



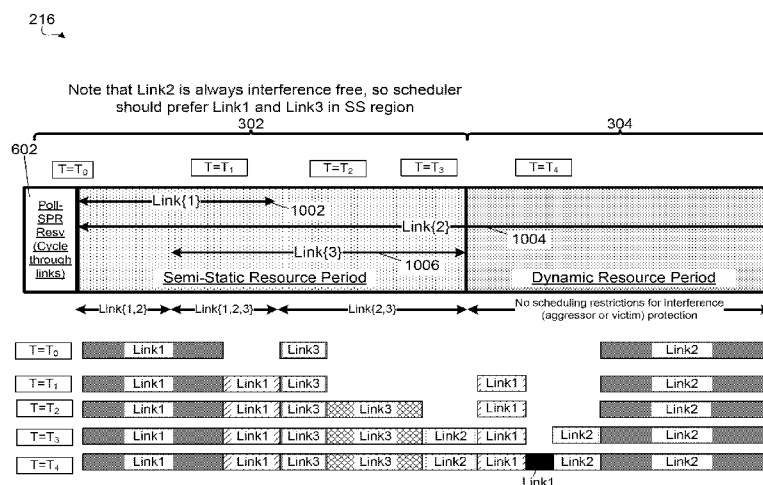
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(54) Title: MESH SCHEDULING MECHANISMS FOR GUARANTEED SERVICES**FIG. 10**

(57) **Abstract:** Methods, systems, and apparatuses for transmitting data between stations (STAs) in a mesh network are disclosed. Embodiments may include transmitting, by a first STA, data to a second STA during one or more link intervals (LIs) in a scheduling interval (SI) of a mesh super-frame. The SI may include a semi-static (SS) period in which data transmissions are interference protected and a dynamic (Dyn) period in which data transmissions are not interference protected. The SI may also include a Poll-Service Period Request (Poll-SPR) period during which a resource scheduler exchanges Poll-SPR information using the one or more LIs to receive periodic status updates of local and remote buffers of the STAs in the mesh network.

MESH SCHEDULING MECHANISMS FOR GUARANTEED SERVICES CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/157,242 which was filed on May 5, 2015, the contents of which is hereby incorporated by reference herein.

BACKGROUND

[0002] A wireless local area network (WLAN) in an Infrastructure Basic Service Set (BSS) mode may have an Access Point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may typically have access, or interface, to a Distribution System (DS), which may connect the BSS to other wired/wireless networks that may carry traffic outside of the DS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to the respective destinations. Traffic between STAs within the BSS may also be sent through the AP, where a source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. This traffic between STAs within a BSS may be considered peer-to-peer traffic. The peer-to-peer traffic may also be sent directly between the source and destination STAs with a direct link setup (DLS) using an Institute of Electrical and Electronics Engineers (IEEE) 802.11e DLS or an IEEE 802.11z tunnelled DLS (TDLS). A WLAN using an Independent BSS (IBSS) mode may have no AP, and STAs within the IBSS may communicate directly with each other. This mode of communication may be referred to as an “ad-hoc” mode of communication.

[0003] The IEEE 802.11s standard may define how wireless devices can interconnect to create a WLAN mesh network, which may be used for static topologies and ad-hoc networks. An IEEE 802.11s mesh network device may be referred to as a Mesh Station (MSTA). MSTAs may form mesh links with one another, over which mesh paths can be established using a routing protocol. The IEEE 802.11s protocol may extend the IEEE 802.11 MAC standard by defining an architecture and protocol that may support both

broadcast/multicast and unicast delivery using radio-aware metrics over self-configuring multi-hop topologies.

