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(54) **Title**: OPEN FLOW FUNCTIONALITY IN A SOFTWARE-DEFINED NETWORK

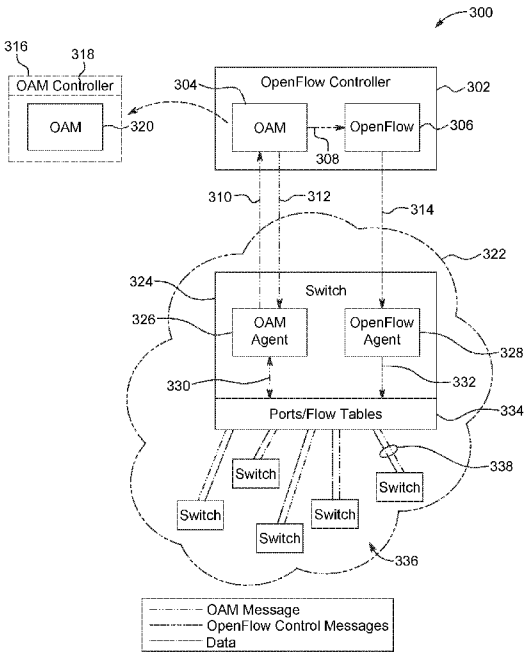


FIG. 3

(57) **Abstract**: A software defined networking (SDN) switch may be configured with an operations, administration, and management (OAM) controller to create and communicate one or more OAM messages to OAM components on other switches. The OAM controller may communicate one or more flow rules to an SDN agent of the SDN switch to configure a flow table or a port of the SDN switch.

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OPEN FLOW FUNCTIONALITY IN A SOFTWARE-DEFINED NETWORK

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/296,856 filed February 18, 2016, the contents of which is hereby incorporated by reference herein.

BACKGROUND

[0002] Software defined networking (SDN) may be utilized for 5th Generation (5G) networks and beyond. SDN is an architecture where network services may be managed through abstraction of lower-level functionality. SDNs help to streamline and simplify networks by providing dynamic and scalable storage environments. SDNs may achieve this by decoupling or disassociating decisions about where traffic is sent, such as by or at a control plane, from a underlying system(s) that forward traffic to a destination, such as by or at a data plane. This simplicity may allow SDNs to provide ultra-reliable low latency communications (URLLs) and makes SDNs optimal for small cell environments.

[0003] OpenFlow is a simplified communications protocol considered for SDNs that may give access to a forwarding plane of a network switch or router over a network for stateless forwarding or packet lookup operation. An impact of stateless operation is that operations, administration, and management/maintenance (OAM), timing, and synchronization functions or services at a switch may be unavailable. However, certain applications may operate more efficiently or need OAM functions at a switch instead of at a controller. Lastly, OAM functions at one or more switches may reduce controller load in a SDN.

SUMMARY

[0004] An operations, administration, and management/maintenance (OAM) agent may be arranged or configured on a switch to receive OAM specific messages and processing in an SDN. The OAM agent may also send

one or more link failure indications to a controller, a switch, or other OAM agent. An OAM agent may also transmit an indication when one or more communication links is determined or detected to be broken, degraded, or restored.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

[0006] FIG. 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented;

[0007] FIG. 1B is a system diagram of an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A;

[0008] FIG. 1C is a system diagram of an example radio access network and an example core network that may be used within the communications system illustrated in FIG. 1A;

[0009] FIG. 2 is a diagram of a software defined networking (SDN) system or OpenFlow network utilizing operations, administration, and management/maintenance (OAM);

[0010] FIG. 3 is a network diagram of a system that utilizes OAM agent(s);

[0011] FIG. 4 is a diagram of a system that utilizes an on-board OAM controller;

[0012] FIG. 5 is a diagram of a network with a local OAM controller serving a group of switches;

[0013] FIG. 6 is a process of operating OAM in an SDN system or OpenFlow network; and

[0014] FIG. 7 is a process of operating OAM agents in an SDN system or OpenFlow network.

DETAILED DESCRIPTION

[0015] Configurations are given herewith to provide stateful software defined networking (SDN), OpenFlow, switch, bridge, or the like functionality to achieve performance needs. Stateful or state-fullness operation may allow support of operation and management/maintenance (OAM) functionality. For the methods and processes described below, the steps recited may be performed out of sequence in any order and sub-steps not explicitly described or shown may be performed. In addition, "coupled", "operatively coupled", "in communication", etc. may mean that objects are linked or communicate but may have zero or more intermediate objects between the linked objects. Also, any combination of the disclosed features/elements may be used in one or more embodiments. When referring to "A or B", it may include A, B, or A and B, which may be extended similarly to longer lists. When using the notation X/Y it may include X or Y. When using the notation X/Y it may also include X and Y. X/Y notation may be extended similarly to longer lists with the same aforementioned logic.

[0016] Any elements shown or described in the figures herewith may be implemented by one or more functions or components on hardware, software, firmware, or the like. Moreover, in the examples herewith, a transmitter may be part of a transceiver or multi-component hardware, as desired. A receiver may be part of a transceiver or multi-component hardware, as desired. Directional arrows utilized or drawn in any of FIGs. 1-7 are for illustrative purposes and may be interchangeable with bi-directional arrows, lines, or interconnects.

[0017] FIG. 1A is a diagram of an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division

multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), or the like.

[0018] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, or 102d, a radio access network (RAN) 104, a core network 106, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, or 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, or 102d may be configured to transmit and/or receive wireless signals and may include user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, or the like.

[0019] The communications systems 100 may also include a base station 114a and a base station 114b. Each of the base stations 114a or 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, or 102d to facilitate access to one or more communication networks, such as the core network 106, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a or 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a site controller, an access point (AP), a wireless router, or the like. While the base stations 114a or 114b are each depicted as a single element, it will be appreciated that the base stations 114a or 114b may include any number of interconnected base stations and/or network elements.

[0020] The base station 114a may be part of the RAN 104, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to

transmit and/or receive wireless signals within a particular geographic region, which may be referred to as a cell (not shown). The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in one embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In another embodiment, the base station 114a may employ multiple-input multiple-output (MIMO) technology and, therefore, may utilize multiple transceivers for each sector of the cell.

[0021] The base stations 114a or 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, or 102d over an air interface 116, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 116 may be established using any suitable radio access technology (RAT).

[0022] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, or the like. For example, the base station 114a in the RAN 104 and the WTRUs 102a, 102b, or 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 116 using wideband CDMA (W-CDMA). W-CDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink Packet Access (HSDPA) and/or High-Speed Uplink Packet Access (HSUPA).

[0023] In another embodiment, the base station 114a and the WTRUs 102a, 102b, or 102c may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface 116 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A).

[0024] In other embodiments, the base station 114a and the WTRUs 102a, 102b, or 102c may implement radio technologies such as IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), cdma2000, cdma2000 1X, cdma2000 EV-DO, Interim Standard 2000 (IS-2000), Interim

Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), or the like.

[0025] The base station 114b in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, or the like. In one embodiment, the base station 114b and the WTRUs 102c or 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In another embodiment, the base station 114b and the WTRUs 102c or 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c or 102d may utilize a cellular-based RAT (e.g., W-CDMA, cdma2000, GSM, LTE, LTE-A, etc.) to establish a picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the core network 106.

[0026] The RAN 104 may be in communication with the core network 106, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, or 102d. For example, the core network 106 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104 and/or the core network 106 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104 or a different RAT. For example, in addition to being connected to the RAN 104, which may be utilizing an E-UTRA radio technology, the core network 106 may also be in communication with another RAN (not shown) employing a GSM radio technology.

[0027] The core network 106 may also serve as a gateway for the WTRUs 102a, 102b, 102c, or 102d to access the PSTN 108, the Internet 110,

and/or other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another core network connected to one or more RANs, which may employ the same RAT as the RAN 104 or a different RAT.

[0028] Some or all of the WTRUs 102a, 102b, 102c, or 102d in the communications system 100 may include multi-mode capabilities, i.e., the WTRUs 102a, 102b, 102c, or 102d may include multiple transceivers for communicating with different wireless networks over different wireless links. For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0029] FIG. 1B is a system diagram of an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130, removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and other peripherals 138. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0030] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Array (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, or the like. The processor 118

may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0031] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station 114a) over the air interface 116. For example, in one embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In another embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In yet another embodiment, the transmit/receive element 122 may be configured to transmit and receive both RF and light signals. It will be appreciated that the transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0032] In addition, although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one embodiment, the WTRU 102 may include two or more transmit/receive elements 122 (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface 116.

