData        FIELD
          SYNTAX          BYTESTRING(0..1500)
          DISPLAY-HINT    "HexDump"
11cSupervisory            PROTOCOL
          SUMMARIZE
               "Default" :
                 "LLC ($SAP) $Function N(R)=$NR"
::= { Data=11cSupervisoryData }
11cInformationData        FIELD
          SYNTAX          BYTESTRING(0..1500)
          ENCAP           11cSap
          DISPLAY-HINT    "HexDump"
11cInformation            PROTOCOL
          SUMMARIZE
               "Default" :
                 "LLC ($SAP) N(R)=$NR N(S)=$NS"
::= { Data=11cInformationData }
--
--   SNAP
--
snapOrgCode     FIELD
          SYNTAX          BYTESTRING(3) { snap("00:00:00"}, ciscoOUl("00:00:0C"),
                          appleOUI("08:00:07") }
          DESCRIPTION
               "Protocol ID or Organizational Code"
vsnapData       FIELD
          SYNTAX          BYTESTRING(46..1500)
          ENCAP           snapOrgCode
          FLAGS           SAMELAYER
          DISPLAY-HINT    "HexDump"
          DESCRIPTION
               "SNAP LLC data"
vsnap     PROTOCOL
          DESCRIPTION
               "SNAP LLC Frame"
::= { OrgCode=snapOrgCode, Data=vsnapData }
vsnap          FLOW
               HEADER { LENGTH=3 }
               DLC-LAYER { PROTOCOL }
               CHILDREN { DESTINATION=OrgCode }
snapType        FIELD
               SYNTAX     INT(16) { xns(0x0600), ip(0x0800), arp(0x0806)
                          vines (0xbad),
                          mop(0x6001), mop2(0x6002), drp(0x6003),
                          lat(0x6004), decDiag(0x6005), lavc(0x6007)
```

-continued

```
                        rarp(0x8035), appleTalk(0x809B), sna(0x80d5),
                        aarp(0x80F3), ipx(0x8137), snmp(0x814c), ipv6(0x86dd) }
                DISPLAY-HINT    "1x:"
                LOOKUP          FILE "EtherType.cf"
                DESCRIPTION
                  "SNAP type field"
snapData          FIELD
        SYNTAX          BYTESTRING(46..1500)
        ENCAP           snapType
        DISPLAY-HINT    "HexDump"
        DESCRIPTION
              "SNAP data"
snap    PROTOCOL
        SUMMARIZE
                "$OrgCode == 00:00:00"
                  "SNAP Type=$SnapType"
                "Default"
                  "VSNAP Org=$OrgCode Type=$SnapType"
        DESCRIPTION
                "SNAP Frame"
::={ SnapType=snapType, Data=snapData }
snap     FLOW
        HEADER { LENGTH=2 }
        DLC-LAYER { PROTOCOL }
        CHILDREN { DESTINATION=SnapType }
-----------------------------------------------------------------------------
--
--  IEEE8023.pdl - IEEE 802.3 frame definitions
--  Description:
--      This file contains the definition for the IEEE 802.3 (Ethernet)
--      protocols.
--
--  Copyright:
--      Copyright (c) 1994-1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--  RCS:
--      $Id: IEEE8023.pdl,v 1.7 1999/01/26 15:15:58 skip Exp $
--
-----------------------------------------------------------------------------
--
--  IEEE 802.3
--
ieee8023Length          FIELD
        SYNTAX UNSIGNED INT(16)
ieee8023Data    FIELD
        SYNTAX          BYTESTRING(38..1492)
        ENCAP           =11c
        LENGTH          "$ieee8023Length"
        DISPLAY-HINT    "HexDump"
ieee8023        PROTOCOL
        DESCRIPTION
              "IEEE 802.3 (Ethernet) frame"
        REFERENCE       "RFC 1042"
::= { MacDest=macAddress, Mac:Src=macAddress, Length=ieee8023Length,
        Data=ieee8023Data }
-----------------------------------------------------------------------------
--
--  IP.pdl - Internet Protocol (IP) definitions
--
--  Description:
--      This file contains the packet definitions for the Internet
--      Protocol. These elements are all of the fields, templates and
--  processes required to recognize, decode and classify IP datagrams
--  found within packets.
--
--  Copyright:
--      Copyright (c) 1994-1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--  RCS:
--      $Id: IP.pdl,v 1.14 1999/01/26 15:15:58 skip Exp $
--
-----------------------------------------------------------------------------
--
--  The following are the fields that make up an IP datagram.
--  Some of these fields are used to recognize datagram elements, build
```

-continued

```
--    flow signatures and determine the next layer in the decode process.
--
ipVersion       FIELD
                SYNTAX INT(4)
                DEFAULT      "4"
ipHeaderLength      FIELD
                SYNTAX INT(4)
ipTypeOfService     FIELD
                SYNTAXBITSTRING(8) { minCost(1), maxReliability(2),
                     maxThruput(3), minDelay(4) }
ipLength        FIELD
                SYNTAX UNSIGNED INT(16)
--
--    This field will tell us if we need to do special processing to support
--    the payload of the datagram existing in multiple packets.
--
ipFlags             FIELD
                SYNTAX BITSTRING(3) { moreFrags(0), dontFrag(1) }
ipFragmentOffset FIELD
                SYNTAX INT(13)
--
--    This field is used to determine the children or next layer of the
--    datagram.
--
ipProtocol      FIELD
                SYNTAX INT(8)
                LOOKUP FILE "IpProtocol.cf"
ipData          FIELD
                SYNTAX          BYTESTRING(0..1500)
                ENCAP           ipProtocol
                DISPLAY-HINT    "HexDump"
--
--    Detailed packet layout for the IP datagram. This includes all fields
--    and format. All offsets are relative to the beginning of the header.
ip    PROTOCOL
           SUMMARIZE
                "$FragmentOffset != 0":
                     "IPFragment ID=$Identification Offset=$FragmentOffset"
                "Default" :
                     "IP Protocol=$Protocol"
           DESCRIPTION
             "Protocol format for the Internet Protocol"
           REFERENCE       "RFC 791"
::= {      Version=ipVersion, HeaderLength=ipHeaderLength,
           TypeOfService=ipTypeOfService, Length=ipLength,
           Identification=UInt16, IpFlags=ipFlags,
           FragmentOffset=ipFragmentOffset, TimeToLive=Int8,
           Protocol=ipProtocol, Checksum=ByteStr2,
           IpSrc=ipAddress, IpDest=ipAddress, Options=ipOptions,
           Fragment=ipFragment, Data=ipData }
--
--    This is the description of the signature elements required to build a flow
--    that includes the IP network layer protocol. Notice that the flow builds on
--    the lower layers. Only the fields required to complete IP are included.
--    This flow requires the support of the fragmentation engine as well as the
--    potential of having a tunnel. The child field is found from the IP
--    protocol field
--
ip         FLOW
           HEADER { LENGTH=HeaderLength, IN-WORDS }
           NET-LAYER {
             SOURCE=IpSrc,
             DESTINATION=IpDest,
             FRAGMENTATION=IPV4,
             TUNNELING
           }
           CHILDREN { DESTINATION=Protocol }
ipFragData       FIELD
                 SYNTAX          BYTESTRING(1..1500)
                 LENGTH          "$ipLength - $ipHeaderLength * 4"
                 DISPLAY-HINT    "HexDump"
ipFragment       Group
                 OPTIONAL        "$FragmentOffset != 0"
::= { Data=ipFragData }
ipOptionCode     FIELD
                 SYNTAXINT(8) { ipRR(0x07), ipTimestamp(0x44),
                      ipLSRR(0x83), ipSSRR(0x89) }
                 DESCRIPTION
                   "IP option code"
```

-continued

```
ipOptionLength      FIELD
                SYNTAX UNSIGNED INT(8)
                DESCRIPTION
                  "Length of IP option"
ipOptionData    FIELD
                SYNTAX          BYTESTRING(0..1500)
                ENCAP           ipOptionCode
                DISPLAY-HINT    "HexDump"
ipOptions       GROUP
                LENGTH          "($ipHeaderLength * 4) - 20"
::= {     Code=ipOptionCode, Length=ipOptionLength, Pointer=UInt8,
          Data=ipOptionData }
--------------------------------------------------------------------------
--
--   TCP.pdl - Transmission Control Protocol (TCP) definitions
--   Description:
--      This file contains the packet definitions for the Transmission
--      Control Protocol. This protocol is a transport service for
--   the IP protocol. In addition to extracting the protocol information
--   the TCP protocol assists in the process of identification of connections
--   for the processing of states.
--
--   Copyright:
--      Copyright (c) 1994-1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--   RCS:
--      $Id: TCP.pdl,v 1.9 1999/01/26 15:16:02 skip Exp $
--
--------------------------------------------------------------------------
--
--   This is the 16 bit field where the child protocol is located for
--   the next layer beyond TCP.
--
tcpPort FIELD
    SYNTAX UNSIGNED INT(16)
    LOOKUP FILE "TcpPort.cf"
tcpHeaderLen FIELD
    SYNTAX INT(4)
tcpFlags FIELD
    SYNTAXBITSTRING(12) { fin(0), syn(1), rst(2), psh(3), ack(4), urg(5) }
tcpData FIELD
        SYNTAX          BYTESTRING(0..1564)
        LENGTH          "($ipLength - ($ipHeaderLength * 4)) - ($tcpHeaderLen * 4)"
        ENCAP           tcpPort
        DISPLAY-HINT    "HexDump"
--
--   The layout of the TCP datagram found in a packet. Offset based on the
--   beginning of the header for TCP.
tcp PROTOCOL
        SUMMARIZE
            "Default" :
                "TCP ACK=$Ack WIN=$WindowSize"
        DESCRIPTION
            "Protocol format for the Transmission Control Protocol"
        REFERENCE       "RFC 793"
::= {   Srcport=tcpPort, DestPort=tcpPort, SequenceNum=UInt32,
        Ack=UInt32, HeaderLength=tcpHeaderLen, TcpFlags=tcpFlags,
        WindowSize=UInt16, Checksum=ByteStr2,
        UrgentPointer=UInt16, Options=tcpOptions, Data=tcpData }
--
--   The flow elements required to build a key for a TCP datagram.
--   Noticed that this FLOW description has a CONNECTION section. This is
--   used to describe what connection state is reached for each setting
--   of the TcpFlags field.
--
tcp         FLOW
        HEADER { LENGTH=HeaderLength, IN-WORDS }
        CONNECTION {
            IDENTIFIER=SequenceNum,
            CONNECT-START="TcpFlags:1",
            CONNECT-COMPLETE="TcpFlags:4",
            DISCONNECT-START="TcpFlags:0",
            DISCONNECT-COMPLETE="TcpFlags:4"
        }
        PAYLOAD { INCLUDE-HEADER }
        CHILDREN { DESTINATION=DestPort, SOURCE=SrcPort }
tcpOptionKind   FIELD
                SYNTAX UNSIGNED INT(8) { tcpOptEnd(0), tcpNop(1), tcpMSS(2),
```

-continued

```
                              tcpWscale(3), tcpTimestamp(4) }
                DESCRIPTION
                    "Type of TCP option"
tcpOptionData   FIELD
                SYNTAX        BYTESTRING(0..1500)
                ENCAP         tcpOptionKind
                FLAGS         SAMELAYER
                DISPLAY-HINT  "HexDump"
tcpOptions      GROUP
                LENGTH        "($tcpHeaderLen * 4) - 20"
--              SUMMARIZE
--                  "Default" :
--                      "Option=$Option, Len=$OptionLength, $OptionData"
::= { Option=tcpOptionKind, optionLength=UInt8, OptionData=tcpOptionData }
tcpMSS          PROTCCOL
::= { MaxSegmentSize=UInt16 }
--------------------------------------------------------------------------
--
--  UDP.pdl - User Datagram Protocol (UDP) definitions
--
--  Description:
--      This file contains the packet definitions for the User Datagram
--      Protocol.
--
--  Copyright:
--      Copyright (c) 1994–1998 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--
--  RCS:
--      $Id: UDP.pdl,v 1.9 1999/01/26 15:16:02 skip Exp $
--
--------------------------------------------------------------------------
udpPort         FIELD
        SYNTAX UNSIGNED INT(16)
        LOOKUPFILE "Udpport.cf"
udpLength FIELD
        SYNTAX          UNSIGNED INT(16)
udpData FIELD
        SYNTAX          BYTESTRING(0..1500)
        ENCAP           udpPort
        DISPLAY-HINT    "HexDump"
udp     PROTOCOL
        SUMARIZE
            "Default" :
                "UDP Dest=$DestPort Src=$SrcPort"
        DESCRIPTION
            "Protocol format for the User Datagram Protocol."
        REFERENCE       "RFC 768"
::= {   SrcPort=udpPort, DestPort=udpPort, Length=udpLength,
        Checksum=ByteStr2, Data=udpData }
udp     FLOW
        HEADER { LENGTH=8 }
        CHILDREN { DESTINATION=DestPort, SOURCE=Srcport }
--------------------------------------------------------------------------
--
--  RPC.pdl - Remote Procedure Calls (RPC) definitions
--
--  Description:
--      This file contains the packet definitions for Remote Procedure
--      Calls.
--
--  Copyright:
--      Copyright (c) 1994–1999 Apptitude,
--        (formerly Technically Elite, Inc.)
--      All rights reserved.
--  RCS:
--      $Id: RPC.pdl,v 1.7 1999/01/26 15:16:01 skip Exp $
--------------------------------------------------------------------------
rpcType       FIELD
      SYNTAX UNSIGNED INT(32) { rpcCall(0), rpcReply(1) }
rpcData       FIELD
      SYNTAX          BYTESTRING(0..100)
      ENCAP           rpcType
      FLAGS           SAMELAYER
      DISPLAY-HINT    "HexDump"
rpc   PROTOCOL
      SUMMARIZE
          "$Type == rpcCall"
```

-continued

```
            "RPC $Program"
          "$ReplyStatus == rpcAcceptedReply" :
            "RPC Reply Status=$Status"
          "$ReplyStatus == rpcDeniedReply"
            "RPC Reply Status=$:Status, AuthStatus=$AuthStatus"
          "Default"
            "RPC $Program"
      DESCRIPTION
          "Protocol format for RPC"
      REFERENCE
          "RFC 1057"
::= {  XID=UInt32, Type=rpcType, Data=rpcData }
rpc   FLOW
      HEADER { LENGTH=0 }
      PAYLOAD { DATA=XID, LENGTH=256 }
-------------
--  RPC Call
-------------
rpcProgram FIELD
      SYNTAX UNSIGNED INT(32) { portMapper(100000), nfs(100003),
          mount(100005), lockManager(100021), statusMonitor(100024) }
rpcProcedure GROUP
      SUMMARIZE
          "Default" :
            "Program=$Program, Version=$Version, Procedure=$Procedure"
::= {  Program=rpcProgram, Version=UInt32, Procedure=UInt32 }
rpcAuthFlavor FIELD
      SYNTAX UNSIGNED INT(32) { null(0), unix(1), short(2) }
rpcMachine   FIELD
      SYNTAX LSTRING(4)
rpcGroup   GROUP
      LENGTH "$NumGroups * 4"
::= {  Gid=Int32 }
rpcCredentials    GROUP
      LENGTH "$CredentialLength"
::= {  Stamp=UInt32, Machine=rpcMachine, Uid=Int32, Gid=Int32,
      NumGroups=UInt32, Groups=rpcGroup }
rpcVerifierData    FIELD
      SYNTAX       BYTESTRING(0..400)
      LENGTH       "$VerifierLength"
rpcEncap    FIELD
      SYNTAX COMBO Program Procedure
      LOOKUP FILE "RPC.cf"
rpcCallData   FIELD
      SYNTAX       BYTESTRING(0..100)
      ENCAP        rpcEncap
      DISPLAY-HINT "HexDump"
rpcCall    PROTOCOL
      DESCRIPTION
          "Protocol format for RPC call"
::= {  RPCVersion=UInt32, Procedure=rpcProcedure,
      CredentialAuthFlavor=rpcAuthFlavor, CredentialLength=UInt32,
      Credentials=rpcCredentials,
      VerifierAuthFlavor=rpcAuthFlavor, VerifierLength=UInt32,
      Verifier=rpcVerifierData, Encap=rpcEncap, Data=rpcCallData }
-------------
--  RPC Reply
-------------
rpcReplyStatus    FIELD
      SYNTAX INT(32) { rpcAcceptedReply(0), rpcDeniedReply(1) }
rpcReplyData  FIELD
      SYNTAX       BYTESTRING(0..40000)
      ENCAP        rpcReplyStatus
      FLAGS        SAMELAYER
      DISPLAY-HINT "HexDump"
rpcReply    PROTOCOL
      DESCRIPTION
          "Protocol format for RPC reply"
::= {  ReplyStatus=rpcReplyStatus, Data=rpcReplyData }
rpcAcceptStatus    FIELD
      SYNTAX INT(32) { Success(0), ProgUnavail(1), ProgMismatch(2),
            ProcUnavail(3), GarbageArgs(4), SystemError(5)
rpcAcceptEncap    FIELD
      SYNTAX BYTESTRING(0)
      FLAGS  NOSHOW
rpcAcceptData FIELD
      SYNTAX       BYTESTRING(0..40000)
      ENCAP        rpcAcceptEncap
      DISPLAY-HINT "HexDump"
```

-continued

```
rpcAcceptedReply PROTOCOL
::= {   VerifierAuthFlavor=rpcAuthFlavor, VerifierLength=UInt32,
        Verifier=rpcVerifierData, Status=rpcAcceptStatus,
        Encap=rpcAcceptEncap, Data=rpcAcceptData }
rpcDeniedstatus      FIELD
        SYNTAX INT(32) { rpcVersionMismatch(0), rpcAuthError(1) }
rpcAuthStatus FIELD
        SYNTAX INT(32) { Okay(0), BadCredential(1), RejectedCredential(2),
            BadVerifier(3), ReDectedVerifier(4), TooWeak(5),
            InvalidResponse(6), Failed(7) }
rpcDeniedReply      PROTOCOL
::= {   Status=rpcDeniedStatus, AuthStatus=rpcAuthStatus }
-------------------
--    RPC Transactions
-------------------
rpcBindLookup PROTOCOL
        SUMMARIZE
            "Default" :
              "RPC GetPort Prog=$Prog, Ver=$Ver, Proto=$Protocol"
::= {   Prog=rpcProgram, Ver=UInt32, Protocol=UInt32 }
rpcBindLookupReply PROTOCOL
        SUMMARIZE
            "Default"
              "RPC GetPortReply Port=$Port"
::= { Port=UInt32 }
---------------------------------------------------------------------------
--
--    NFS.pdl - Network File System (NFS) definitions
--
--    Description:
--        This file contains the packet definitions for the Network File
--        System.
--    Copyright:
--        Copyright (c) 1994-1998 Apptitude, Inc.
--          (formerly Techhically Elite, Inc.)
--        All rights reserved.
--    RCS:
--        $Id: NFS.pdl,v 1.3 1999/01/26 15:15:59 skip Exp $
---------------------------------------------------------------------------
nfsString      FIELD
        SYNTAX LSTRING(4)
nfsHandle      FIELD
        SYNTAX            BYTESTRING(32)
        DISPLAY-HINT      "16x\n          "
nfsData            FIELD
        SYNTAX            BYTESTRING(0..100)
        DISPLAY-HINT      "HexDump"
nfsAccess      PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS Access $Filename"
::= { Handle=nfsHandle, Filename=nfsString }
nfsStatus      FIELD
        SYNTAX INT(32) { OK(0), NoSuchFile(2) }
nfsAccessReply      PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS AccessReply $Status"
::= { Status=nfsStatus }
nfsMode               FIELD
        SYNTAX UNSIGNED INT(32)
        DISPLAY-HINT "4o"
nfsCreate      PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS Create $Filename"
::= { Handle=nfsHandle, Filename=nfsString, Filler=Int8, Mode=nfsMode,
        Uid=Int32, Gid=Int32, Size=Int32, AccessTime=Int64, ModTime=Int64 }
nfsFileType    FIELD
        SYNTAX INT(32) { Regular(1), Directory(2) }
nfsCreateReply      PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS CreateReply $Status"
::= { Status=nfsStatus, Handle=nfsHandle, FileType=nfsFileType,
        Mode=nfsMode, Links=UInt32, Uid=Int32, Gid=Int32, Size=Int32,
        BlockSize=Int32, NumBlocks=Int64, FileSysId=UInt32, FileId=UInt32,
        AccessTime=Int64, ModTime=Int64, InodeChangeTime=Int64 }
nfsRead      PROTOCOL
```

-continued

```
        SUMMARIZE
            "Default" :
              "NFS Read Offset=$Offset Length=$Length"
::= { Length=Int32, Handle=nfsHandle, Offset=UInt64, Count=Int32 }
nfsReadReply   PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS ReadReply $Status"
::= { Status=nfsStatus, FileType=nfsFileType,
        Mode=nfsMode, Links=UInt32, Uid=Int32, Gid=Int32, Size=Int32,
        BlockSize=Int32, NumBlocks=Int64, FileSysId=UInt32, FileId=UInt32,
        AccessTime=Int64, ModTime=Int64, InodeChangeTime=Int64 }
nfsWrite PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS Write Offset=$Offset"
::= { Handle=nfsHandle, Offset=Int32, Data=nfsData }
nfsWriteReply PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS WriteReply $Status"
::= { Status=nfsStatus, FileType=nfsFileType,
        Mode=nfsMode, Links=UInt32, Uid=Int32, Gid=Int32, Size=Int32,
        BlockSize=Int32, NumBlocks=Int64, FileSysId=UInt32, FileId=UInt32,
        AccessTime=Int64, ModTime=Int64, InodeChangeTime=Int64 }
nfsReadDir    PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS ReadDir"
::= { Handle=nfsHandle, Cookie=Int32, Count=Int32 }
nfsReadDirReply       PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS ReadDirReply $Status"
::= { Status=nfsStatus, Data=nfsData }
nfsGetFileAttr       PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS GetAttr"
::= { Handle=nfsHandle }
nfsGetFileAttrReply PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS GetAttrReply $Status $FileType"
::= { Status=nfsStatus, FileType=nfsFileType,
        Mode=nfsMode, Links=UInt32, Uid=Int32, Gid=Int32, Size=Int32,
        BlockSize=Int32, NumBlocks=Int64, FileSysId=UInt32, FileId=UInt32,
        AccessTime=Int64, ModTime=Int64, InodeChangeTime=Int64 }
nfsReadLink    PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS ReadLink"
::= { Handle=nfsHandle }
nfsReadLinkReply   PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS ReadLinkReply Path=$Path"
::= { Status=nfsStatus, Path=nfsString }
nfsMount          PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS Mount $Path"
::= { Path=nfsstring
nfsMountReply PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS MountReply $MountStatus"
::= { MountStatus=nfsStatus, Handle=nfsHandle }
nfsStatFs       PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS StatFs"
::= { Handle=nfsHandle }
nfsStatFsReply       PROTOCOL
        SUMMARIZE
            "Default" :
              "NFS StatFsReply $Status"
::= { Status=nfsStatus, TransferSize=UInt32, BlockSize=UInt32,
        TotalBlocks=UInt32, FreeBlocks=UInt32, AvailBlocks=UInt32 }
```

-continued

```
nfsRemoveDir   PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS RmDir $Name"
::= { Handle=nfsHandle, Name=nfsString }
nfsRemoveDirReply   PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS RmDirReply $Status"
::= { Status=nfsStatus }
nfsMakeDir    PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS MkDir $Name"
::= { Handle=nfsHandle, Name=nfsString }
nfsMakeDirReply   PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS MkDirReply $Status"
::= { Status=nfsStatus }
nfsRemove       PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS Remove $Name"
::= { Handle=nfsHandle, Name=nfsString }
nfsRemoveReply   PROTOCOL
        SUMMARIZE
             "Default" :
                "NFS RemoveReply $Status"
::= { Status=nfsStatus
--------------------------------------------------------------------------
--
--    HTTP.pdl - Hypertext Transfer Protocol (HTTP) definitions
--
--    Description:
--        This file contains the packet definitions for the Hypertext Transfer
--        Protocol.
--
--    Copyright:
--        Copyright (c) 1994–1999 Apptitude, Inc.
--        (formerly Technically Elite, Inc.)
--        All rights reserved.
--    RCS:
--        $Id: HTTP.pdl,v 1.13 1999/04/13 15:47:57 skip Exp $
--
--------------------------------------------------------------------------
httpData     FIELD
             SYNTAX            BYTESTRING(1..1500)
             LENGTH               "($ipLength - ($ipHeaderLength * 4)) - ($tcpHeaderLen
* 4)"
             DISPLAY-HINT    "Text"
             FLAGS             NOLABEL
http         PROTOCOL
             SUMMARIZE
                  "$httpData m/^GET|^HTTP|^HEAD|^POST/" :
                     "HTTP $httpData"
                  "$httpData m/^[Dd]ate|^[Ss]erver|^[L1]ast-[Mm]odified/" :
                     "HTTP $httpData"
                  "$httpData m/^[Cc]ontent-/" :
                     "HTTP $httpData"
                  "$httpData m/^<HTML>/" :
                     "HTTP [HTML document]"
                  "$httpData m/^GIF/" :
                     "HTTP [GIF image]"
                  "Default" :
                     "HTTP [Data]"
             DESCRIPTION
                  "Protocol format for HTTP."