[0004] The IEEE 802.11ad standard may include Very High Throughput using the 60 GHz band due to the available wide bandwidth spectrum at 60 GHz is available. The IEEE 802.11ad standard may support up to 2 GHz operating bandwidths with data rates that may reach up to 6 Gbps. Since propagation loss at 60 GHz may be more significant than at the 2.4 GHz and 5 GHz bands, beamforming may be used as a means to extend the coverage range. Another feature of the IEEE 802.11ad standard may be the addition of a scheduled channel access mode in addition to contention-based access. This may allow an AP and a STA to gain predictable access to the channel. Further, in addition to the IBSS, the IEEE 802.11ad standard may include the concept of a Personal Basic Service Set (PBSS) as an ad-hoc network. Similar to the IBSS, the PBSS is a type of IEEE 802.11 LAN in which STAs communicate directly with each other. However, unlike the IBSS, in the PBSS one STA may assume the role of the PBSS control point (PCP).

SUMMARY

[0005] Embodiments described herein may include methods, systems, and apparatuses for relay communications. In an embodiment, a method for transmitting data between stations (STAs) in a mesh network is disclosed. The method may include: receiving, by a first STA, scheduling information from a controller for a scheduling interval (SI) of a mesh super-frame, wherein the SI comprises a semi-static (SS) period in which data transmissions are interference protected by constraining them to one or more link intervals (LIs) and a dynamic (Dyn) period in which data transmissions are not constrained to the one or more LIs; and transmitting, by the first STA, data to a second STA during the one or more LIs based on the received scheduling information..

In another embodiment, a station (STA) for use in a mesh network is disclosed. The STA may include: a receiver circuit configured to receive scheduling information from a controller for a scheduling interval (SI) of a mesh super-frame, wherein the SI comprises a semi-static (SS) period in

which data transmissions are interference protected by constraining them to one or more link intervals (LIs) and a dynamic (Dyn) period in which data transmissions are not constrained to the one or more LIs; and a transmitter circuit configured to transmit data to a peer STA during the one or more LIs based on the received scheduling information

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

[0007] Figure 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented;

[0008] Figure 1B is a system diagram of an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in Figure 1A;

[0009] Figure 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 Figure 1A;

[0010] FIG. 2 is a diagram of a mesh super-frame 202 and an IEEE 802.11ad super frame 204;

[0011] FIG. 3 is a diagram illustrating a Scheduling Interval (SI) divided into a semi-static (SS) period and a dynamic (Dyn) period;

[0012] FIG. 4 is diagram showing a comparison of uni-directional link intervals (LIs) and bi-directional LIs in the SI;

[0013] FIG. 5 is a diagram illustrating possible SI variants with different LI configurations;

[0014] FIG. 6 is a diagram illustrating LIs that may support a Poll-Service Period Request (Poll-SPR) period;

[0015] FIGS. 7-9 are diagrams illustrating exemplary radio SIs;

[0016] FIG. 10 is a diagram of an example scheduling operation in a SI;

[0017] FIG. 11 is a diagram of an example link modulation and coding scheme (MCS) determination procedure;

[0018] FIG. 12 is a diagram of an example interference measurement scenario and an interference matrix;

[0019] FIG. 13 is a diagram of the top view of packet queues at the switch and the medium access control (MAC) layer; and

[0020] FIG. 14 is a diagram of an example Open VSwitch (OVS) logic and class of service (CoS) queueing.

DETAILED DESCRIPTION

[0021] 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), and the like.

[0022] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 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, 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, 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, and the like.

[0023] The communications systems 100 may also include a base station 114a and a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 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, 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, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0024] 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.

[0025] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 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).

[0026] 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, and the like. For example, the base station 114a in the RAN 104 and the WTRUs

102a, 102b, 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 (WCDMA). WCDMA 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).

[0027] In another embodiment, the base station 114a and the WTRUs 102a, 102b, 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).

[0028] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 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), and the like.

[0029] 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, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 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, 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, 102d may utilize a cellular-based RAT (e.g., WCDMA, 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.

[0030] 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, 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.

[0031] The core network 106 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 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.

[0032] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities, i.e., the WTRUs 102a, 102b, 102c, 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.

[0033] 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.

[0034] 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, and 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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, and 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).

[0039] 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, and the like.

[0040] 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, 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.

[0041] 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, and the like.

[0042] 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, 102c over the air interface 116. The RAN 104 may also be in communication with the core network 106.

