US009270643B2

(12) **United States Patent**
Sahita

(10) **Patent No.: US 9,270,643 B2**
(45) **Date of Patent: Feb. 23, 2016**

(54) **STATE-TRANSITION BASED NETWORK INTRUSION DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1429 days.

(21) Appl. No.: **10/718,843**

(22) Filed: **Nov. 21, 2003**

(65) **Prior Publication Data**

US 2005/0111460 A1 May 26, 2005

(51) **Int. Cl.**
H04L 29/06 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 63/0254*** (2013.01); ***H04L 63/1416*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 63/0254
USPC 726/22
See application file for complete search history.

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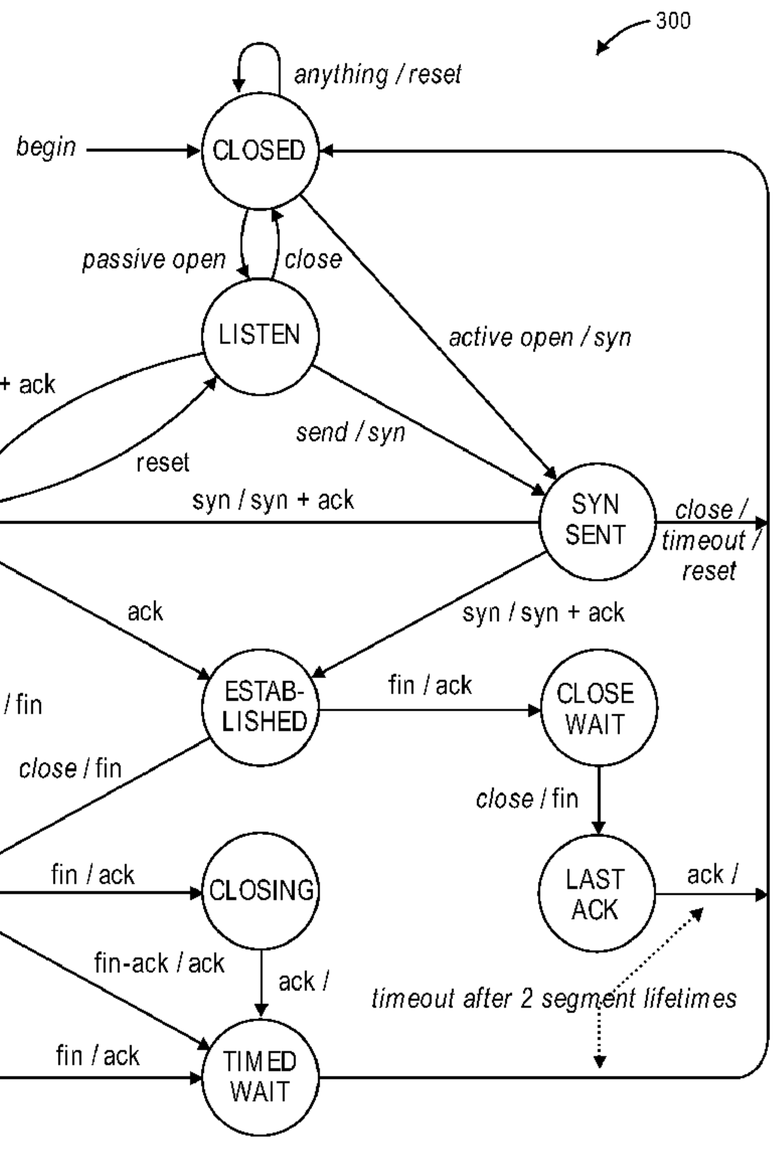
(57) **ABSTRACT**

A network intrusion detection unit (NIDU) identifies a protocol used to transmit a packet and the flow to which the packet belongs. The NIDU determines whether a rules table exists for the protocol, and determines, if the rules table exists, whether a state table includes a matching flow entry corresponding to the flow. If the state table includes the matching flow entry, the NIDU determines whether a state of the flow will transition from a current state indicated in the matching flow entry to a valid destination state indicated in a state-transition rule in the rules table. If the state of the flow will not transition to a valid destination state, the NIDU discards the packet.

29 Claims, 8 Drawing Sheets



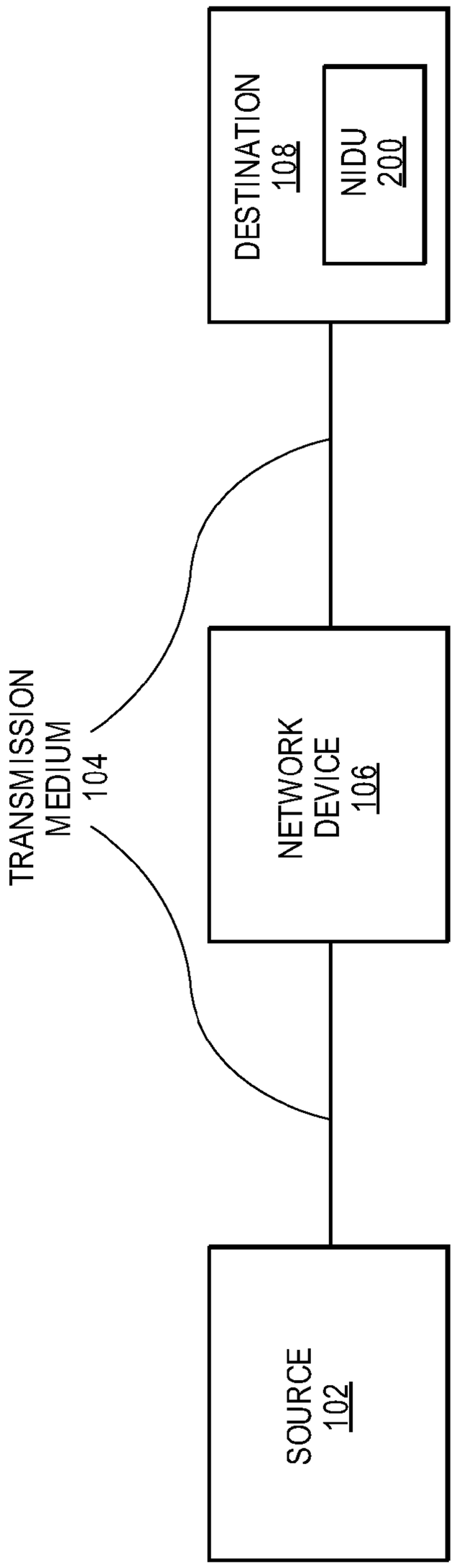

DESTINATION
108
NIDU
200
TRANSMISSION
MEDIUM
104
NETWORK
DEVICE
106
SOURCE
102

FIG. 1

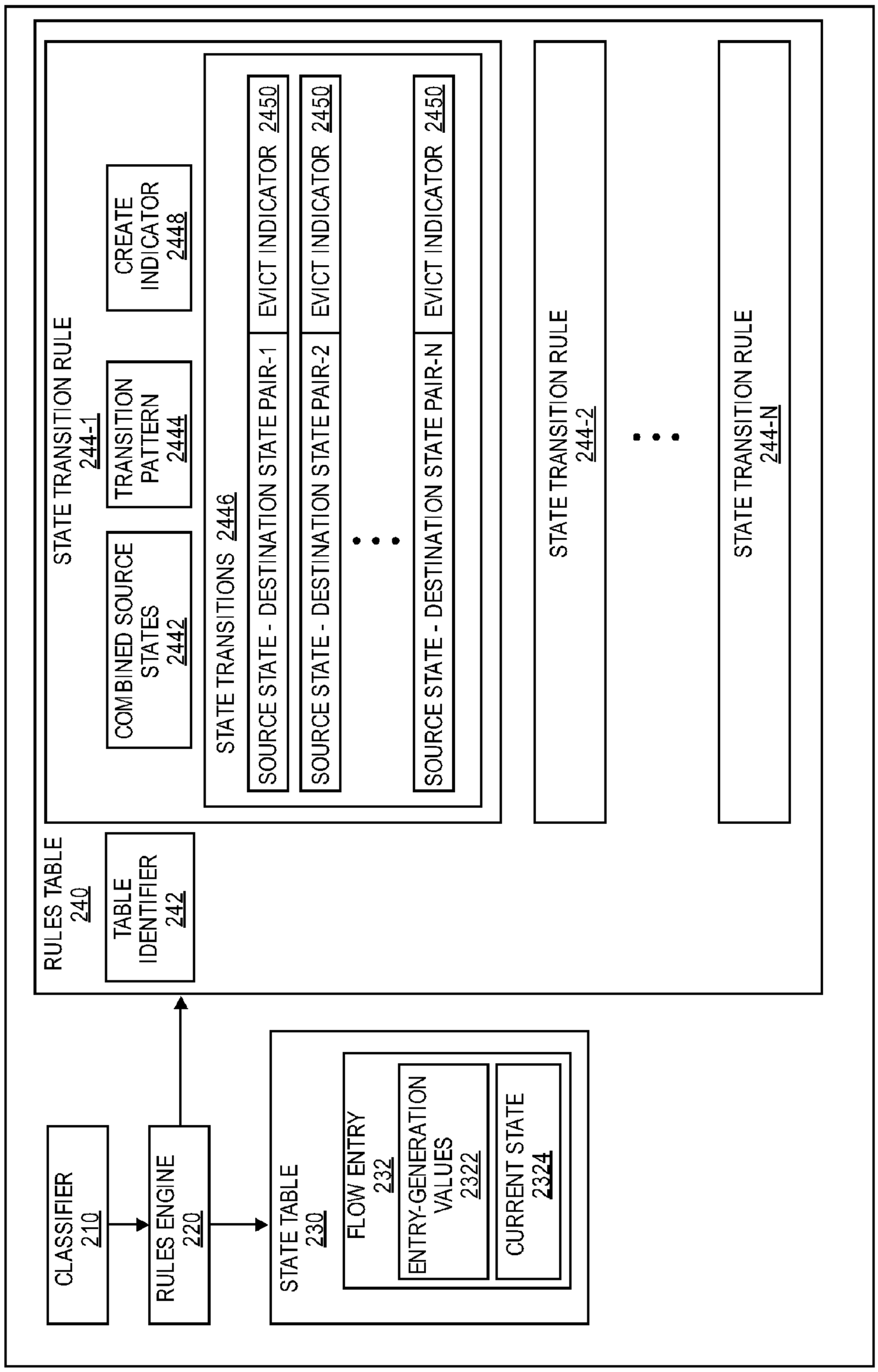

CLASSIFIER 210
RULES ENGINE 220
STATE TABLE 230
FLOW ENTRY 232
ENTRY-GENERATION VALUES 2322
CURRENT STATE 2324
RULES TABLE 240
TABLE IDENTIFIER 242
STATE TRANSITION RULE 244-1
COMBINED SOURCE STATES 2442
TRANSITION PATTERN 2444
STATE TRANSITIONS 2446
SOURCE STATE - DESTINATION STATE PAIR-1
SOURCE STATE - DESTINATION STATE PAIR-2
SOURCE STATE - DESTINATION STATE PAIR-N
EVICT INDICATOR 2450
EVICT INDICATOR 2450
EVICT INDICATOR 2450
CREATE INDICATOR 2448
STATE TRANSITION RULE 244-2
STATE TRANSITION RULE 244-N