::= { Data=httpData }
http         FLOW
             CONNECTION { INHERITED }
             PAYLOAD { INCLUDE-HEADER, DATA=Data, LENGTH=256 }
             STATES
                  "S0:   CHECKCONNECT, GOTO S1
                         DEFAULT NEXT S0
                   S1:   WAIT 2, GOTO S2, NEXT S1
                         DEFAULT NEXT S0
                   S2:   NATCH
                            '\n\r\n'                  900 0 0 255 0, NEXT S3
```

-continued

```
                    '\n\n'             900 0 0 255 0, NEXT 53
                    'POST /tds?'        50 0 0 127 1, CHILD sybaseWebsq1
                    '.hts HTTP/1.0'     50 4 0 127 1, CHILD sybaseJdbc
                    'jdbc:sybase:Tds'   50 4 0 127 1, CHILD sybaseTds
                    'PCN-The Poin'     500 4 1 255 0, CHILD pointcast
                    't: BW-C-'         100 4 1 255 0, CHILD backweb
                    DEFAULT NEXT S3
            S3:   MATCH
                    '\n\r\n'           50 0 0   0 0, NEXT S3
                    '\n\n'              50 0 0   0 0, NEXT S3
                    'Content-Type:'    800 0 0 255 0, CHILD mime
                    'PCN-The Poin'     500 4 1 255 0, CHILD pointcast
                    't: BW-C-'         100 4 1 255 0, CHILD backweb
                    DEFAULT NEXT S0"
sybaseWebsql  FLOW
              STATE-BASED
sybaseJdbc    FLOW
              STATE-BASED
sybaseTds     FLOW
              STATE-BASED
pointcast     FLOW
              STATE-BASED
backweb       FLOW
              STATE-BASED
mime          FLOW
              STATE-BASED
              STATES
                "S0:       MATCH
                              'application'  900 0 0   1 0, CHILD mimeApplication
                              'audio'        900 0 0   1 0, CHILD mimeAudio
                              'image'         50 0 0   1 0, CHILD mimeImage
                              'text'          50 0 0   1 0, CHILD mimeText
                              'video'         50 0 0   1 0, CHILD mimeVideo
                              'x-world'      500 4 1 255 0, CHILD mimeXworld
                           DEFAULT GOTO S0"
mimeApplication  FLOW
                 STATE-BASED
mimeAudio   FLOW
            STATE-BASED
            STATES
              "S0:   MATCH
                       'basic'            100 0 0 1 0, CHILD pdBasicAudio
                       'midi'             100 0 0 1 0, CHILD pdMidi
                       'mpeg'             100 0 0 1 0, CHILD pdMpeg2Audio
                       'vnd.m-realaudio'  100 0 0 1 0, CHILD pdRealAudio
                       'wav'              100 0 0 1 0, CHILD pdWav
                       'x-aiff'           100 0 0 1 0, CHILD pdAiff
                       'x-midi'           100 0 0 1 0, CHILD pdMidi
                       'x-mpeg'           100 0 0 1 0, CHILD pdMpeg2Audio
                       'x-mpgurl'         100 0 0 1 0, CHILD pdMpeg3Audio
                       'x-pn-realaudio'   100 0 0 1 0, CHILD pdRealAudio
                       'x-wav'            100 0 0 1 0, CHILD pdWav
                     DEFAULT GOTO S0"
mimeImage     FLOW
              STATE-BASED
mimeText      FLOW
              STATE-BASED
mimeVideo     FLOW
              STATE-BASED
mimeXworld    FLOW
              STATE-BASED
pdBasicAudio  FLOW
              STATE-BASED
pdMidi        FLOW
              STATE-BASED
pdMpeg2Audio  FLOW
              STATE-BASED
pdMpeg3Audio  FLOW
              STATE-BASED
pdRealAudio   FLOW
              STATE-BASED
pdWav         FLOW
              STATE-BASED
pdAiff        FLOW
              STATE-BASED
```

What is claimed is:

1. A method of performing protocol specific operations on a packet passing through a connection point on a computer network, the method comprising:

(a) receiving the packet:

(b) receiving a set of protocol descriptions for a plurality of protocols that conform to a layered model, a protocol description for a particular protocol at a particular layer level including:

(i) if there is at least one child protocol of the protocol at the particular layer level, the-one or more child protocols of the particular protocol at the particular layer level, the packet including for any particular child protocol of the particular protocol at the particular layer level information at one or more locations in the packet related to the particular child protocol,

(ii) the one or more locations in the packet where information is stored related to any child protocol of the particular protocol, and

(iii) if there is at least one protocol specific operation to be performed on the packet for the particular protocol at the particular layer level, the one or more protocol specific operations to be performed on the packet for the particular protocol at the particular layer level; and

(c) performing the protocol specific operations on the packet specified by the set of protocol descriptions based on the base protocol of the packet and the children of the protocols used in the packet,

the method further comprising:

storing a database in a memory, the database generated from the set of protocol descriptions and including a data structure containing information on the possible protocols and organized for locating the child protocol related information for any protocol, the data structure contents indexed by a set of one or more indices, the database entry indexed by a particular set of index values including an indication of validity,

wherein the child protocol related information includes a child recognition pattern,

wherein step (c) of performing the protocol specific operations includes, at any particular protocol layer level starting from the base level, searching the packet at the particular protocol for the child field, the searching including indexing the data structure until a valid entry is found, and

whereby the data structure is configured for rapid searches using the index set.

2. A method according to claim 1, wherein the protocol descriptions are provided in a protocol description language, the method further comprising:

compiling the PDL descriptions to produce the database.

3. A method according to claim 1, wherein the data structure comprises a set of arrays, each array identified by a first index, at least one array for each protocol, each array further indexed by a second index being the location in the packet where the child protocol related information is stored, such that finding a valid entry in the data structure provides the location in the packet for finding the child recognition pattern for an identified protocol.

4. A method according to claim 3, wherein each array is further indexed by a third index being the size of the region in the packet where the child protocol related information is stored, such that finding a valid entry in the data structure provides the location and the size of the region in the packet for finding the child recognition pattern.

5. A method according to claim 4, wherein the data structure is compressed according to a compression scheme that takes advantage of the sparseness of valid entries in the data structure.

6. A method according to claim 5, wherein the compression scheme combines two or more arrays that have no conflicting common entries.

7. A method according to claim 1, wherein the data structure includes a set of tables, each table identified by a first index, at least one table for each protocol, each table further indexed by a second index being the child recognition pattern, the data structure further including a table that for each protocol provides the location in the packet where the child protocol related information is stored, such that finding a valid entry in the data structure provides the location in the packet for finding the child recognition pattern for an identified protocol.

8. A method according to claim 7, wherein the data structure is compressed according to a compression scheme that takes advantage of the sparseness of valid entries in the set of tables.

9. A method according to claim 8, wherein the compression scheme combines two or more tables that have no conflicting common entries.

10. A method of performing protocol specific operations on a packet passing through a connection point on a computer network, the method comprising:

(a) receiving the packet;

(b) receiving a set of protocol descriptions for a plurality of protocols that conform to a layered model, a protocol description for a particular protocol at a particular layer level including:

(i) if there is at least one child protocol of the protocol at the particular layer level, the-one or more child protocols of the particular protocol at the particular layer level, the packet including for any particular child protocol of the particular protocol at the particular layer level information at one or more locations In the packet related to the particular child protocol,

(ii) the one or more locations in the packet where information is stored related to any child protocol of the particular protocol, and

(iii) if there is at least one protocol specific operation to be performed on the packet for the particular protocol at the particular layer level, the one or more protocol specific operations to be performed on the packet for the particular protocol at the particular layer level: and

(c) performing the protocol specific operations on the packet specified by the set of protocol descriptions based on the base protocol of the packet and the children of the protocols used in the packet,

wherein the protocol specific operations include one or more parsing and extraction operations on the packet to extract selected portions of the packet to form a function of the selected portions for identifying the packet as belonging to a conversational flow.

11. A method according to claim 10, wherein step (c) of performing protocol specific operations is performed recursively for any children of the children.

12. A method according to claim 10, wherein which protocol specific operations are performed is step (c) depends on the contents of the packet such that the method adapts to different protocols according to the contents of the packet.

13. A method according to claim 10, wherein the protocol descriptions are provided in a protocol description language.

14. A method according to claim 13, further comprising:

compiling the PDL descriptions to produce a database and store the database in a memory, the database generated from the set of protocol descriptions and including a data structure containing information on the possible protocols and organized for locating the child protocol related information for any protocol, the data structure contents indexed by a set of one or more indices, the database entry indexed by a particular set of index values including an indication of validity,

wherein the child protocol related information includes a child recognition pattern, and

wherein the step of performing the protocol specific operations includes, at any particular protocol layer level starting from the base level, searching the packet at the particular protocol for the child field, the searching including indexing the data structure until a valid entry is found,

whereby the data structure is configured for rapid searches using the index set.

15. A method according to claim 10, further comprising:

looking up a flow-entry database comprising at least one flow-entry for each previously encountered conversational flow, the looking up using at least some of the selected packet portions and determining if the packet matches an flow-entry in the flow-entry database

if the packet is of an existing flow, classifying the packet as belonging to the found existing flow; and

if the packet is of a new flow, storing 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;

wherein for at least one protocol, the parsing and extraction operations depend on the contents of one or more packet headers.

16. A method according to claim 10, wherein the protocol specific operations further include one or more state processing operations that are a function of the state of the flow of the packet.

17. A method of performing protocol specific operations on a packet passing through a connection point on a computer network, the method comprising:

(a) receiving the packet;

(b) receiving a set of protocol descriptions for a plurality of protocols that conform to a layered model, a protocol description for a particular protocol at a particular layer level including:

(i) if there is at least one child protocol of the protocol at the particular layer level, the one or more child protocols of the particular protocol at the particular layer level, the packet including for any particular child protocol of the particular protocol at the particular layer level information at one or more locations in the packet related to the particular child protocol,

(ii) the one or more locations in the packet where information is stored related to any child protocol of the particular protocol, and

(iii) if there is at least one protocol specific operation to be performed on the packet for the particular protocol at the particular layer level, the one or more protocol specific operations to be performed on the packet for the particular protocol at the particular layer level; and

(c) performing the protocol specific operations on the packet specified by the set of protocol descriptions based on the base protocol of the packet and the children of the protocols used in the packet,

wherein the packet belongs to a conversational flow of packets having a set of one or more states, and wherein the protocol specific operations include one or more state processing operations that are a function of the state of the conversational flow of the packet, the state of the conversational flow of the packet being indicative of the sequence of any previously encountered packets of the same conversational flow as the packet.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,665,725 B1 Page 1 of 2
DATED : December 16, 2003
INVENTOR(S) : Dietz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,
Line 47, change "NBTBIOS" to -- NETBIOS --.
Line 55, change "Diferent" to -- Different --.

Column 16,
Line 27, change "FIG. 6 FIG 6" to
-- FIG. 6.
FIG6 --.

Column 18,
Line 17, change "updatelookup" to -- update-lookup --.

Column 25,
Line 38, change "server-say" to -- server—say --.

Column 53,
Line 4, change ""Default"" to -- "Default" : --.
Line 45, shift "DISPLAY-HINT" to the right so its beginning lines up with the beginning of "SYNTAX" in line 42 and with the beginning of "LENGTH" in line 43.
Line 46, shift "FLAGS" to the right so its beginning lines up with the beginning of "SYNTAX" in line 42 and with the beginning of "LENGTH" in line 43.

Column 61,
Aprox. line 32, change "rip" to -- r1p --.

Column 71,
Line 9, from the bottom, change "netbios (0x3c00," to -- netbios (0x3c00) --.

Column 73,
Aprox. Line 25, change "tyop" to -- type --.

Column 79,
Line 4 from the bottom, change "SYNTAXINT(8)" to -- SYNTAX INT (8) --.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,665,725 B1
DATED : December 16, 2003
INVENTOR(S) : Dietz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 81,
Approx. line 41, change "SYNTAXBITSRING(12)" to -- SYNTAX BITSTRING (12) --.

Column 83,
Approx. line 36, change "LOOKUPFILE" to -- LOOKUP FILE --.

Column 93,
Approx. line 45, change "vnd.m-relaudio" to -- 'vnd.rn-realaudio' --.

Column 96,
Line 38, change "In" to -- in --.

Signed and Sealed this

Twenty-ninth Day of June, 2004

Jon W. Dudas

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,665,725 B1
APPLICATION NO. : 09/609179
DATED : December 16, 2003
INVENTOR(S) : Russell S. Dietz, Andrew A. Koppenhaver and James F. Torgerson

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

IN THE CLAIMS:

Column 1, lines 15 and 16, claim 14, change "searching the packet at the particular protocol" to --searching the packet at the particular protocol level--.

Signed and Sealed this
Eighth Day of October, 2013

Teresa Stanek Rea
Deputy Director of the United States Patent and Trademark Office

US006839751B1

(12) **United States Patent**
Dietz et al.

(10) **Patent No.: US 6,839,751 B1**
(45) **Date of Patent: Jan. 4, 2005**

(54) **RE-USING INFORMATION FROM DATA TRANSACTIONS FOR MAINTAINING STATISTICS IN NETWORK MONITORING**

(75) Inventors: **Russell S. Dietz**, San Jose, CA (US); **Joseph R. Maixner**, Aptos, CA (US); **Andrew A. Koppenhaver**, Littleton, CO (US)

(73) Assignee: **Hi/fn, Inc.**, Los Gatos, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 728 days.

(21) Appl. No.: **09/608,126**

(22) Filed: **Jun. 30, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/141,903, filed on Jun. 30, 1999.

(51) **Int. Cl.**^{7} **G06F 15/173**

(52) **U.S. Cl.** **709/224**; 709/223; 709/230

(58) **Field of Search** 709/223, 224, 709/231, 232, 230; 370/252, 231; 379/32; 704/43; 714/39; 340/825

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,972,453	A	*	11/1990	Daniel et al.	379/9.03
5,535,338	A	*	7/1996	Krause et al.	709/222
5,703,877	A		12/1997	Nuber et al.	370/395
5,720,032	A	*	2/1998	Picazo, Jr. et al.	709/250
5,761,429	A	*	6/1998	Thompson	709/224
5,799,154	A	*	8/1998	Kuriyan	709/223
5,802,054	A	*	9/1998	Bellenger	370/401
5,850,388	A	*	12/1998	Anderson et al.	370/252
5,892,754	A		4/1999	Kompella et al.	370/236
6,097,699	A	*	8/2000	Chen et al.	370/231
6,115,393	A	*	9/2000	Engel et al.	370/469
6,269,330	B1	*	7/2001	Cidon et al.	704/43
6,279,113	B1	*	8/2001	Vaidya	713/201
6,282,570	B1	*	8/2001	Leung et al.	709/224
6,330,226	B1	*	12/2001	Chapman et al.	370/232
6,363,056	B1	*	3/2002	Beigi et al.	370/252
6,381,306	B1	*	4/2002	Lawson et al.	379/32
6,424,624	B1	*	7/2002	Galand et al.	370/231
6,453,345	B2	*	9/2002	Trcka et al.	709/224
6,625,657	B1	*	9/2003	Bullard	709/237
6,651,099	B1	*	11/2003	Dietz et al.	709/224

OTHER PUBLICATIONS

NOV94: Packet Filtering in the SNMP Remote Monitor ; www.skrymir.com/dobbs/articles/1994/9411/9411h/9411h.htm.*

GTrace—A Graphical Traceroute Tool authored by Ram Periakaruppan, Evi Nemeth ; http://www.caida.org/outreach/papers/1999/GTrace/index.xml.*

Advanced Methods for Storage and Retrieval in Image ; http://www.cs.tulane.edu/www/Prototype/proposal.html; 1998.*

Measurement and analysis of the digital DECT propagation channel; IEEE 1998.*

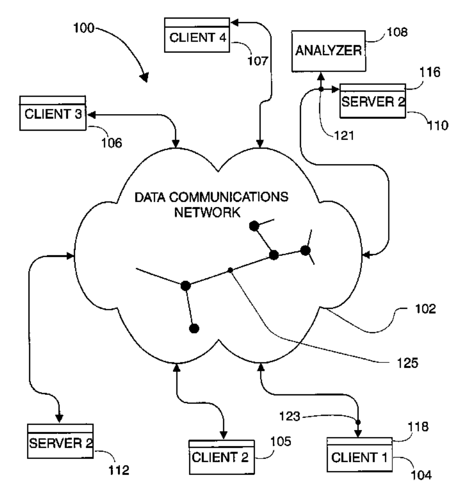
* cited by examiner

Primary Examiner—Thong Vu
(74) *Attorney, Agent, or Firm*—Dov Rosenfeld; Inventek

(57) **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.

21 Claims, 18 Drawing Sheets



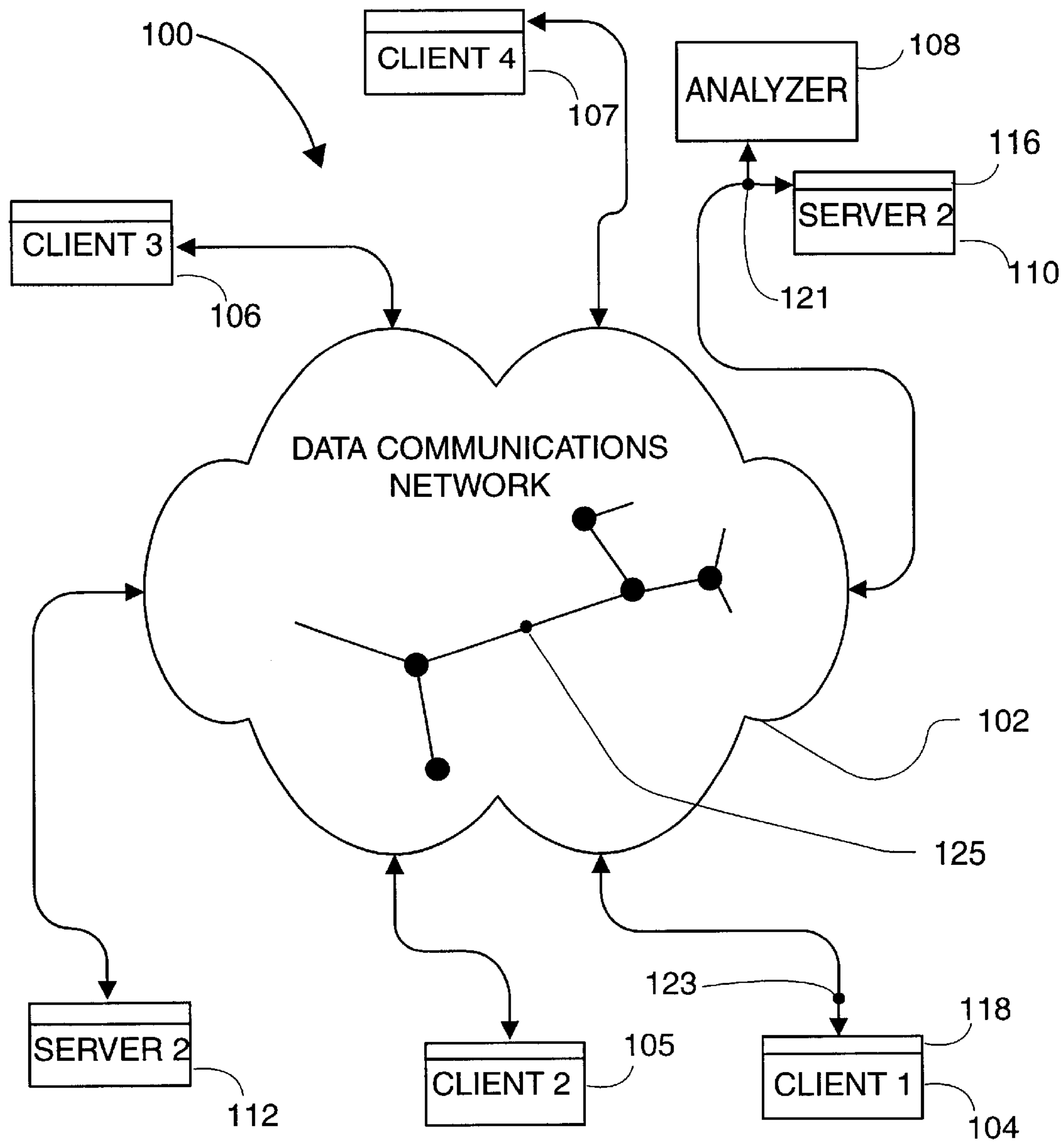

100
CLIENT 4
107
ANALYZER
108
116
SERVER 2
110
121
CLIENT 3
106
DATA COMMUNICATIONS
NETWORK
102
125
123
118
SERVER 2
112
CLIENT 2
105
CLIENT 1
104

FIG. 1

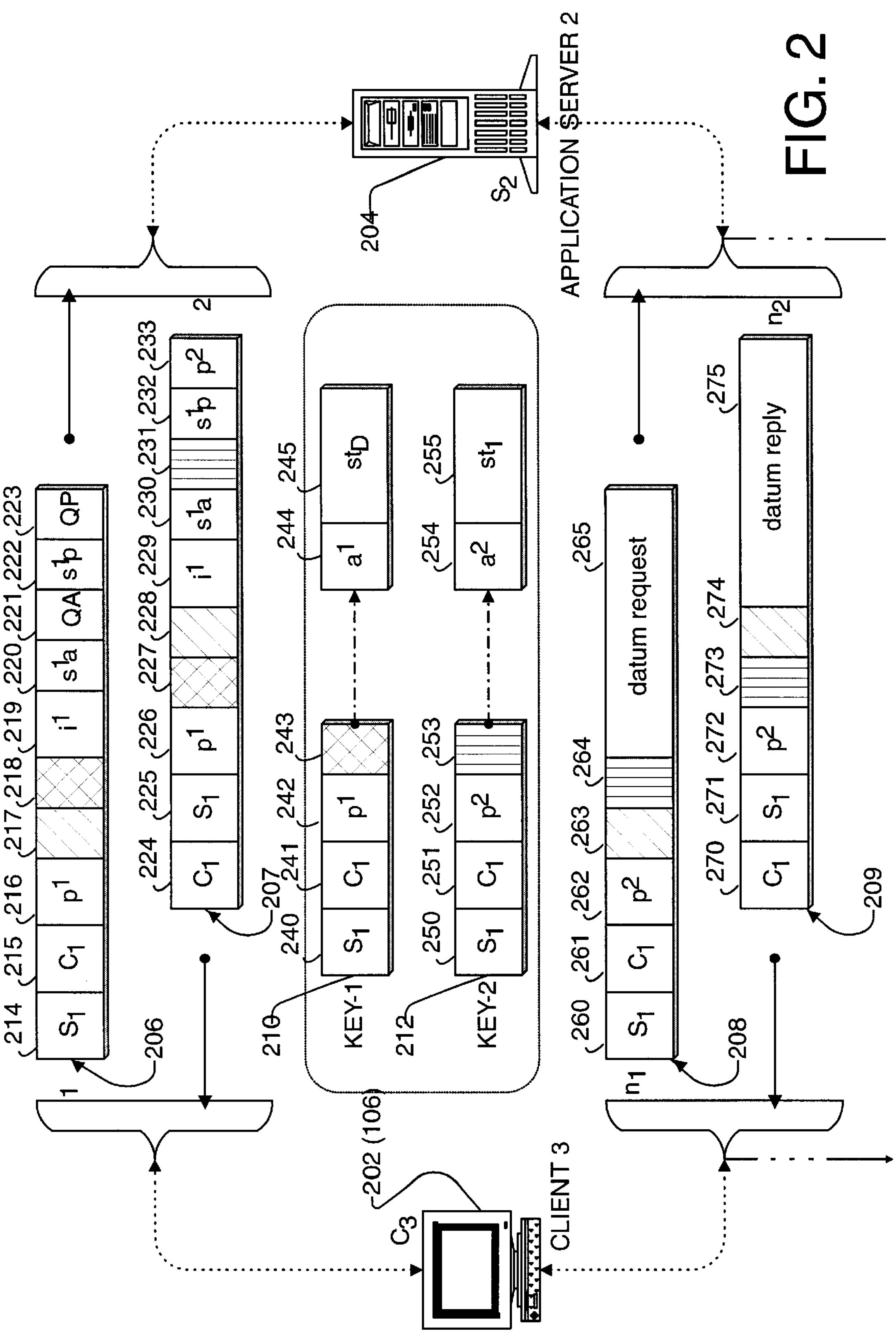

APPLICATION SERVER 2
CLIENT 3
KEY-1
KEY-2
datum request
datum reply
204
202 (106)
206
207
208
209
210
212
214 215 216 217 218 219 220 221 222 223
224 225 226 227 228 229 230 231 232 233
240 241 242 243 244 245
250 251 252 253 254 255
260 261 262 263 264 265
270 271 272 273 274 275

FIG. 2

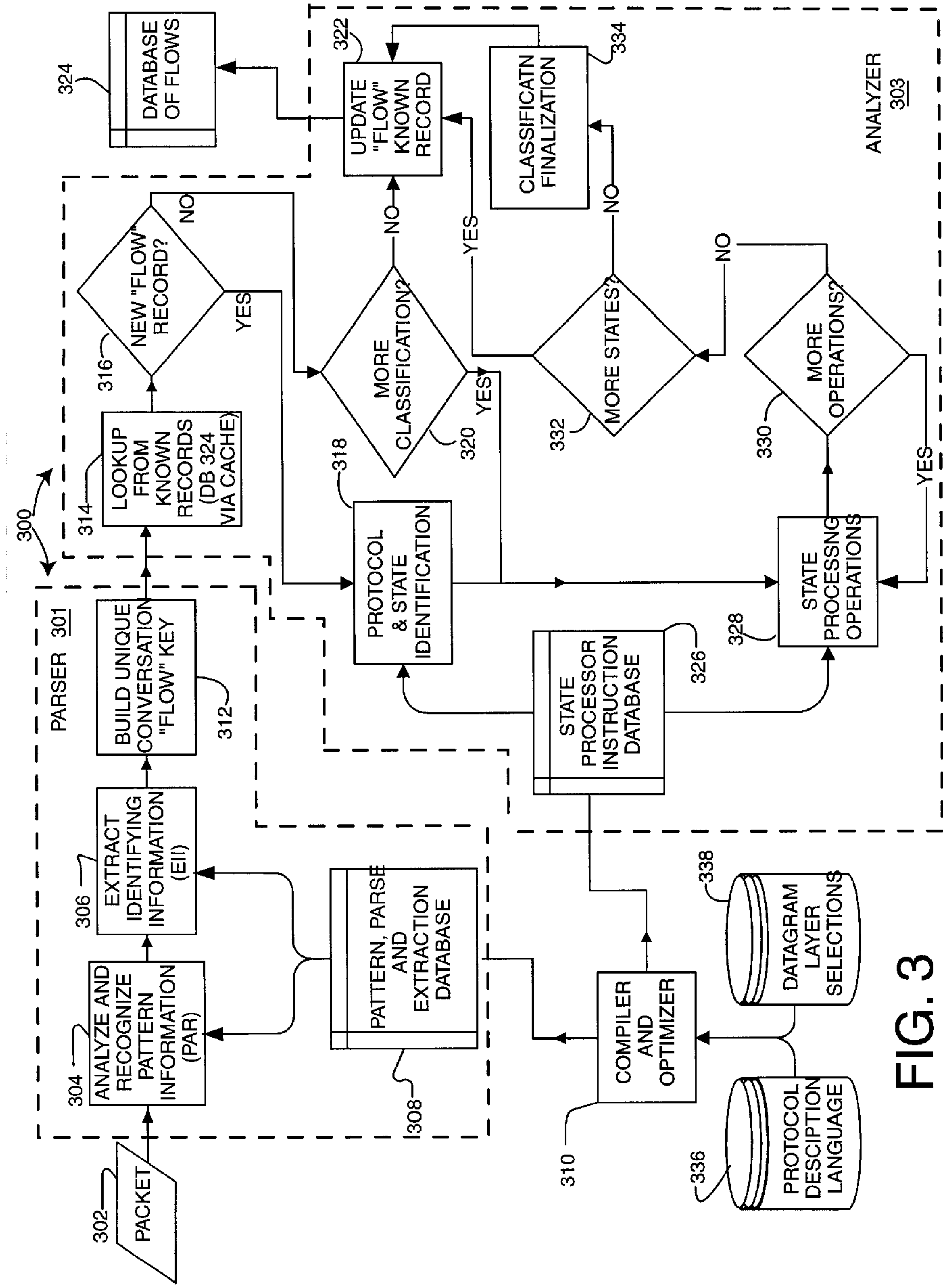
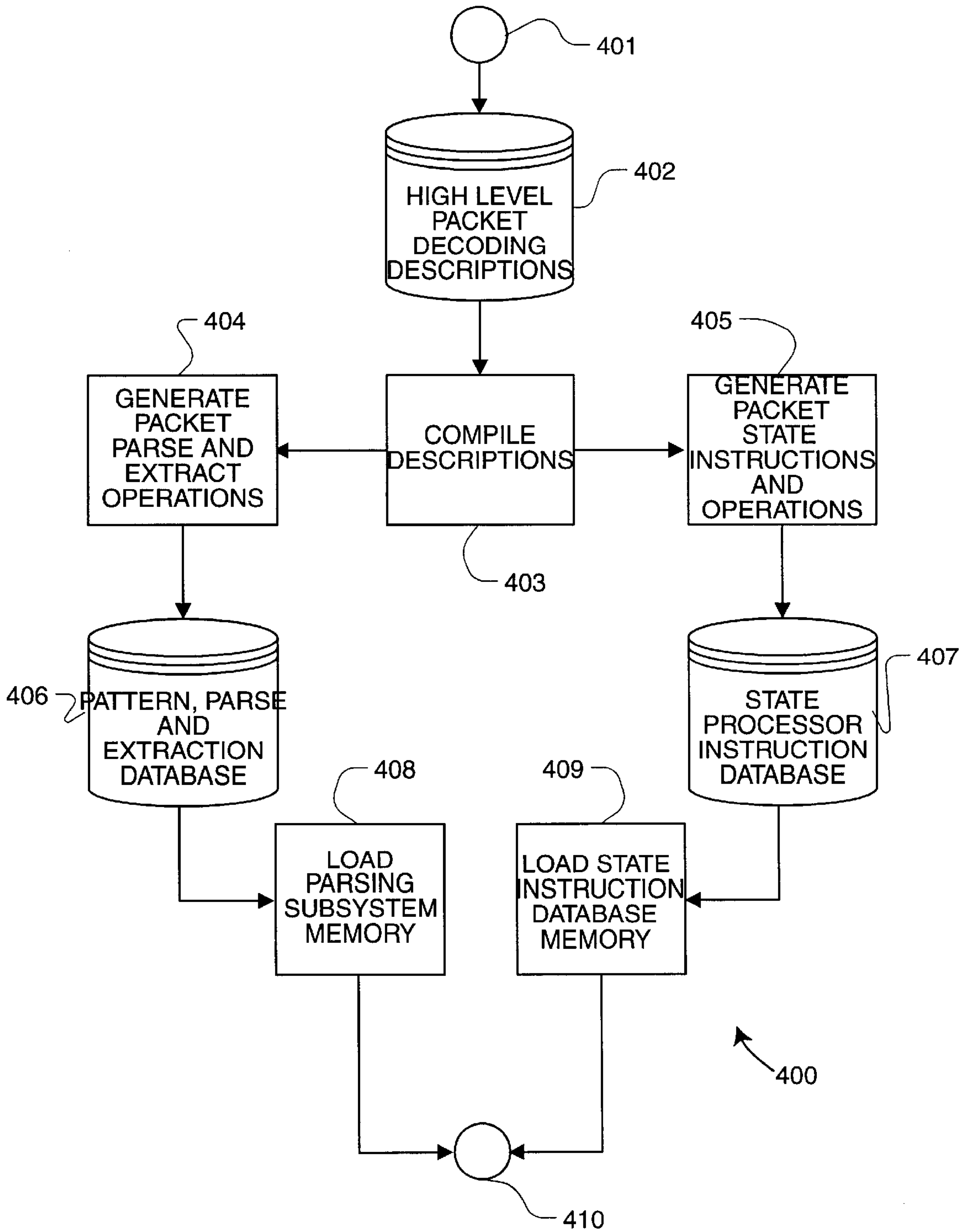

300
PACKET
302
PARSER 301
ANALYZE AND RECOGNIZE PATTERN INFORMATION (PAR)
304
EXTRACT IDENTIFYING INFORMATION (EII)
306
BUILD UNIQUE CONVERSATION "FLOW" KEY
312
PATTERN, PARSE AND EXTRACTION DATABASE
308
LOOKUP FROM KNOWN RECORDS (DB 324 VIA CACHE)
314
NEW "FLOW" RECORD?