[0043] The RAN 104 may include eNode-Bs 140a, 140b, 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, 140c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the eNode-Bs 140a, 140b, 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.

[0044] Each of the eNode-Bs 140a, 140b, 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, and the like. As shown in FIG. 1C, the eNode-Bs 140a, 140b, 140c may communicate with one another over an X2 interface.

[0045] 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.

[0046] The MME 142 may be connected to each of the eNode-Bs 140a, 140b, 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, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and 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 WCDMA.

[0047] The serving gateway 144 may be connected to each of the eNode Bs 140a, 140b, 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, 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, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0048] The serving gateway 144 may also be connected to the PDN gateway 146, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0049] The core network 106 may facilitate communications with other networks. For example, the core network 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 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, 102c with access to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0050] 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, 170b. The communication between access router 165 and APs 170a, 170b may be via wired Ethernet (IEEE 802.3 standards), or any type of wireless communication protocol. AP 170a is in wireless communication over an air interface with WTRU 102d.

[0051] FIG. 2 is a diagram of a mesh super-frame 202 and an IEEE 802.11ad super frame 204. In an embodiment, the mesh super-frame 202 may be an EdgeHaul super-frame and may be used in a self-organizing millimeter wave Gbps transport system, such as an EdgeHaul™ system. The IEEE 802.11ad super-frame 804 is shown for reference. The 802.11ad Beacon Transmission Interval (BTI) 206, Association-Beamforming Training Interval

(A-BFT) 208 and Announcement Time Interval (ATI) 210 may be used in a similar fashion in the EdgeHaul super-frame. The Data Transmission Interval (DTI) 212 of the mesh super-frame 202 may consist of a Contention Based Access Period (CBAP) 214 at the beginning followed by several Scheduling Intervals (SIs) 216.

[0052] Referring to FIG. 3, each SI 216 may be further divided into a semi-static (SS) period 302 and a dynamic (Dyn) period 304. Data transmissions during the semi-static period 302 may be interference protected, while those in the dynamic period 304 may not be. A SI 216 may have one or more Link Intervals (LIs). A LI corresponds to a channel time when one or both nodes associated with a link are permitted to transmit without suffering or causing interference. Accordingly, a LI may be either uni-directional or bidirectional. In an embodiment, a central controller (not shown) may provide nodes (i.e., STAs) of the mesh network with a starting time and length of each LI in the SS period 302 as well as the overall SI 216 length. In addition, the central controller may determine and set the length of the SS period 302 and the length of the Dyn period 304.

[0053] The central controller may provide centralized provisioning, configuration, policy definition, ongoing network management and wireless and security services for nodes in the mesh network. At the central controller, the service requirements from users at each node may be combined with other inputs, such as information in a computed interference matrix, signal strengths, and/or link qualities, to calculate a SS/Dyn split for each SI and minimal LI durations for each link. These initial LI durations may be extended to accommodate additional traffic and/or bursty traffic. The LI extensions may be chosen based on one or more usage criteria, such as expected excess traffic from each user, one or more fairness criteria, or extra service fees. It should be noted that these LI extensions may result in overlapping LIs on links, which may provide greater flexibility to a local PCP scheduler to appropriately match available resources with requests across multiple links.

[0054] A uni-directional LI may be defined on a per link direction basis, wherein the link may be between a first STA and a second STA (i.e., the first node and the second node). For example, there may be a different LI defined from A node $\rightarrow$ B node and for B node $\rightarrow$ A node.

[0055] A bi-directional LI may be defined for both directions of a link between the first STA and the second STA. For example, there may be a single LI defined that covers both A node $\rightarrow$ B node and B node $\rightarrow$ A node. A bi-directional LI may typically, but not necessarily, be the intersection of uni-directional LIs of the same link. FIG. 3 is a diagram illustrating overlapping bi-directional link intervals, Link 1 306 and Link 2 308, in the semi-static period 302 and a single bi-directional LI 310 in the dynamic period 304 that may be transmitted without interference protections.