[0033] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as UTRA and IEEE 802.11, for example.

[0034] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, or the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0035] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), etc.), solar cells, fuel cells, or the like.

[0036] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset 136, the WTRU 102 may receive location information over the air interface 116 from a base station (e.g., base stations 114a or 114b) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0037] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, or the like.

[0038] FIG. 1C is a system diagram of the RAN 104 and the core network 106 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, or 102c over the air interface 116. The RAN 104 may also be in communication with the core network 106.

[0039] The RAN 104 may include eNode-Bs 140a, 140b, or 140c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 140a, 140b, or 140c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, or 102c over the air interface 116. In one embodiment, the eNode-Bs 140a, 140b, or 140c may implement MIMO technology. Thus, the eNode-B 140a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0040] Each of the eNode-Bs 140a, 140b, or 140c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink and/or downlink, or the like. As shown in FIG. 1C, the eNode-Bs 140a, 140b, or 140c may communicate with one another over an X2 interface.

[0041] The core network 106 shown in FIG. 1C may include a mobility management entity gateway (MME) 142, a serving gateway 144, and a packet data network (PDN) gateway 146. While each of the foregoing elements are depicted as part of the core network 106, it will be appreciated that any one of

these elements may be owned and/or operated by an entity other than the core network operator.

[0042] The MME 142 may be connected to each of the eNode-Bs 140a, 140b, or 140c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 142 may be responsible for authenticating users of the WTRUs 102a, 102b, or 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, or 102c, or the like. The MME 142 may also provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM or W-CDMA.

[0043] The serving gateway 144 may be connected to each of the eNode Bs 140a, 140b, or 140c in the RAN 104 via the S1 interface. The serving gateway 144 may generally route and forward user data packets to/from the WTRUs 102a, 102b, or 102c. The serving gateway 144 may also perform other functions, such as anchoring user planes during inter-eNode B handovers, triggering paging when downlink data is available for the WTRUs 102a, 102b, or 102c, managing and storing contexts of the WTRUs 102a, 102b, or 102c, or the like.

[0044] The serving gateway 144 may also be connected to the PDN gateway 146, which may provide the WTRUs 102a, 102b, or 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, or 102c and IP-enabled devices.

[0045] The core network 106 may facilitate communications with other networks. For example, the core network 106 may provide the WTRUs 102a, 102b, or 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, or 102c and traditional land-line communications devices. For example, the core network 106 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the core network 106 and the PSTN 108. In addition, the core network 106 may provide the WTRUs 102a, 102b, or 102c with access to other networks 112,

which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0046] Other network 112 may further be connected to an IEEE 802.11 based wireless local area network (WLAN) 160. The WLAN 160 may include an access router 165. The access router may contain gateway functionality. The access router 165 may be in communication with a plurality of access points (APs) 170a or 170b. The communication between access router 165 and APs 170a or 170b may be via wired Ethernet (IEEE 802.3 standards), or any type of wireless communication protocol. AP 170a may be in wireless communication over an air interface with WTRU 102d.

[0047] Certain wireless applications and devices may need Gbits/sec and above of throughput, simple architecture, high traffic density area operation, very low latency, and very low power consumption. Such applications or devices may include tactile internet, Internet of Things (IoTs), sensors, mission-critical communications (MTCs), millimeter wave (mmWave) systems, ultra-reliable and low latency communications (URLLCs), enhanced mobile broadband (eMBB), Collaborative Research in Packet Transport – 5G Crosshaul Fifth Generation Public Private Partnership (5G-PPP) compatible networks, or the like. SDN or OpenFlow may be utilized to achieve one or more of these needs.

[0048] Configurations are given herewith to provide stateful SDN or OpenFlow functionality to a network node (e.g., switch, router, bridge, etc.) to meet performance requirements of future wireless systems. Stateful or state-fullness operation may allow support of operation and management/maintenance (OAM) functionality, dynamic reconfiguration, event counting, creating/managing timers, connection configuration/reconfiguration, link management, link failure detection, link failure correction, network failure detection, network failure correction, performing specific actions after detecting a set of events, packet generation, fault management, fault correction, performance monitoring, control data management, or the like. OAM functionality may be desirable for dynamic and efficient operation and configuration adjustments of SDN or OpenFlow

switches. Low latency needs or requirements of 5G may also be met by having stateful operations at a switch instead of mostly at a controller in an SDN or OpenFlow network. Stateful switches may especially be beneficial when a controller is geographically distant from a switch.

[0049] In the examples forthcoming, an OAM controller may be configured as an on-board OAM controller, local OAM controller, OAM agent, or the like. A central OAM controller may also be configured to operate or manage a local OAM controller, an on-board OAM controller, or OAM agent. In addition, an SDN or OpenFlow network may utilize Ethernet, 802.3x, or the like local area network protocols for communicating among components. Ethernet OAM may utilize complex and stateful mechanisms, for example, where states are maintained and information is retained. Decisions or actions may be taken based on states and/or retained information. States and information may be determined using standardized protocols including fault management and performance monitoring (ITU-T Y.1731), connectivity fault management (IEEE 802.1ag), link layer discovery (IEEE 802.1ab), and Ethernet protection switching (ITU G.8031).

[0050] FIG. 2 is a diagram of an SDN system or OpenFlow network 200 utilizing OAM. Controller 202 may communicate with switch 206 over interface 204 and south bound interface (SBI) 205. SBI may be utilized to configure forwarding rules on switch 206. For certain configurations, interface 204 may be utilized as a central interface such as when controller 202 is configured as an OAM central controller. In addition, controller 202 may communicate with other central controllers or controller nodes utilizing fiber optics, wired, wireless, cable, ethernet, or the like interfaces. Switch 206 may communicate with other switches utilizing fiber optics, wired, wireless, cable, ethernet, or the like interfaces.

[0051] Stateful logic may be implemented on a data plane in switch 206 utilizing external software interacting with OAM controller 210. OAM controller 210 may perform tasks such as receiving substantially all frames destined to switch 206, processing OAM-specific packets for a switch, forwarding predetermined frames locally to agent 208 with utilization of

interface 211, creating flow rules and one or more configurations through agent 208, or the like. Agent 208 may configure or update flow rules in switch 212 using interface 209. In addition, OAM controller 210 may be configured as an on-board OAM controller and also function or operate as an OAM agent. When configured as an agent, OAM controller 210 functionality may be restricted to OAM specific handling, i.e., generating/consuming OAM messages and network performance reports or link failures conditions reports or the like using interface 204. As on-board OAM agent configuration, forwarding rules configuration may be handled by controller 202 to agent 208, which may be configured as an OpenFlow agent, using SBI 205.

[0052] OAM controller 210 may be configured by controller 202 and utilized to offload certain operations, such as latency measurements, from controller 202. Executing certain operations at switch 206 may increase reactiveness due to locality. However, some OAM functions may still be performed at controller 202 such as when centralized operation is desirable. For instance, controller 202 may manage configuration of flow table rules on one or more switches based on regular information obtained from a link layer discovery protocol (LLDP) or link conditions reported by OAM controller 210. Receiving indications from OAM controller 210 may reduce the time needed for controller 202 to re-configure new flow rules on appropriate switches.

[0053] OAM functionality may be added to switches other than switch 206. OAM controller 210 may be configured to serve a group of switches, a hierarchy of switches, or the like to reduce OAM control traffic. In this configuration, OAM controller 210 may be an OAM local controller and/or interact with other central OAM controllers. As explained in forthcoming examples, a central OAM controller may be configured with a direct interface with local OAM controllers instead of access through an OpenFlow controller.

[0054] OAM mechanisms may dynamically configure or reconfigure OAM controller 210 through interface 204 according to network, controller, or performance needs. OAM mechanisms or functions may be defined by finite state machines. An action at switch 206 may be associated with each state or external events. For example, a packet reception or timer expiration may

trigger a transition to a new state. The generation of OAM packets, the consumption of OAM packets, counters, timers, and associated actions may all be incorporated and used by a finite state machine. In comparison to agent 208, different actions may be performed by switch 206 subsequent to a detected link failure by OAM controller 210 when configured with fault/performance support or state machines.

[0055] In one configuration of SDN system or OpenFlow network 200, an OAM function or operation may initially or for a certain time period be performed at local OAM controller 210. Subsequently or at expiration of the time period, controller 202 and/or a central OAM controller may take over the OAM function or operation for longer term control. Longer term control may include data analysis, display to a human operator, maintenance planning, or the like, with added statistics populated to a central OAM controller.