316
YES
NO
DATABASE OF FLOWS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

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

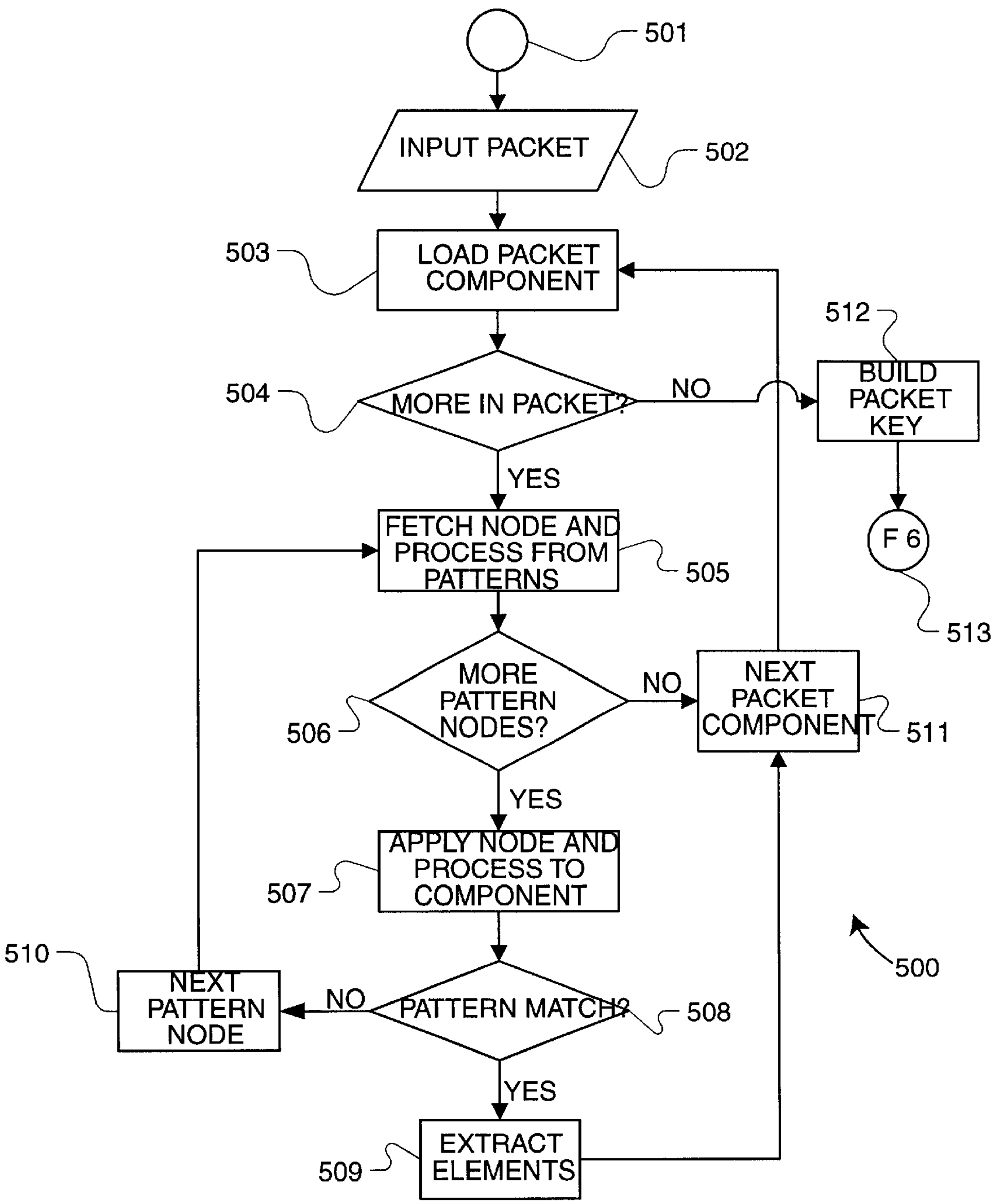

501
INPUT PACKET
502
503
LOAD PACKET COMPONENT
512
BUILD PACKET KEY
504
MORE IN PACKET?
NO
YES
FETCH NODE AND PROCESS FROM PATTERNS
505
F 6
513
MORE PATTERN NODES?
506
NO
NEXT PACKET COMPONENT
511
YES
APPLY NODE AND PROCESS TO COMPONENT
507
500
510
NEXT PATTERN NODE
NO
PATTERN MATCH?
508
YES
EXTRACT ELEMENTS
509

FIG. 5

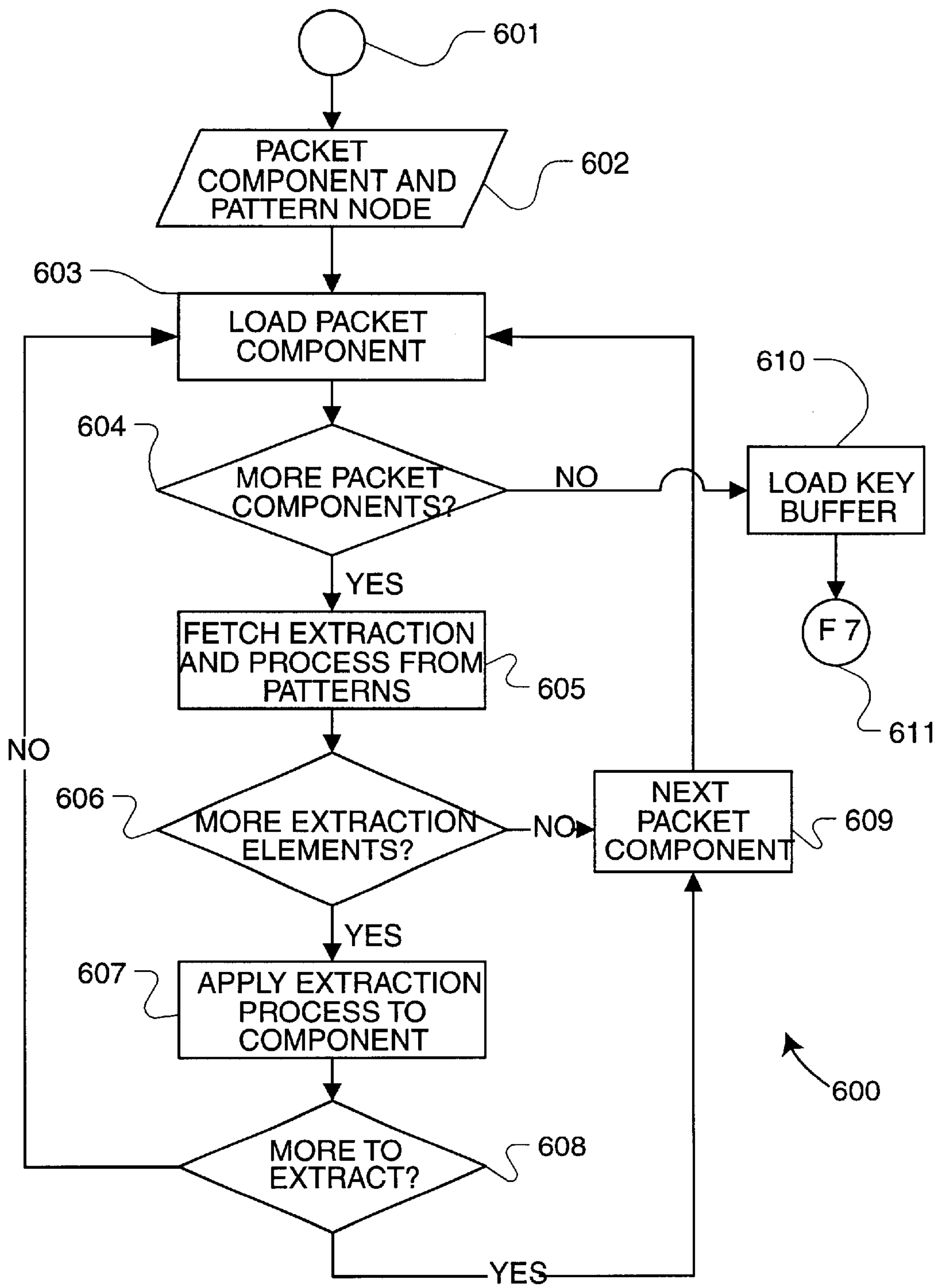

601
PACKET COMPONENT AND PATTERN NODE
602
603
LOAD PACKET COMPONENT
604
MORE PACKET COMPONENTS?
NO
610
LOAD KEY BUFFER
F 7
611
YES
FETCH EXTRACTION AND PROCESS FROM PATTERNS
605
NO
606
MORE EXTRACTION ELEMENTS?
NO
NEXT PACKET COMPONENT
609
YES
607
APPLY EXTRACTION PROCESS TO COMPONENT
600
MORE TO EXTRACT?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

FIG. 6

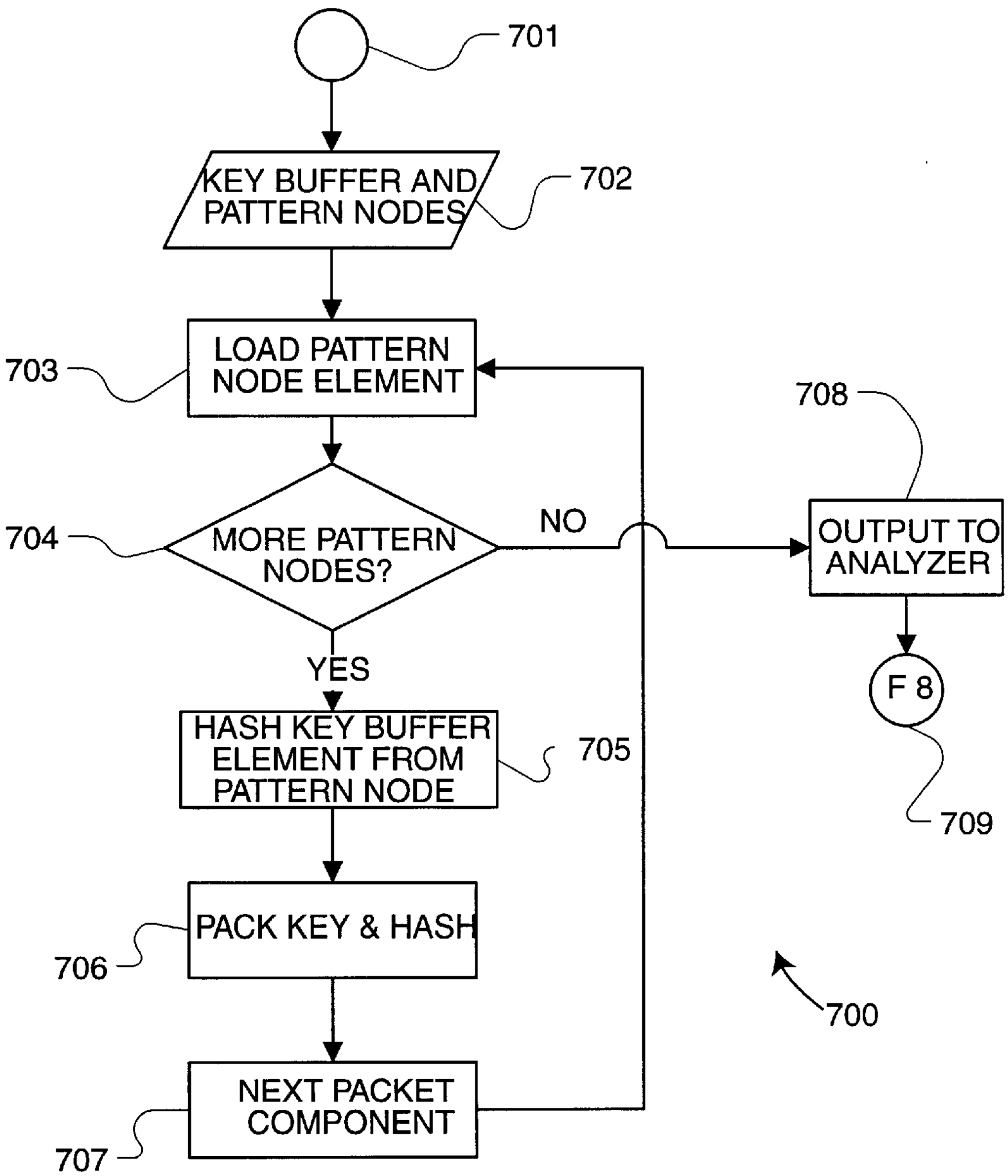

701
KEY BUFFER AND PATTERN NODES
702
703
LOAD PATTERN NODE ELEMENT
704
MORE PATTERN NODES?
NO
YES
708
OUTPUT TO ANALYZER
F 8
709
HASH KEY BUFFER ELEMENT FROM PATTERN NODE
705
706
PACK KEY & HASH
700
707
NEXT PACKET COMPONENT

FIG. 7

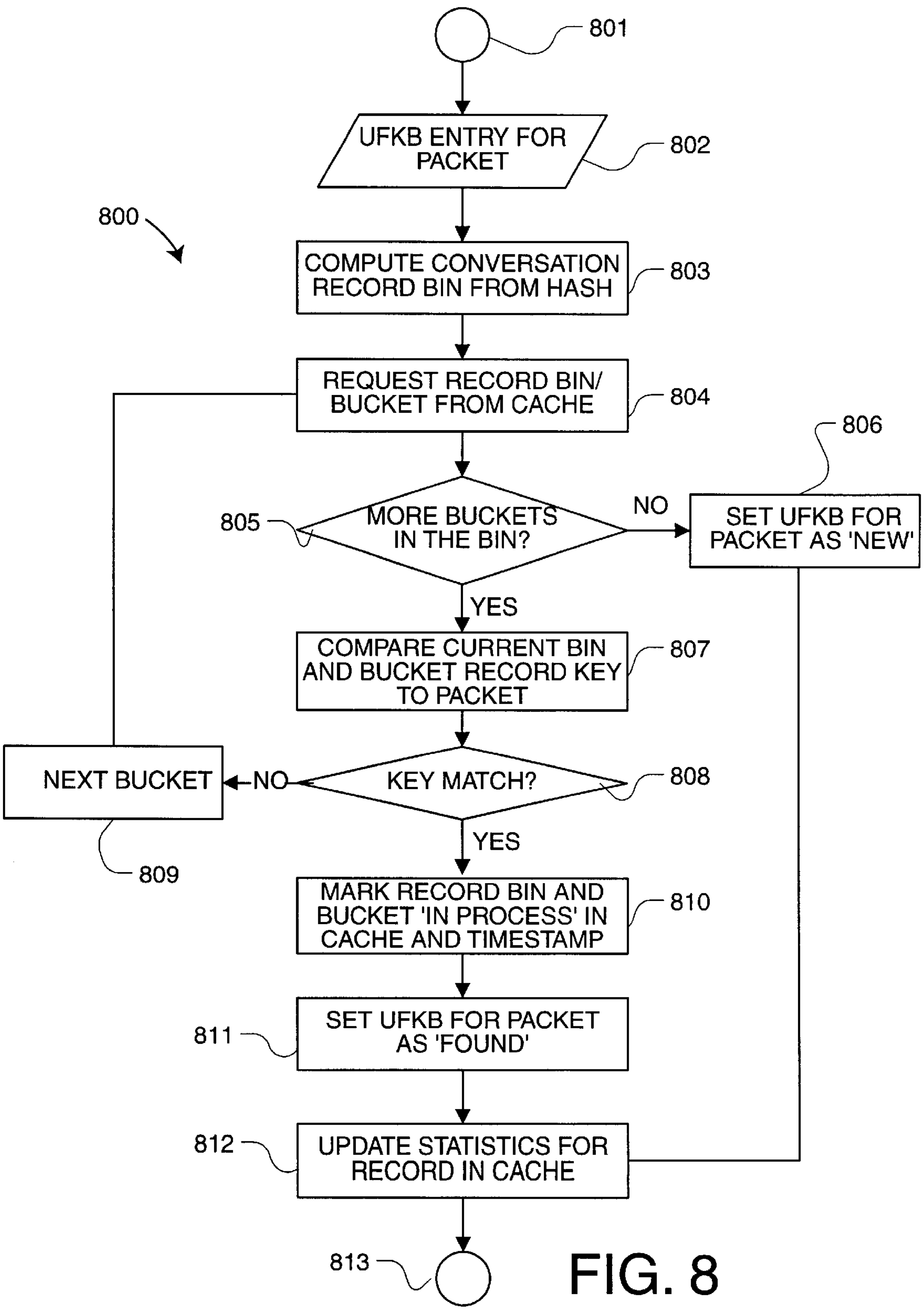

801
UFKB ENTRY FOR PACKET
802
800
COMPUTE CONVERSATION RECORD BIN FROM HASH
803
REQUEST RECORD BIN/ BUCKET FROM CACHE
804
806
805
MORE BUCKETS IN THE BIN?
NO
SET UFKB FOR PACKET AS 'NEW'
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
807
NEXT BUCKET
NO
KEY MATCH?