FIG. 2

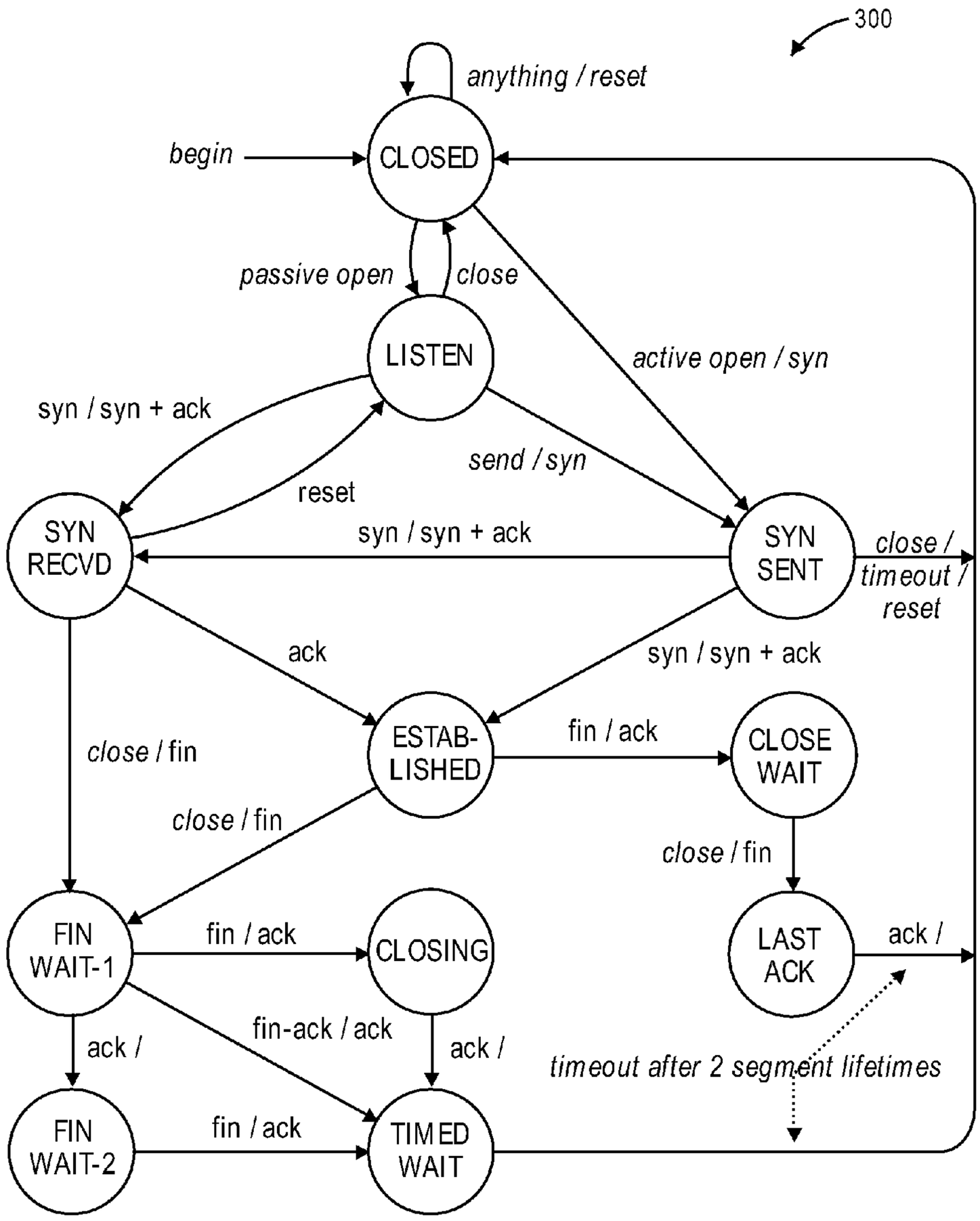

300
anything / reset
begin
CLOSED
passive open
close
LISTEN
active open / syn
syn / syn + ack
send / syn
reset
SYN RECVD
syn / syn + ack
SYN SENT
close / timeout / reset
ack
syn / syn + ack
close / fin
ESTAB-LISHED
fin / ack
CLOSE WAIT
close / fin
close / fin
FIN WAIT-1
fin / ack
CLOSING
LAST ACK
ack /
fin-ack / ack
ack /
ack /
timeout after 2 segment lifetimes
FIN WAIT-2
fin / ack
TIMED WAIT

FIG. 3

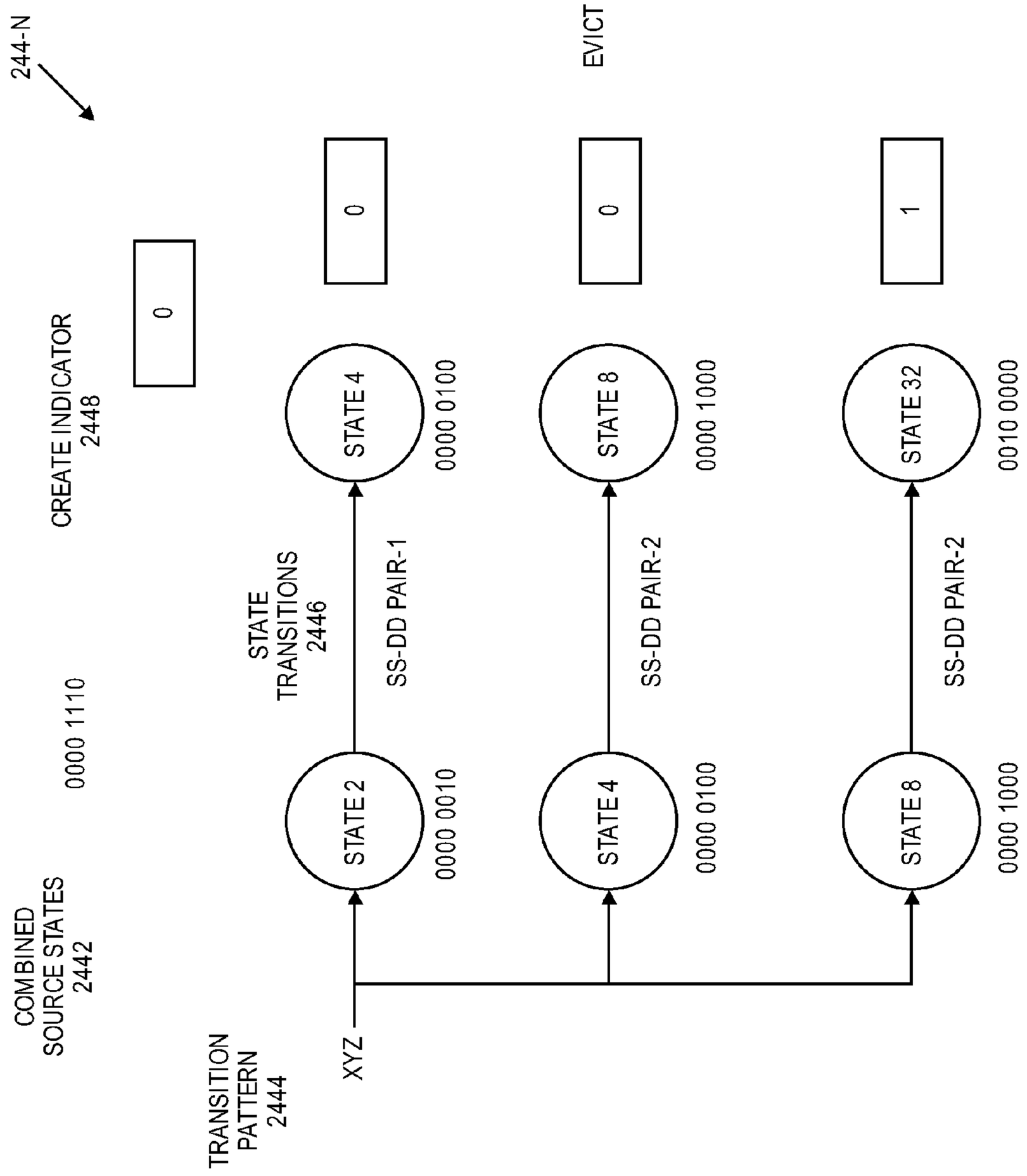

244-N
COMBINED SOURCE STATES 2442
0000 1110
CREATE INDICATOR 2448
0
EVICT INDICATOR 2450
0
STATE TRANSITIONS 2446
SS-DD PAIR-1
SS-DD PAIR-2
SS-DD PAIR-2
STATE 2
0000 0010
STATE 4
0000 0100
STATE 8
0000 1000
STATE 4
0000 0100
STATE 8
0000 1000
STATE 32
0010 0000
0
0
1
TRANSITION PATTERN 2444
XYZ