[0056] FIG. 4 is a diagram showing a comparison of uni-directional and bi-directional LIs in the SI 216. Each bi-directional LI (Link(1) 402, Link(2) 404, Link(3) 406) may provide interference and scheduling information that is true for both directions of the link. As previously mentioned, the bi-directional LIs may typically be the intersections of uni-directional LIs.

[0057] Each uni-directional LI (Link(1)Tx 408, Link(1)Rx 410, Link(2)Tx 412, Link(2)Rx 414, Link(3)Tx 416, Link(4)Rx 418) may provide interference and scheduling information for one direction of the link (e.g., transmit (Tx) or receive (Rx)). Accordingly, each uni-directional LI is usually larger than an equivalent bi-directional LI and therefore may impose fewer scheduling restrictions.

[0058] LIs may be defined by a start-stop time or start-length time. It should be noted that a pair of uni-directional LIs may be defined by a set of four points that may be signaled in various other (but equivalent) methods. In the SS period 302 of the SI 216, received signals in the LI may be protected from interference and transmitted signals may pose limited interference to signals in other LIs. In addition, during this period, a radio resource scheduler residing in the scheduling entity for the associated links (e.g., the PCP/AP) may be limited to scheduling data on LIs. Exceptions may be made for short duration control signals (e.g., ACKs), which may typically be the case when

uni-directional LI's are used. These exceptions may be indicated with an information block from a central SDN controller.

[0059] If a LI extends into the Dyn period 304, such as Link(2)Tx 412, the link may be protected from interference and poses limited interference to other signals. However, the radio resource scheduler may use any link (and link direction) during the Dyn period 304. The scheduler may benefit from having the information of the LI in the Dyn period 304, for example by preferentially using LIs in the Dyn region so as to make more resources available in other links.

[0060] FIG. 5 is a diagram illustrating possible SI 216 variants with different LI configurations. As shown in the top example of FIG. 5, all three links (Link(1) 502, Link(2) 504, Link(3) 506) may have some interference constraints and they may be limited transmission during the SS period 302. However, as shown in the bottom example of FIG. 5, Link(2) 510 may have no interference constraints, and accordingly, it may occupy the whole SI 216, including the Dyn period 304.

[0061] FIG. 6 is a diagram illustrating LIs that may support a Poll-Service Period Request (Poll-SPR) period 602. The Poll-SPR period 602 of the SI 216 may be reserved using a similar mechanism as is used for data. A supplemental short set of LIs may be provided to enable Poll-SPR exchanges (e.g., at the start or end of an SI 216) so that the radio resource scheduler may receive periodic updates of STA remote buffer status. This may enable the scheduler to perform Poll-SPR protected from interference. In general, any number of start-stop intervals may be provided.

[0062] As shown in FIG. 6, there may be multiple options for LI's to support Poll-SPR. For example, as shown in Option 1 610, SPRs may immediately follow Polls. In this example, only one more set of LI's (Link(1) 604, Link(2) 606, Link(3) 608) may need to be provided. Alternatively, as shown in Option 2 612, Polls 614 and SPRs 616 may be separated to reduce interframe spacing (IFS) requirements. In this example, a first set of LIs (618, 620, 622) in the poll-part 614 and a second set of LIs (624, 626, 628) in the SPR-part may be provided.

[0063] Additional buffer checking and poll-SPR-grants may also occur. In the SS period 302, a master node (e.g., the PCP) may check local buffers to determine if additional data has been queued. The master node may then schedule the additional data in previously un-scheduled radio resources, provided it observes the LI restrictions. In the SS region 302, additional Poll-SPR-grants may also be exchanged to further utilize radio resources provided they observe the LI restrictions. Additional Poll-SPR-grants may also be exchanged in the Dyn period 304 without constraint.

[0064] FIGS. 7-9 are diagrams illustrating exemplary radio SIs 216. More specifically, FIGS. 7-9 shows exemplary SIs 216 where packet transmissions are scheduled. In FIG. 7, the PCP may not collect buffer status information from its associated STAs at the start of the SI. The PCP may schedule downlink transmissions to individual STAs at the start of their respective LIs. The PCP may then surrender the remaining part of the LI for uplink transmission from the STA.