808
YES
809
MARK RECORD BIN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

FIG. 8

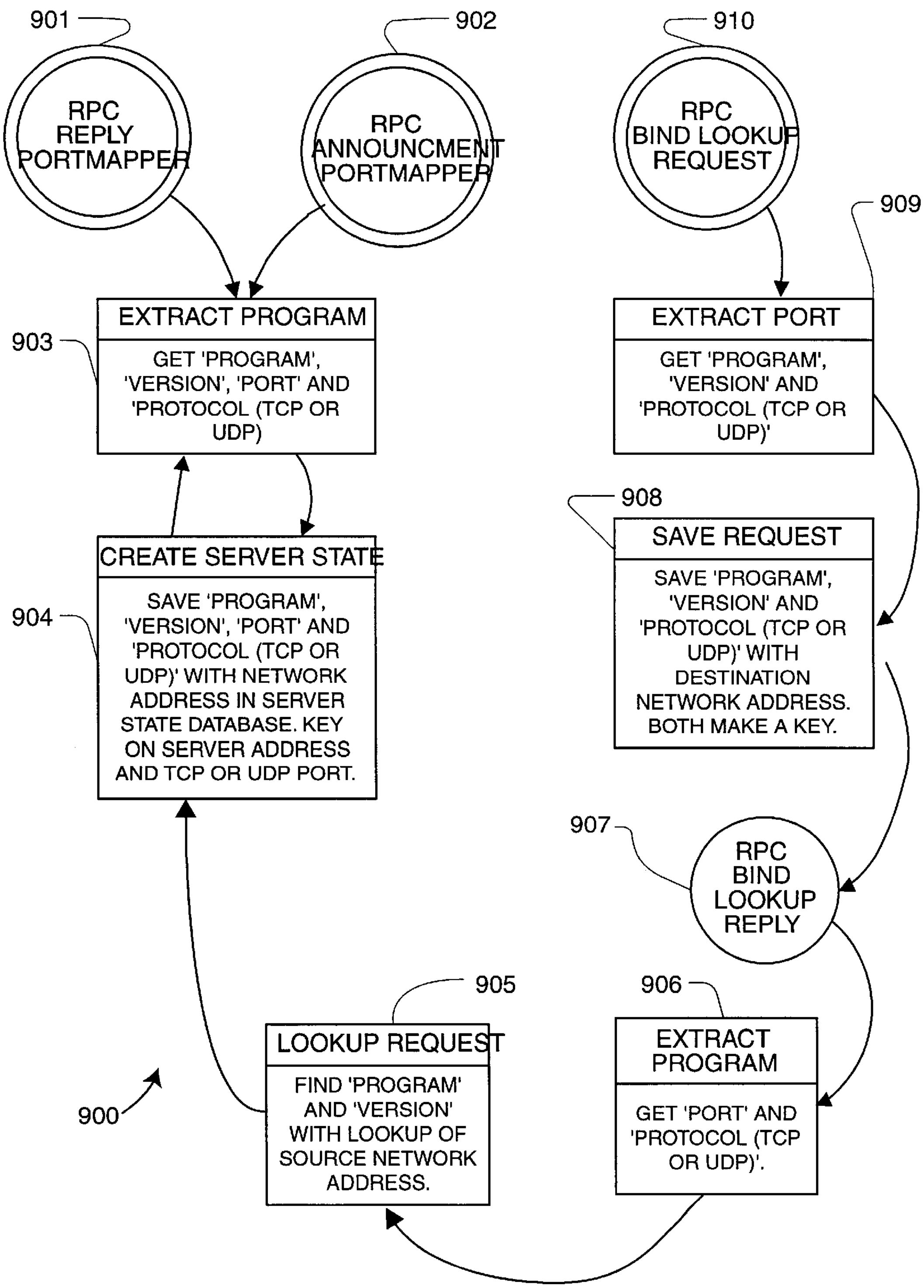

901
RPC REPLY PORTMAPPER
902
RPC ANNOUNCMENT PORTMAPPER
910
RPC BIND LOOKUP REQUEST
909
903
EXTRACT PROGRAM
GET 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)
EXTRACT PORT
GET 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'
908
SAVE REQUEST
SAVE 'PROGRAM', 'VERSION' AND 'PROTOCOL (TCP OR UDP)'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

FIG. 9

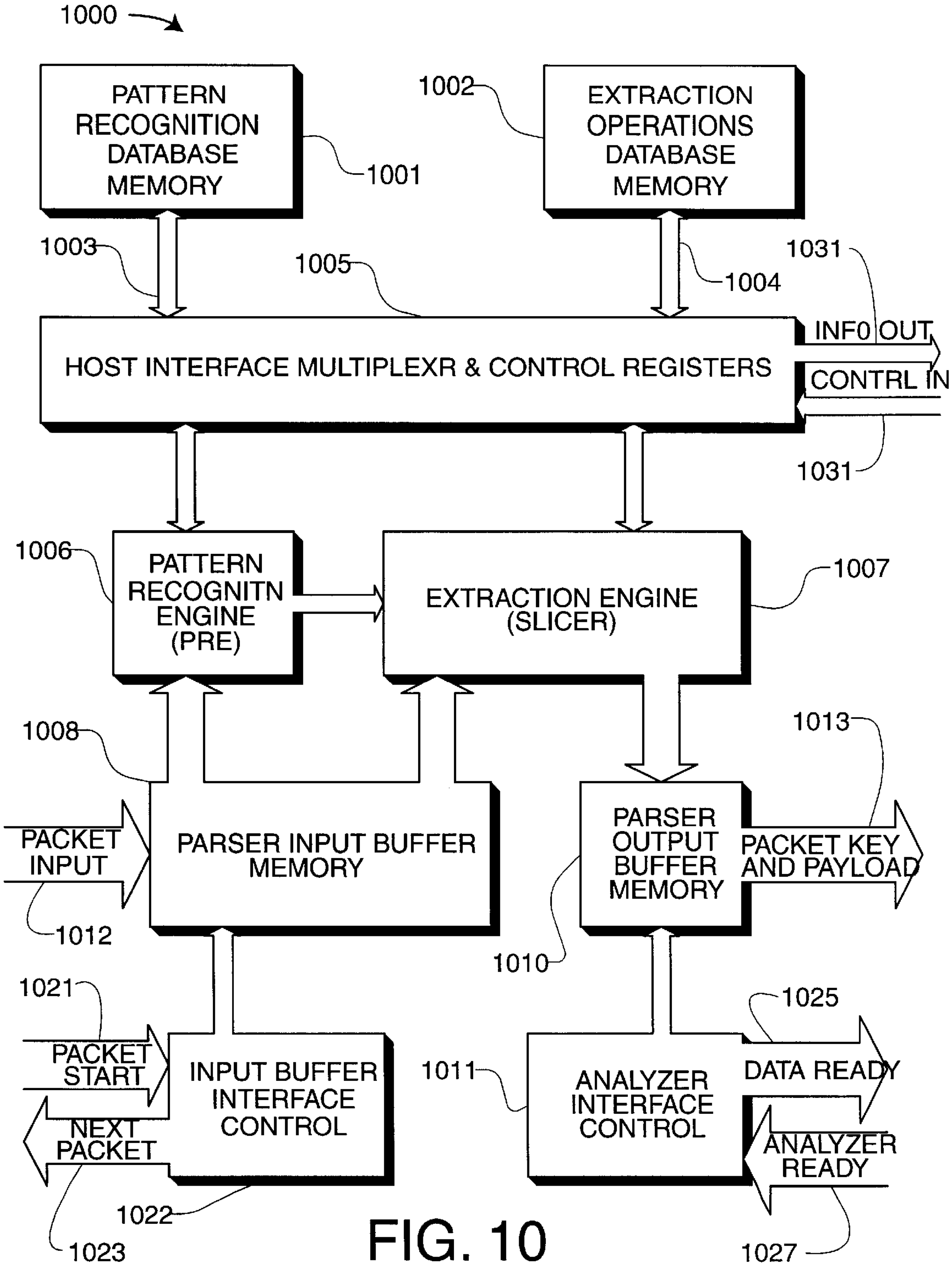

1000
PATTERN RECOGNITION DATABASE MEMORY
1001
1002
EXTRACTION OPERATIONS DATABASE MEMORY
1003
1005
1004
1031
HOST INTERFACE MULTIPLEXR & CONTROL REGISTERS
INF0 OUT
CONTRL IN
1031
1006
PATTERN RECOGNITN ENGINE (PRE)
EXTRACTION ENGINE (SLICER)
1007
1008
1013
PACKET INPUT
PARSER INPUT BUFFER MEMORY
PARSER 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

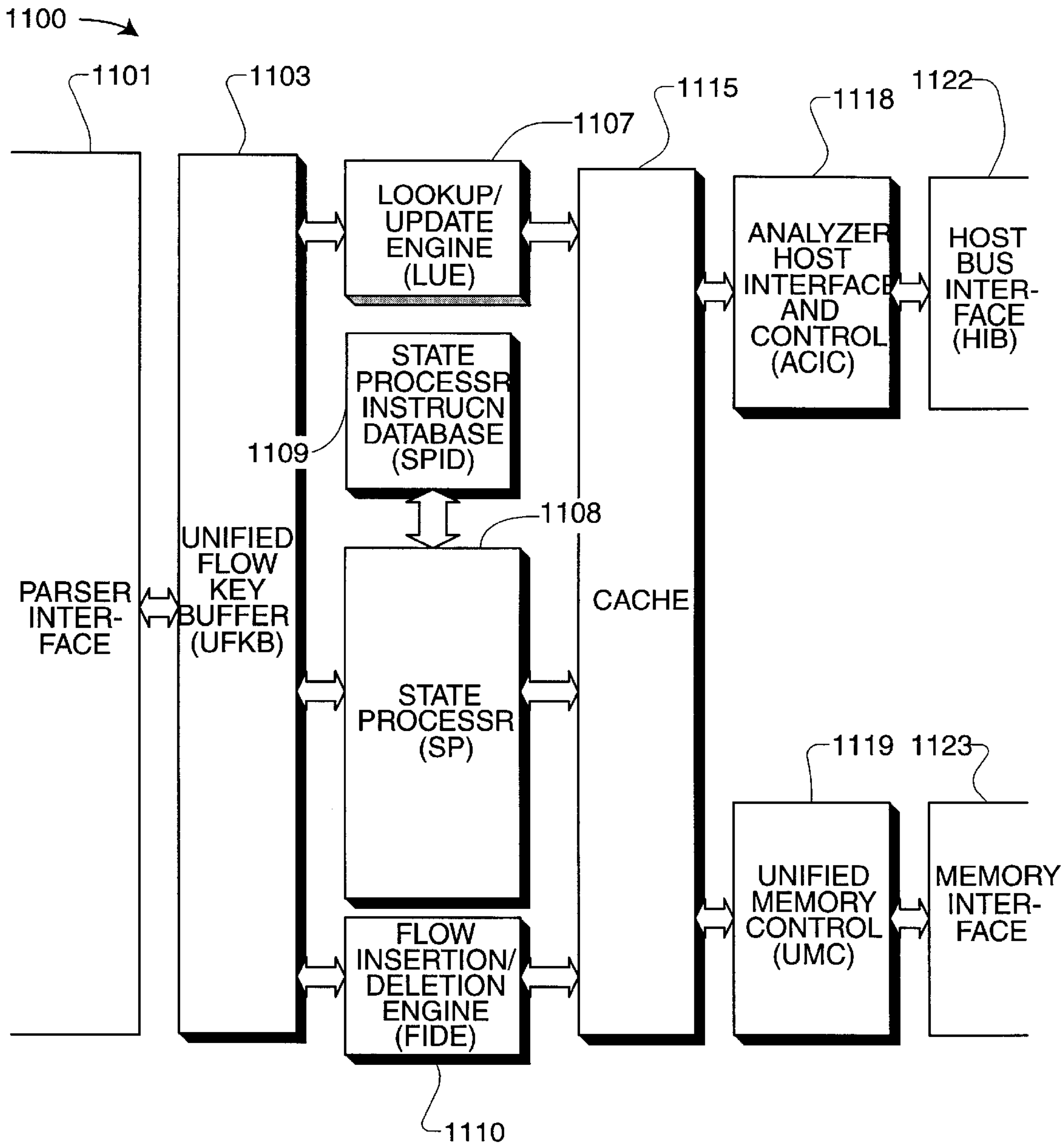

1100
1101
1103
1107
1115
1118
1122
LOOKUP/ UPDATE ENGINE (LUE)
ANALYZER HOST INTERFACE AND CONTROL (ACIC)
HOST BUS INTER- FACE (HIB)
STATE PROCESSR INSTRUCN DATABASE (SPID)
1109
1108
UNIFIED FLOW KEY BUFFER (UFKB)
PARSER INTER- FACE
CACHE
STATE PROCESSR (SP)
1119
1123
UNIFIED MEMORY CONTROL (UMC)
MEMORY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

FIG. 11

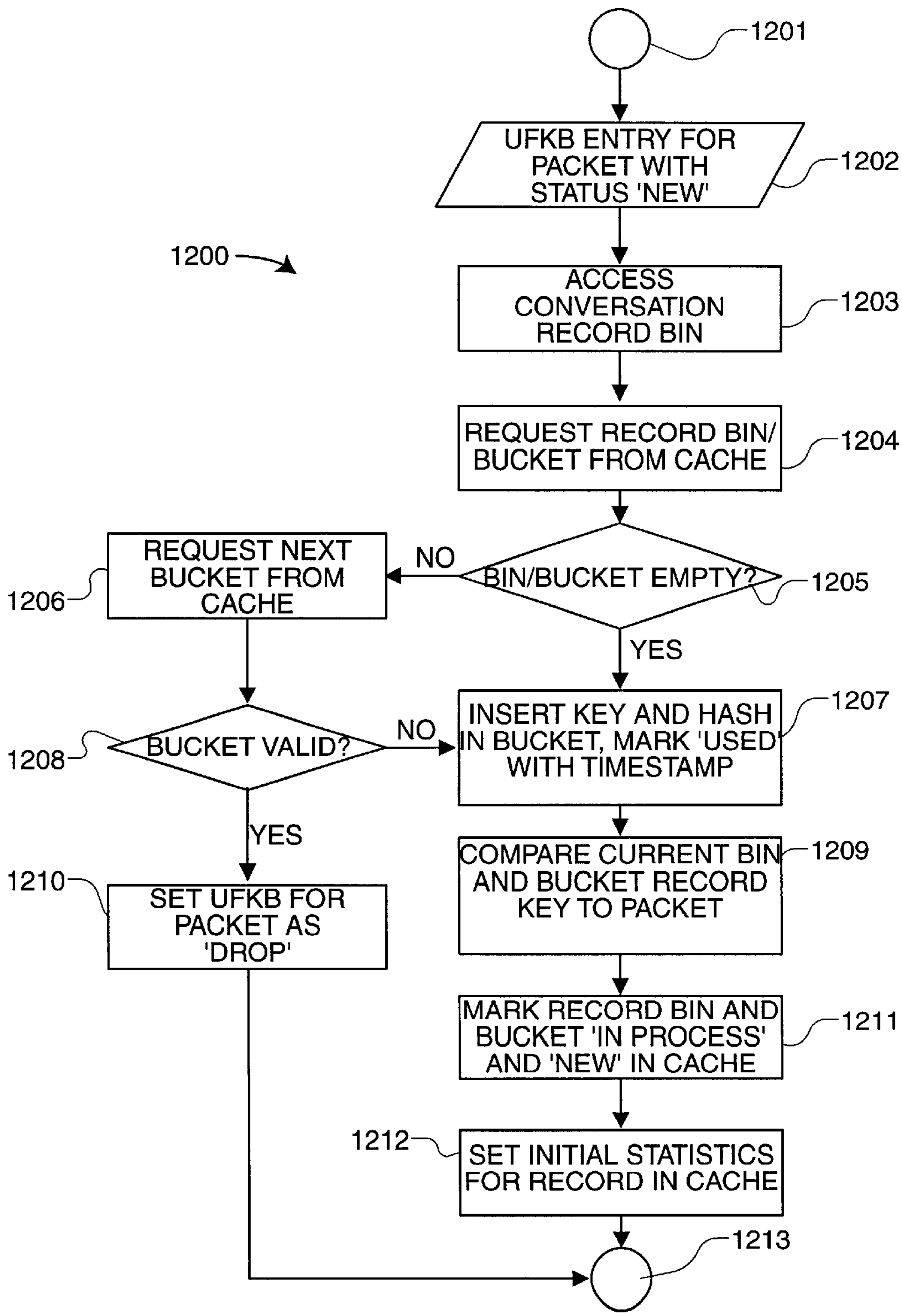

1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
REQUEST NEXT BUCKET FROM CACHE
1206
NO
BIN/BUCKET EMPTY?
1205
YES
INSERT KEY AND HASH IN BUCKET, MARK 'USED' WITH TIMESTAMP
1207
BUCKET VALID?
1208
NO
YES
COMPARE CURRENT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

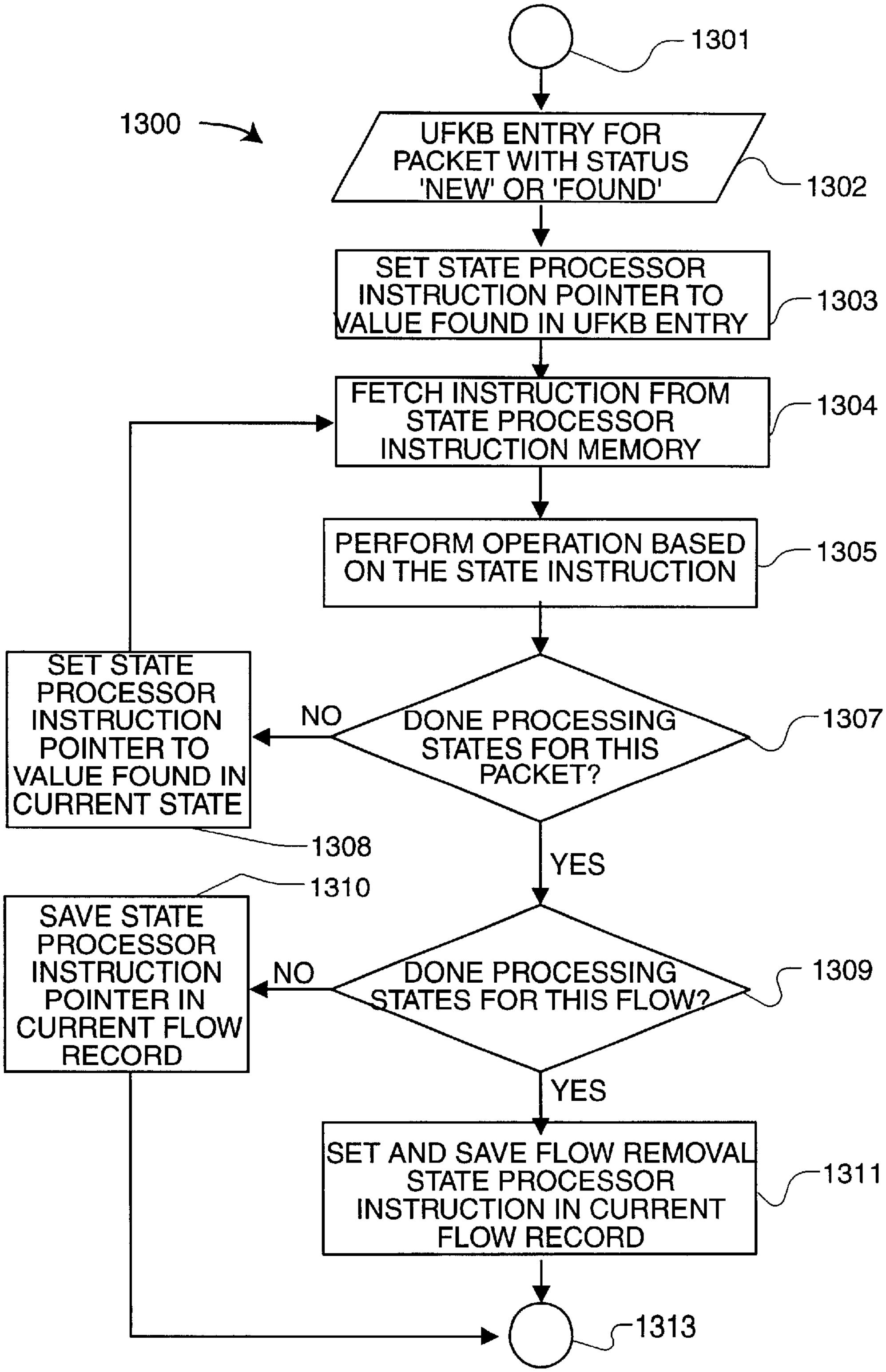

1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE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

FIG. 13

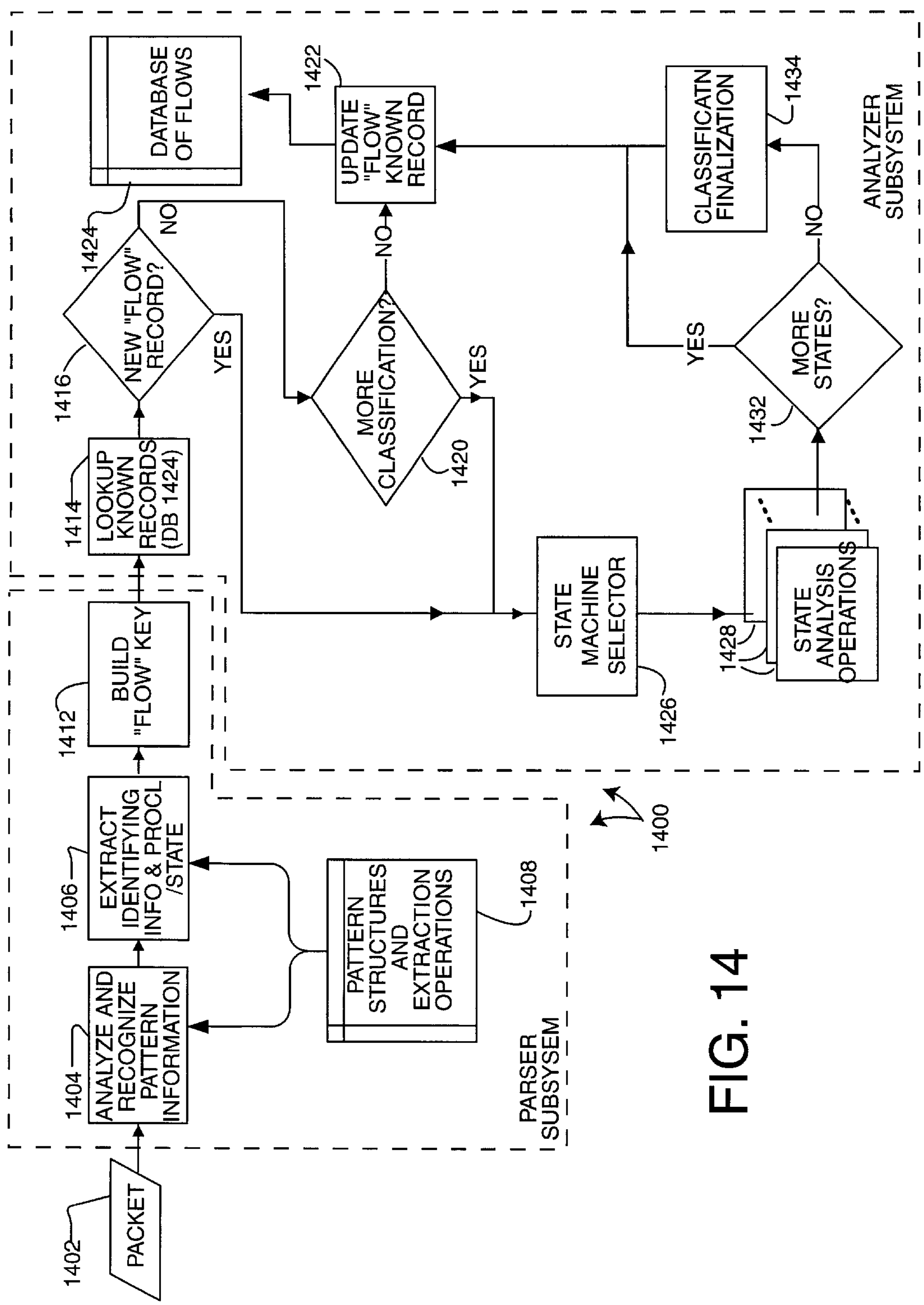

PACKET
1402
ANALYZE AND RECOGNIZE PATTERN INFORMATION
1404
EXTRACT IDENTIFYING INFO & PROCL /STATE
1406
PATTERN STRUCTURES AND EXTRACTION OPERATIONS
1408
PARSER SUBSYSEM
BUILD "FLOW" KEY
1412
LOOKUP KNOWN RECORDS (DB 1424)
1414
NEW "FLOW" RECORD?
1416
YES
NO
DATABASE OF FLOWS
1424
MORE CLASSIFICATION?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

FIG. 14

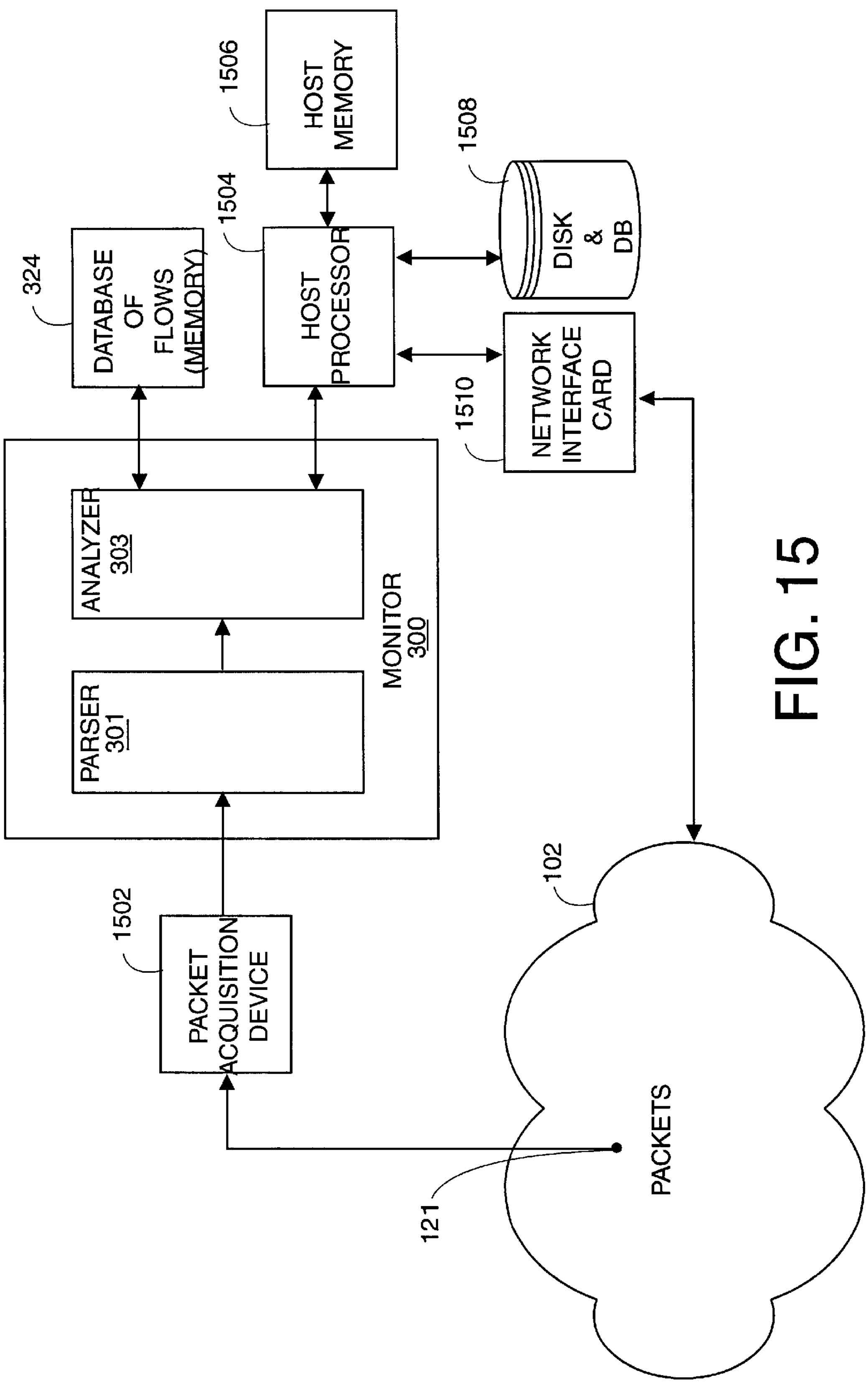

HOST MEMORY
1506
DATABASE OF FLOWS (MEMORY)
324
HOST PROCESSOR
1504
DISK & DB
1508
NETWORK INTERFACE CARD
1510
ANALYZER
303
PARSER
301
MONITOR
300
PACKET ACQUISITION DEVICE
1502
PACKETS
102
121

FIG. 15

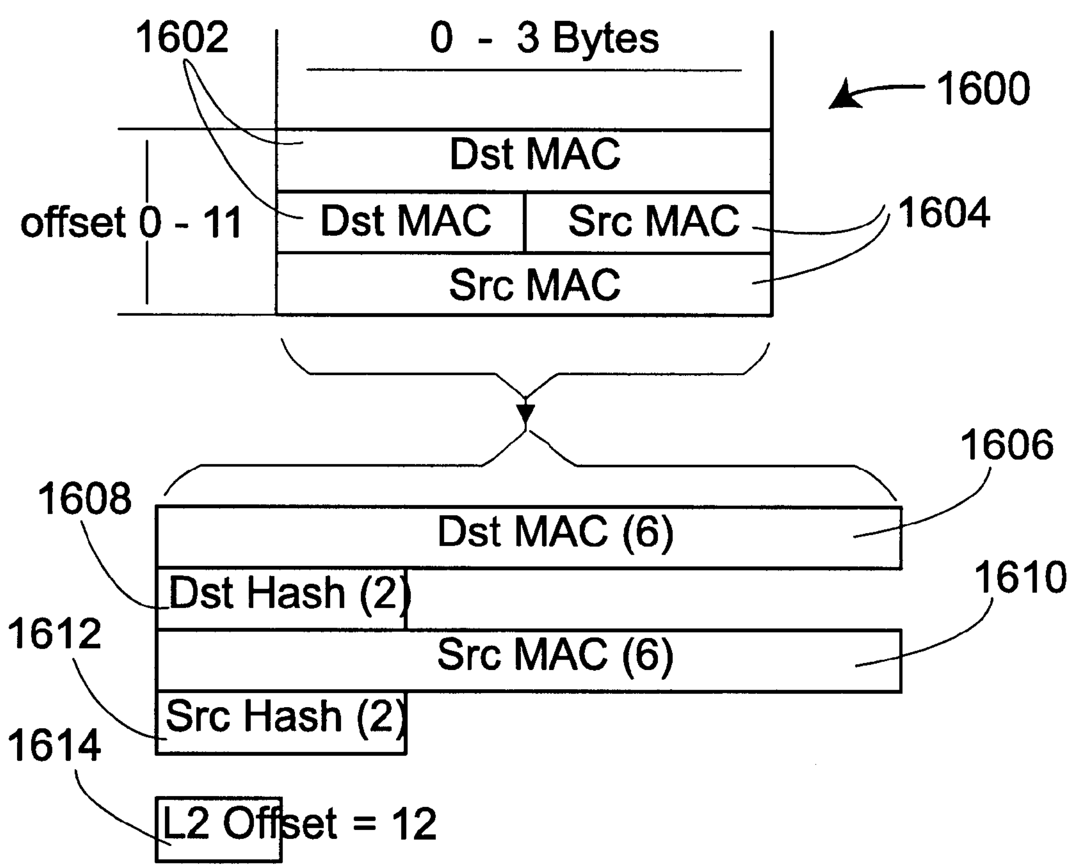

1602
0 - 3 Bytes
1600
Dst MAC
offset 0 - 11
Dst MAC
Src MAC
1604
Src MAC
1606
1608
Dst MAC (6)
Dst Hash (2)
1610
1612
Src MAC (6)
Src Hash (2)
1614
L2 Offset = 12

FIG. 16

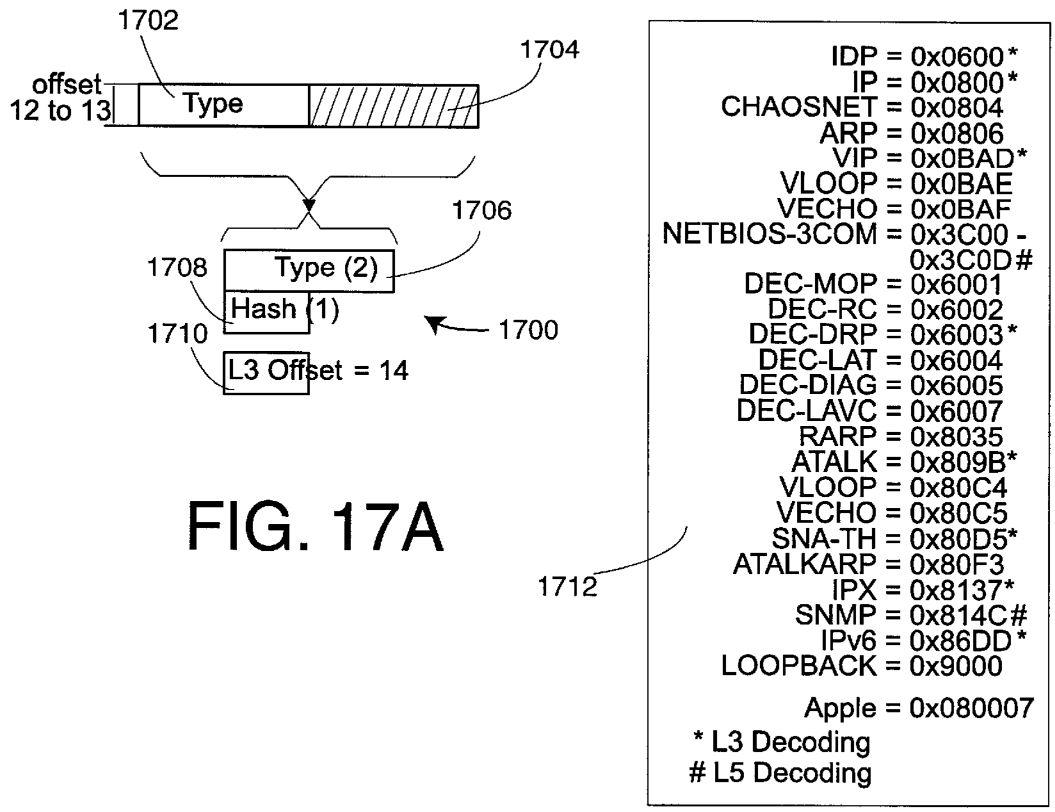


FIG. 17A

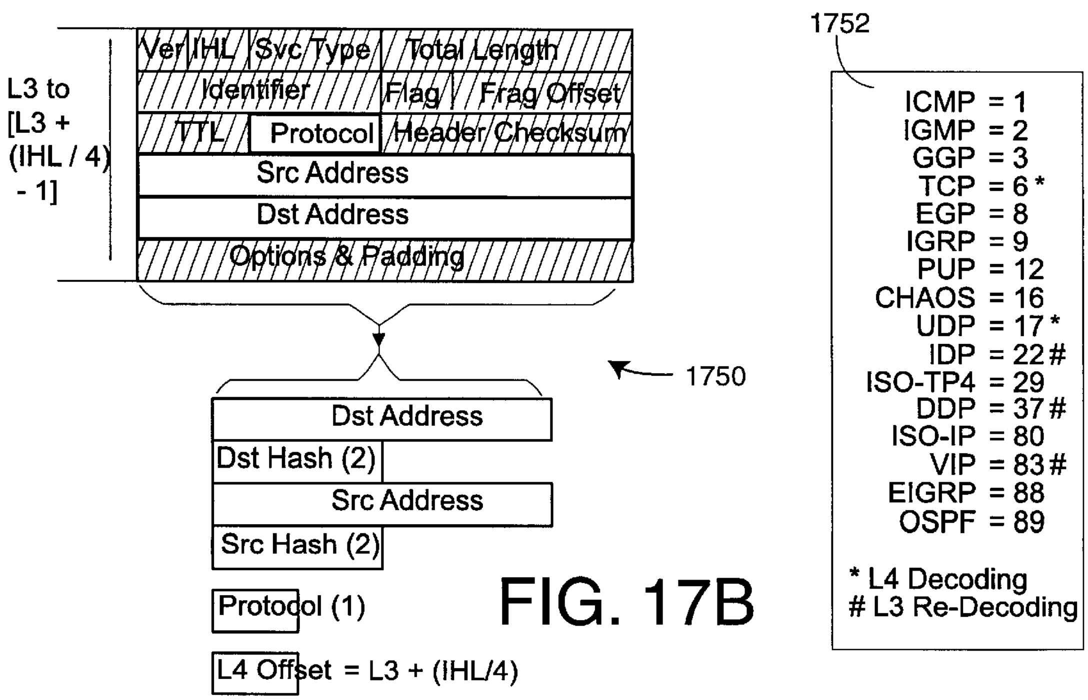


FIG. 17B

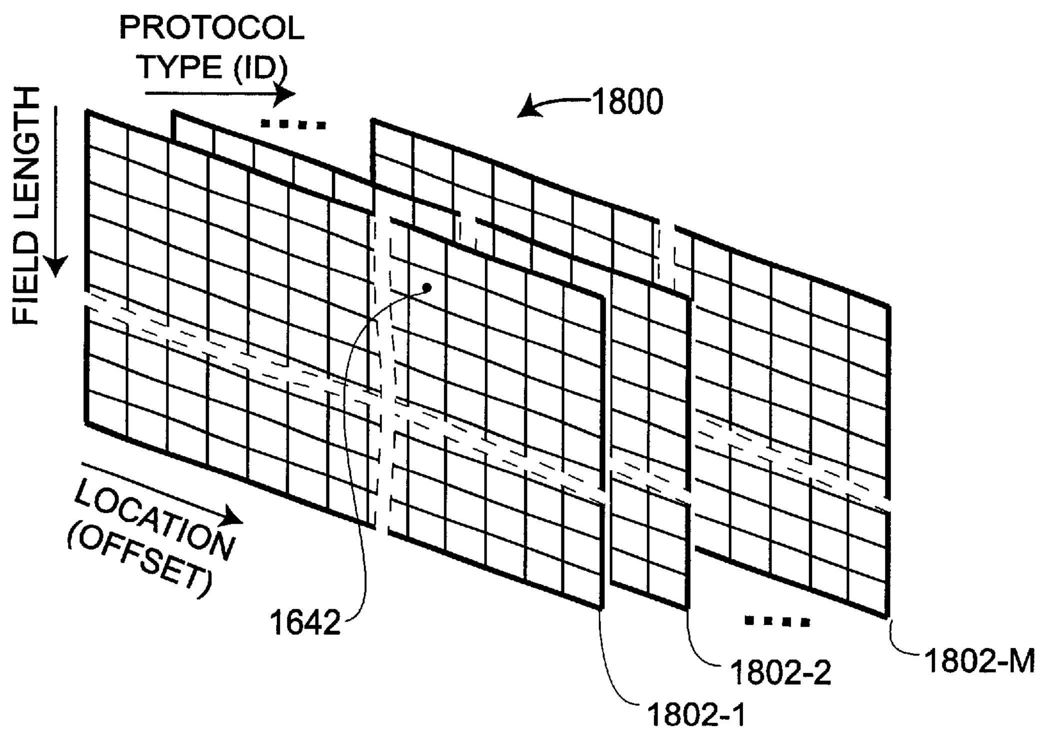


FIG. 18A

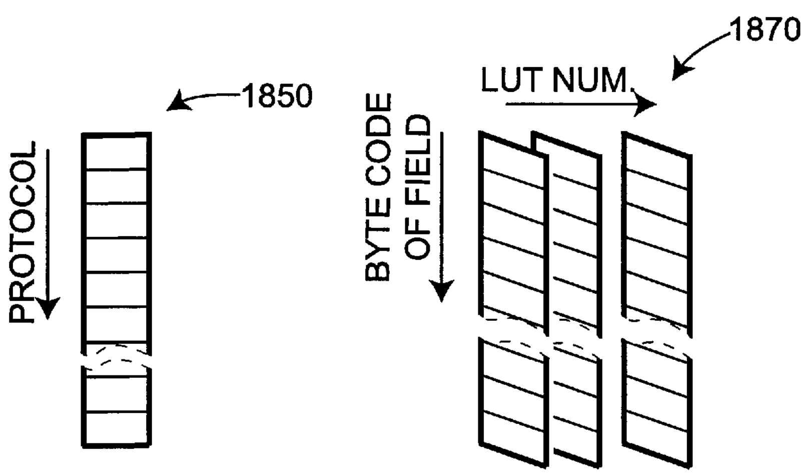


FIG. 18B

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 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. 09/608,237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK, to inventors Dietz, et al., filed Jun. 30, 2000, and incorporated herein by reference.

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, 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, 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, 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.

COPYRIGHT NOTICE

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 notificatior of network problems.

Related and incorporated by reference U.S. patent application Ser. No. 09/607,237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK, to inventors Dietz, et al, 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. **17**A 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. **17**B is an example of an IP packet, for example, of the Ethertype packet shown in FIGS. **16** and **17**A, and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. **18**A 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. **18**B 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 so 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—an 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 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 process or 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, 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.

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 $R=X_{max}-X_{min}$.

$$\text{Arithmetic Mean } \overline{X} = \frac{\sum X}{N}.$$

$$\text{Root Mean Square } RMS = \sqrt{\frac{\sum (X^2)}{N}}.$$

$$\text{Variance } \sigma^2 = \frac{\sum (X-\overline{X})^2}{N} = \frac{\left(\sum X^2\right) - 2\overline{X}\left(\sum X\right) + N(\overline{X}^2)}{N}.$$

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

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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1^{st} 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

-continued

Metric Specification			
Metric	Applicability	Units	Description
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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) from the Server to the Client and is demarcated (or terminated) by 1^{st} 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 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Client to the Server and is demarcated (or terminated) by 1^{st} 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

-continued

Metric Specification			
Metric	Applicability	Units	Description
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 1^{st} Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) a transaction request from the Client to the Server and is demarcated (or terminated) by 1^{st} 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 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Server to the Client and is demarcated (or terminated) by 1^{st} 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)

-continued

Metric Specification			
Metric	Applicability	Units	Description
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 a and the start of their subsequent transaction response from the Client to the Server.

A Server->Client transaction starts with the 1^{st} Transport Protocol Data Packet/Unit (TPDU) of a transaction request from the Server to the Client and is demarcated (or terminated) by 1^{st} 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 1^{st} Transport Protocol Data Packet/Unit (TPDU) a transaction request from the Server to the Client and is demarcated (or terminated) by 1^{st} 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 1^{st} 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 Connection GracefulTermination 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, CSConnectionRetransmissions 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, SCConnectionRetransmissions 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, CSConnectionOutOfOrders 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 CSConnectionRetransmissions 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, SCConnectionOutOfOrders 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 SCConnectionRetransmissions 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, CSConnectionWindow 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, SSConnectionWindow measures number of Transport-level Acknowledges within established connection lifetimes and their relative sizes from the to 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, SCConnectionWindow 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, CSConnectionWindow 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, SCConnectionWindow 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.

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 coupled to the connection point;

(b) for each received packet, looking up a flow-entry database for containing one or more flow-entries for previously encountered conversational flows, the looking up to determine if the received packet is of an existing flow, a conversational flow including an exchange of a sequence of one or more packets in any direction between two network entities as a result of a particular activity using a particular layered set of one or more network protocols, a conversational flow further having a set of one or more states, including an initial state;

(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