[0056] In one configuration, agent 208 may control configuration of rules for flow forwarding to ports 214 while OAM controller 210 may manage OAM specific operations such as heartbeat generation and monitoring, network health checking, or the like. Heartbeat monitoring may provide or include link failure detection, which may be reported to a central OAM controller.

[0057] OAM controller 210 may detect one or more link failure conditions and subsequently report such a failure to controller 202 through interface 204. Controller 202, that may be configured as a central OAM controller, may also be configured to handle OAM operational parameter configurations onto on-board OAM controller 210.

[0058] FIG. 3 is a network diagram of a system 300 that may utilize OAM agent(s). OpenFlow controller 302 may configure flow rules on OpenFlow agent 328, on switch 324 residing in network 322, with utilization of interface 314. Although one switch is shown in system 300, OpenFlow controller 302 may communicate or configure multiple switches. OAM controller agent 304 may configure operational parameters with OAM agent 326, configured on-board on switch 324, over interface 312. Received and processed OAM specific messages by OAM agent 326, sent/received via interface 330, may be used to inform OAM controller agent 304 of network

conditions, via interface 310. OAM information may be forwarded to OpenFlow controller component 306 and used to configure new forwarding rule on OpenFlow agent 328, via interface 314. OpenFlow agent may configure port flow/tables 334 via interface 332. Port flow/tables 334 may be configured, setup, reconfigured, or updated by OpenFlow agent 328 through interface 332.

[0059] OAM agent 326 may also create OAM messages to be sent to other switches 336 by utilization of links 338. Data may also be communicated to switches 336 by utilization of links 338. OAM messages may be heartbeat messages, latency measurement messages, or the like. Interface 310 may be utilized by OAM agent 326 to send link failure indications, link quality reports, or the like to OAM controller agent 304 when detected. OAM controller agent 304 may also inform OpenFlow controller component 306 over interface 308 of such a condition to update flow rules at OpenFlow agent 328 by utilizing interface 314.

[0060] OpenFlow controller 302 may be a node that implements OpenFlow controller component 306 and OAM controller agent 304 functionalities. Alternatively, OAM controller agent 304 may be implemented outside of OpenFlow controller 302. For instance, OAM controller 318 may be configured or setup an external entity component or node 316, operationally or physically separate from OpenFlow controller 302. In this configuration, interaction between external entity component or node 316 and OpenFlow controller component 306 may still be needed, via interface 308 which is then external. External entity component or node 316 and OAM controller 318 may receive one or more indications from OAM controller agent 304 when a link is broken, degraded, restored, or the like. OAM controller 318 may implement OAM functionality with OAM agent 320. OpenFlow controller component 306 may handle configuration of flow table rules onto a switch, based on the information obtained with the utilization of on-board OAM agent 326 and/or central OAM controller agent 304 or OAM agent 320. For example, link conditions reported by OAM agent 326 to OAM controller agent 304 or OAM agent 320 may be provided to OpenFlow controller component 306.

[0061] FIG. 4 is a diagram of system 400 that may utilize an on-board OAM controller. OpenFlow controller component 406 may implement OpenFlow functionality and configure flow rules on switch 424 in network 422 with utilization of interface 414. Although one switch is shown, OpenFlow controller component 406 may communicate or configure a plurality or group of switches.

[0062] OAM controllers 404 or 418 may be central OAM controllers and may configure operational parameters on switch 424 via interactions with local OAM controller 426 using interface 412. OAM-specific messages may be received, processed, or managed by OAM controller 426. OAM messages may include heartbeat messages, latency measurement messages, or the like. OAM message may also be created by OAM controller 426 and communicated to switches 436 utilizing interface 430 and links 438. Data may also be communicated to switches 436 by utilization of interface 430 and links 438. OAM controller 426 may configure new or updated flow rules on OpenFlow agent 428 when needed, such as subsequent to a detected link failure, using interface 427. This operation may be reduce latency by being performed directly or locally skipping or bypassing the need to signal OpenFlow controller 402 and waiting for a new configuration thereby.

[0063] OAM controller 426 may react to error conditions and re-configure flow rules locally. Central OAM controller 404 may be notified using interface 410 about error conditions or a link failure and newly configured rules. Central OAM controller 404 may inform OpenFlow controller component 406 of such a condition or new configuration through interface 408. OpenFlow controller 402 may then update flow rules on other appropriate switches as needed.

[0064] Similar to system 300, OAM specific messages may be received and processed by OAM controller 426 via interface 430. OAM controller may also create OAM messages to be sent to other switches, e.g., heartbeat message, latency measurements, etc. via interface 430. Port flow/tables 434 may be configured, setup, reconfigured, or updated by OpenFlow agent 428 through interface 432. In addition, like system 300, an external component or

node 416 and OAM controller 418 may receive one or more indications from OAM controller 404, that may be a local OAM controller, when a link is broken, degraded, restored, or the like. OAM controller 418 may report such indications when appropriate to OAM agent 420. External component or node 416 may be used instead of central OAM Controller 404 which is co-located with OpenFlow controller component 406 on OpenFlow controller 402.

[0065] OAM controller 426 may be capable of fault/performance management and periodically report statistics about various faults/events to central OAM controller 404. Central OAM controller 404 may store these statistics for future reference, share them with other entities for analysis and forwarding decisions, perform analysis, display them on an operator's graphical tool (e.g., a graphical user interface (GUI)) for maintenance/performance planning, or the like.

[0066] System 400 may be configured such that critical operations/decisions may be handled locally at switch 424, thus minimizing latency, and performing less critical operations at central OAM controller 404. As an example, switch 424 may have a very unstable, but operational link status that meets an application's minimum need. This condition may not be known by or reported to central OAM controller 404 when the link gets broken but is backed up within a number of missed heartbeats. For this scenario, OAM controller 426 may keep statistics of every event, such as the number of heartbeats missing and report that number to central OAM controller 404 utilizing interface 410.

[0067] Statistics that may be collected locally by OAM controller 426 and reported to central OAM controller 404 may include a number of heartbeat messages missing since the last report per switch, a number of link failures detected since the last report per switch, a number of flow rules re-configuration since the last report per switch, a number of latency above threshold events since the last report per switch, or the like.

[0068] OAM controller 426 may manage different states or events. Tables 1 and 2 show examples of various states or events. In tables 1 and 2 "++" signifies an addition of 1 to a variable or parameter. The managed states

may be maintained per link, and for example, per specific port/switch combination. For instance, a heartbeat message received from Switch_A on port #3 may be treated differently than the same event or condition received from Switch_B on port #1. Events may include a heartbeat timeout (HBTimeout) event as a trigger to send heartbeat messages to all ports/switches, a GlobalStatsTimeout event to periodically report global statistics to central OAM controller 404 for further or longer term analysis, an RxOAMpacket indicating reception of an OAM packet which may contain a heartbeat message, RxHB indicating reception of a heartbeat message, and a MissHBTimeout event may indicate an expected heartbeat message was not received.

[0069] Moreover, states may include an alive state in which regular heartbeat messages may be received, an idle state in which a heartbeat is not received, a starting state in which heartbeat messages may be received but is unstable or not used for forwarding yet, or the like.

[0070] An OAM configuration, which may include operational parameters, received from central OAM controller 404 may be referenced by a state machine. Examples OAM configurations, including global operational parameters, may include a HeartbeatPeriod which may be defined as a period at which an heartbeat message may be sent/received to/from switches, a MissedHBThreshold which may be defined according to a number of consecutive heartbeat messages missed before bypassing a port/switch – set to IDLE, and a NbRxHBThreshold which may be defined as a number of consecutive heartbeat messages to be received for reconsideration of a port/switch as alive.

[0071] Examples of local counters per port/switch may include a totalHBrcvd which may indicate a total number of heartbeat messages received from a port/switch and may be used for global statistics to be reported to central OAM controller 404, a nbHBrcvd counter indicative of a number of consecutive heartbeat messages received from a port/switch, a nbHBmissed counter indicative of a number of consecutive heartbeat messages missed from a port/switch, a totalHBmissed counter indicative of a total number of

heartbeat message missed from a port/switch which may be used for global statistics to be reported to central OAM controller 404, or the like.