FIG. 4

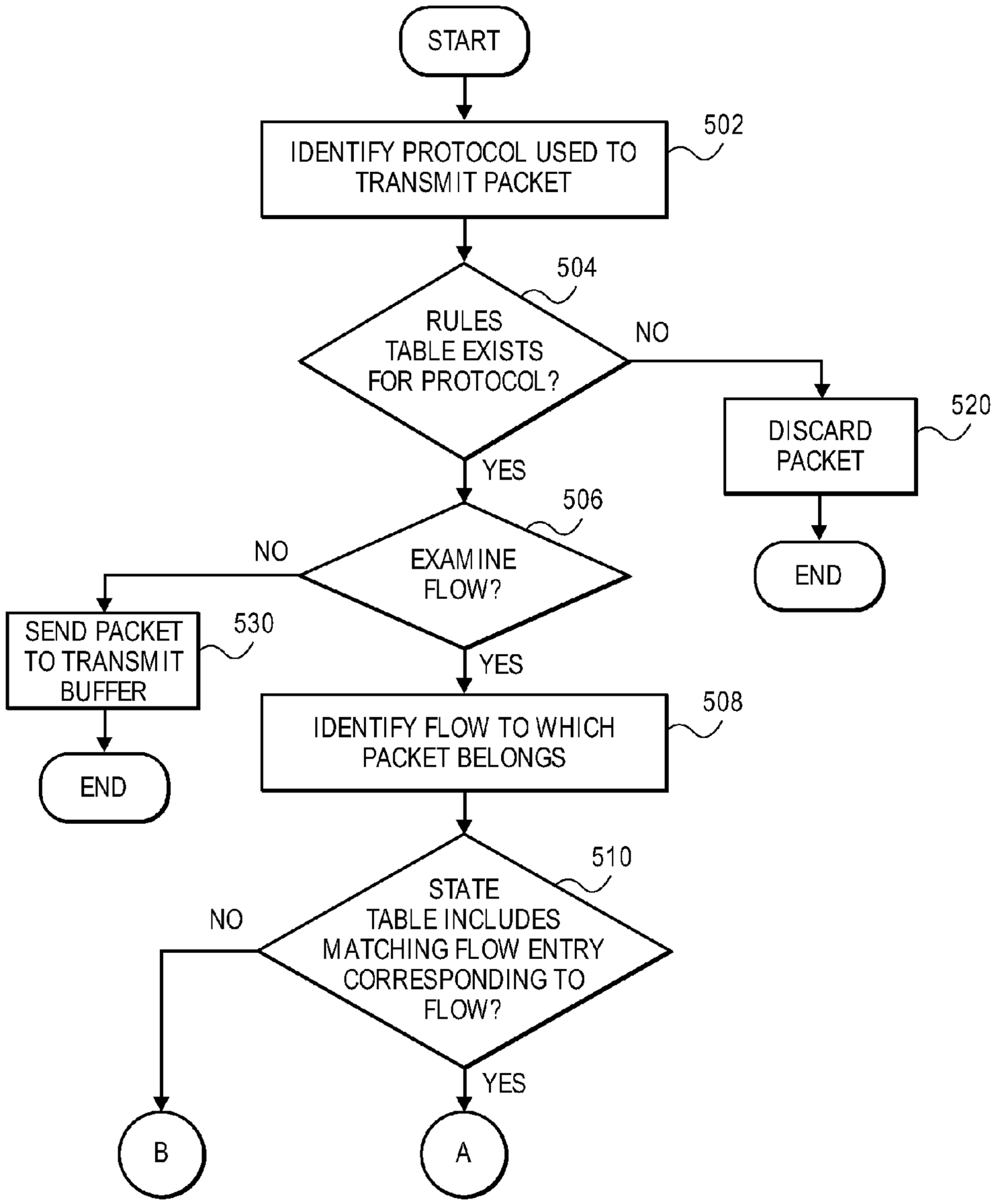

START
IDENTIFY PROTOCOL USED TO TRANSMIT PACKET
502
RULES TABLE EXISTS FOR PROTOCOL?
504
NO
DISCARD PACKET
520
END
YES
EXAMINE FLOW?
506
NO
SEND PACKET TO TRANSMIT BUFFER
530
END
YES
IDENTIFY FLOW TO WHICH PACKET BELONGS
508
STATE TABLE INCLUDES MATCHING FLOW ENTRY CORRESPONDING TO FLOW?
510
NO
B
YES
A

FIG. 5

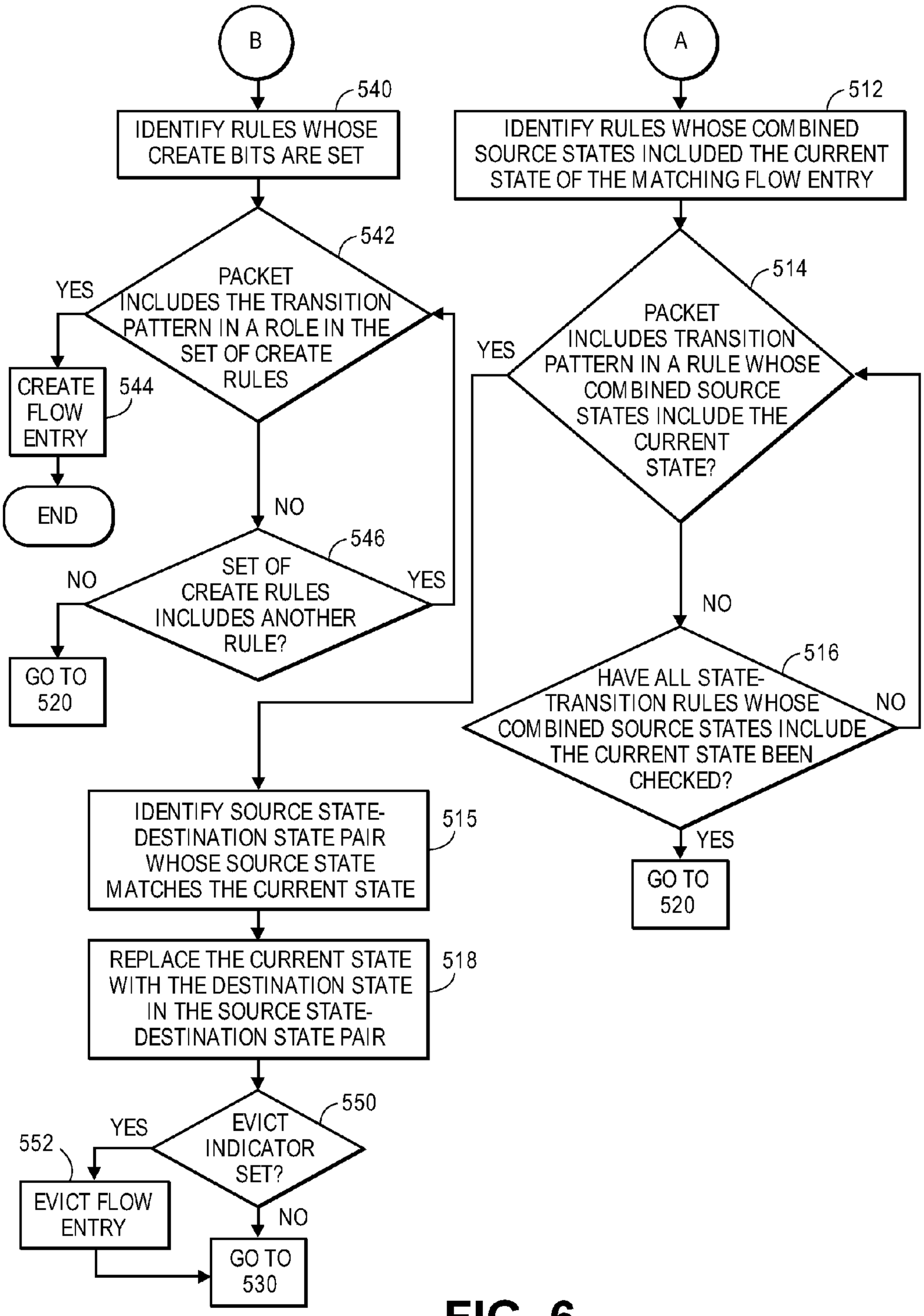

A
512
IDENTIFY RULES WHOSE COMBINED SOURCE STATES INCLUDED THE CURRENT STATE OF THE MATCHING FLOW ENTRY
514
PACKET INCLUDES TRANSITION PATTERN IN A RULE WHOSE COMBINED SOURCE STATES INCLUDE THE CURRENT STATE?
YES
NO
516
HAVE ALL STATE-TRANSITION RULES WHOSE COMBINED SOURCE STATES INCLUDE THE CURRENT STATE BEEN CHECKED?
NO
YES
GO TO 520
B
540
IDENTIFY RULES WHOSE CREATE BITS ARE SET
542
PACKET INCLUDES THE TRANSITION PATTERN IN A ROLE IN THE SET OF CREATE RULES
YES
CREATE FLOW ENTRY
544
END
NO
546
SET OF CREATE RULES INCLUDES ANOTHER RULE?
NO
YES
GO TO 520
515
IDENTIFY SOURCE STATE-DESTINATION STATE PAIR WHOSE SOURCE STATE MATCHES THE CURRENT STATE
518
REPLACE THE CURRENT STATE WITH THE DESTINATION STATE IN THE SOURCE STATE-DESTINATION STATE PAIR
550
EVICT INDICATOR SET?
YES
552
EVICT FLOW ENTRY
NO
GO TO 530