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, and

wherein at least one step of the set consisting of of step (a) and step (b) includes identifying the protocol being used in the packet from a plurality of protocols at a plurality of protocol layer levels,

such that the flow-entry database is to store flow entries for a plurality of conversational flows using a plurality of protocols, at a plurality of layer levels, including levels above the network layer.

2. A method according to claim **1**, wherein step (b) includes

extracting identifying portions from the packet,

wherein the extracting at any layer level is a function of the protocol being used at the layer level, and

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 **1**, 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 (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 (d) 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 for containing one or more flow-entries for previously encountered conversational flows to which a received packet may belong, a conversational flow including an exchange of a sequence of one or more packets in any direction between two network entities as a result of a particular activity using a particular layered set of one or more network protocols, a conversational flow further having a set of one or more states, including an initial state; and

(c) an analyzer subsystem coupled to the packet acquisition device configured to lookup 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,

wherein the analyzer subsystem is further configured to identify the protocol being used in the packet from a plurality of protocols at a plurality of protocol layer levels, and

wherein the database is to store flow entries for a plurality of conversational flows using a plurality of protocols, at a plurality of layer levels, including levels above the network layer.

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.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,839,751 B1 Page 1 of 1
DATED : January 4, 2005
INVENTOR(S) : Dietz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

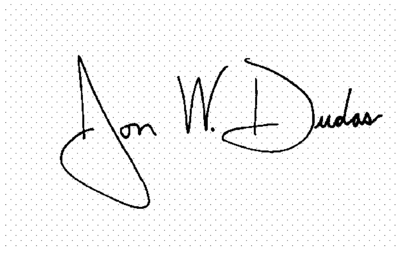
Column 6,
Line 65, please change “In so” to -- In some --.

Column 13,
Line 23, please change, “pattern—a signature—an be” to -- pattern—a signature—can be --.

Column 51,
Line 13, please change “claim 1” to -- claim 7 --.

Signed and Sealed this

Eighth Day of March, 2005



JON W. DUDAS
Director of the United States Patent and Trademark Office

US006954789B2

(12) **United States Patent**
Dietz et al.

(10) **Patent No.: US 6,954,789 B2**
(45) **Date of Patent: Oct. 11, 2005**

(54) **METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK**

(75) Inventors: **Russell S. Dietz**, San Jose, CA (US); **Joseph R. Maixner**, Aptos, CA (US); **Andrew A. Koppenhaver**, Littleton, CO (US); **William H. Bares**, Germantown, TN (US); **Haig A. Sarkissian**, San Antonio, TX (US); **James F. Torgerson**, Andover, MN (US)

(73) Assignee: **Hi/fn, Inc.**, Los Gatos, CA (US)

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

(21) Appl. No.: **10/684,776**

(22) Filed: **Oct. 14, 2003**

(65) **Prior Publication Data**

US 2004/0083299 A1 Apr. 29, 2004

Related U.S. Application Data

(63) Continuation of application No. 09/608,237, filed on Jun. 30, 2000, now Pat. No. 6,651,099.

(60) Provisional application No. 60/141,903, filed on Jun. 30, 1999.

(51) **Int. Cl.**[7] **G06F 15/173**

(52) **U.S. Cl.** **709/224**; 370/392

(58) **Field of Search** 709/200, 201, 709/220, 223, 224, 231, 232, 236, 238–240, 246; 370/389, 392

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,949,369 A	4/1976	Churchill, Jr.	711/128
4,458,310 A	7/1984	Chang	711/119
4,559,618 A	12/1985	Houseman et al.	365/49

(Continued)

FOREIGN PATENT DOCUMENTS

JP	2003-44510 A	2/2003

OTHER PUBLICATIONS

Advanced Methods for Storage and Retrieval in Image; http://www.cs.tulane.edu/ww/Prototype/proposal.html; 1998.

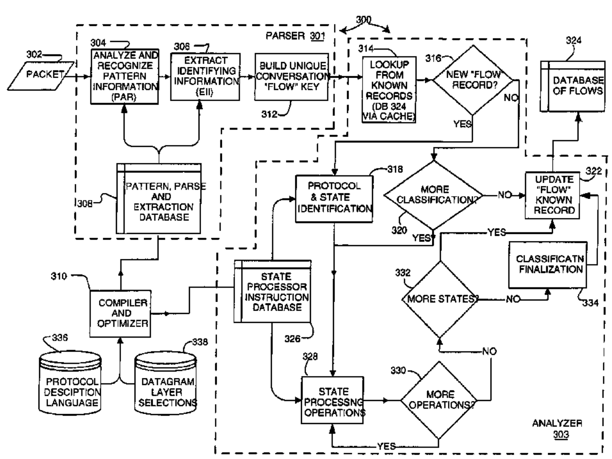
(Continued)

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.

49 Claims, 18 Drawing Sheets



U.S. PATENT DOCUMENTS

4,736,320	A		4/1988	Bristol	364/300
4,891,639	A		1/1990	Nakamura	340/825.5
4,910,668	A		3/1990	Okamoto et al.	711/207
4,972,453	A		11/1990	Daniel, III et al.	379/10
5,101,402	A		3/1992	Chiu et al.	370/17
5,247,517	A		9/1993	Ross et al.	370/85.5
5,247,693	A		9/1993	Bristol	395/800
5,249,292	A		9/1993	Chiappa	395/650
5,315,580	A		5/1994	Phaal	370/13
5,339,268	A		8/1994	Machida	365/49
5,351,243	A		9/1994	Kalkunte et al.	370/92
5,365,514	A		11/1994	Hershey et al.	370/17
5,375,070	A		12/1994	Hershey et al.	364/550
5,394,394	A		2/1995	Crowther et al.	370/60
5,414,650	A		5/1995	Hekhuis	364/715.02
5,414,704	A		5/1995	Spinney	370/60
5,430,709	A		7/1995	Galloway	370/13
5,432,776	A		7/1995	Harper	370/17
5,493,689	A		2/1996	Waclawsky et al.	395/821
5,500,855	A		3/1996	Hershey et al.	370/17
5,511,213	A		4/1996	Correa	395/800
5,511,215	A		4/1996	Terasaka et al.	395/800
5,530,834	A		6/1996	Colloff et al.	711/136
5,530,958	A		6/1996	Agarwal et al.	711/3
5,535,338	A		7/1996	Krause et al.	395/200.2
5,568,471	A		10/1996	Hershey et al.	370/17
5,574,875	A		11/1996	Stansfield et al.	395/403
5,586,266	A		12/1996	Hershey et al.	395/200.11
5,606,668	A		2/1997	Shwed	395/200.11
5,608,662	A		3/1997	Large et al.	364/724.01
5,634,009	A		5/1997	Iddon et al.	395/200.11
5,651,002	A		7/1997	Van Seters et al.	370/392
5,680,585	A		10/1997	Bruell	703/26
5,684,954	A		11/1997	Kaiserswerth et al.	395/200.2
5,703,877	A		12/1997	Nuber et al.	370/395
5,720,032	A		2/1998	Picazo, Jr. et al.	395/200.2
5,721,827	A		2/1998	Logan et al.	709/217
5,732,213	A		3/1998	Gessel et al.	395/200.11
5,740,355	A		4/1998	Watanabe et al.	395/183.21
5,749,087	A		5/1998	Hoover et al.	711/108
5,761,424	A		6/1998	Adams et al.	395/200.47
5,761,429	A		6/1998	Thompson	709/224
5,764,638	A		6/1998	Ketchum	370/401
5,781,735	A		7/1998	Southard	395/200.54
5,784,298	A		7/1998	Hershey et al.	364/557
5,787,253	A		7/1998	McCreery et al.	395/200.61
5,799,154	A		8/1998	Kuriyan	709/223
5,802,054	A		9/1998	Bellenger	370/401
5,805,808	A		9/1998	Hasani et al.	395/200.2
5,812,529	A		9/1998	Czarnik et al.	370/245
5,819,028	A		10/1998	Manghirmalani et al.	395/185.1
5,825,774	A		10/1998	Ready et al.	370/401
5,835,726	A		11/1998	Shwed et al.	395/200.59
5,838,919	A		11/1998	Schwaller et al.	395/200.54
5,841,895	A		11/1998	Huffman	382/155
5,850,386	A		12/1998	Anderson et al.	370/241
5,850,388	A		12/1998	Anderson et al.	370/252
5,862,335	A		1/1999	Welch, Jr. et al.	395/200.54
5,878,420	A		3/1999	de la Salle	707/10
5,893,155	A		4/1999	Cheriton	711/144
5,903,754	A		5/1999	Pearson	395/680
5,917,821	A		6/1999	Gobuyan et al.	370/392
6,003,123	A		12/1999	Carter et al.	711/207
6,014,380	A		1/2000	Hendel et al.	370/392
6,097,699	A		8/2000	Chen et al.	370/231
6,115,393	A		9/2000	Engel et al.	370/469
6,118,760	A	*	9/2000	Zaumen et al.	370/229
6,243,667	B1	*	6/2001	Kerr et al.	703/27
6,269,330	B1		7/2001	Cidon et al.	704/43
6,272,151	B1		8/2001	Gupta et al.	370/489
6,279,113	B1		8/2001	Vaidya	713/201
6,282,570	B1		8/2001	Leung et al.	709/224
6,330,226	B1		12/2001	Chapman et al.	370/232
6,363,056	B1		3/2002	Beigi et al.	370/252
6,381,306	B1		4/2002	Lawson et al.	379/32
6,424,624	B1		7/2002	Galand et al.	370/231
6,430,409	B1		8/2002	Rossmann	455/422.1
6,452,915	B1	*	9/2002	Jorgensen	370/238
6,453,345	B2		9/2002	Trcka et al.	709/224
6,453,360	B1	*	9/2002	Muller et al.	709/250
6,466,985	B1	*	10/2002	Goyal et al.	709/238
6,483,804	B1	*	11/2002	Muller et al.	370/230
6,510,509	B1	*	1/2003	Chopra et al.	712/13
6,516,337	B1		2/2003	Tripp et al.	709/202
6,519,568	B1		2/2003	Harvey et al.	705/1
6,570,875	B1	*	5/2003	Hegde	370/389
6,625,657	B1		9/2003	Bullard	709/237
6,651,099	B1		11/2003	Dietz et al.	709/224
6,791,947	B2	*	9/2004	Oskouy et al.	370/238

OTHER PUBLICATIONS

Measurement and Analysis of the Digital DECT propagation Channel; IEEE; 1998.

R, Periakaruppam and E. Nemeth. "GTrace–A Graphical Traceroute Tool." 1999 Usenix LISA. Available on www.caida.org, URL: http://www.caida.org/outreach/papers/1999/GTrace/GTrace.pdf.

W. Stallings. "Packet Filtering in the SNMP Remote Monitor." Nov. 1994. Available on www.ddj.com, URL: http://www.ddj.com/documents/s=1013/ddj9411h/9411h.htm.

"Technical Note: the Narus System," Downloaded Apr. 29, 1999 from www.narus.com, Narus Corporation, Redwood City California.