Table 1

Events	Possible Actions
HBTimeout	• Send heartbeat message on all ports for link failure detection; • Restart HB timer for "HeartbeatPeriod" duration; or • Update stats – totalHBsent++
RxOAMpacket	• Determine from which switch/port the message has been received and execute through the state machine based on the associated state and counters (see table 2); or • Possible values: RxHB is shown in this example
GlobalStats Timeout	• Obtain statistics associated to the various switches/ports • Forward these statistics to the central OAM controller

Table 2

Events \ States	ALIVE	IDLE	STARTING
RxHB	• Restart "MissHB" timer; or • Update stats: totalHBrcvd++, nbHBmissed=0	• Restart "MissHB" timer; • Update stats: totalHBrcvd++, nbHBrcvd++; or • Move to "STARTING" state	• Restart "MissHB" timer; • Update stats: totalHBrcvd++, nbHBrcvd++; or • if nbHBrcvd == NbRxHBThreshold - Move to "ACTIVE" state - Re-evaluate & re-configure local flow rules
MissHB Timeout	• Update stats: nbHBmissed++; or • if nbHBmissed == MissedHBThreshold • Move to "IDLE" state; • Re-evaluate & re-configure local flow rules; or • Update stats: nbHBrcvd=0	• Update stats: nbHBmissed++, totalHBmissed++	• Update stats: nbHBmissed++, totalHBmissed++, nbHBrcvd=0; or • Move to "IDLE" state

[0072] FIG. 5 is a diagram of a network 500 with local OAM controller 520 serving group of switches 516 that each may have an OAM agent. In network 500, instead of having substantially the same OAM functionality installed on every or a subset of switches, a mix of OAM agent and OAM controller functionality may be utilized in a network. OAM agent functionality may include reporting events, waiting for new configurations, or any other functionality described for systems 200, 300, or 400. OAM controller functionality may also include reacting to events and locally reconfiguring flow tables.

[0073] In network 500, local OAM controller functionality may be installed on local OAM controller 520 in a separate node or selected switch with local OAM controller 522 that serve group of switches 516 and 518, respectively, of OAM groups 514. With group of switches 516 and 518 having OAM agent functionality, failures/events meeting a certain criteria may be reported to local OAM controller 520 or selected switch with local OAM controller 522. Local OAM controller 520 may be serving group of switches 516 which may be physically located close or in proximity to each other in network 510 helping to keep communication delays to a minimum or at an acceptable level. Having local OAM controller 520 in proximity to group of switches 516 also reduces delays since communication with OAM central controller 504, which may be geographically remote or distant, in network 502 may be unnecessary. As a result, traffic between group of switches 516 and OAM central controller 504 over interface 506 may be reduced and scalability improved with local OAM controller serving multiple switches.

[0074] Local OAM controller 520 may help group of switches 516 to react quicker and more efficiently to link failures and reconfigure all impacted switches in group of switches 516 based on a single or plurality of OAM-faults. For example, failures detected by one of the switches in group of switches 516 may affect other switches that may be located in network 510. If switch #1 reports a link failure with switch #2 in group of switches 516, local OAM controller 520 may determine that switch #2 should by bypassed by other switches for a certain period of time. As a result, local OAM controller 520 may inform impacted switches in group of switches 516 to reconfigure flow tables accordingly. This preemptive action may prevent link failures from occurring in group of switches 516 thereby improving uptime and performance. When a failure is a detected, having the switches bundled together, such as in advance, may enable local OAM controller 520 to correct impacted switches in group of switches 516 increasing management efficiency.

[0075] In network 512, OAM roles may be configured on every or a subset of switches in group of switches 518 and selected switch with local OAM controller 522 role. Switches in group of switches 518 may receive the

address of local switch with local OAM controller 522, via the OAM specific operational parameters configured by OAM central controller 504, such as to be able to reach or communicate with it. Switch with local OAM controller 522 may also receive OAM configurations 528 to update operation from group of switches 518 or from OAM central controller 504 through interface 508.

[0076] FIG. 6 is a process 600 of operating OAM in an SDN system or OpenFlow network. An OAM controller at a switch in an SDN system or OpenFlow network may receive or create OAM messages or flow rules (602). The OAM messages or flow rules may be communicated to an agent at the switch (604) which may reconfigure or update the switch or ports in or near the switch (606). The OAM controller may selectively communicate local OAM changes to a controller outside, remote, or elsewhere from the switch (608).

[0077] FIG. 7 is a process 700 of operating OAM agents in an SDN system or OpenFlow network. An OAM agent in an OpenFlow controller may manage OAM with an OAM agent in a switch in an SDN system or OpenFlow network (702). OpenFlow agent in the switch may update ports or flow tables of or near the switch (704). The OAM agent in the switch may receive or create OAM messages and send relevant OAM messages to other switches (706). The OAM agent in the switch may send OAM information e.g. about link conditions to the OAM agent in the OpenFlow controller to provide to an OpenFlow controller component (708) which may update rules based on this information.

[0078] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory,

semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

* * *

CLAIMS

What is claimed is:

1. A software defined networking (SDN) switch comprising:

an operations, administration, and management (OAM) controller configured to create and communicate one or more OAM messages to OAM components on other switches;

a processor configured to cause the OAM controller to create and communicate one or more flow rules to an SDN agent of the SDN switch, wherein the flow rules are utilized to configure a flow table or a port of the SDN switch; and

wherein a subset of the one or more OAM messages and the one or more flow rules are reported to a controller in communication with the SDN switch.

2. The SDN switch of claim 1, wherein the SDN agent is an OpenFlow agent.

3. The SDN switch of claim 1, wherein the subset of the one or more OAM messages is reported to the controller using a central interface.

4. The SDN switch of claim 1, wherein the SDN switch is configured as an OpenFlow switch and the controller is configured as an OpenFlow controller.

5. The SDN switch of claim 1, wherein the OAM controller is configured as an OAM agent that communicates with another OAM agent in the controller to manage OAM in the switch.

6. The SDN switch of claim 5, wherein the OAM agent communicates the one or more OAM messages to another SDN switch.

7. The SDN switch of claim 1, wherein the OAM controller communicates a flow update to another OAM agent to provide to an OpenFlow controller component in the controller.

8. The SDN switch of claim 1, wherein the OAM controller is an on-board OAM controller.

9. The SDN switch of claim 1, wherein the OAM controller is a local OAM controller.

10. A method performed by a software defined networking (SDN) switch, the method comprising:

creating, by an operations, administration, and management (OAM) controller of the SDN switch, one or more OAM messages;

communicating, by the OAM controller, the one or more OAM messages to OAM components on other switches;

communicating, by the OAM controller, one or more flow rules to an SDN agent of the SDN switch, wherein the flow rules are utilized to configure a flow table or a port of the SDN switch; and

reporting, by the SDN switch, a subset of the one or more OAM messages and the one or more flow rules to a controller in communication with the SDN switch.

11. The method of claim 10, wherein the SDN agent is an OpenFlow agent.

12. The method of claim 10, wherein the subset of the one or more OAM messages is reported to the controller using a central interface.

13. The method of claim 10, wherein the SDN switch is configured as an OpenFlow switch and the controller is configured as an OpenFlow controller.

14. The method of claim 10, wherein the OAM controller is configured as an OAM agent that communicates with another OAM agent in the controller to manage OAM in the switch.

15. The method of claim 14, wherein the OAM agent communicates the one or more OAM messages to another SDN switch.

16. The method of claim 10, wherein the OAM controller communicates a flow update to another OAM agent to provide to an OpenFlow controller component in the controller.