[0065] FIGS. 8 and 9 show two different configurations of Poll-SPR exchanges (802, 902) between the PCP and three associated STAs. There may be one Poll and one SPR per each of the three associated STAs. In FIG. 8, each Poll transmission by the PCP to a STA is immediately followed by a SPR response from that STA. In FIG. 9, the PCP may transmit all Polls consecutively and the SPR transmissions from polled STAs may be sent consecutively after the Polls are finished. In this case, each Poll message may contain the scheduled start time for the corresponding SPR transmission.

[0066] FIG. 10 is a diagram of an example scheduling operation in a SI 216. The example scheduling operation involves three links (Link(1) 1002, Link(2) 1004, Link(3) 1006) associated with a PCP. It should be noted that, for this example, it is assumed that interference protection is assured in both link directions (i.e., bi-directional LI). The PCP may therefore schedule the use of the link in either direction without restriction.

[0067] The scheduler operation will now be described. There may be a reserved Poll-SPR period 602 at the start of the SI 216 for all links arranged to be interference protected. The scheduler may have a full picture of buffers

at the start of the SI 216. In the SS period 302, there may be a permitted transmission-reception (Tx-Rx) period for each link, which may be interference-free. The link interval definition may be per-direction which may be more efficient.

[0068] In the Dyn period 304, there may be links indicated as interference-free. Based on internal buffers and the Poll-SPR 602, the PCP may assign resources for each link (Tx and Rx). In the SS period 302, the assigned resources may be constrained to the link intervals. In the Dyn period 304, there may be no constraints. There may be unassigned resources in the SI 216 after this first phase of resource assignments. When time elapses to the point where there are unassigned resources, another Poll-SPR, specifically a Poll-SPR for a link may be conducted on any remaining portion of that link's interval. Based on updated internal buffers and the optional Poll-SPR, the PCP may assign resources for each link on remaining resources.

[0069] Referring to the example in FIG. 10, at $T=T_0$, assignments may be made to Link(1) 1002, Link(2) 1004, and Link(3) 1006 based on the current buffer and Poll-SPR period 602. A strategy may be employed to make assignments that have the least impact to other links, but fall under the given constraints. At this point, Link(1) 1002 Tx-Rx may start.

[0070] At $T=T_1$, Link(1) 1102 may run out of data and there may be a resource gap. The scheduler may poll Link(1) 1002, Link(2) 1004, and Link(3) 1006 and may check local buffers. In an embodiment, Link(1) 1002 may be polled, possibly because Link(1) 1002 may have the least remaining interference-free time left or the Link(1) 1002 local buffer may have data, or the like. At this point, assignments for Link(1) 1002 may be made, which may utilize resources that may otherwise go unused. The Link(1) 1002 Tx-Rx may continue. Between T_1 and T_2 , Link(1) 1002 may stop and Link(3) 1006 may start.

[0071] At $T=T_2$, Link(3) 1006 may run out of data and there may be a resource gap. The scheduler may poll Link(2) 1004 and/or Link(3) 1006 and may check local buffers. It should be noted that Link(1) 1002 may not be polled since the interval of Link(1) 1002 has expired. In the example shown in

FIG. 10, Link(3) 1006 may be polled. At this point, assignments may be made for Link(3) 1006. Link(3) 1006 Tx-Rx may continue.

[0072] At $T=T_3$, Link(3) 1006 may run out of data again and there may be a resource gap. The scheduler may poll Link(2) 1004 or Link(3) 1006 and may check local buffers. It should be noted that Link(1) 1002 may not be polled since its interval has expired. In the example shown in FIG. 10, Link(2) 1004 may be polled. At this point, assignments may be made for Link(2) 1004. Link(2) 1004 Tx-Rx may start. Between T_3 and T_4 , Link(2) 1004 may stop and Link(1) 1002 may start. This may be beginning of Dyn period 304, during which any LI may be used.