* cited by examiner

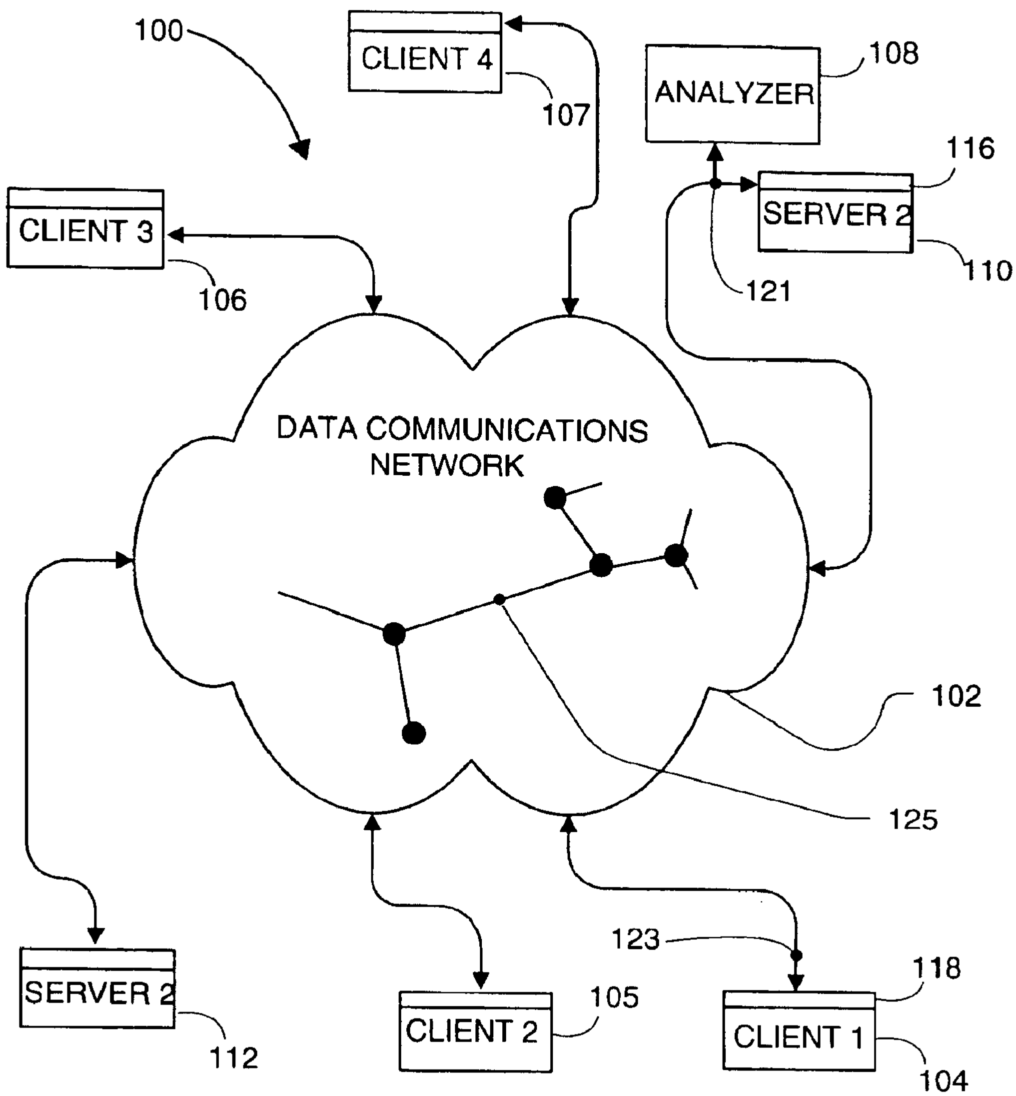

100
CLIENT 4
107
ANALYZER
108
116
SERVER 2
110
121
CLIENT 3
106
DATA COMMUNICATIONS
NETWORK
102
125
123
118
SERVER 2
112
CLIENT 2
105
CLIENT 1
104

FIG. 1

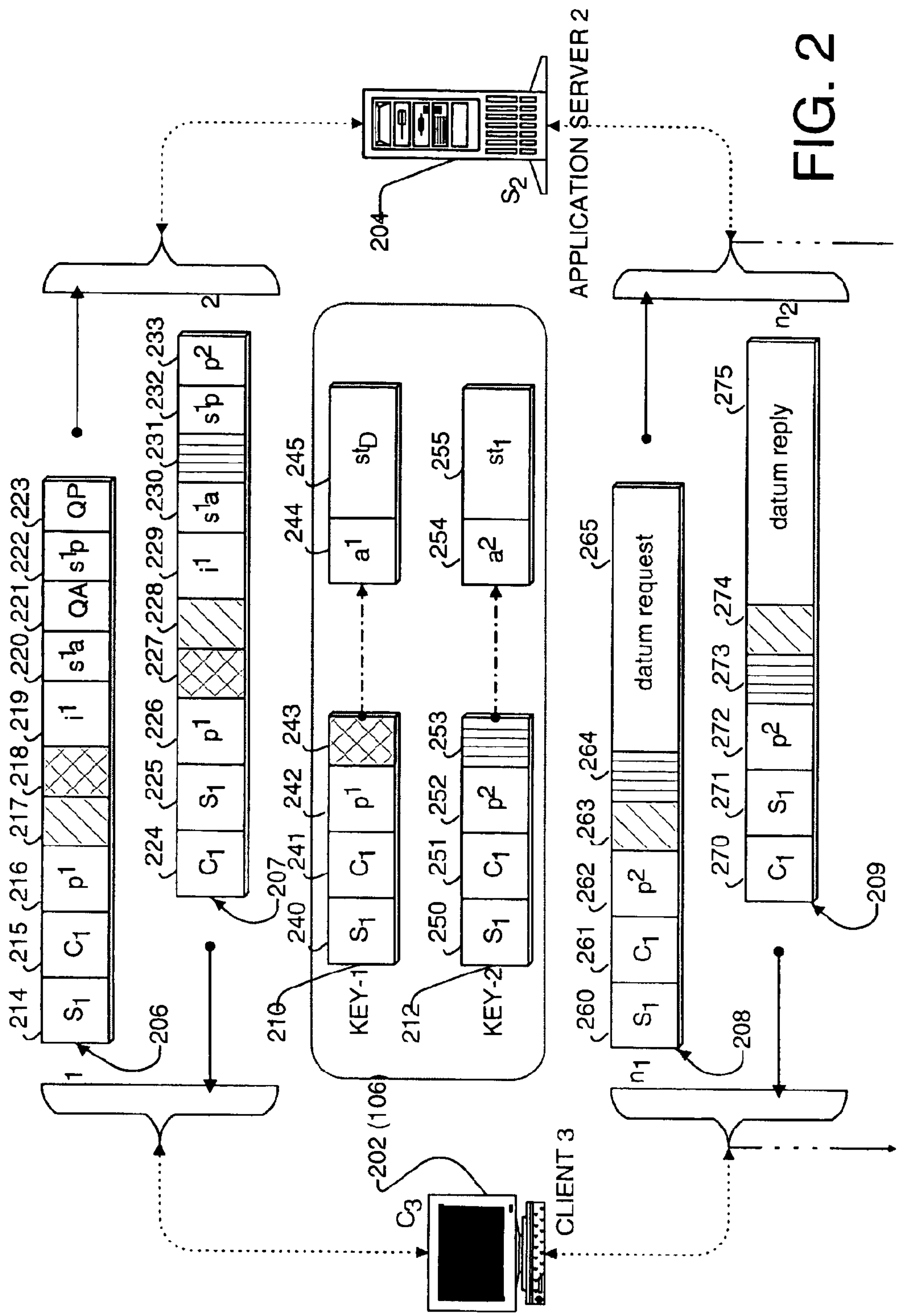
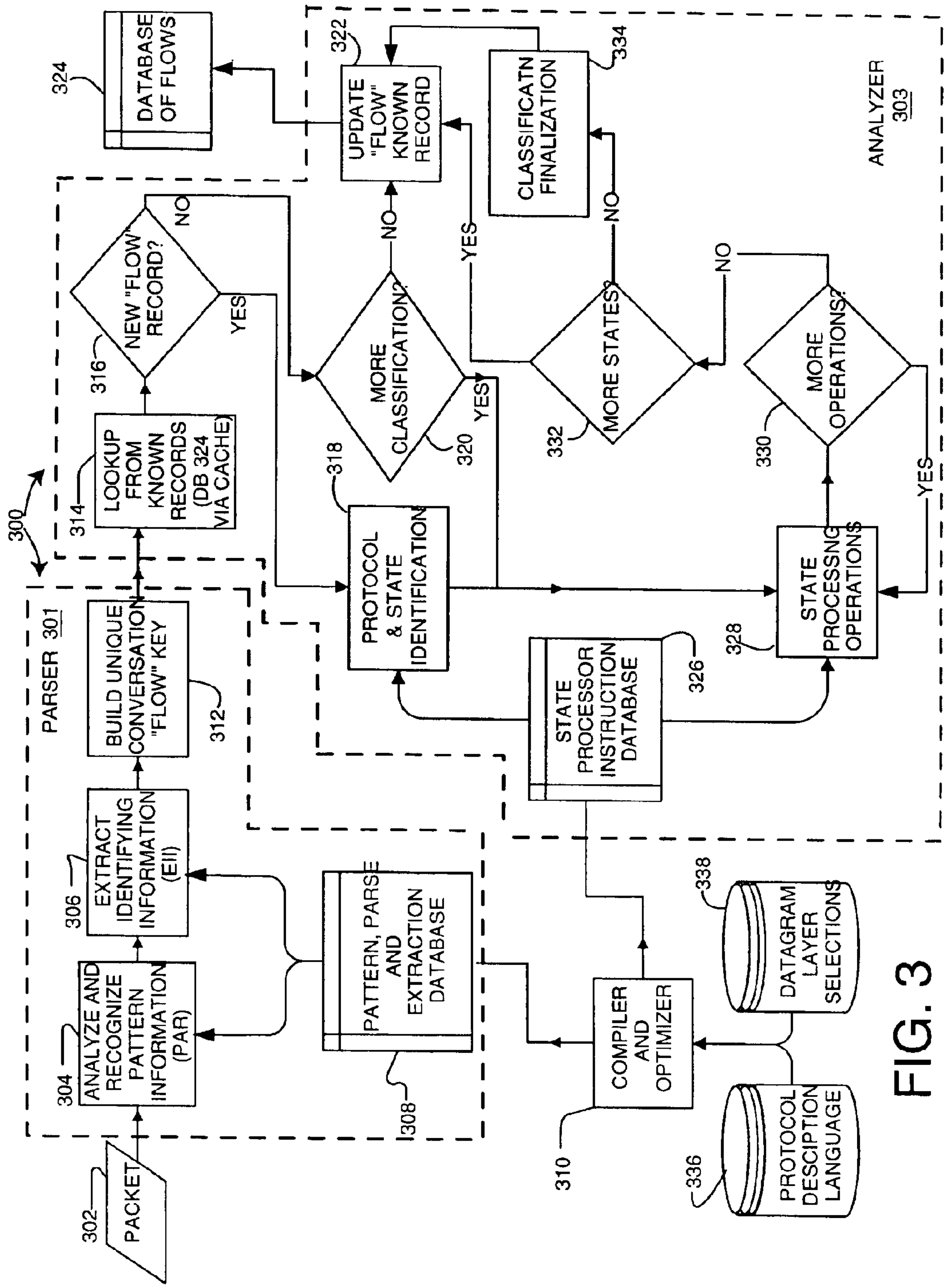

APPLICATION SERVER 2
CLIENT 3
KEY-1
KEY-2
datum request
datum reply

FIG. 2


300
PACKET
302
ANALYZE AND RECOGNIZE PATTERN INFORMATION (PAR)
304
EXTRACT IDENTIFYING INFORMATION (EII)
306
PATTERN, PARSE AND EXTRACTION DATABASE
308
BUILD UNIQUE CONVERSATION "FLOW" KEY
312
PARSER 301
LOOKUP FROM KNOWN RECORDS (DB 324 VIA CACHE)
314
NEW "FLOW" RECORD?
316
YES
NO
PROTOCOL & STATE IDENTIFICATION
318
MORE CLASSIFICATION?
320
UPDATE "FLOW" KNOWN RECORD
322
DATABASE OF FLOWS
324
CLASSIFICATN FINALIZATION
334
MORE STATES?
332
MORE OPERATIONS?
330
STATE PROCESSING OPERATIONS
328
STATE PROCESSOR INSTRUCTION DATABASE
326
ANALYZER 303
COMPILER AND OPTIMIZER
310
DATAGRAM LAYER SELECTIONS
338
PROTOCOL DESCIPTION LANGUAGE
336
FIG. 3

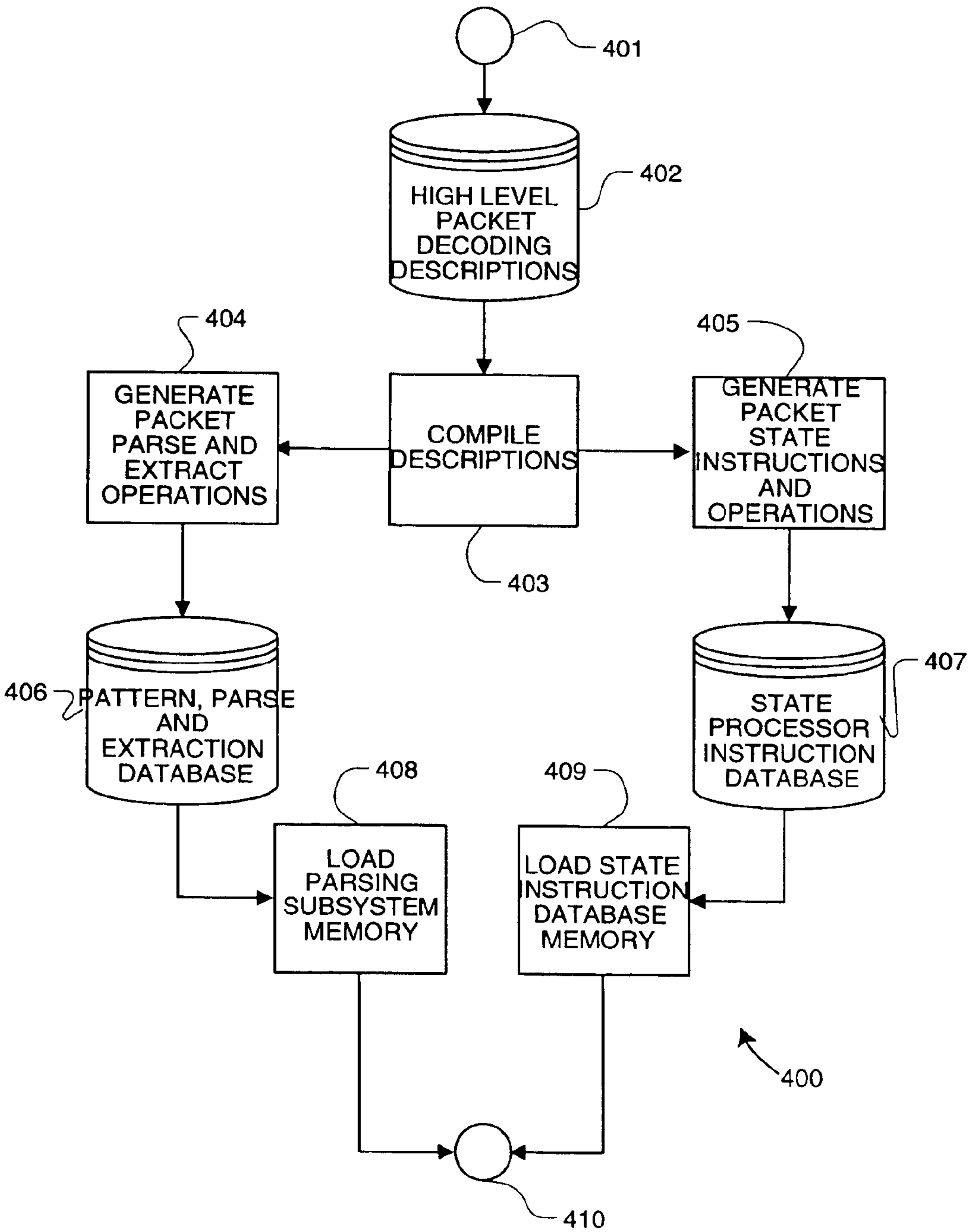
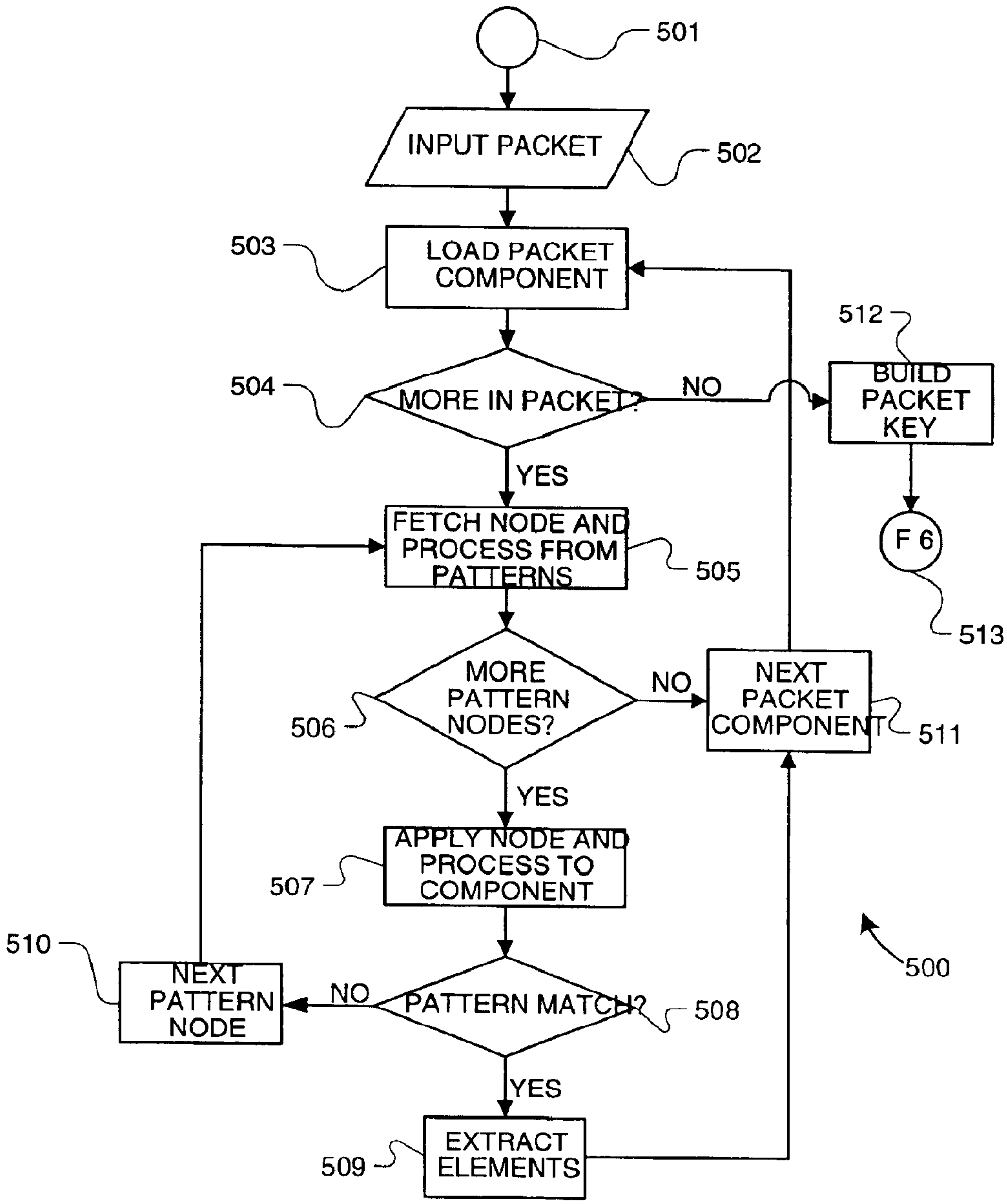

401
HIGH LEVEL PACKET DECODING DESCRIPTIONS
402
404
GENERATE PACKET PARSE AND EXTRACT OPERATIONS
COMPILE DESCRIPTIONS
403
405
GENERATE PACKET STATE INSTRUCTIONS AND OPERATIONS
406
PATTERN, PARSE AND EXTRACTION DATABASE
407
STATE PROCESSOR INSTRUCTION DATABASE
408
LOAD PARSING SUBSYSTEM MEMORY
409
LOAD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

FIG. 4



501
INPUT PACKET
502
503
LOAD PACKET COMPONENT
512
504
MORE IN PACKET?
NO
BUILD PACKET KEY
YES
FETCH NODE AND PROCESS FROM PATTERNS
505
F 6
513
MORE PATTERN NODES?
NO
NEXT PACKET COMPONENT
506
511
YES
APPLY NODE AND PROCESS TO COMPONENT
507
510
500
NEXT PATTERN NODE
NO
PATTERN MATCH?
508
YES
EXTRACT ELEMENTS
509

FIG. 5

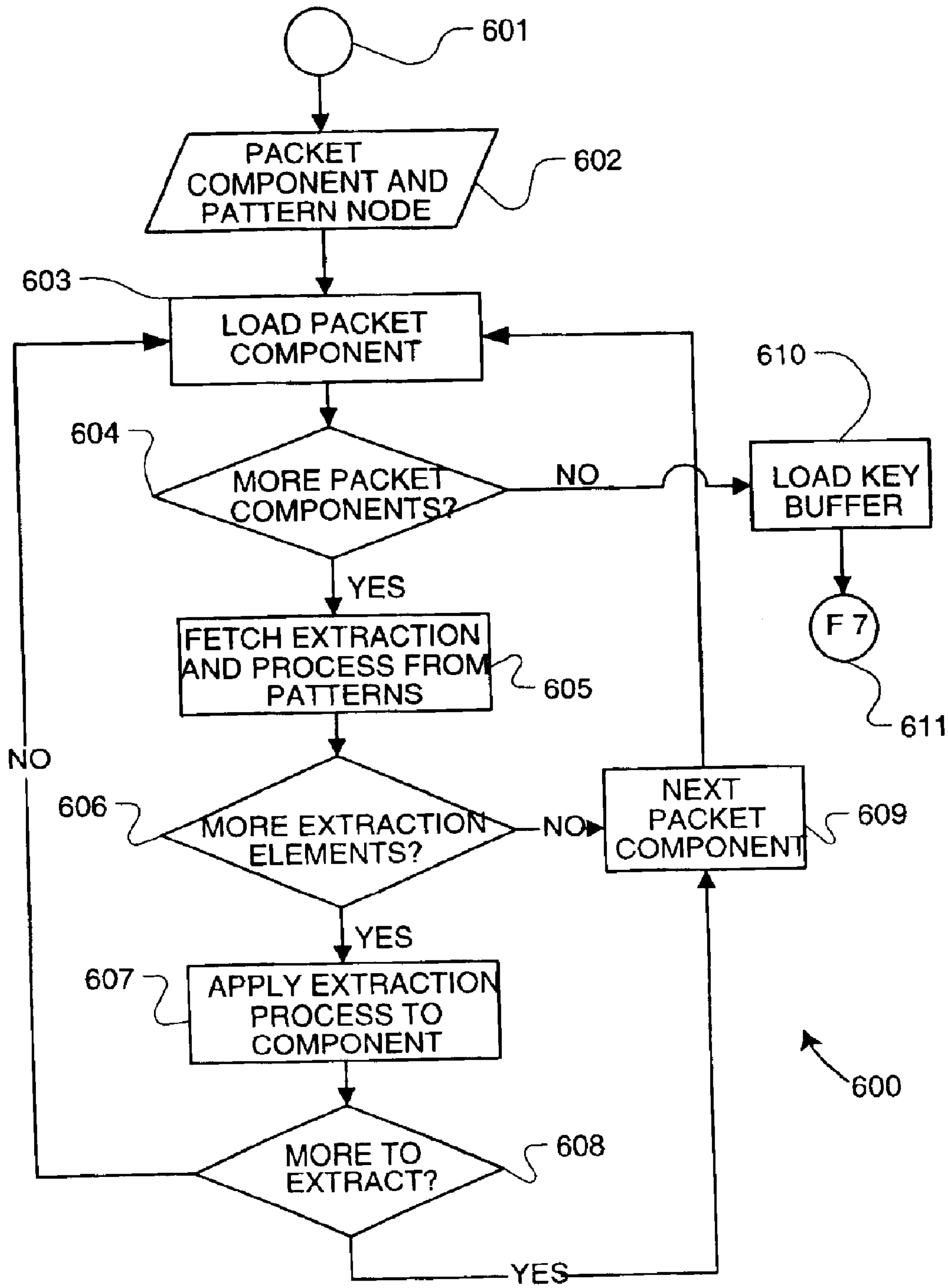

601
PACKET COMPONENT AND PATTERN NODE
602
603
LOAD PACKET COMPONENT
604
MORE PACKET COMPONENTS?
NO
610
LOAD KEY BUFFER
F 7
611
YES
FETCH EXTRACTION AND PROCESS FROM PATTERNS
605
NO
606
MORE EXTRACTION ELEMENTS?
NO
NEXT PACKET COMPONENT
609
YES
607
APPLY EXTRACTION PROCESS TO COMPONENT
600
MORE TO EXTRACT?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

FIG. 6

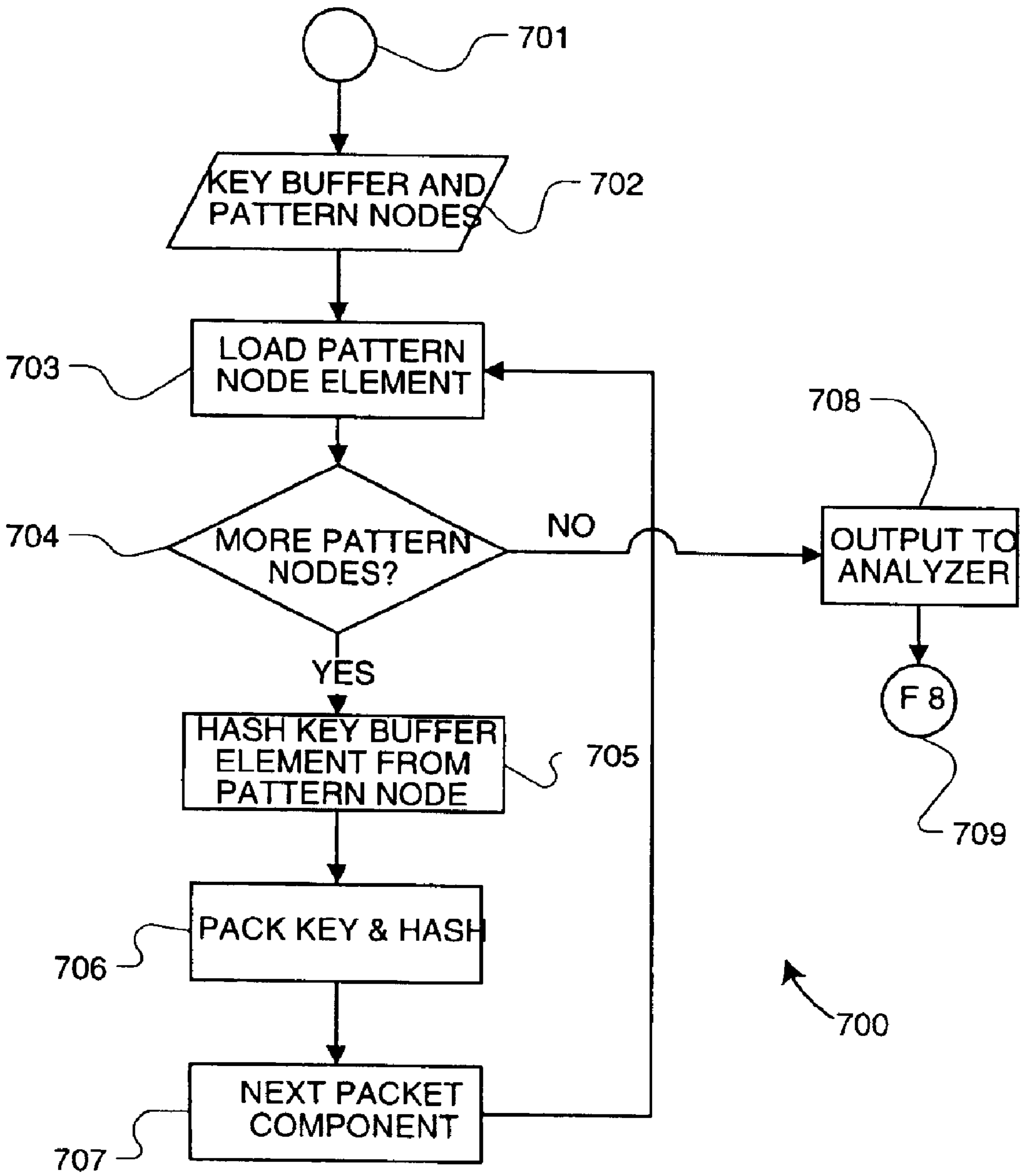

701
KEY BUFFER AND PATTERN NODES
702
703
LOAD PATTERN NODE ELEMENT
704
MORE PATTERN NODES?