FIG. 6

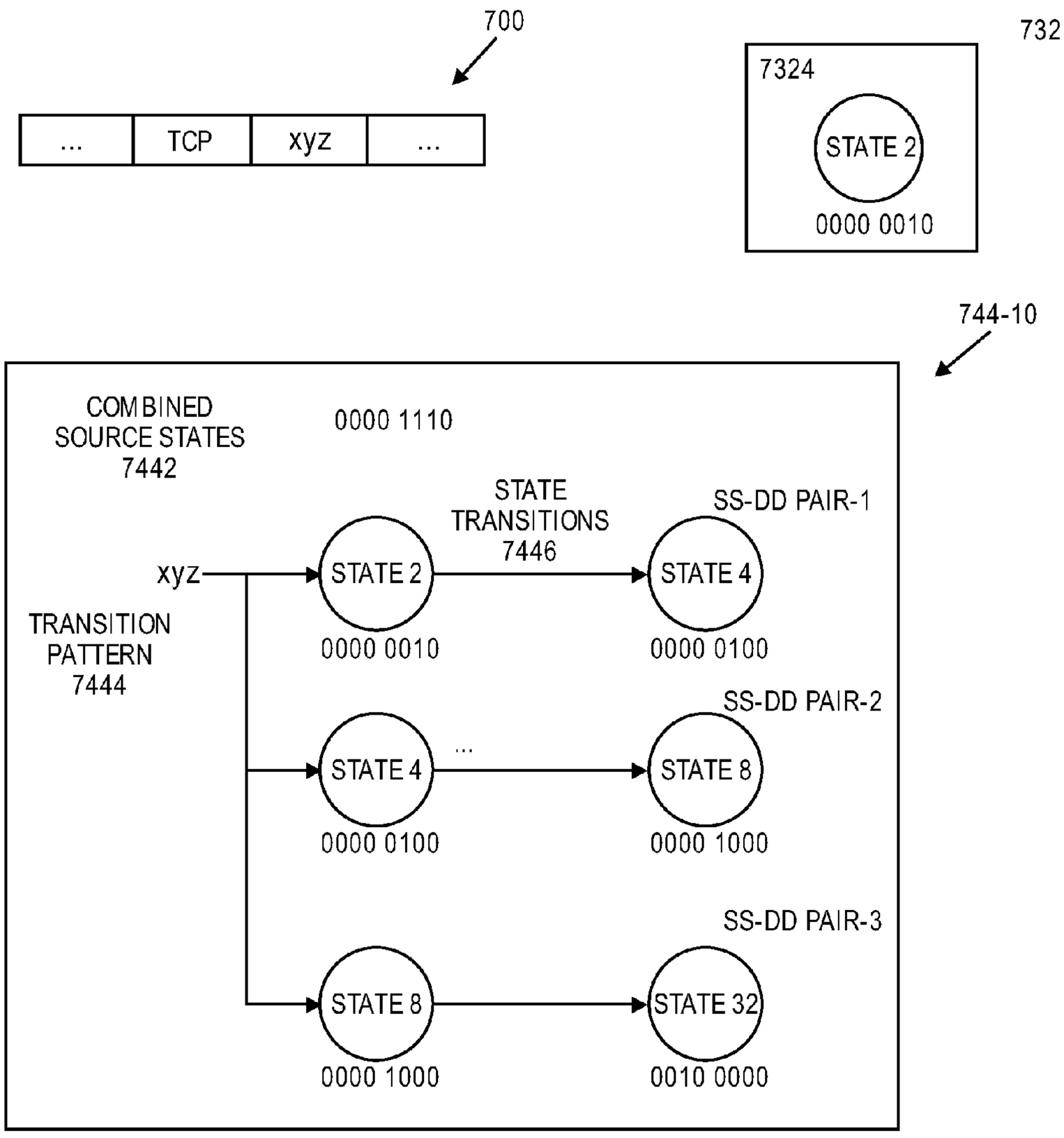

700
... TCP xyz ...
732
7324
STATE 2
0000 0010
744-10
COMBINED SOURCE STATES 7442
0000 1110
STATE TRANSITIONS 7446
SS-DD PAIR-1
xyz
STATE 2
STATE 4
0000 0010
0000 0100
TRANSITION PATTERN 7444
SS-DD PAIR-2
STATE 4
...
STATE 8
0000 0100
0000 1000
SS-DD PAIR-3
STATE 8
STATE 32
0000 1000
0010 0000

FIG. 7

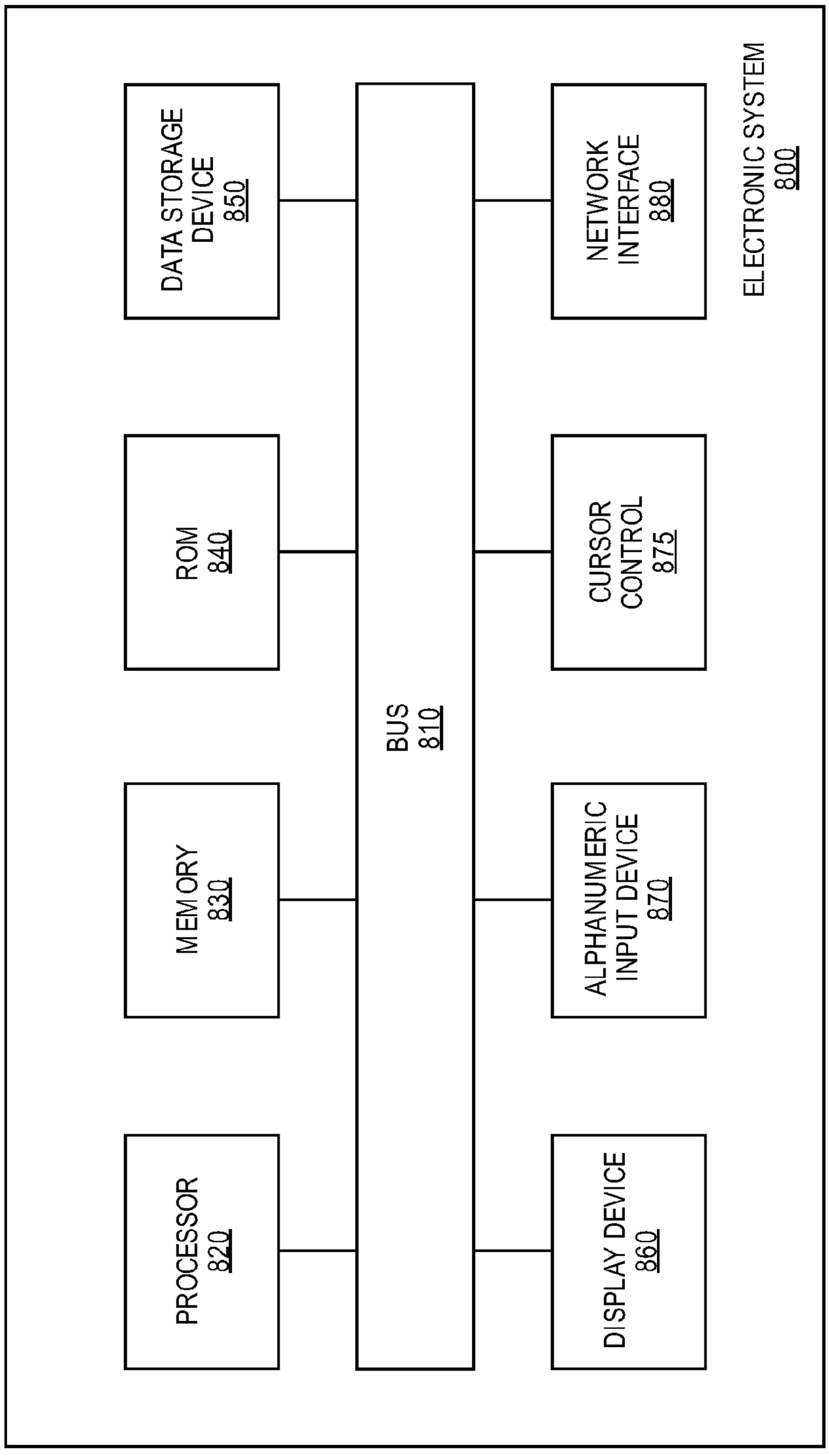

ELECTRONIC SYSTEM
800
DATA STORAGE DEVICE
850
NETWORK INTERFACE
880
ROM
840
CURSOR CONTROL
875
MEMORY
830
BUS
810
ALPHANUMERIC INPUT DEVICE
870
PROCESSOR
820
DISPLAY DEVICE
860

FIG. 8

STATE-TRANSITION BASED NETWORK INTRUSION DETECTION

TECHNICAL FIELD

Embodiments of the invention are generally related to the field of networking and, in particular, to network intrusion detection.

BACKGROUND

In general, a network is a group of two or more electronic systems linked by a wired or wireless transmission medium to transmit data, commonly referred to as a data packet or a packet, from a source electronic system to a destination electronic system. Data packets are transmitted based on a set of rules, commonly referred to as a protocol, that are used by the source and the destination during a communication session. Examples of networks include a personal area network, a local area network, a metropolitan area network and a wide area network, such as the Internet. Examples of electronic systems include a personal computer, a personal digital assistant (PDA), a laptop or palmtop computer, a cellular phone, a computer system, a network access device, and a television set-top box.

A data packet may travel through one or more intermediate electronic systems, commonly referred to as network devices, during transmission from a source to a destination. Examples of network devices include, but are not limited to, a switch, a router or a bridge. In general, a network device is a packet-forwarding device that receives a data packet and determines an electronic system (either another network device or a destination) to which to forward the data packet.

An unauthorized user may attempt to access a network. Unauthorized access of a network is commonly referred to as network intrusion. A network intruder may attempt to inhibit the ability of authorized users to access the network, or attempt to prevent the use of a service on the network, for example, electronic mail (or e-mail). Such an attack on a network is commonly referred to as a denial-of-service (DoS) attack.

One technique for implementing a DoS attack is to send a large amount of data to a service that is unable to handle the data and thus begins dropping data. For example, a network intruder may transmit a large number of requests to connect to an e-mail server that is unable keep up with the connection requests. As a result, the e-mail server may start dropping connection requests, including legitimate requests, thereby inhibiting authorized users' access to e-mail service.

A network intrusion detection system (NIDS) is a system used to determine whether a network is under attack. Typically, a NIDS examines packets entering a network to determine whether an unauthorized user is attempting to access the network. For example, a NIDS may determine whether there are a large number of connection request packets, which may indicate an attempted DoS attack. A NIDS may run either at a destination, where the destination's incoming traffic is examined, or on a network device between a source and a destination, in which case all network traffic is examined.