17. The method of claim 10, wherein the OAM controller is an on-board OAM controller.

18. The method of claim 10, wherein the OAM controller is a local OAM controller.

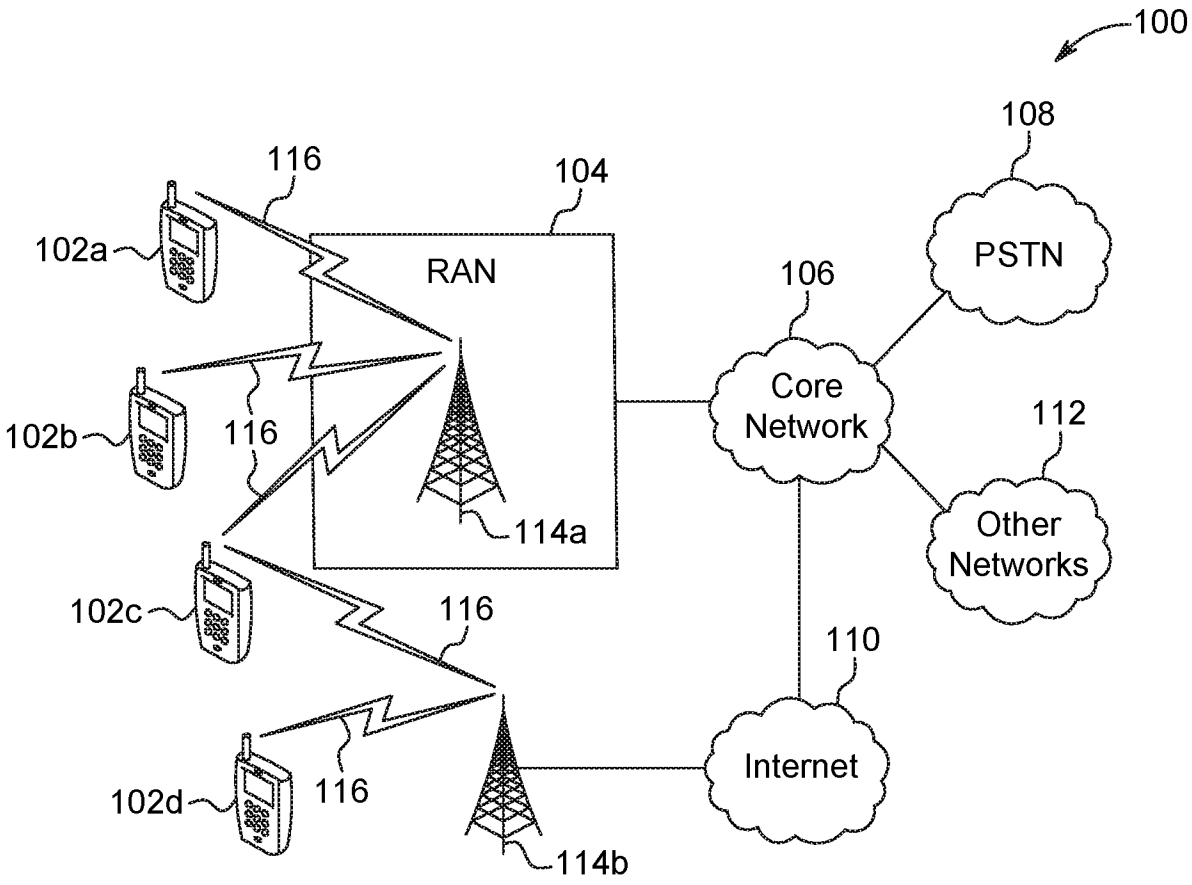

100
108
116
104
102a
RAN
PSTN
106
102b
116
Core
Network
112
114a
Other
Networks
102c
116
110
Internet
102d
116
114b

FIG. 1A

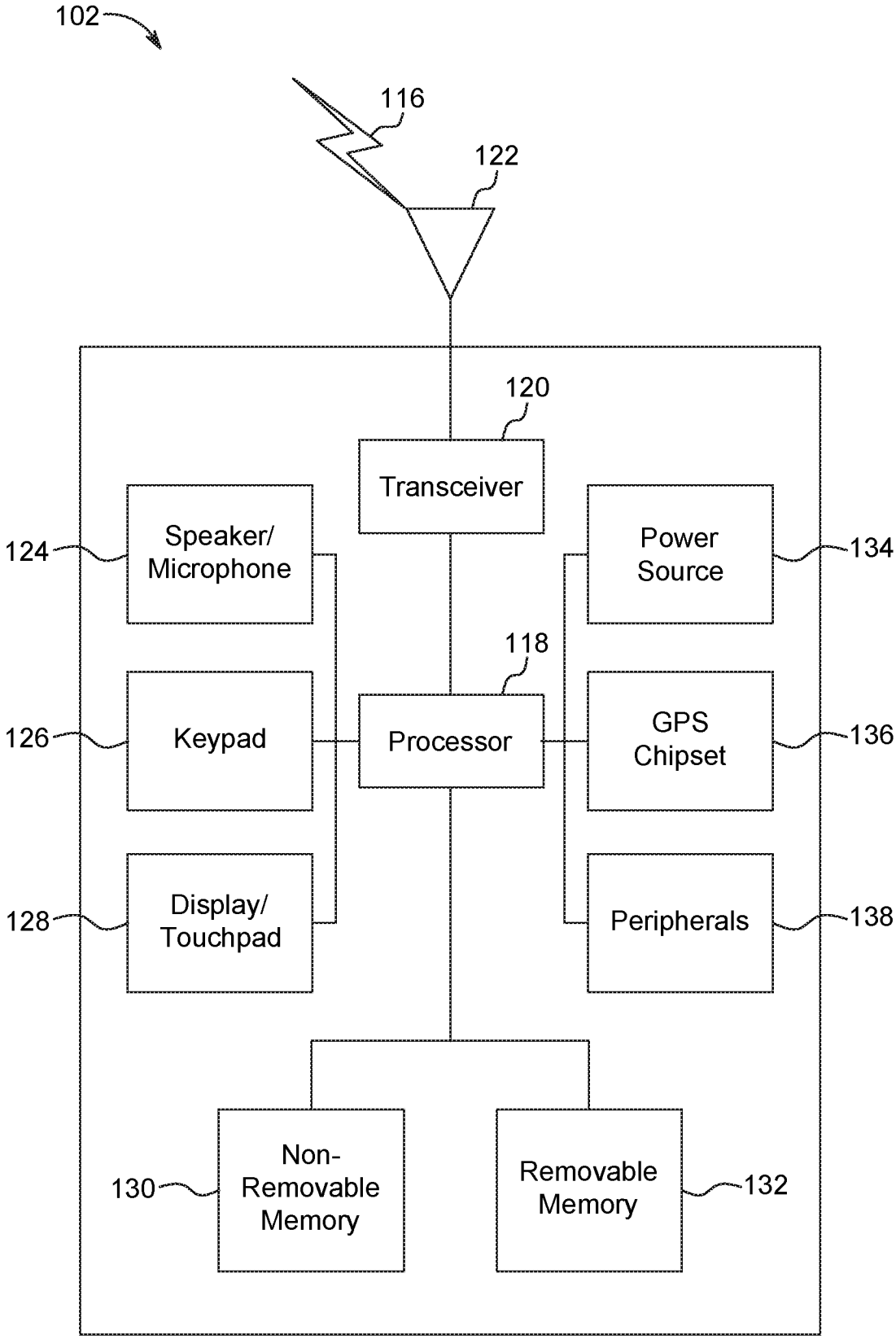

102
116
122
120
Transceiver
124
Speaker/
Microphone
Power
Source
134
118
126
Keypad
Processor
GPS
Chipset
136
128
Display/
Touchpad
Peripherals
138
130
Non-
Removable
Memory
Removable
Memory
132