NO
YES
708
OUTPUT TO ANALYZER
F 8
709
HASH KEY BUFFER ELEMENT FROM PATTERN NODE
705
PACK KEY & HASH
706
NEXT PACKET COMPONENT
707
700

FIG. 7

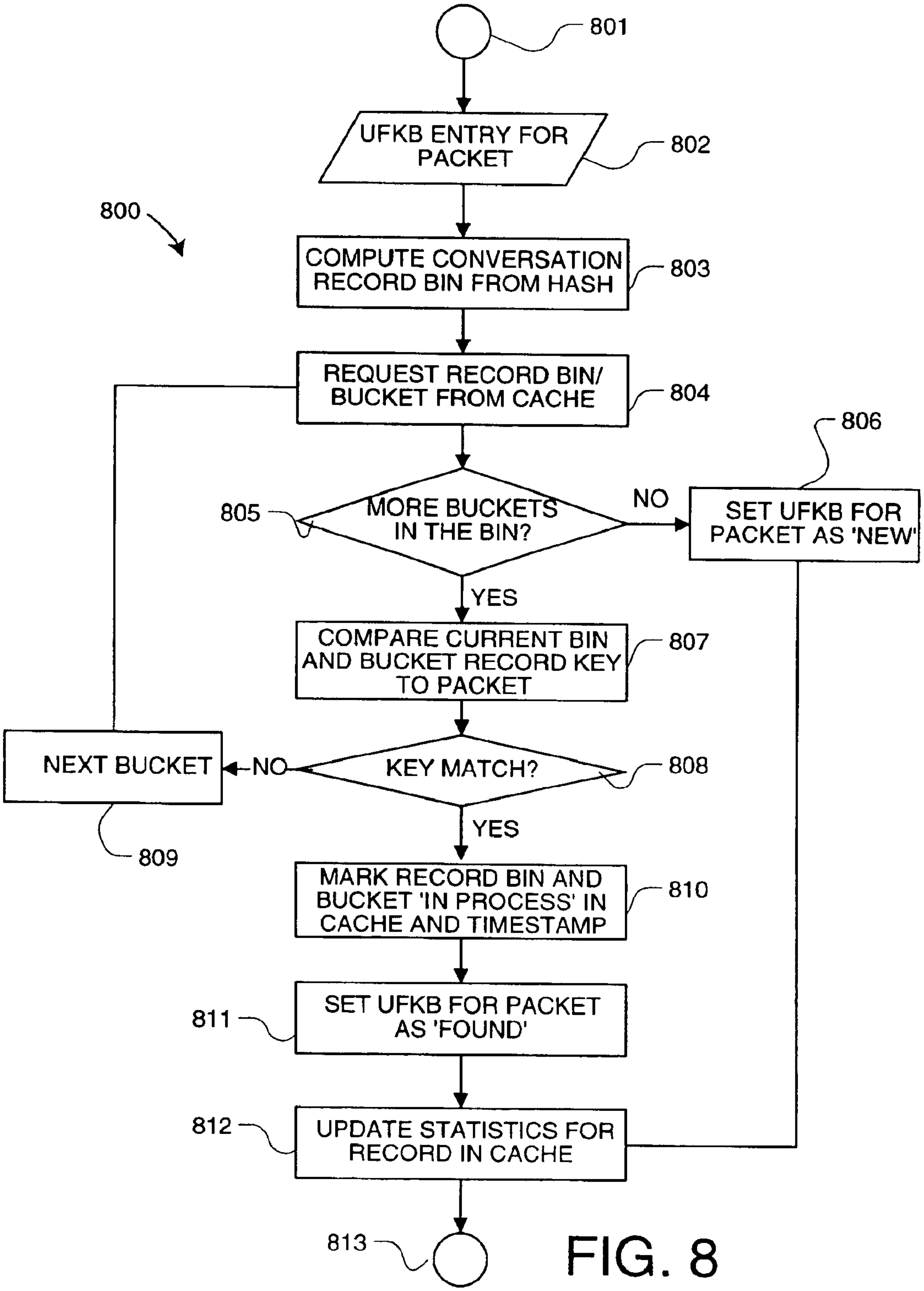
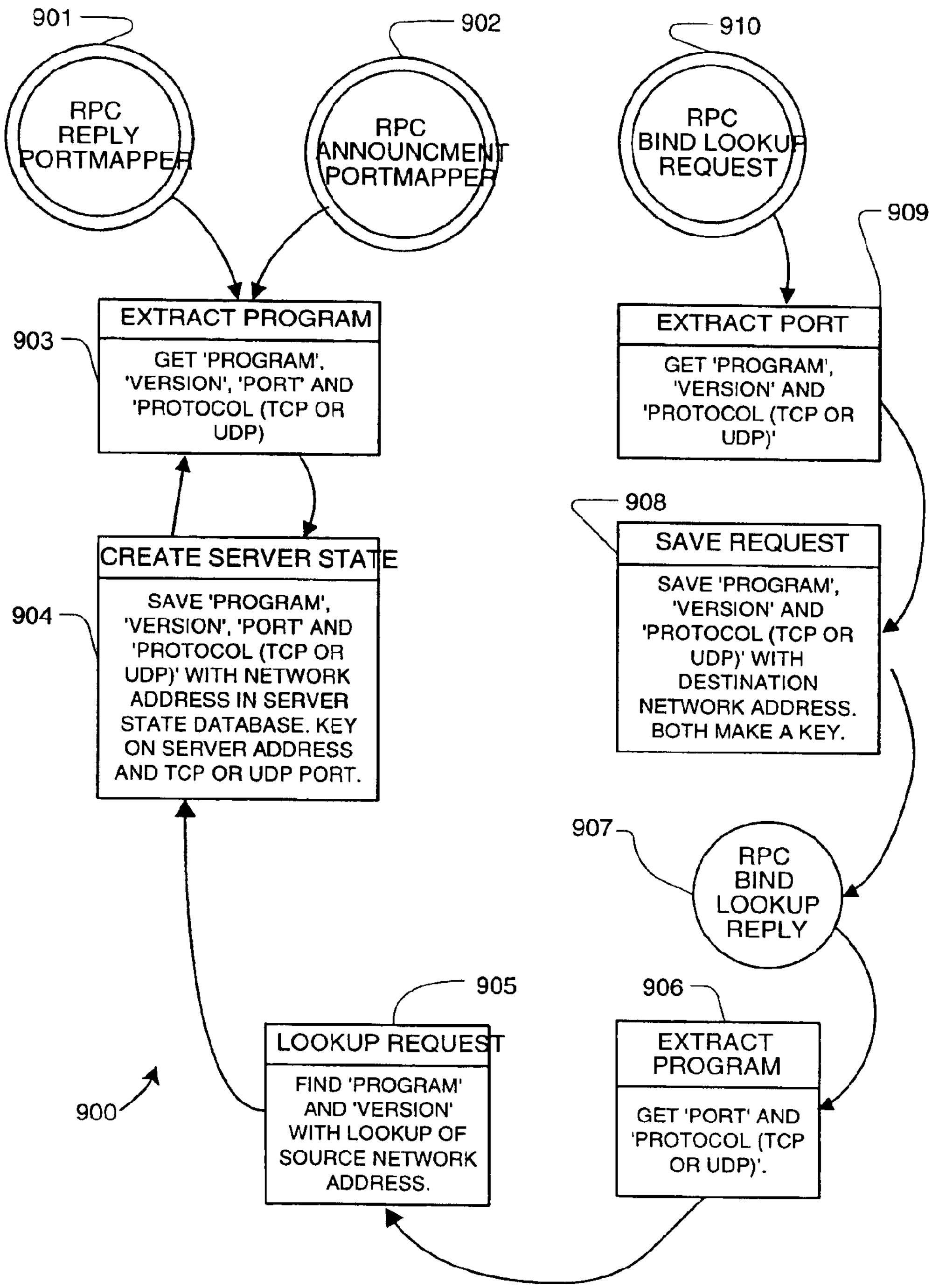

801
UFKB ENTRY FOR PACKET
802
800
COMPUTE CONVERSATION RECORD BIN FROM HASH
803
REQUEST RECORD BIN/ BUCKET FROM CACHE
804
806
805
MORE BUCKETS IN THE BIN?
NO
SET UFKB FOR PACKET AS 'NEW'
YES
COMPARE CURRENT BIN AND BUCKET RECORD KEY TO PACKET
807
NEXT BUCKET
NO
KEY MATCH?
808
809
YES
MARK RECORD BIN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

FIG. 8



901
RPC REPLY PORTMAPPER
902
RPC ANNOUNCMENT PORTMAPPER
910
RPC BIND LOOKUP REQUEST
909
903
EXTRACT PROGRAM
GET 'PROGRAM', 'VERSION', 'PORT' AND 'PROTOCOL (TCP OR UDP)
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.
904
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.
907
RPC BIND LOOKUP REPLY
905
LOOKUP REQUEST
FIND 'PROGRAM' AND 'VERSION' WITH LOOKUP OF SOURCE NETWORK ADDRESS.
906
EXTRACT PROGRAM
GET 'PORT' AND 'PROTOCOL (TCP OR UDP)'.
900

FIG. 9

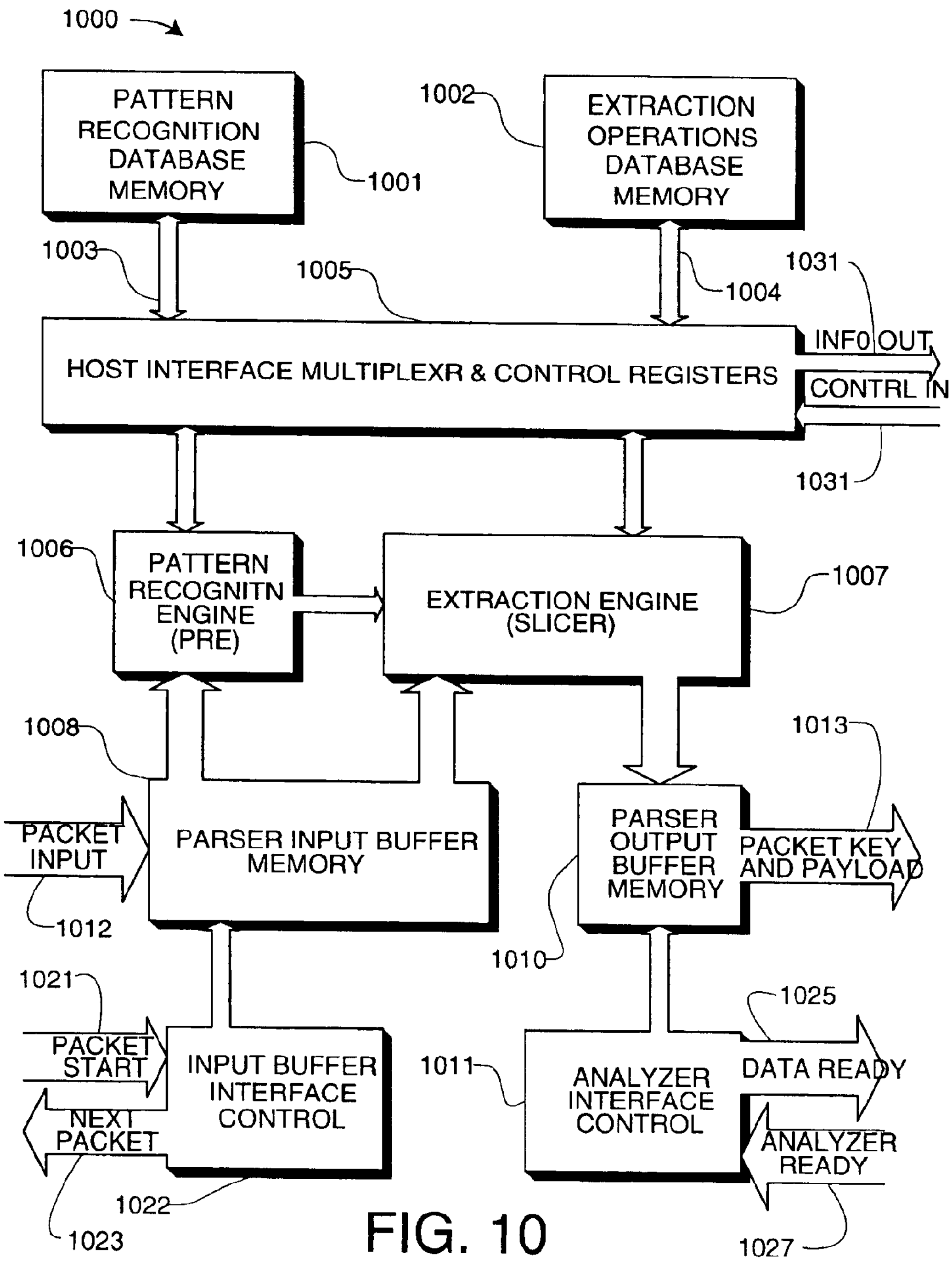

1000
PATTERN RECOGNITION DATABASE MEMORY
1001
1002
EXTRACTION OPERATIONS DATABASE MEMORY
1003
1005
1004
1031
HOST INTERFACE MULTIPLEXR & CONTROL REGISTERS
INFO OUT
CONTRL IN
1031
1006
PATTERN RECOGNITN ENGINE (PRE)
EXTRACTION ENGINE (SLICER)
1007
1008
1013
PACKET INPUT
PARSER INPUT BUFFER MEMORY
PARSER 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

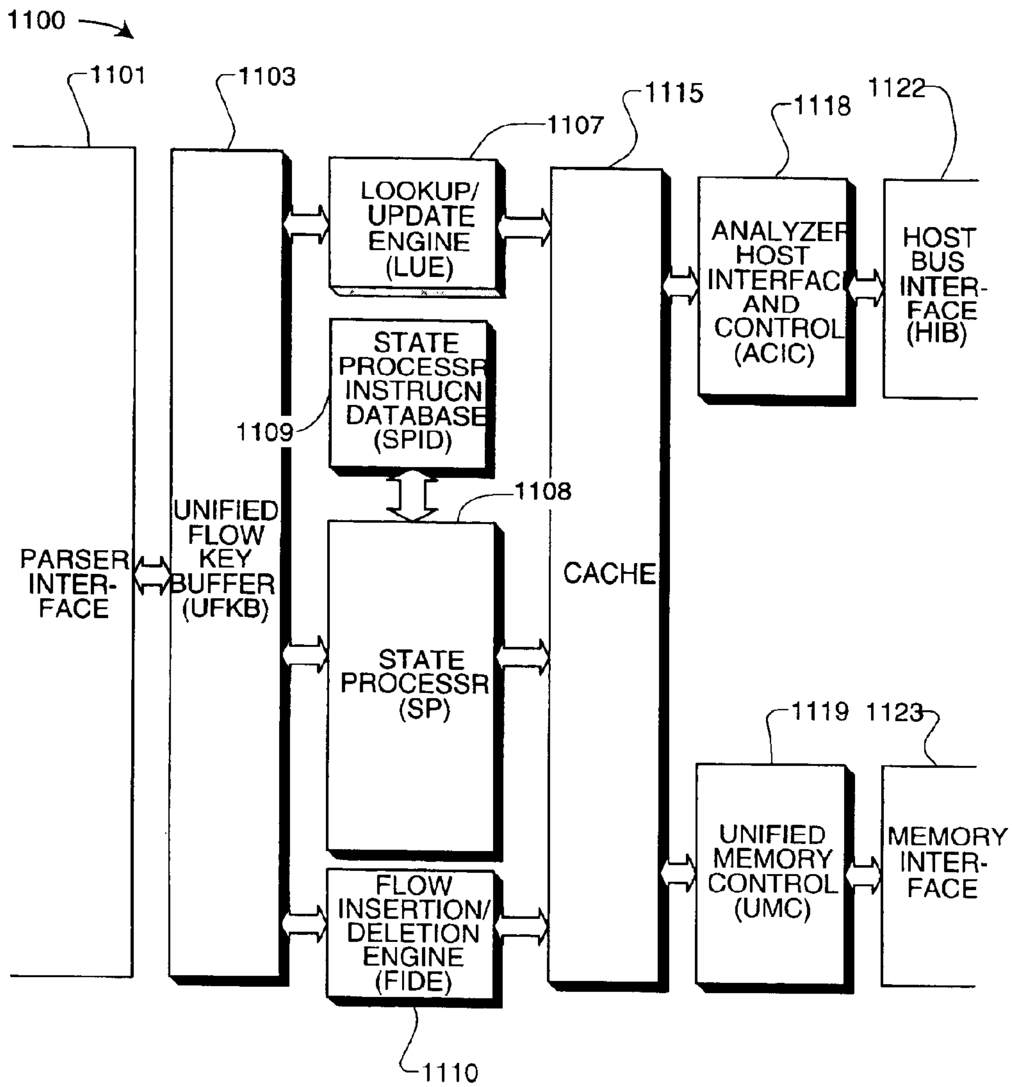

1100
1101
1103
1107
1115
1118
1122
LOOKUP/
UPDATE
ENGINE
(LUE)
CACHE
ANALYZER
HOST
INTERFACE
AND
CONTROL
(ACIC)
HOST
BUS
INTER-
FACE
(HIB)
STATE
PROCESSR
INSTRUCN
DATABASE
(SPID)
1109
1108
PARSER
INTER-
FACE
UNIFIED
FLOW
KEY
BUFFER
(UFKB)
STATE
PROCESSR
(SP)
1119
1123
UNIFIED
MEMORY
CONTROL
(UMC)
MEMORY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

FIG. 11

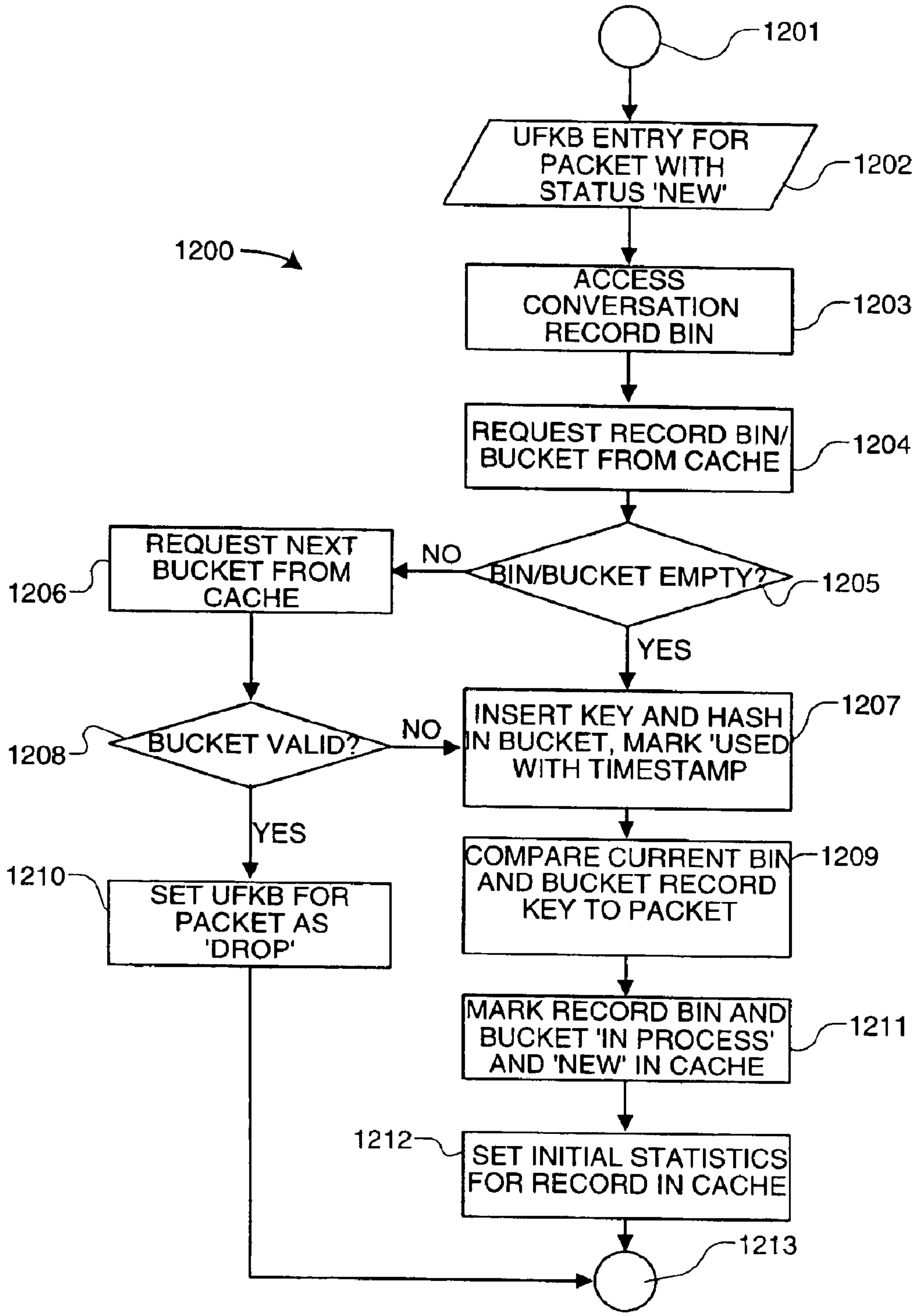

1201
UFKB ENTRY FOR PACKET WITH STATUS 'NEW'
1202
1200
ACCESS CONVERSATION RECORD BIN
1203
REQUEST RECORD BIN/ BUCKET FROM CACHE
1204
REQUEST NEXT BUCKET FROM CACHE
1206
NO
BIN/BUCKET EMPTY?
1205
YES
BUCKET VALID?
1208
NO
INSERT KEY AND HASH IN BUCKET, MARK 'USED WITH TIMESTAMP
1207
YES
COMPARE CURRENT 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

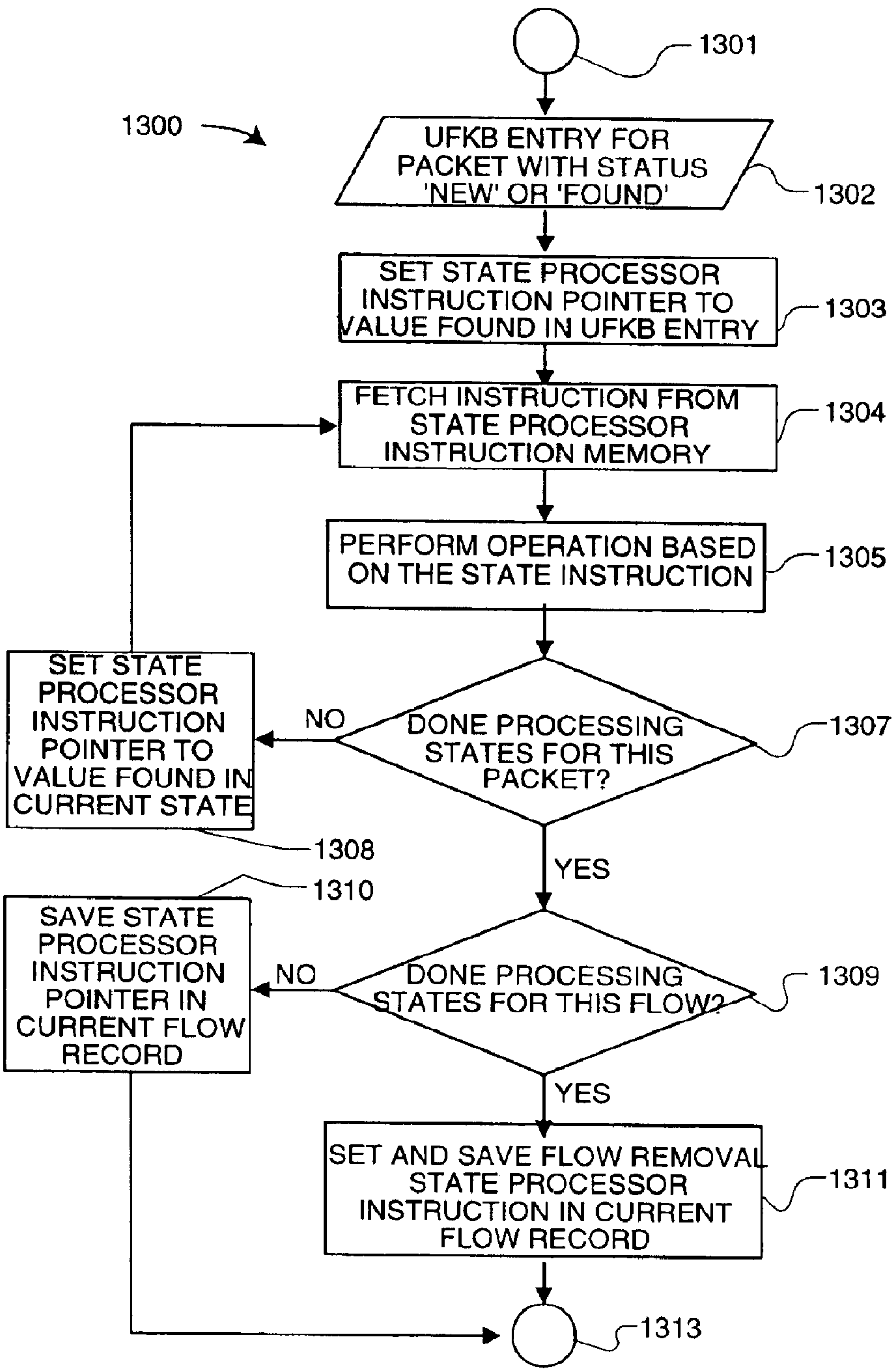

1301
1300
UFKB ENTRY FOR PACKET WITH STATUS 'NEW' OR 'FOUND'
1302
SET STATE PROCESSOR INSTRUCTION POINTER TO VALUE FOUND IN UFKB ENTRY
1303
FETCH INSTRUCTION FROM STATE PROCESSOR INSTRUCTION MEMORY
1304
PERFORM OPERATION BASED ON THE STATE INSTRUCTION
1305
DONE PROCESSING STATES FOR THIS PACKET?
1307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

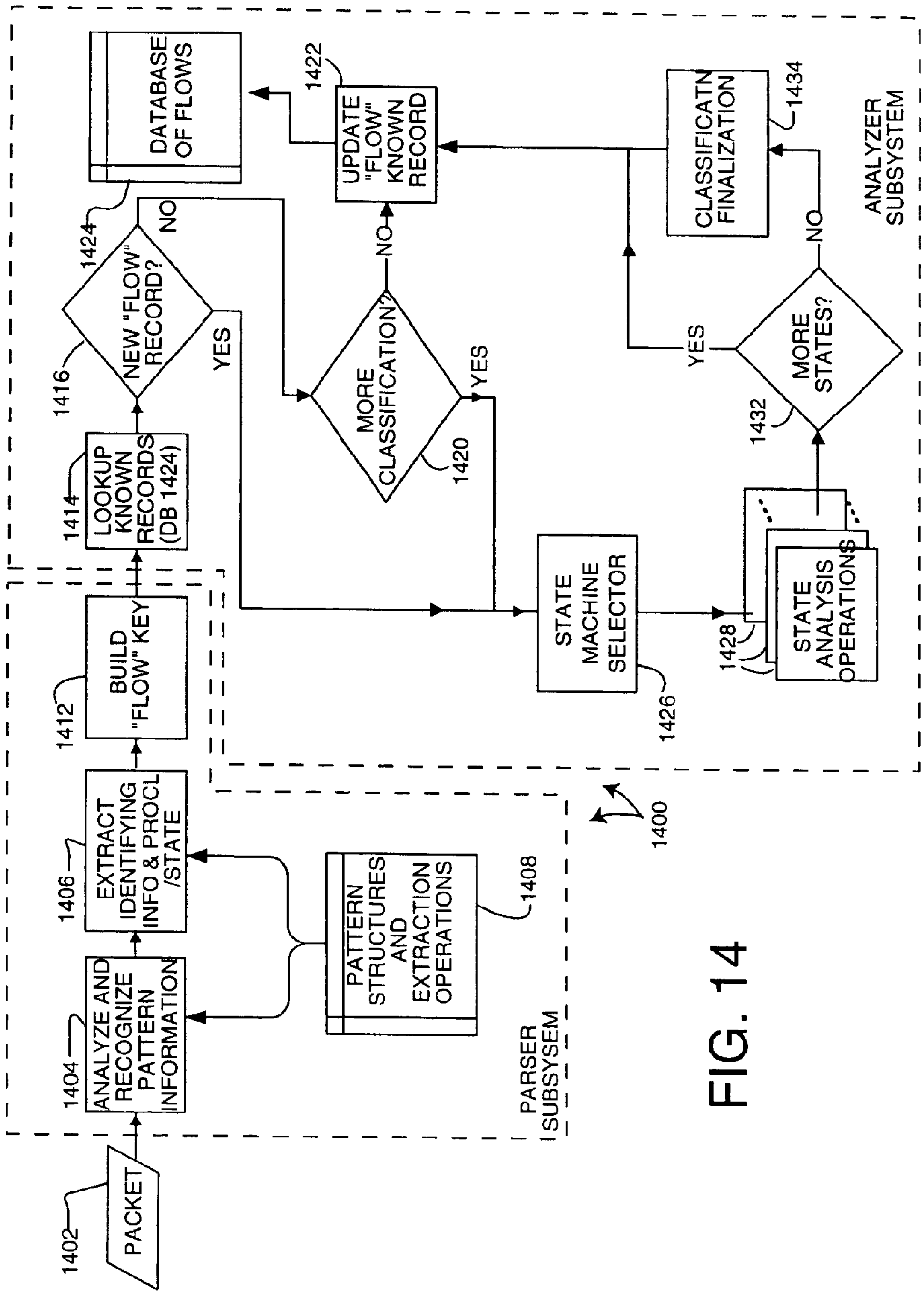

PACKET
1402
ANALYZE AND RECOGNIZE PATTERN INFORMATION
1404
EXTRACT IDENTIFYING INFO & PROCL /STATE
1406
PATTERN STRUCTURES AND EXTRACTION OPERATIONS
1408
PARSER SUBSYSEM
BUILD "FLOW" KEY
1412
LOOKUP KNOWN RECORDS (DB 1424)
1414
NEW "FLOW" RECORD?