[0073] At $T=T_4$, Link(1) 1002 may run out of data and there may be a resource gap. The scheduler may poll any link in the Dyn period 304 and may check local buffers. In this case, no poll may be made, for example, since the remaining resources are small, but the local buffer for Link(1) 1002 may have accumulated more data. At this point, assignments may be made for Link(1) 1002. Link(1) 1002 Tx-Rx may start. Sometime after T_4 , Link(1) 1002 may stop and Link(2) 1004 may start. Link(2) 1004 Tx-Rx may continue to the end of the SI 216.

[0074] Additional sets of LIs (or equivalently, segmented LIs) may be provided to achieve greater flexibility. Additional start-stop, start-length parameters may be added for any link (bi-directional or uni-directional). Alternatively, a “start-length-length-length-...-length” format may be used, where each “length” parameter may indicate a toggle between start and stop.

[0075] A beam refinement protocol (BRP) LI may be a segment of a normal LI that may provide additional protection for beam refinement. The BRP beams may be nearby neighbors of the current beam. The central controller may use existing interference measurements to predict the other impacted links and may shorten the LIs of other nodes to accommodate the BRP LIs. Results of each beam in the BPR may be provided to the central controller for later use in the interference management.

[0076] Different SIs may have different LIs defined with a pattern for each SI provided by the central controller. For example, the follow sets of SIs

may each have a different set of LIs defined: $SI = \{1, k, 2k, \dots\}$, use LI set 1; $SI = \{2, k+1, 2k+1, \dots\}$, use LI set 2; ...; $SI = \{k-1, 2k-1, 3k-1, \dots\}$, use LI set $k-1$. An example application of this may be to schedule BPR LI's with a low frequency or to schedule low rate delay tolerant flows.

[0077] A modulation and coding scheme (MCS) selection algorithm may select a MCS on a per link basis and may be based on interference protected periods of the LIs. This may help to attain a target packet error rate (PER) provided in an Information Block from the central controller. MCS offsets may be provided from the central controller to be added or subtracted to the MCS target provided by the MCS selection algorithm.

[0078] The MCS offset may be associated with the re-transmission number of the highest re-transmission service frame in the IEEE 802.11ad packet. The MCS offset may also, or alternatively, be associated with the queue from which the packet is drawn or the priority of the highest priority frame in the IEEE 802.11ad packet. Priority may be a function of any of multiple priority indicating bits (e.g., QoS, CoS, TID, VLAN, or DSCP).

[0079] FIG. 11 is a diagram of an example link MCS determination procedure. If a MCS that is used is lower than the MCS provided by the MCS algorithm, the algorithm may be prevented from increasing the target MCS if an ACK is received. If a MCS that is used is lower than the MCS provided by the MCS algorithm, the algorithm may be forced to more aggressively decrease the target MCS if an ACK is not received. FIG. 11 shows the link adaptation and MCS offset mechanism.

[0080] FIG. 12 is a diagram of an example interference measurement scenario and an interference matrix. Initial beam alignment and power backoff is described herein. A uni-directional interference matrix may be created by scheduling transmissions from each transmission link to each reception link. Results of received signal strength indicators (RSSI) on the direct link may be used to determine links with excess signal-to-noise ratio (SNR). A transmission power backoff may be determined and sent to a corresponding link. Results of RSSI on the interference links may be used to create the uni-directional interference matrix, which may indicate the level of

interference observed on all other uni-directional links. A bi-directional interference matrix may be constructed from the uni-directional interference matrix as needed.

[0081] Multi-beam evaluation for interference reduction is described herein. The central controller may examine results of the BRP to identify any other beams that are sufficient for the link. Additional beams may be signaled to the node/link from the central controller to be scheduled for interference measurements. If the interference measurements using these other beams indicate that interference may be sufficiently reduced without excessive loss or performance in the link, this beam may be signaled to the node/link to be used for the link.