FIG. 1B

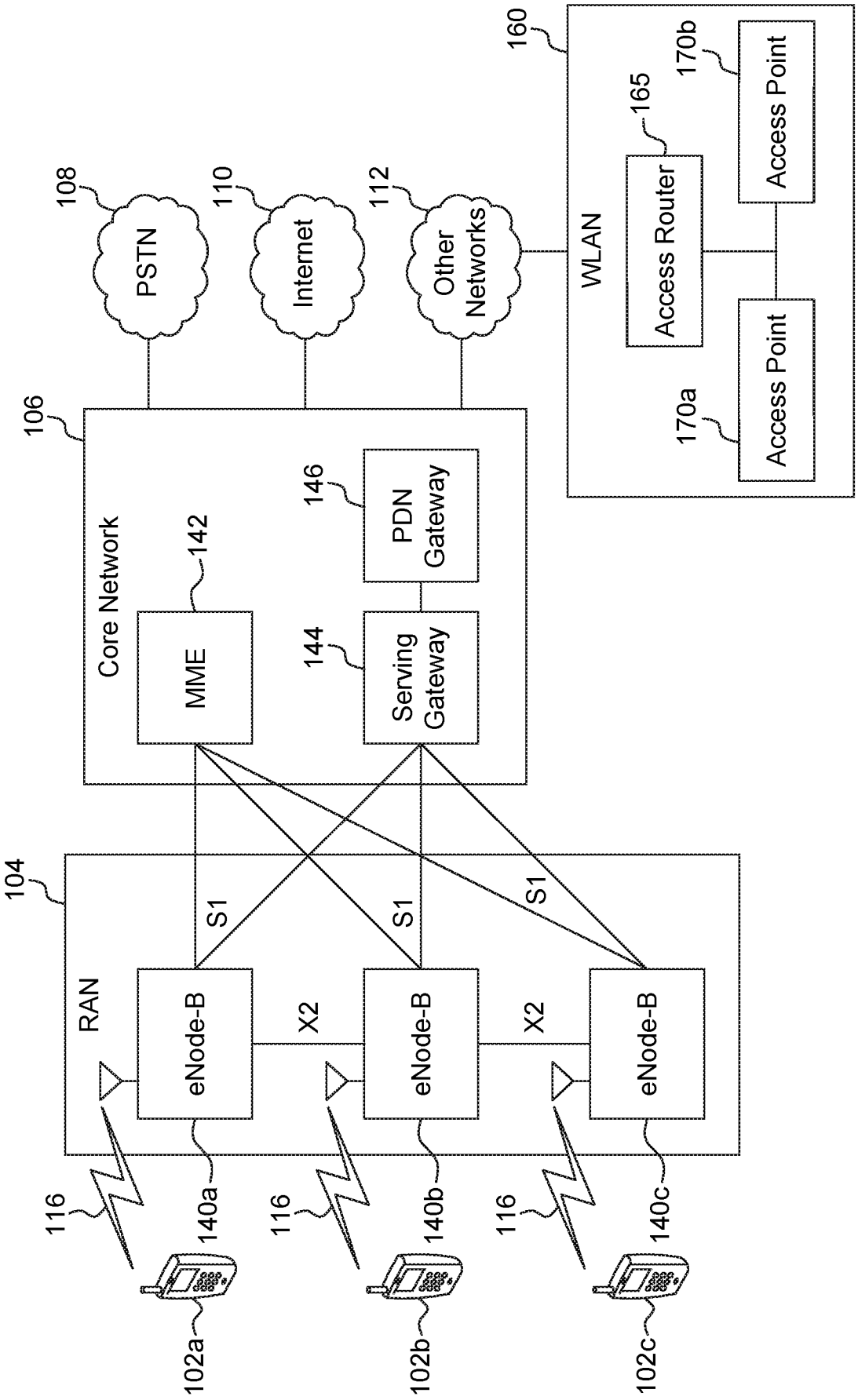

102a
102b
102c
116
116
116
140a
140b
140c
RAN
104
eNode-B
eNode-B
eNode-B
X2
X2
S1
S1
S1
Core Network
106
MME
142
Serving Gateway
144
PDN Gateway
146
PSTN
108
Internet
110
Other Networks
112
WLAN
160
Access Router
165
Access Point
170a
Access Point
170b