One type of NIDS is a signature-based NIDS, where the NIDS determines whether a packet includes a particular string of data that associates the packet with a network attack. Because the signature-based approach is based on data in the packet, only known attacks, i.e., attacks where a particular string of data is known to be associated with particular network attack, may be addressed. In addition, a signature-based NIDS examines an intrusive packet's data after the packet

reaches an application that provides a service, which means that the attack is successful. Consequently, the goal of a signature-based approach is to prevent future attacks from being successful.

Another type of NIDS is an anomaly-based NIDS, in which network behavior is predicted and modeled, and certain behavior is identified as abnormal. An anomaly-based approach may be based on known protocol behavior, rather than on packet data known to be associated with a network attack. Consequently, an anomaly-based NIDS can address unknown, as well as known, attacks. In addition, an anomaly-based NIDS can prevent an attack before an intrusive packet reaches an application that provides a service. An anomaly-based NIDS is difficult to implement because of the difficulty in predicting and modeling network behavior and identifying abnormal behavior.

A conventional NIDS is susceptible to an attack in which packets are transmitted at high rates of speed, sometimes referred to as a saturation attack. A conventional NIDS examines the packets of each flow. In general, a flow is a stream of packets transmitted between a source and a destination during a communication session. If packets are transmitted faster than the NIDS is able to examine them, the NIDS may start dropping packets or even completely shut down. A conventional NIDS is not able to throttle flow examination, i.e., examine the packets of fewer than all flows, which would reduce the likelihood of a successful saturation attack.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings in which like reference numerals refer to similar elements.

FIG. **1** is a block diagram illustrating an example of a network.

FIG. **2** is a block diagram illustrating an example embodiment of a network intrusion detection unit.

FIG. **3** illustrates an example of a finite state machine.

FIG. **4** illustrates an example embodiment of a state transition rule.

FIG. **5** and FIG. **6** are a flow chart illustrating an example embodiment of a method of network intrusion detection.

FIG. **7** illustrates an example embodiment of determining a valid state transition.

FIG. **8** is a block diagram illustrating an example embodiment of an electronic system.

DETAILED DESCRIPTION

State-transition based network intrusion detection is described. In the following description, for purposes of explanation, numerous specific details are set forth. It will be apparent, however, to one skilled in the art that embodiments of the invention can be practiced without these specific details. In other instances, structures and devices are shown in block diagram form in order to avoid obscuring the understanding of this description.

FIG. **1** is a block diagram illustrating an example of a network. Network **100** may be any type of wired or wireless network, including, but not limited to, a personal area network, a local area network, a metropolitan area network, or a wide area network. Network **100** includes source **102**, which transmits data packets over transmission medium **104** through network device **106** to destination **108**. For simplicity, network **100** is shown with one source, one network

device and one destination. However, network **100** may include more than one source, network device and/or destination.

Source **102** is intended to represent a broad range of electronic systems including, but not limited to, a personal computer, a personal digital assistant (PDA), a laptop or palmtop computer, a computer system, a network access device or a television set-top box, that transmits data packets to destination **108**. Transmission medium **104** is intended to represent any wired or wireless transmission medium, or a combination thereof, including, but not limited to, fiber-optic cable, coaxial cable, twisted-pair wire, or air, which carries, for example, radio or satellite signals, over which data packets are transmitted from source **102** to destination **108**.

Network device **106** is intended to represent any number of network devices including, but not limited to, a router, a switch or a bridge, that include network intrusion detection unit (NIDU) **200**. As explained in more detail below, the integration of NIDU **200** in network device **106** enables network device **106** to determine, based on the expected state transition of a flow, whether to transmit a data packet belonging to the flow to destination **108**. Although network **100** is described in terms of a data packet traveling through network device **106**, a data packet may be transmitted directly from source **102** to destination **108** without traveling though network device **106**.

Destination **108** is intended to represent a broad range of electronic systems, including, but not limited to, a server, a personal computer, a personal digital assistant (PDA), a laptop or palmtop computer, a computer system, a network access device or a television set-top box, that include NIDU **200**. As explained in more detail below, the integration of NIDU **200** in destination **108** enables destination **108** to determine, based on the expected state transition of a flow, whether to process a data packet belonging to the flow.

Network device **106** and/or destination **108** further includes a receive buffer (not shown) and a transmit buffer (not shown). NIDU **200** receives a packet via the receive buffer, and sends the packet to the transmit buffer if the packet is to be transmitted to destination **108** or processed at destination **108**, as applicable, rather than discarded. Consequently, if NIDU **200** is running on a separate device, for example, a network processor or a network interface card, within network device **106** and/or destination **108**, NIDU **200** is able to examine a packet before an intrusive packet reaches an application that is providing a service on destination **108**.

FIG. **2** is a block diagram illustrating an example embodiment of a network intrusion detection unit. NIDU **200** may be implemented in software, hardware, for example, on a network interface card or network processor, or a combination thereof. Although embodiments of the invention are described in terms of network intrusion detection, embodiments of the invention are also applicable to an application-aware firewall.

NIDU **200** includes classifier **210**, rules engine **220**, one or more state tables **230** and one or more rules tables **240**. Although classifier **210** and rules engine **220** are described below as separate functional elements, they may be combined into a single multifunctional element that performs the functions of classifier **210** and rules engine **220**. In addition, one or more of the functions described as being performed by classifier **210** may be performed by rules engine **220**, and one or more of the functions described as being performed by rules engine **220** may be performed by classifier **210**.

As explained in more detail below, classifier **210** identifies a protocol used to transmit a packet, and a flow to which the packet belongs. Many flows may exist for a single protocol, since any number of sources and destinations may be using a particular protocol to transmit packets during a communication session. Identifying the protocol and the flow is commonly referred to as classification.

State table (ST) **230** and rules table (RT) **240** are tables or other data structures related to a protocol used to transmit a packet. A user configures NIDU **200** to examine the flows of one or more protocols. ST **230** and RT **240** exist for each protocol NIDU **200** is configured to examine. ST **230** includes one or more flow entries **232**, which identify each flow being transmitted using the protocol. Each flow entry **232** is an index representing a flow, and includes entry-generation values **2322**, which indicate the values used to generate flow entry **232**. For example, if the protocol is the Transmission Control Protocol (TCP), entry-generation values **2322** may include source address, destination address, source port number, and destination port. See, e.g., Request for Comments (RFC) **793**, "Transmission Control Protocol DARPA [Defense Advanced Research Projects Agency] Internet Program, Protocol Specification," September 1981. In addition, each flow entry **232** indicates a current state **2324** of the flow. Current state **2324** is represented by a bit-vector. For purposes of illustration and ease of explanation, ST **230** includes one flow entry. However, ST **230** may include any number of flow entries.

Rules table (RT) **240** includes table identifier **242** and one or more state-transition rules **244-1** through **244**-N, where N is any number. Table identifier **242** may be any indicator known in the art for identifying a table or other data structure. Each state-transition rule **244** includes combined source states **2442**, transition pattern **2444**, state transitions **2446** and create indicator **2448**. For purposes of illustration and ease of explanation, RT **240** includes one state transition rule, which is referred to herein generally as state-transition rule **244**-N. However, RT **240** may include any number of state transition rules.

Typically, the operation of a protocol can be described based on a theoretical model commonly referred to as a finite state machine (FSM). A FSM is commonly represented as a set of unique states for a system, and a set of transitions between the states. Combined source states **2442** and state transitions **2446** correspond to states in a protocol's FSM, and are represented by bit-vectors.

FIG. **3** illustrates an example of a finite state machine. Example FSM **300** is a FSM known in the art for TCP. In general, a flow begins at state 0 and transitions from state to state, based on data transmitted between source **102** and destination **108**. For example, in order to transition from state 0 to state 1, source **102** sends a SYN packet to destination **108**. The various symbols and notations in FSM **300** are known to those of ordinary skill in the art, and thus will not be described in detail.

For purposes of illustration and ease of explanation, embodiments of the invention will be described in terms of TCP. However, the protocol may be any protocol whose operation is capable of being defined by a FSM. Examples of other protocols include, but are not limited to, File Transfer Protocol (FTP), Telnet, Hypertext Transfer Protocol (HTTP), H.323, Real Time Transport Protocol (RTP)/Real Time Control Protocol (RTCP) and Secure Shell Protocol (SSH). See e.g., IETF RFC 959, "File Transfer Protocol (FTP)," October 1985; IETF RFC 854, "Telnet Protocol Specification," May 1983; IETF RFC 2616, "Hypertext Transfer Protocol—HTTP/1.1," June 1999; IETF RFC 3550 "A Transport Protocol for Real-Time Applications," July 2003; International Telecommunication Union-Telecommunication Standardization Sector (ITU-T), "H.323 System Implementers Guide;

Series H: Audiovisual and Multimedia Systems, Infrastructure of Audiovisual Services—Communication Procedures," May 30, 2003; and IETF Network Working Group, SSH Communications Security Corp, "SSH Protocol Architecture," Jul. 14, 2003 (Internet-Draft, Expires: Jan. 12, 2004.

State transitions **2446** include source state-destination state (SS-DD) pair 1 through SS-DD pair N, where N is any number. An SS-DD pair indicates a source state of a flow and a valid destination state to which the state of the flow will transition. State transitions **2446** may include any number of SS-DD pairs. For purposes of illustration and ease of explanation, one or more SS-DD pairs are referred to herein generally as SS-DD Pair N. Transition pattern **2444** indicates a pattern that is included in a packet if the state of the packet's flow is going to transition from a source state to a destination state included in an SS-DD Pair N. Combined source states **2442** indicates all of the source states in each SS-DD pair.

One or more state transitions **2446** further include evict indicator **2450**. Evict indicator **2450** is used to indicate that a SS-DD pair corresponds to a final transition, and will cause a flow entry associated with the state-transition rule **244**-N for the SS-DD pair to be removed from ST **230** or marked as invalid. Evict indicator **2450** may be, but is not limited to, a bit that when set indicates that a flow entry is to be evicted. For purposes of illustration and ease of explanation, evict indicator **2450** will be described in terms of an evict bit.