1416
YES
NO
DATABASE OF FLOWS
1424
MORE CLASSIFICATION?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

FIG. 14

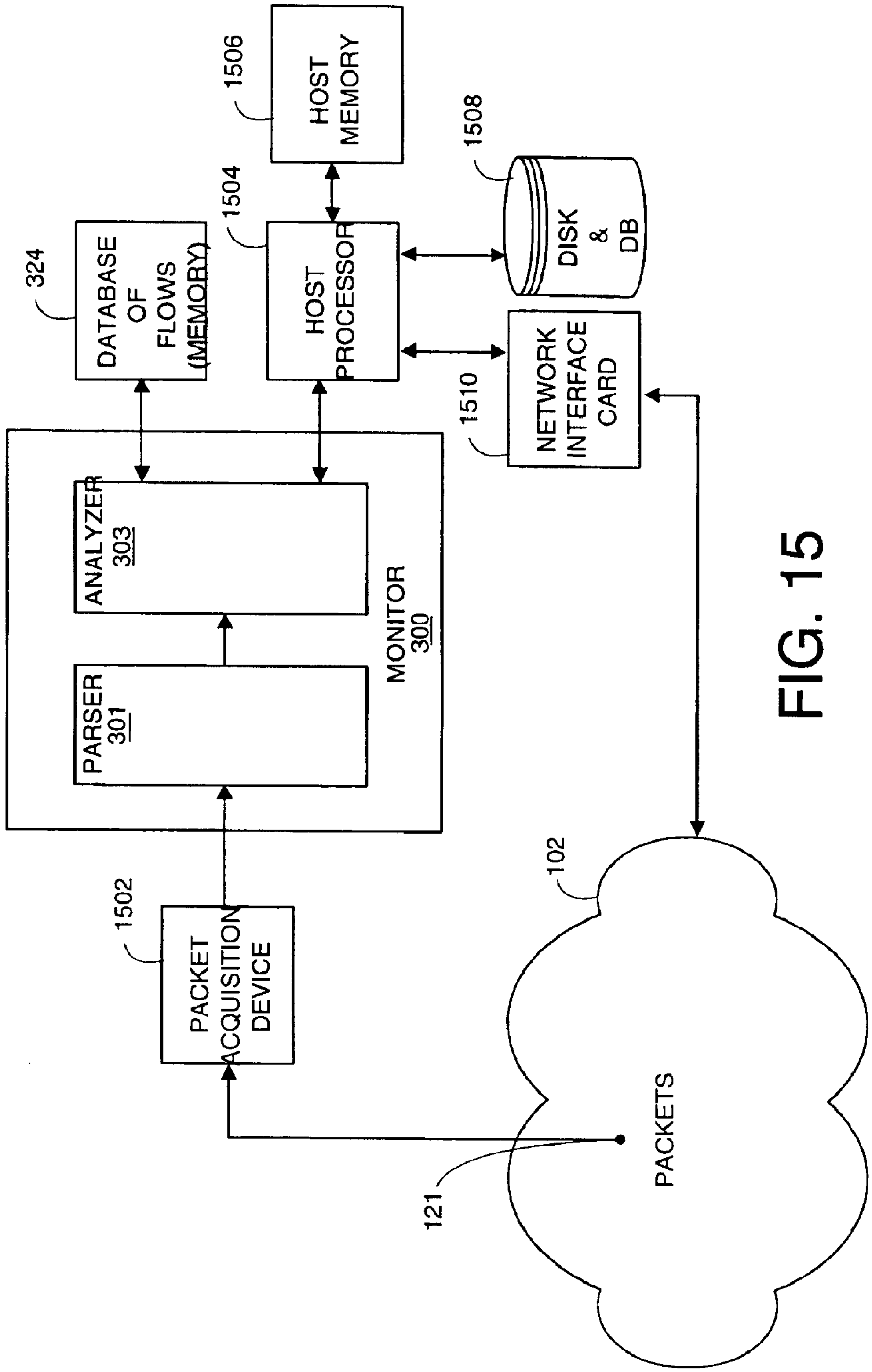

1506
HOST MEMORY
324
DATABASE OF FLOWS (MEMORY)
1504
HOST PROCESSOR
1508
DISK & DB
1510
NETWORK INTERFACE CARD
ANALYZER 303
PARSER 301
MONITOR 300
1502
PACKET ACQUISITION DEVICE
102
PACKETS
121

FIG. 15

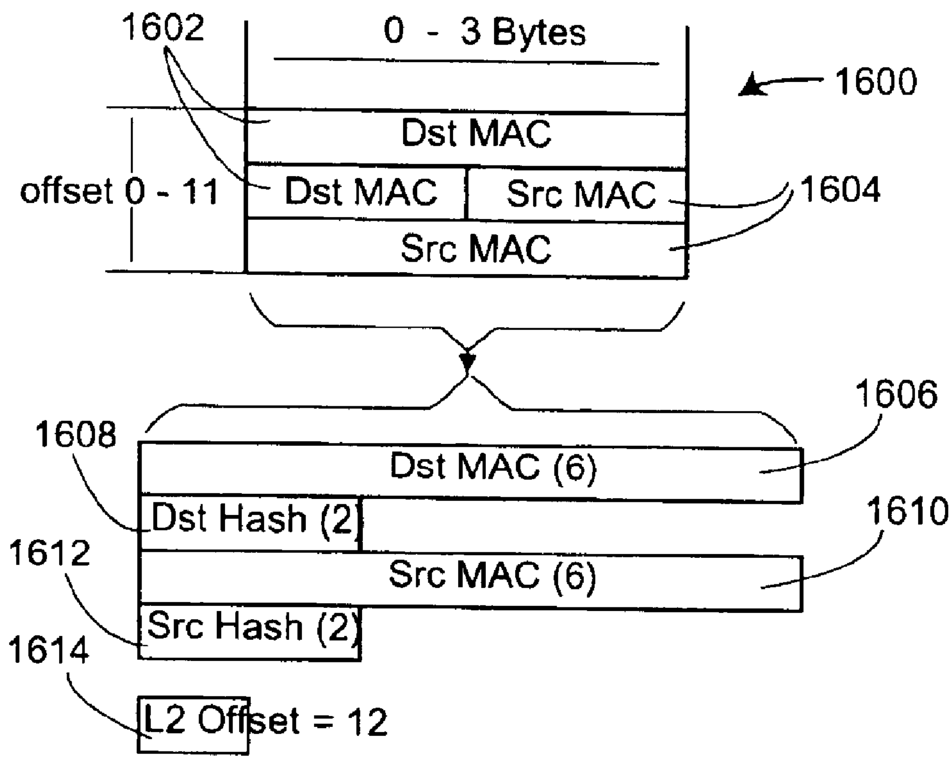

1602
0 - 3 Bytes
1600
Dst MAC
offset 0 - 11
Dst MAC
Src MAC
1604
Src MAC
1606
1608
Dst MAC (6)
Dst Hash (2)
1610
1612
Src MAC (6)
Src Hash (2)
1614
L2 Offset = 12

FIG. 16

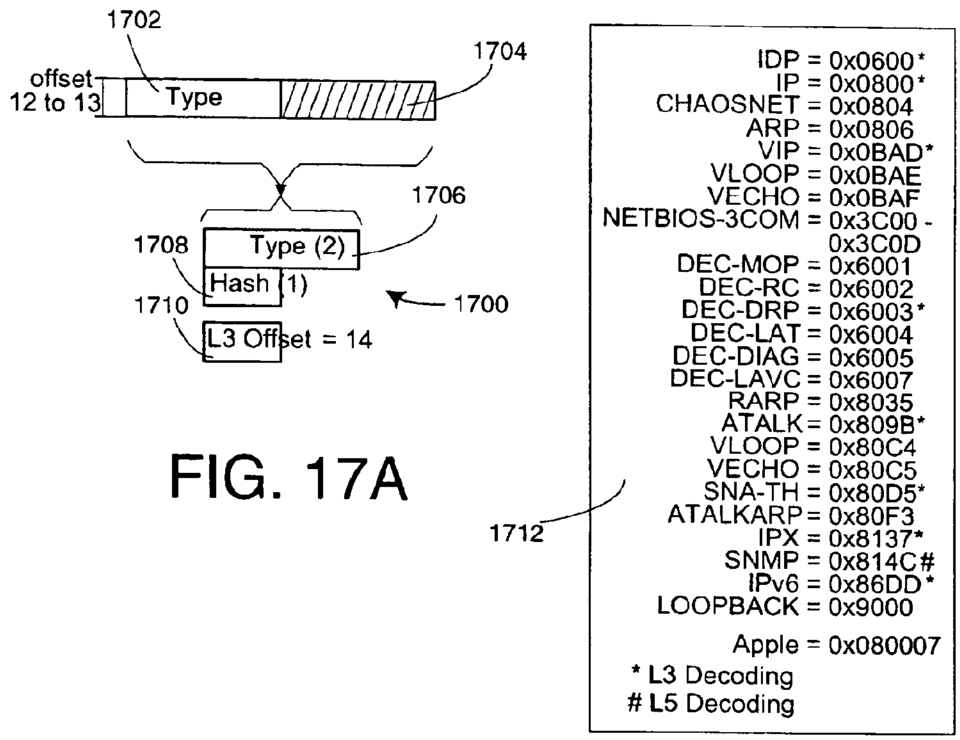


FIG. 17A

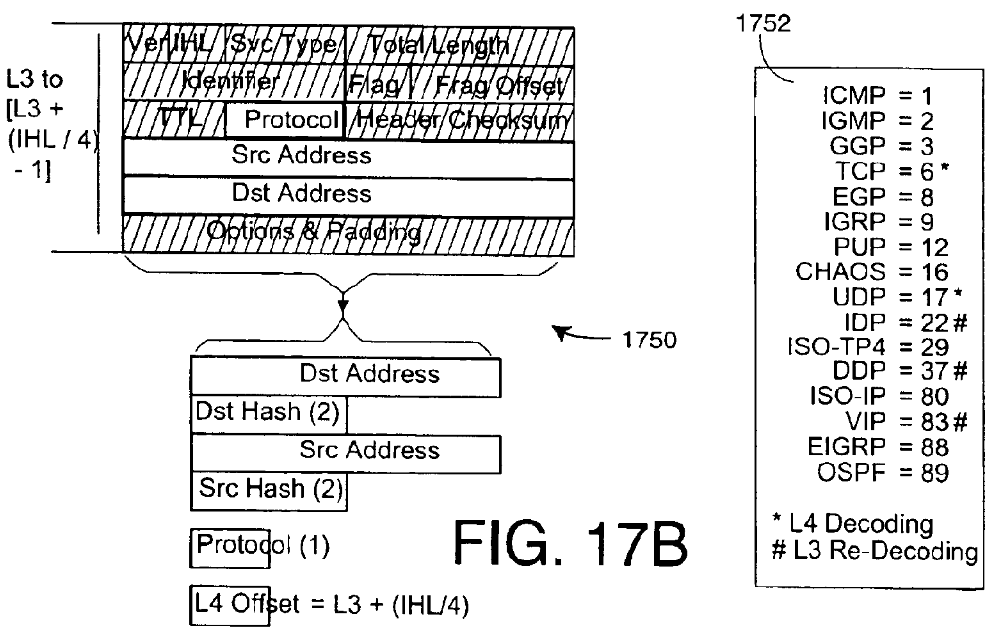


FIG. 17B

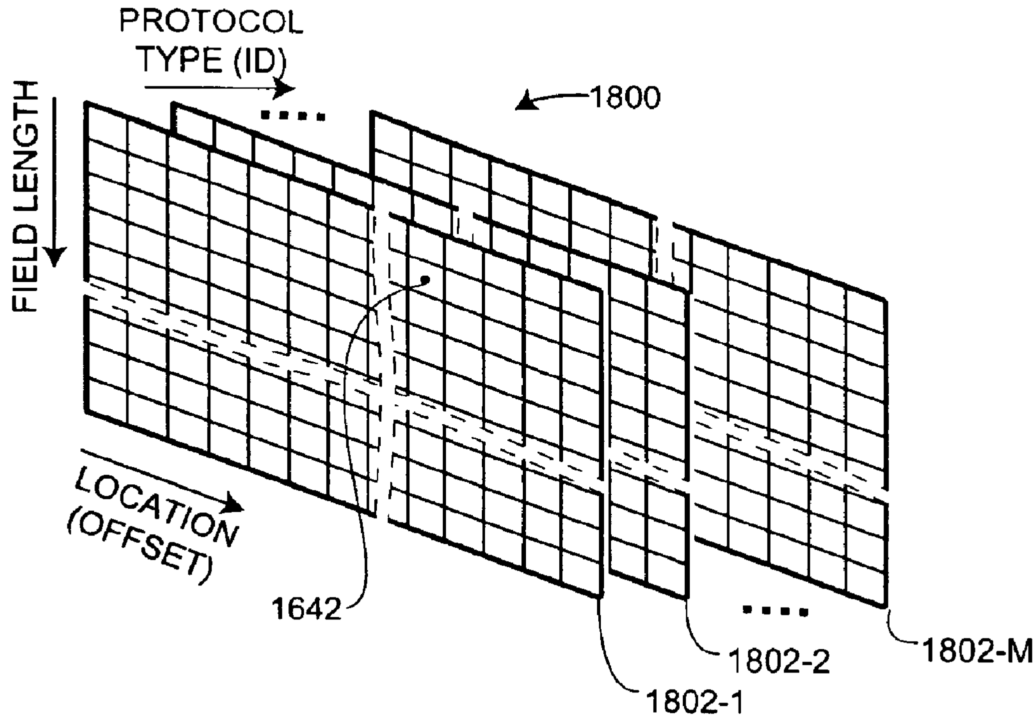


FIG. 18A

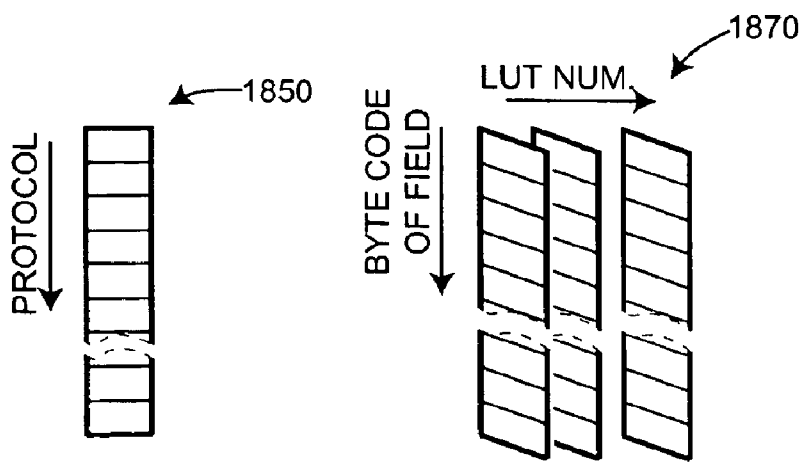


FIG. 18B

METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK

CROSS-REFERENCE TO RELATED APPLICATION

This invention is a continuation of U.S. patent application Ser. No. 09/608,237 for METHOD AND APPARATUS FOR MONITORING TRAFFIC IN A NETWORK to inventors Dietz, et al., filed Jun. 30, 2000, now U.S. Pat. No. 6,651, 099, the contents of which are incorporated herein by reference.

This invention 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 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, now U.S. Pat. No. 6,665,725, 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, now U.S. Pat. No. 6,839,751, 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, now U.S. Pat. No. 6,771,646, 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, now U.S. Pat. No. 6,789,116, 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, Wash.) 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 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.

Providing a flexible processing 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. **17**A 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. **17**B is an example of an IP packet, for example, of the Ethertype packet shown in FIGS. **16** and **17**A, and some of the elements that may be extracted to form a signature according to one aspect of the invention.

FIG. **18**A 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. **18**B 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 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 layer 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 128 K 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. **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 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 bidirectional 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 bidirectional 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, 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, 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 **10**) 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 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.

We claim:

1. A method of examining packets passing through a connection point on a computer network, each packets conforming to one or more protocols, the method comprising:

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

(b) performing one or more parsing/extraction operations on the packet to create a parser record comprising a function of selected portions of the packet;

(c) looking up a flow-entry database comprising none or more flow-entries for previously encountered conversational flows, the looking up using at least some of the selected packet portions and determining if the packet is of an existing flow;

(d) if the packet is of an existing flow, classifying the packet as belonging to the found existing flow; 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 identifying information for future packets to be identified with the new flow-entry,

wherein the parsing/extraction operations depend on one or more of the protocols to which the packet conforms.

2. A method according to claim **1**, wherein each packet passing through the connection point is examined in real time.

3. A method according to claim **1**, wherein classifying the packet as belonging to the found existing flow includes updating the flow-entry of the existing flow.

4. A method according to claim **3**, wherein updating includes storing one or more statistical measures stored in the flow-entry of the existing flow.

5. A method according to claim **4**, 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.

6. A method according to claim **1**, wherein the function of the selected portions of the packet forms a signature that includes the selected packet portions and that can identify future packers, wherein the lookup operation uses the signature and wherein the identifying information stored in the new or updated flow-entry is a signature for identifying future packets.

7. A method according to clalm **1**, wherein at least one of the protocols of the packet uses source and destination addresses, and wherein the selected portions of the packet include the source and destination addresses.

8. A method according to claim **7**, wherein the function of the selected portions for packets of the same flow is consistent independent of the direction of the packets.

9. A method according to claim **8**, wherein the source and destination addresses are placed in an order determined by the order of numerical values of the addresses in the function of selected portions.

10. A method according to claim **9**, wherein the numerically lower address is placed before the numerically higher address in the function of selected portions.

11. A method according to claim **1**, wherein the looking up of the flow-entry database uses a hash of the selected packet portions.

12. A method according to claim **1**, wherein the parsing/extraction operations are according to a database of parsing/extraction operations that 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.

13. A method according to claim **1**, wherein step (d) includes if the packet is of an existing flow, obtaining 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.

14. A method according to claim **13**, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow.

15. A method according to claim **13**, wherein the state operations include updating the flow-entiy, including storing identifying information for future packets to be identified with the flow-entry.

16. A method according to claim **15**, wherein the state processing of each received packet of a flow furthers the identifying of the application program of the flow.

17. A method according to claim **13**, wherein the state operations include searching the parser record for the existence of one or more reference strings.

18. A method according to claim **13**, wherein the state operations are carried out by a programmable state processor according to a database of protocol dependent state operations.

19. 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) an input buffer memory coupled to and configured to accept a packet from the packet acquisition device;

(c) a parser subsystem coupled to the input buffer memory and including a slicer, the parsing subsystem configured to extract selected portions of the accepted packet and to output a parser record containing the selected portions;

(d) a memory for storing a database comprising none or more flow-entries for previously encountered conversational flows, each flow-entry identified by identifying information stored in the flow-entry;

(e) a lookup engine coupled to the output of the parser subsystem and to the flow-entry memory and configured to lookup whether the particular packet whose parser record is output by the parser subsystem has a matching flow-entry, the looking up using at least some of the selected packet portions and determining if the packet is of an existing flow; and

(f) a flow insertion engine coupled to the flow-entry memory and to the lookup engine and configured to create a flow-entry in the flow-entry database, the flow-entry including identifying information for future packets to be identified with the new flow-entry, the lookup engine configured such that if the packet is of an existing flow, the monitor classifies the packet as belonging to the found existing flow; and if the packet is of a new flow, the flow insertion engine 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, wherein the operation of the parser subsystem depends on one or more of the protocols to which the packet conforms.

20. A monitor according to claim **19**, wherein each packet passing through the connection point is accepted by the packet buffer memory and examined by the monitor in real time.

21. A monitor according to claim **19**, wherein the lookup engine updates the flow-entry of an existing flow in the case that the lookup is successful.

22. A monitor according to claim **19**, further including a mechanism for building a hash from the selected portions, wherein the hash is included in the input for a particular packet to the lookup. engine, and wherein the hash is used by the lookup engine to search the flow-entry database.

23. A monitor according to claim **19**, further including a memory containing a database of parsing/extraction operations, the parsing/extraction database memory coupled to the parser subsystem, wherein the parsing/extraction operations are according to one or more parsing/extraction operations looked up from the parsing/extraction database.

24. A monitor according to claim **23**, wherein the database 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.

25. A monitor according to claim **19**, further including a flow-key-buffer (UFKB) coupled to the output of the parser subsystem and to the lookup engine and to the flow insertion engine, wherein the output of the parser monitor is coupled to the lookup engine via the UFKB, and wherein the flow insertion engine is coupled to the lookup engine via the UFKB.

26. A method according to claim **19**, further including a state processor coupled to the lookup engine and to the flow-entry-database memory, and configured to perform any state operations specified for the state of the flow starting from the last encountered state of the flow in the case that the packet is from an existing flow, and to perform any state operations required for the initial state of the new flow in the case that the packet is from an existing flow.

27. A method according to claim **19**, wherein the set of possible state operations that the state processor is configured to perform includes searching for one or more patterns in the packet portions.

28. A monitor according to claim **26**, wherein the state processor is programmable, the monitor further including a state patterns/operations memory coupled to the state processor, the state operations memory configured to store a database of protocol dependent state patterns/operations.

29. A monitor according to claim **25**, further including a state processor coupled to the UFKB and to the flow-entry-database memory, and configured to perform any state operations specified for the state of the flow starting from the last encountered state of the flow in the case that the packet is from an existing flow, and to perform any state operations required for the initial state of the new flow in the case that the packet is from an existing flow.

30. A monitor according to claim **26**, wherein the state operations include updating the flow-entry, including identifying information for future packets to be identified with the flow-entry.

31. A packet monitor according to claim **19**, 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 any children protocols thereof, and

translating the protocol description language commands into a plurality of parsing/extraction operations that are initialized into the parsing/extraction operations memory.

32. A packet monitor according to claim **28**, 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 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 programs, and

translating the protocol description language commands into a plurality of state patterns and state operations that are initialized into the state patterns/operations memory.

33. A packet monitor according to claim **19**, further comprising:

a cache subsystem coupled to and between the lookup engine and the flow-entry database memory providing for fast access of a set of likely-to-be-accessed flow-entries from the flow-entry database.

34. A packet monitor according to claim **33**, wherein the cache subsystem is an associative cache subsystem including one or more content addressable memory cells (CAMs).

35. A packet monitor according to claim **34**, wherein the cache subsystem is also a least-recently-used cache memory such that a cache miss updates the least recently used cache entry.

36. A packet monitor according to claim **19**, wherein each flow-entry stores one or more statistical measures about the flow, the monitor further comprising

a calculator for updating at least one of the statistical measures in the flow-entry of the accepted packet.

37. A packet monitor according to claim **36**, 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.

38. A packet monitor according to claim **36**, further including a statistical processor configured to determine one or more network usage metrics related to the flow from one or more of the statistical measures in a flow-entry.

39. A monitor according to claim **19**, wherein:

flow-entry-database is organized into a plurality of bins that each contain N-number of flow-entries, and wherein said bins are accessed via a hash data value created by a parser subsystem based on the selected packet portions, wherein N is one or more.

40. A monitor according to claim **39**, wherein the hash data value is used to spread a plurality of flow-entries across the flow-entry-database and allows fast lookup of a flow-entry and shallower buckets.

41. A monitor according to claim **26**, wherein the state processor analyzes both new and existing flows in order to classify them by application and proceeds from state-to-state based on a set of predefined rules.

42. A monitor according to claim **19**, wherein the lookup engine begins processing as soon as a parser record arrives from the parser subsystem.

43. A monitor according to claim **26**, wherein the lookup engine provides for flow state entry checking to see if a flow key should be sent to the state processor, and that outputs a protocol identifier for the flow.

44. A method of examining packets passing through a connection point on a computer network, the method comprising:

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

(b) performing one or more parsing/extraction operations on the packet according to a database of parsing/extraction operations to create a parser record comprising a function of selected portions of the packet, the database of parsing/extraction operations including information on how to determine a set of one or more protocol dependent extraction operations from data in the packet that indicate a protocol is used in the packet;

(c) looking up a flow-entry database comprising none or more flow-entries for previously encountered conversational flows, the looking up using at least some of the selected packet portions, and determining if the packet is of an existing flow;

(d) if the packet is of an existing flow, obtaining 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

(e) if the packet is of a new flow, performing any analysis 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 identifying information for future packets to be identified with the new flow-entry.

45. A method according to claim **44**, wherein one of the state operations specified for at least one of the states includes updating the flow-entry, including identifying information for future packets to be identified with the flow-entry.

46. A method according to claim **44**, wherein one of the state operations specified for at least one of the states includes searching the contents of the packet for at least one reference string.

47. A method according to claim **45**, wherein one of the state operations specified for at least one of the states includes creating a new flow-entry for future packets to be identified with the flow, the new flow-entry including identifying information for future packets to be identified with the flow-entry.

48. A method according to claim **44**, further comprising forming a signature from the selected packet portions, wherein the lookup operation uses the signature and wherein the identifying information stored in the new or updated flow-entry is a signature for identifying future packets.

49. A method according to claim **44**, wherein the state operations are according to a database of protocol dependent state operations.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,954,789 B2 Page 1 of 1
DATED : October 11, 2005
INVENTOR(S) : Dietz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9,
Line 60, change "layer model" to -- layered model --.

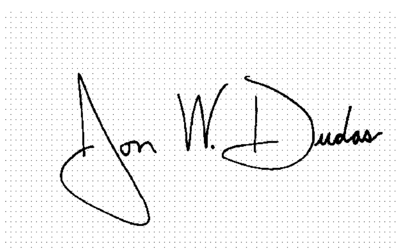
Column 33,
Line 60, insert between "and a" and "denoted as" the phrase -- next-state that the state processor should proceed to for more complex recognition jobs, --.

Column 35,
Lline 51, change "clalm" to -- claim --.

Column 37,
Line 14, change "ciaim" to -- claim --.

Signed and Sealed this

Seventh Day of March, 2006



JON W. DUDAS
Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,954,789 B2
APPLICATION NO. : 10/684776
DATED : October 11, 2005
INVENTOR(S) : Russell S. Dietz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

IN THE CLAIMS:

Column 35, line 47, claim 6, change “packers” to --packets--.

Column 36, line 18, claim 15, change “entiy” to --entry--.

Column 37, line 32, claim 26, change “method” to --monitor--.

Column 37, line 40, claim 27, change “method” to --monitor--.

Column 37, lines 55 and 56, claim 29, change “for the initial state of the new flow in the case that the packet is from an existing flow” to --for the initial state of the new flow in the case that the packet is not from an existing flow--.

Signed and Sealed this
First Day of October, 2013

Teresa Stanek Rea
Deputy Director of the United States Patent and Trademark Office