FIG. 1C

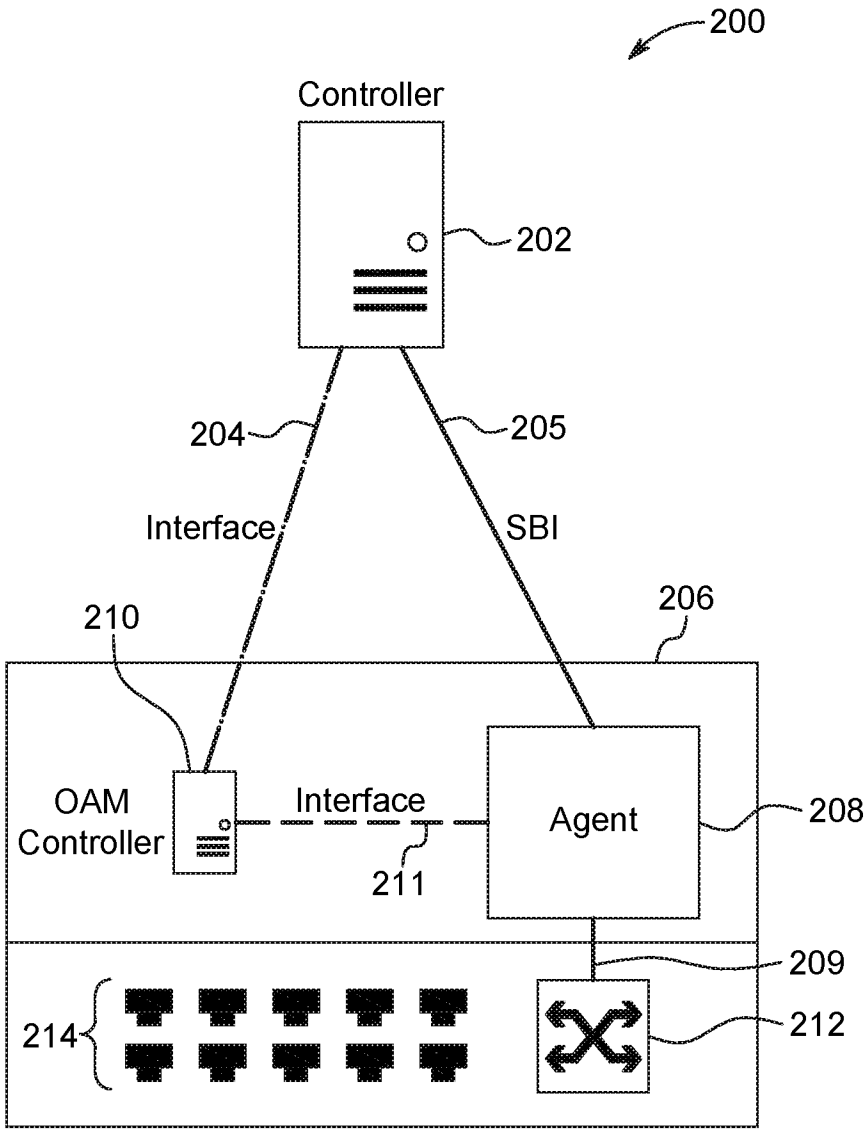

200
Controller
202
204
205
Interface
SBI
210
206
OAM
Controller
Interface
211
Agent
208
209
214
212

FIG. 2

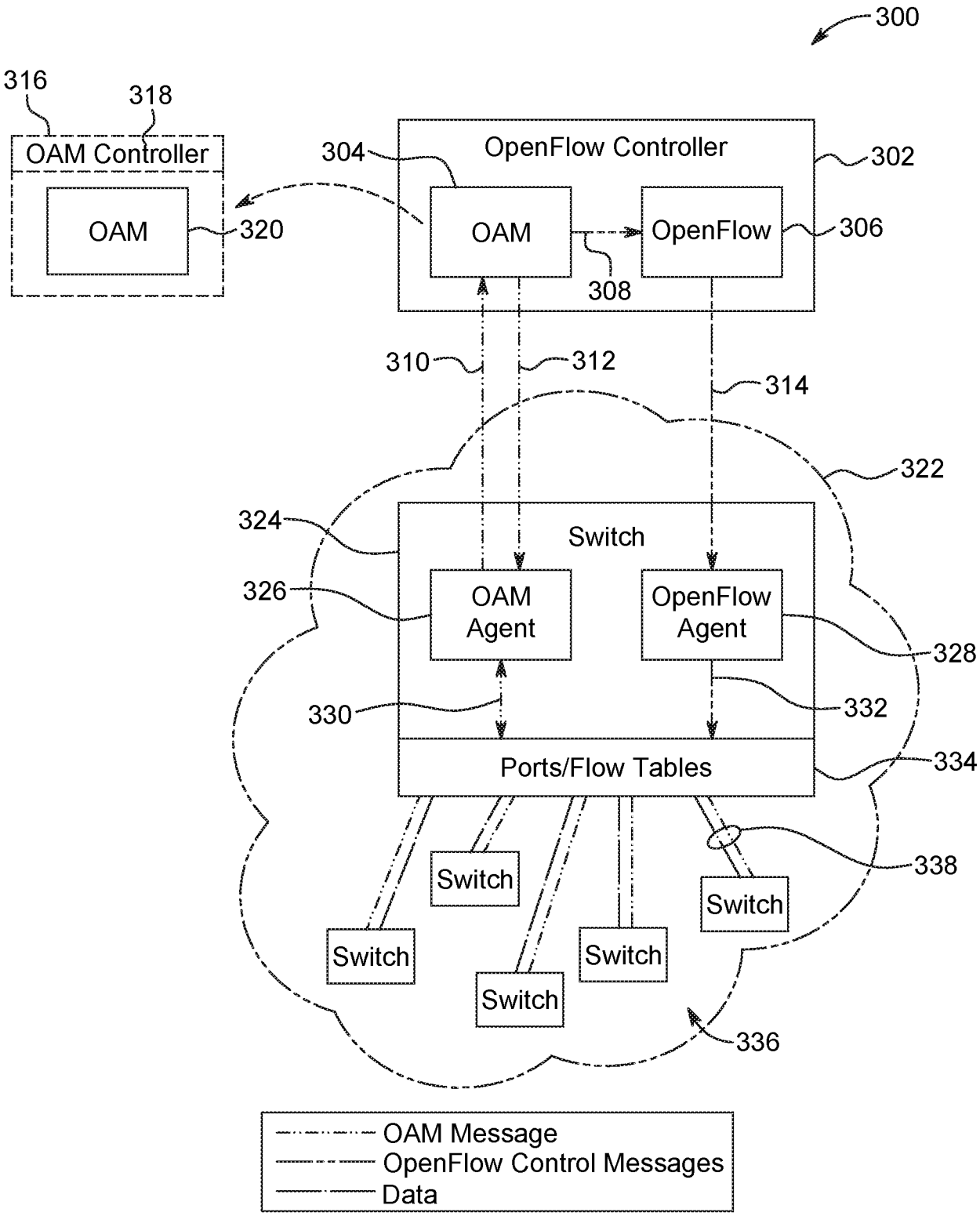

300
316
318
OAM Controller
OAM
320
304
OpenFlow Controller
302
OAM
OpenFlow
306
308
310
312
314
322
324
Switch
326
OAM Agent
OpenFlow Agent
328
330
332
Ports/Flow Tables
334
338
Switch
Switch
Switch
Switch
Switch
336
OAM Message
OpenFlow Control Messages
Data

FIG. 3

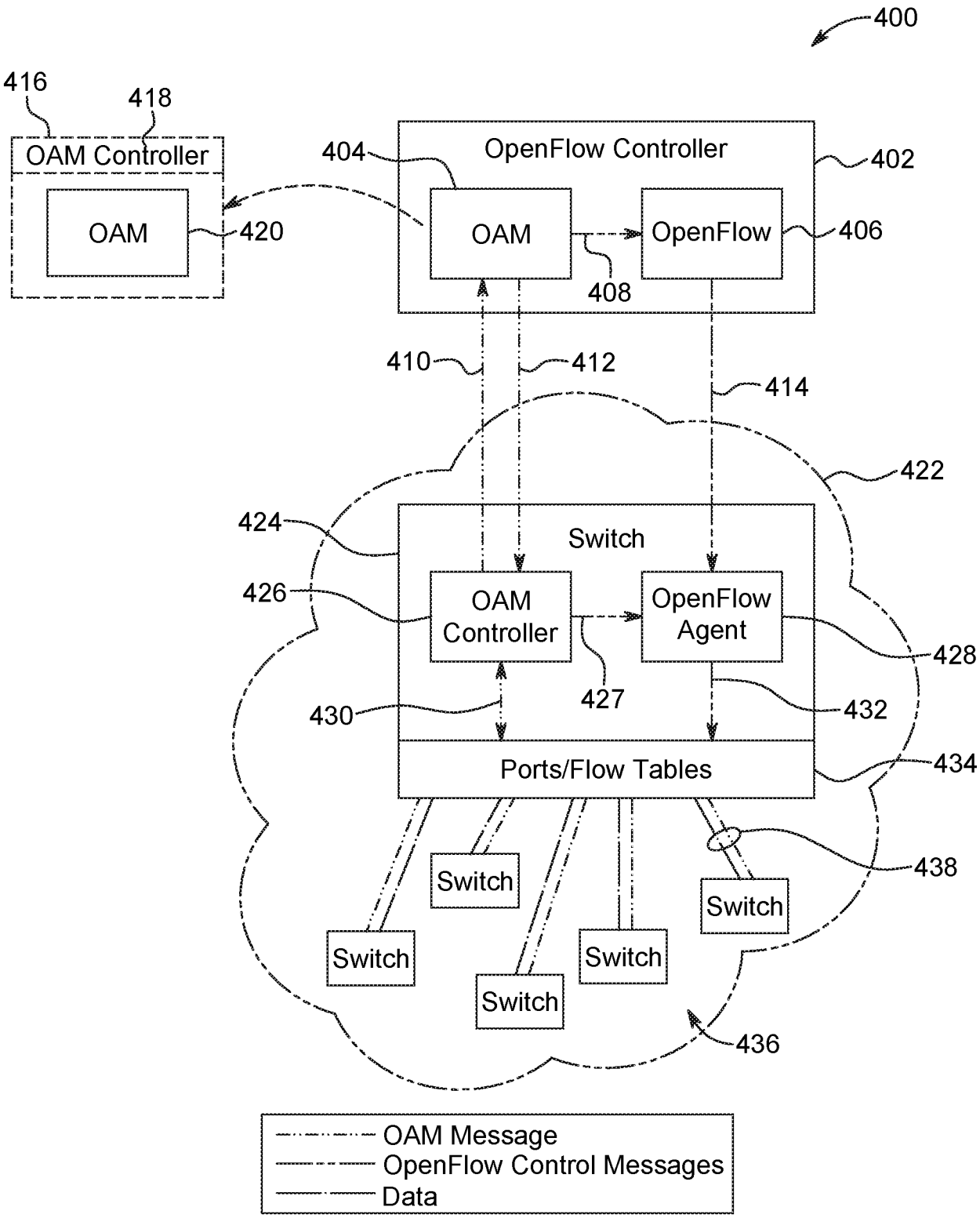

400
416
418
OAM Controller
OAM
420
404
OpenFlow Controller
402
OAM
OpenFlow
406
408
410
412
414
422
424
Switch
426
OAM Controller
OpenFlow Agent
428
427
430
432
Ports/Flow Tables
434
438
Switch
Switch
Switch
Switch
Switch
436
OAM Message
OpenFlow Control Messages
Data