Create indicator **2448** indicates that a flow entry is to be created for a flow. Create indicator **2448** may be, but is not limited to, a bit that when set indicates that a flow entry is to be created in ST **230**. This applies when a flow is to be examined, but NIDU **200** has not yet received a packet belonging to the flow. As explained in more detail below, if a packet belonging to the flow includes the correct transition pattern **2444**, a flow entry corresponding to the flow will be created in ST **230**. Once the flow entry has been created, the create bit is set so that rules engine **220** does not create another flow entry corresponding to the flow. For purposes of illustration and ease of explanation, create indicator **2448** will be described in terms of a create bit.

FIG. **4** illustrates an example embodiment of a state transition rule. State-transition rule **244**-N indicates the source states of a flow as states **2**, **4** or **8**. Thus, state-transition rule **244**-N indicates combined source states **2442** as bit-vector 00001110, which shows, by the 1 in the bit positions corresponding to binary numbers 2, 4 and 8, that states 2, 4 and 8 are source states.

State transition rule **244**-N further includes state transitions **2446**, which includes three SS-DD Pairs: SS-DD Pair 1 indicates state 2 as a source state and state 4 as its destination state; SS-DD Pair 2 indicates state 4 as a source state and state 8 as its destination state, and SS-DD Pair 3 indicates state 8 as a source state and state 32 as its destination state. Although state bit-vectors in FIG. **4** are described in terms of binary format, other formats may be used, for example, hexadecimal format.

Each SS-DD Pair includes evict indicator **2450**, which in this case is an evict bit. Evict indicator **2450** for SS-DD Pairs 1 and 2 are set to 0 to indicate non-eviction, while evict indicator **2450** for Pair 3 is set to 1 to indicate eviction. Although FIG. **4** is described in terms of 0 for non-eviction and 1 for eviction, embodiments of the invention may be implemented using 1 to indicate non-eviction and 0 to indicate eviction.

For state-transition rule **244**, transition pattern **2444** is XYZ. This means that if a packet belonging to a flow whose source state is 2, 4 or 8 includes the pattern XYZ, then the flow's next state is 4, 8 or 32, respectively. In addition, create indicator **2448** is set to 0. This indicates that a packet belonging to the flow corresponding to state-transition rule **244**-N has been examined at NIDU **200**, and thus a flow entry for the flow exists in ST **230**.

As described in more detail below, rules engine **220** performs a hashing function based on data in a packet, and determines whether flow entry **232** in ST **230** matches the result of the hashing function. A matching flow entry **232** identifies a flow to which the packet belongs. If a matching flow entry **232** exists, rules engine **220** identifies current state **2324** of the flow.

Rules engine **220** uses current state **2324** to identify one or more state-transition rules **244**-N having combined sources states **2442** that includes a source state corresponding to current state **2324**. Rules engine **220** determines whether the packet includes transition pattern **2444** included in the state-transition rule **244**. If the packet includes the transition pattern **2444**, the packet is a valid packet, i.e., is not associated with an attempted network intrusion. However, if the packet does not include the transition pattern **2444**, the packet is deemed to be associated with an attempted network intrusion.

Therefore, unlike a conventional network intrusion detection system, NIDU **200** is able to predict and model network behavior, and identify abnormal behavior. NIDU **200** does not detect network intrusion based solely on data in a packet, but rather also based on known protocol behavior. Consequently, NIDU **200** is able to prevent unknown and known network attacks, and can prevent network intrusions before an invasive packet reaches an application that provides a service.

A state-transition rule **244**-N that has create bit **2448** set may also have additional values associated with it, specifically, a threshold value T and a step value S. T indicates a threshold number of flows being transmitted using the same protocol, while S indicates a step increment of flows, both measured in connections-per-second. Once a flow entry is created for a flow, the T and S values may be used to determine which flows to examine, and a number of hashing functions to perform when determining whether a flow entry **232** corresponding to a flow is present in ST **230**.

As explained in more detail below, rules engine **220** may use a skip count to determine whether to examine a flow and thus examine a packet belonging to that flow. A skip count indicates the number of flows to skip before examining a flow. Rules engine **220** determines the skip count N to generate a 1-in-N (1/N) flow examination function, where N indicates the number of flows to examine after skipping N−1 flows. For example, if N is set to a default rate equal to 1, rules engine **220** examines every flow that is being transmitted using a particular protocol, and thus every packet for that protocol is examined. If N is set to 3, rules engine **220** examines a packet belonging to 1 out of every 3 flows, after skipping 2 flows.

Rules engine **220** can adjust N from a user-configured default value to another value, based on user-configured values for S and T. If the current number of actual flows C is less than T, rules engine **220** examines every 1-in-N flows. For example, if N is set to a default value of 1, T is set to a default value of 200, and the current number of actual flows C is below 200, rules engine **220** examines each flow of a protocol. Once C exceeds T, as indicated, for example, by a new flow entry having been created, rules engine **220** increases N to reduce number of flows examined. In other words, unlike a conventional network intrusion detection system, NIDU **200** is able to throttle flow examination, which reduces the likelihood of a successful saturation attack on NIDU **200**.

Rules engine **220** increases N based on the product of a user-defined skip-count modifier A, and a number X of steps S by which C exceeds T. For example, if T is set to 200, S is

set to 50, A is set to 2, and C is 200, then X is 2, since C exceeds T by 100, i.e., 2 times S. Thus, rules engine **220** increases N to A times X, which equals 4, and thus 1 in 4 flows will be examined for a valid state transition. If, for example, C increases further, to 510, then X is 6, since C exceeds T by 310, which is nearest to 6 times S. Thus, rules engine **220** increases N to 12, and 1 in 12 flows will be examined for a valid state transition. In one embodiment, rules engine **220** uses the whole number component of X. In another embodiment, rules engine **220** rounds X up or down to nearest whole number.

As described in more detail below, rules engine **220** performs a hashing function based on values in a packet, to determine whether a flow entry **232** corresponding to a flow is present in ST **230**. In order for there to be a flow entry **232** corresponding to a flow, the flow entry **232** has to match the result of the hashing function, and the hashed values from the packet have to match entry-generation values **2322** indicated in the flow entry **232**.

Any number of values when hashed can generate the same result. Therefore, it is possible that rules engine **220** fails to locate a matching flow entry **232** because the hashed values from the packet fail to match entry-generation values **2322**, though the flow entry **232** matches the result of the hashing function. If rules engine **220** fails to locate a matching flow entry **232** after performing a hashing function, rules engine **220** may perform any number of additional hashing functions R.

The flow examination function **11**N can affect the number of additional hashing functions R performed. In general, as N increases, meaning that fewer flows are being examined, R increases, and thus the probability of locating a flow in ST **230** should increase. It follows that as N decreases, meaning that more flows are examined, R decreases, since the probability of locating a flow in ST **230** should increase as more flows are examined. This is because performing multiple hashing functions and monitoring fewer flows reduces the probability of locating a flow entry **232** that matches the result of the hashing function, but whose entry-generation values **2322** do not match the packet values hashed to generate the result. Similarly, performing fewer hashing functions and monitoring more flows also reduces this probability.

R_{min} is a user-configured minimum number of additional hashing functions related to N, and R_{max} is a user-configured maximum number of additional hashing functions. When N is at its default value, the number of additional hashing functions performed is R_{min}. As rules engine **220** increases N, the number of additional hashing functions performed increases to R, which is between R_{min} and R_{max}. As rules engine **220** further increases N, R increases until it reaches R_{max}, and does not increase further. Similarly, as rules engine **220** decreases N to its default value, R decreases until it reaches R_{min}.

FIG. **5** and FIG. **6** are a flow chart illustrating an example embodiment of a method of network intrusion detection. At **502** of method **500**, classifier **210** identifies a protocol used to transit a packet received in a receive buffer. The protocol may be identified based, for example, on a protocol identifier. A protocol identifier may be, for example, a protocol flag in the protocol field of the packet's header, or other data in the packet's header or payload.

Once the protocol is identified, at **504** rules engine **220** determines whether a RT **240** exists for the identified protocol. In one embodiment, rules engine **220** determines whether a RT **240** includes table identifier **242** that corresponds to the packet's protocol identifier. In one embodiment, if RT **240** does not exist for the protocol, at **520**, rules engine **220** discards the packet. In another embodiment, if RT **240** does not exist for the protocol, the packet is transmitted. In yet another embodiment, if RT **240** does not exist for the protocol, rules engine **220** updates statistics regarding the number of packets belonging to an intrusive flow. If the packet has caused a user-configured number of intrusive packets to be reached, the packet is discarded, while the packet is transmitted if it has not caused the number of intrusive packets to be reached.

At **506**, rules engine **220** determines whether the flow is to be examined to determine whether the flow will transition from a current state **2324** indicated in ST **230** to a destination state in valid destination states **2446** indicated in RT **240**, and thus constitutes a valid packet that is not associated with a network intrusion. Although FIG. **5** and FIG. **6** are described in terms of rules engine **220** determining whether a flow is to be examined, embodiments of the invention may be practiced without rules engine **220** determining whether a flow is to be examined.

Rules engine **220** determines whether to examine the flow based on a skip count. If the skip count indicates that a flow is not to be examined, rules engine **220** increments the skip count to indicate that a flow has been skipped. If the flow is to be examined, rules engine **220** resets the skip count to restart counting the number of flows to skip before examining a flow.

If the flow is not examined, at **530**, rules engine **220** sends the packet belonging to the flow to a transmit buffer, to be transmitted to destination **108**, if NIDU **200** is running on network device **106**, or to be processed at destination **108**, if NIDU **200** is running on destination **108**. For purposes of illustration and ease of explanation, the remainder of FIG. **5** and FIG. **6** will be described in terms of NIDU **200** running on destination **108**.

If the flow is to be examined, at **508** classifier **210** identifies the flow to which the packet belongs. Classifier **210** can identify the flow in any manner known in the art. For example, the flow may be identified based on the protocol, where, for example, a flow transmitted using TCP is identified by certain information in the packet's header, while a flow transmitted using FTP is identified by different information in the packet's header.