FIG. 4

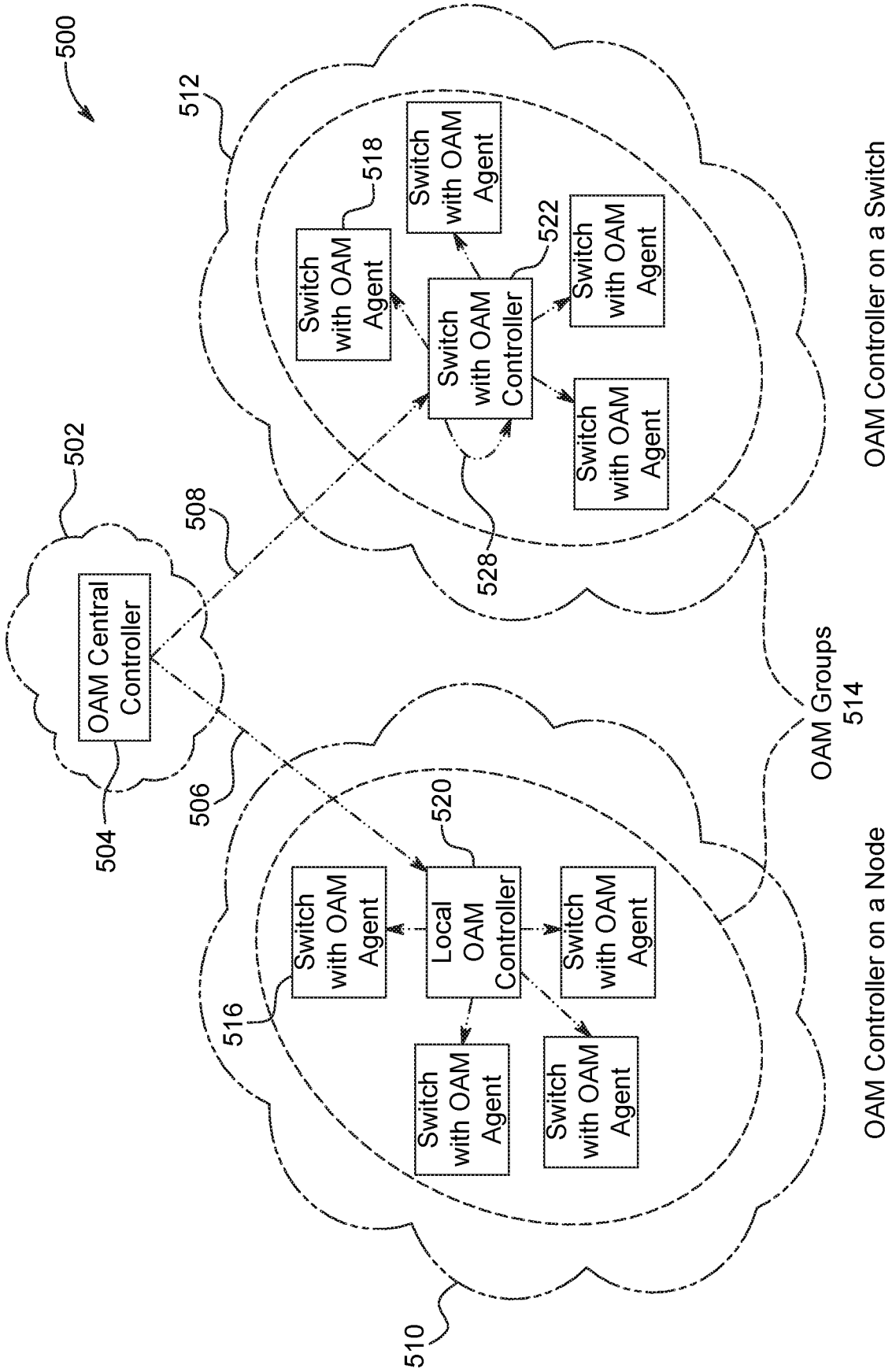

500
502
OAM Central Controller
504
506
508
510
512
516
518
520
522
528
514
OAM Groups
Switch with OAM Agent
Switch with OAM Controller
Local OAM Controller
OAM Controller on a Node
OAM Controller on a Switch

FIG. 5

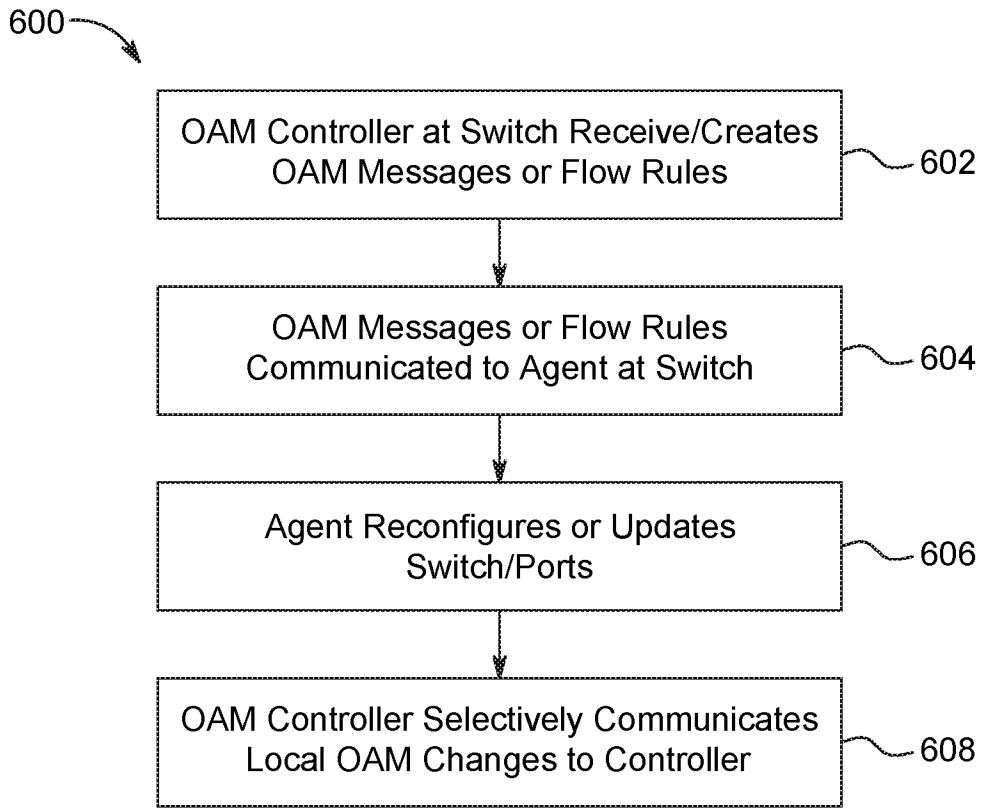

600
OAM Controller at Switch Receive/Creates OAM Messages or Flow Rules
602
OAM Messages or Flow Rules Communicated to Agent at Switch
604
Agent Reconfigures or Updates Switch/Ports
606
OAM Controller Selectively Communicates Local OAM Changes to Controller
608

FIG. 6

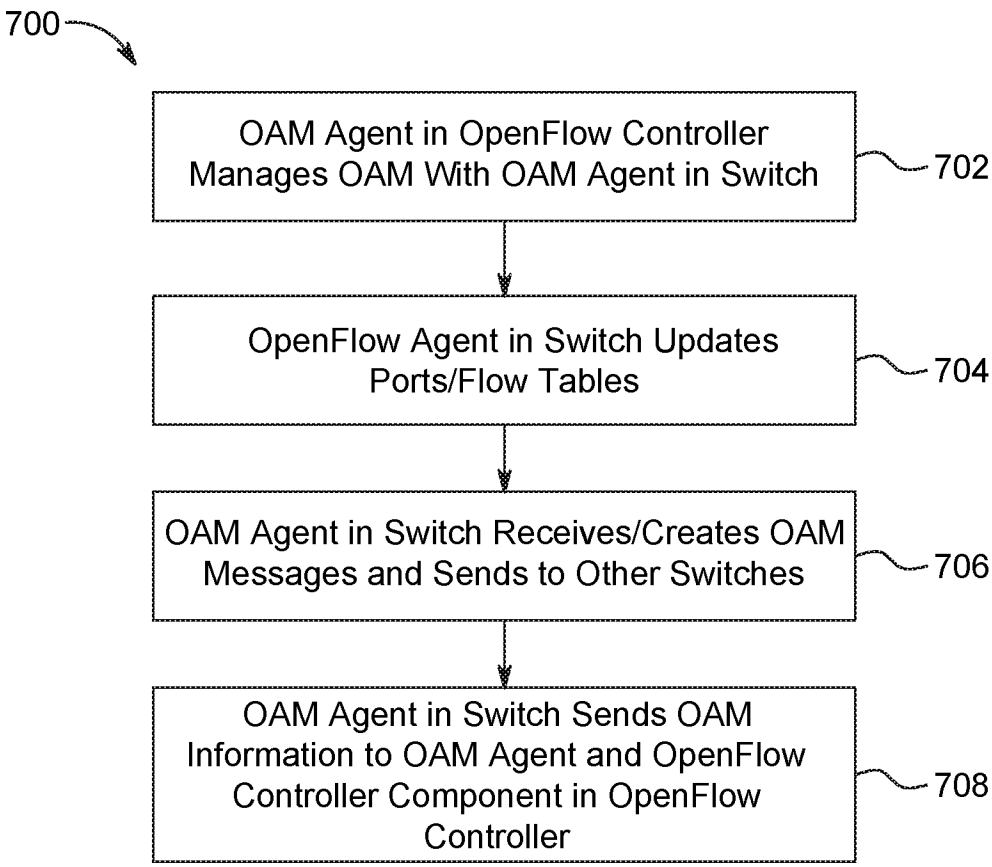

700
OAM Agent in OpenFlow Controller Manages OAM With OAM Agent in Switch
702
OpenFlow Agent in Switch Updates Ports/Flow Tables
704
OAM Agent in Switch Receives/Creates OAM Messages and Sends to Other Switches
706
OAM Agent in Switch Sends OAM Information to OAM Agent and OpenFlow Controller Component in OpenFlow Controller
708

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/017777

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L12/24
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 863 585 A1 (ERICSSON TELEFON AB L M [SE]) 22 April 2015 (2015-04-22) paragraphs [0002], [0006] - [0008], [0015] - [0018], [0024], [0030], [0067] - [0075] paragraphs [0082], [0083], [0090], [0104]; claims; figures	1-18
X	WO 2015/070608 A1 (ZTE CORP) 21 May 2015 (2015-05-21) the whole document & EP 3 070 879 A1 (ZTE CORP [CN]) 21 September 2016 (2016-09-21) paragraphs [0013], [0025], [0026], [0043] - [0046]; claims; figures	1-18
X	CN 104 734 876 A (ZTE CORP) 24 June 2015 (2015-06-24) the whole document	1-8

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 April 2017	12/04/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ceccarini, Giulio

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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