Once the flow has been identified, at **510** rules engine **220** determines whether ST **230** includes a matching flow entry **232** corresponding to the flow. In one embodiment, rules engine **220** performs a hashing function based on values in the packet, determines whether a flow entry **232** matches the result of the hashing function, and determines whether the hashed values from the packet match entry-generation values **2322** indicated in the flow entry **232**. For example, if the protocol is TCP, the source address, destination address, source port, and destination port values may be entry-generation values **2322**, as well as values in a packet used to perform a hashing function. Rules engine **220** may perform any hashing function known in the art.

In one embodiment, rules engine **220** performs multiple hashing functions, that is, one or more hashes where the values used to perform the hashing function are in their original locations in the packet, and one or more hashes where the values are switched. For example, if the protocol is TCP, rules engine **220** could perform two hashing functions, the first hash being a regular four-tuple, as is known in the art, and the other hash performed with the source and destination fields switched and the source port and destination port fields switched. If hashing values are switched to perform a hashing function, rules engine **220** determines whether the order of entry-generation values **2322** correspond to the order of the values in the packet as hashed to generate the hash result. In

another embodiment, rules engine **220** performs a single hashing function, for example a hashing function with values in a packet in their regular positions, or a hashing function with values switched.

In one embodiment, if matching flow entry **232** is not found initially, rules engine **220** performs a number of additional hashes according to R, as described above. In another embodiment, rules engine **220** does not perform additional hashes if a match is not found after the initial hashing function.

If a matching flow entry **232** is not found after one or more attempts, at **540**, rules engine **220** identifies a set of one or more state-transition rules **244**-N whose create bits **2448** are set. At **542**, rules engine **220** determines whether the packet includes transition pattern **2444** included in one of the state-transition rules **244**-N in the set of create rules. If the packet includes transition pattern **2444**, at **544** rules engine **220** performs a hashing function based on data in the packet to create a flow entry **232** corresponding to the packet's flow. The hashing function may be any hashing function known in the art.

However, if the packet does not include transition pattern **2444**, at **546** rules engine **220** determines whether the set of create rules includes another state-transition rule **244**. If the set includes another state-transition rule **244**, rules engine **220** returns to **542**. Conversely, if the set does not include another state-transition rule **244**-N (or if no state-transition rule indicates creating a flow entry), the packet is deemed to be associated with a network intrusion, because the packet's flow is neither included in ST **230** nor targeted for inclusion in ST **230**. In one embodiment, rules engine **220** discards the packet at **520**. In another embodiment, rules engine **220** discards the packet if it causes a number of intrusive packets to be reached, but otherwise transmits the packet, as described previously.

However, if at **510** ST **230** includes a matching flow entry **232** corresponding to the flow, at **512** rules engine **220** identifies a set of state-transition rules **244**-N whose combined source states **2442** include current state **2324** of matching flow entry **232**. In one embodiment, rules engine **220** performs an AND operation using combined source states **2442** and current state **2324**. Rules engine **220** compares the result of the AND operation to current state **2324**, to identify state-transition rules **244**-N whose combined source states include current state **2324**. A state-transition rule **244**-N includes current state **2324** if current state **2324** matches the result of the AND operation performed using the state transition rule's combined source states. Although an AND operation is described, other operations such as, but not limited to, tree search operations, may be used.

Once the state-transition rules **244**-N whose combined source states **2442** include current state **2324** of matching flow entry **232**, at **514** rules engine **220** determines whether the packet includes transition pattern **2444** included in one of the state-transition rules. If the packet does not include transition pattern **2444**, at **516** rules engine **220** determines whether all state-transition rules that include the matching flow entry **232** have been checked. If not, rules engine **220** returns to **514**. Conversely, all state-transition rules that include the matching flow entry **232** have not been checked, rules engine **220** discards the packet at **520**. In another embodiment, rules engine **220** discards the packet if it causes a number of intrusive packets to be reached, but otherwise transmits the packet, as described previously.

If at **514** the packet includes transition pattern **2444**, at **515** rules engine **220** identifies a SS-DD Pair whose source state matches current state **2324**. At **518**, rules engine **220** replaces current state **2324** with the destination state of the SS-DD Pair whose source state matches current state **2324**. At **550**, rules engine **220** determines whether evict bit **2450** of the SS-DD Pair is set. If evict bit **2450** is not set, rules engine **220** sends the packet to the transmit buffer at **530**. If the evict bit is set, at **552** rules engine **220** evicts matching flow entry **232** from ST **230** and sends the packet to the transmit buffer at **530**.

FIG. **7** illustrates an example embodiment of determining a valid state transition. A packet that includes a pattern XYZ arrives in the receive buffer of NIDU **200**. A protocol identifier in packet **700** indicates packet **700**'s protocol as TCP. Rules engine **220** determines that the protocol is TCP and determines based on a table identifier **242**, which matches packet **700**'s protocol identifier, that a RT **240** exists for TCP.

Rules engine **220** identifies the flow to which packet **700** belongs, and identifies a flow entry **732** that corresponds to the flow of packet **700**. The current state **7324** is state 2, as indicated by the bit-vector 00000010. Rules engine **220** performs an AND operation using current state **7324** and combined source states **2442** of state-transition rules **244**-N. One of the state-transition rules whose combined source states **7442** include current state **7324** is state-transition rule **744-10**. Specifically, the result of the AND operation using combined source states **7442** (00001110) and current state **7324** (00000010) is 00000010, which matches current state **7324**. Packet **700** includes transition pattern **7444**, i.e., XYZ, in state transition rule **744-10**. Consequently, a destination state of SS-DD Pair-1 in transition states **7446**, i.e., state **4**, which corresponds to source state 2 in SS-DD Pair-1, indicates the next state of the flow represented by flow entry **732**. Therefore, packet **700** is a valid packet, and rules engine **220** replaces state 2 in current state **7324** with state 4 from SS-DD Pair-1.

FIG. **8** is a block diagram of one embodiment of an electronic system. In one embodiment, the technique described herein can be implemented as sequences of instructions executed by an electronic system. The electronic system is intended to represent a range of electronic systems, including, for example, a personal computer, a personal digital assistant (PDA), a laptop or palmtop computer, a cellular phone, a computer system, a network access device, etc. Other electronic systems can include more, fewer and/or different components. The electronic system can be coupled to a wired network, e.g., via a coaxial cable, fiber-optic cable or twisted-pair wire, a wireless network, e.g., via radio or satellite signals, or a combination thereof. The sequences of instructions can be stored by the electronic system. In addition, the instructions can be received by the electronic system (e.g., via a network connection).

Electronic system **800** includes a bus **810** or other communication device to communicate information, and processor **820** coupled to bus **810** to process information. While electronic system **800** is illustrated with a single processor, electronic system **800** can include multiple processors and/or co-processors.

Electronic system **800** further includes random access memory (RAM) or other dynamic storage device **830** (referred to as memory), coupled to bus **810** to store information and instructions to be executed by processor **820**. Memory **830** also can be used to store temporary variables or other intermediate information while processor **820** is executing instructions. Electronic system **800** also includes read-only memory (ROM) and/or other static storage device **840** coupled to bus **810** to store static information and instructions for processor **820**. In addition, data storage device **850** is coupled to bus **810** to store information and instructions. Data

storage device **850** may comprise a magnetic disk (e.g., a hard disk) or optical disc (e.g., a CD-ROM) and corresponding drive.

Electronic system **800** may further comprise a display device **860**, such as a cathode ray tube (CRT) or liquid crystal display (LCD), to display information to a user. Alphanumeric input device **870**, including alphanumeric and other keys, is typically coupled to bus **810** to communicate information and command selections to processor **820**. Another type of user input device is cursor control **875**, such as a mouse, a trackball, or cursor direction keys to communicate direction information and command selections to processor **820** and to control cursor movement on flat-panel display device **860**. Electronic system **800** further includes network interface **880** to provide access to a network, such as a local area network or wide area network.

Instructions are provided to memory from a machine-accessible medium, or an external storage device accessible via a remote connection (e.g., over a network via network interface **880**) providing access to one or more electronically-accessible media, etc. A machine-accessible medium includes any mechanism that provides (i.e., stores and/or transmits) information in a form readable by a machine (e.g., a computer). For example, a machine-accessible medium includes random-access memory (RAM), such as static RAM (SRAM) or dynamic RAM (DRAM); ROM; magnetic or optical storage medium; flash memory devices; electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals); etc.

In alternative embodiments, hard-wired circuitry can be used in place of or in combination with software instructions to implement the embodiments of the invention. Thus, the embodiments of the invention are not limited to any specific combination of hardware circuitry and software instructions.

Reference in the foregoing specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes can be made thereto without departing from the broader spirit and scope of the embodiments of the invention. The specification and drawings are, accordingly, are to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A method for filtering packets, wherein a flow corresponds to a stream of packets for a particular communication session, comprising:

identifying a protocol used to transmit a packet;

identifying the flow to which the packet belongs;

determining that a rules table exists for the protocol;

determining that a state table includes a matching flow entry corresponding to the flow;

determining whether a skip count is reached, wherein the skip count indicates a flow to examine after skipping a number of flows;

examining the flow when the skip count has been reached;

resetting the skip count when the flow is examined;

skipping and not examining the flow when the skip count has not been reached; and

incrementing the skip count when the flow is skipped;

determining whether the flow will transition from a current state indicated in the matching flow entry to a valid destination state indicated in a state-transition rule in the rules table; and

discarding the packet if the state of the flow will not transition to the valid destination state.

2. The method of claim **1**, wherein the protocol comprises a protocol whose operation is capable of being defined by a finite state machine.

3. The method of claim **2**, wherein the protocol comprises one of the following: File Transfer Protocol, Telnet, Hypertext Transfer Protocol, H.323, Real Time Transport Protocol/Real Time Control Protocol and Secure Shell Protocol.

4. The method of claim **1**, further comprising discarding the packet, if no rules table exists for the protocol.

5. The method of claim **1**, further comprising transmitting the packet if no rules table exists for the protocol.

6. The method of claim **1**, further comprising transmitting the packet if the flow will transition to the valid destination state.

7. The method of claim **1**, further comprising:

determining that a number of actual flows fails to exceed a preset threshold of flows; and

examining flows based on the skip count, as a result of the number of actual flows failing to exceed the preset threshold.

8. The method of claim **1**, further comprising:

determining that a number of actual flows exceeds a preset threshold of flows;

determining a number of preset steps by which the number of actual flows exceeds the preset threshold;

multiplying the number of preset steps by a preset skip-count modifier; and

changing the skip count to a different skip count equal to the product of the preset number of steps and the preset skip-count modifier.

9. The method of claim **1**, wherein determining that the state table includes the matching flow entry comprises:

performing a hashing function based, at least in part, on values in the packet;

determining that a flow entry matches a result of the hashing function;

determining that the packet values hashed to generate the result match values used to generate the flow entry; and

determining that the flow entry is the matching flow entry.

10. The method of claim **9**, further comprising:

performing one or more additional hashing functions according to a number of a flow skip count, if no flow entry matches the result of the hashing function, wherein the skip count indicates a flow to examine after skipping a number of flows; and

performing the one or more additional hashing functions according to the number related to the skip count, if the flow entry matches the result of the hashing function, but the packet values fail to match the values used to generate the flow entry.

11. The method of claim **10**, wherein performing the one or more additional hashing functions according to the number related to the skip count comprises:

performing a preset minimum number of additional hashing functions, if the skip count comprises a first value;

performing an increased number of additional hashing functions, if the skip count is increased, wherein the increased number of additional hashing functions is greater than the preset minimum number of additional hashing functions, but less than a preset maximum number of additional hashing functions; and

performing the preset maximum number of additional hashing functions, when the increased number of additional hashing functions reaches the preset maximum number of additional hashing functions.

12. The method of claim **9**, further comprising:

identifying, if the state table fails to include the matching flow entry, a set of one or more state-transition rules having an indication to create an additional flow entry;

determining whether the packet includes a transition pattern indicated in a state-transition rule in the set, wherein the transition pattern indicates that the additional flow entry is to be created;

creating the additional flow entry, if the packet includes the transition pattern; and

discarding the packet, if the packet fails to include the transition pattern.

13. The method of claim **1**, wherein determining the flow will transition to the valid destination state comprises:

performing an AND operation using the current state and combined source states indicated in a state-transition rule;

determining that the current state matches a result of the operation;

determining that the combined source states include the current state;

determining that the packet includes a transition pattern indicated in the state-transition rule; and

determining that the state of the flow will transition from the current state to the valid destination state in the state-transition rule in the set.

14. The method of claim **13**, further comprising:

identifying in the state-transition rule a source state-destination state pair that includes the current state; and

replacing the current state with the destination state indicated in the source state-destination state pair.

15. The method of claim **14**, further comprising:

determining that the source state-destination state pair includes an evict indication; and

evicting the matching flow entry from the state table.

16. The method of claim **13**, further comprising:

discarding the packet, if the packet fails to include the transition pattern included in a plurality of state-transition rules whose combined source states include the current state.

17. The method of claim **1**, wherein discarding the packet comprises:

determining whether the packet causes a predetermined number of packets associated with invalid transitions to be reached; and

discarding the packet, if the packet causes the predetermined number to be reached.

18. An apparatus comprising:

a classifier to identify a protocol used to transmit a packet and identify a stream of packets to which the packet belongs, wherein the stream of packets comprises a flow;

one or more rules tables that include one or more state-transition rules;

one or more state tables for the protocol that include one or more flow entries and values used to generate the flow entries; and

a rules engine to:

determine that a rules table exists for the protocol,

determine that a state table includes a matching flow entry corresponding to the flow;

determine whether a skip count is reached, wherein the skip count indicates a flow to examine after skipping a number of flows;

examine the flow when the skip count has been reached;

reset the skip count when the flow is examined;

skip and not examining the flow when the skip count has not been reached; and

increment the skip count when the flow is skipped;

determine whether the flow will transition from a current state indicated in the matching flow entry to a valid destination state indicated in a state-transition rule in the rules table; and

discard the packet if the state of the flow will not transition to the valid destination state.

19. The apparatus of claim **18**, wherein the rules engine determines whether the state table includes the matching flow entry by performing a hashing function based, at least in part, on values in the packet, determining whether a flow entry matches a result of the hashing function, determining, if the flow entry matches the result, whether the packet values hashed to generate the result match values used to generate the flow entry, and determining, if the packet values match the values used to generate the flow entry, that the flow entry is the matching flow entry.

20. An article of manufacture comprising:

a non-transitory machine-accessible medium including thereon sequences of instructions that, when executed, cause an electronic system to:

identify a protocol used to transmit a packet;

identify the flow to which the packet belongs;

determine that a rules table exists for the protocol;

determine that a state table includes a matching flow entry corresponding to the flow;

determine whether a skip count is reached, wherein the skip count indicates a flow to examine after skipping a number of flows;

examine the flow when the skip count has been reached;

reset the skip count when the flow is examined;

skip and not examine the flow when the skip count has not been reached; and

increment the skip count when the flow is skipped;

determine whether the flow will transition from a current state indicated in the matching flow entry to a valid destination state indicated in a state-transition rule in the rules table; and

discard the packet if the state of the flow will not transition to the valid destination state.

21. The article of manufacture of claim **20**, wherein the machine-accessible medium further comprises sequences of instructions that, when executed, cause the electronic system to:

determine that a number of actual flows fails to exceed a preset threshold of flows; and

examine flows based on the skip count, as a result of the number of actual flows failing to exceed the preset threshold.

22. The article of manufacture of claim **20**, wherein the machine-accessible medium further comprises sequences of instructions that, when executed, cause the electronic system to:

determining that a number of actual flows exceeds a preset threshold of flows;

determine a number of preset steps by which the number of actual flows exceeds the preset threshold;

multiply the number of preset steps by a preset skip-count modifier; and

change the skip count to a different skip count equal to the product of the preset number of steps and the preset skip-count modifier.

23. The article of manufacture of claim **20**, wherein the sequences of instructions that, when executed, cause the electronic system to determine whether the state table includes the matching flow entry comprise sequences of instructions that, when executed, cause the electronic system to:

perform a hashing function based, at least in part, on values in the packet;

determine whether a flow entry matches a result of the hashing function;

determine, if the flow entry matches the result, whether the packet values hashed to generate the result match values used to generate the flow entry; and

determine, if the packet values match the values used to generate the flow entry, that the flow entry is the matching flow entry.

24. The article of manufacture of claim **23**, wherein the machine-accessible medium further comprises sequences of instructions that, when executed, cause the electronic system to:

identify, if the state table fails to include the matching flow entry, a set of one or more state-transition rules having an indication to create an additional flow entry;

determine whether the packet includes a transition pattern indicated in a state-transition rule in the set, wherein the transition pattern indicates that the additional flow entry is to be created;

create the additional flow entry, if the packet includes the transition pattern; and

discard the packet, if the packet fails to include the transition pattern.

25. The article of manufacture of claim **20**, wherein the sequences of instructions that, when executed, cause the electronic system to determine whether the state of the flow will transition to the valid destination state comprise sequences of instructions that, when executed, cause the electronic system to:

perform an AND operation using the current state and combined source states indicated in a state-transition rule;

determine whether the current state matches a result of the operation;

determine, if the current state matches the result of the operation, that the combined source states include the current state;

determine, as a result of the combined source states including the current state, whether the packet includes a transition pattern indicated in the state-transition rule; and

determine, if the packet includes the transition pattern, that the state of the flow will transition from the current state to the valid destination state in the state-transition rule in the set.

26. A system comprising:

a processor;

a network interface coupled with the processor; and

an article of manufacture comprising a machine-accessible medium including thereon sequences of instructions that, when executed, cause k electronic system to:

identify a protocol used to transmit a packet;

identify the flow to which the packet belongs;

determine that a rules table exists for the protocol;

determine that a state table includes a matching flow entry corresponding to the flow;

determine whether a skip count is reached, wherein the skip count indicates a flow to examine after skipping a number of flows;

examine the flow when the skip count has been reached;

reset the skip count when the flow is examined;

skip and not examine the flow when the skip count has not been reached; and

increment the skip count when the flow is skipped;

determine whether the flow will transition from a current state indicated in the matching flow entry to a valid destination state indicated in a state-transition rule in the rules table; and

discard the packet if the state of the flow will not transition to the valid destination state.

27. The system of claim **26**, wherein the sequences of instructions that, when executed, cause the electronic system to determine whether the state table includes the matching flow entry comprise sequences of instructions that, when executed, cause the electronic system to:

perform a hashing function based, at least in part, on values in the packet;

determine whether a flow entry matches a result of the hashing function;

determine, if the flow entry matches the result, whether the packet values hashed to generate the result match values used to generate the flow entry; and

determine, if the packet values match the values used to generate the flow entry, that the flow entry is the matching flow entry.

28. The system of claim **26**, wherein the machine-accessible medium further comprises sequences of instructions that, when executed, cause the electronic system to:

identify, if the state table fails to include the matching flow entry, a set of one or more state-transition rules having an indication to create an additional flow entry;

determine whether the packet includes a transition pattern indicated in a state-transition rule in the set, wherein the transition pattern indicates that the additional flow entry is to be created;

create the additional flow entry, if the packet includes the transition pattern; and

discard the packet, if the packet fails to include the transition pattern.

29. The system of claim **26**, wherein the sequences of instructions that, when executed, cause the electronic system to determine whether the state of the flow will transition to the valid destination state comprise sequences of instructions that, when executed, cause the electronic system to:

perform an AND operation using the current state and combined source states indicated in a state-transition rule;

determine whether the current state matches a result of the operation;

determine, if the current state matches the result of the operation, that the combined source states include the current state;

determine, as a result of the combined source states including the current state, whether the packet includes a transition pattern indicated in the state-transition rule; and

determine, if the packet includes the transition pattern, that the state of the flow will transition from the current state to the valid destination state in the state transition rule in the set.

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