[0082] FIG. 13 is a diagram of the top view of packet queues at the switch and the medium access control (MAC) layer. FIG. 13 shows the interaction between the SDN Controller and an Open VSwitch. In addition, FIG. 13 shows the queueing and scheduling operation at the OVS, which may be based on the packet Quality of Service (QoS) and color. Multiple inputs may be routed into multiple output buffers targeted at different egress interfaces. The packets in the buffers may then be scheduled for over the air transmissions by the local schedulers.

[0083] FIG. 14 is a diagram of an example OVS logic and class of service (CoS) queueing. FIG. 14 illustrates the switching structure, wherein packets may get routed to the appropriate egress interface based on one or more parameters, such as QoS and color. Here, the switching decisions may be based on the included S-tags, but may be based on any fields or hashes of fields.

[0084] A new sounding frame format may be defined for inter-Basic Service Set (BSS) interference measurements. For example, a sounding frame may not contain a preamble or a data field. Instead, the sounding frame may be constructed using N-chip long pseudo-random binary sequences (e.g., $N = 128$) that have a recursive construction, and are selected to have good properties relative to one another. The pseudo-random sequences (e.g. Golay, Gold codes, and the like) used for interference measurements are designed to

have good auto correlation properties (low non-zero lag peaks) and/or low cross correlation peaks between members of the possible pseudo-random sequence. This may allow the filtering out of unintended signals during interference measurements, even at low SNRs, and also the performance of accurate signal time-of-flight measurements.

[0085] A small set of codes may be selected and stored in a dictionary. Each node may be given a separate index into the dictionary to choose a pseudo-random sequence for interference measurements. Alternately, all nodes belonging to a BSS and/or PBSS may share a common index into the dictionary. In another example, a set of nodes may be chosen across multiple BSSs and/or PBSSs, forming an interference measuring cluster, to share a common index. Nodes belonging to an interference measuring cluster may not simultaneously transmit interference measurement sounding frames, but may simultaneously transmit sounding frames across multiple interference measuring clusters. In yet another example, a node may use different pseudo-random sequence indexes while transmitting sounding packets to a different neighbor. This may allow the measuring node to make precise time-of-flight measurements for packet transmissions by the same transmitting node in different directions.

[0086] Although the solutions described herein consider IEEE 802.11 specific protocols, it is understood that the solutions described herein are not restricted to this scenario and are applicable to other wireless systems as well.

[0087] 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 method for transmitting data between stations (STAs) in a mesh network, the method comprising:

receiving, by a first STA, scheduling information from a controller for a scheduling interval (SI) of a mesh super-frame, wherein the SI comprises a semi-static (SS) period in which data transmissions are interference protected by constraining them to one or more link intervals (LIs) and a dynamic (Dyn) period in which data transmissions are not constrained to the one or more LIs; and

transmitting, by the first STA, data to a second STA during the one or more LIs based on the received scheduling information.

2. The method of claim 1, wherein the one or more LIs comprise a channel time when the first STA, the second STA, or the first STA and the second STA are permitted to transmit without suffering or posing interference.

3. The method of claim 1, wherein the one or more LIs are uni-directional and defined on a per link direction basis.

4. The method of claim 1, wherein the one or more LIs are bi-directional and defined for both a transmit direction and a receive direction of a link.

5. The method of claim 1, wherein the scheduling information for the SI comprises a length of the SI, a length of the one or more LIs, a length of the SS period, and a length of the Dyn period.

6. The method of claim 1, wherein the scheduling information for the SI is calculated by the central controller based on service requirements

from users at the first STA and the second STA, an interference matrix, and signal strength measurements.

7. The method of claim 1, wherein the scheduling information for the SI is dynamically adjusted by the central controller to allow for additional data transmissions based on one or more usage criteria.

8. The method of claim 1, wherein one or more LIs that extend from the SS period into the Dyn period are interference protected in the Dyn period.

9. The method of claim 1, wherein the SI further comprises a Poll-Service Period Request (Poll-SPR) period during which a radio resource scheduler exchanges Poll-SPR information using the one or more LIs to receive periodic updates of buffer status for the first STA and the second STA.

10. The method of claim 9, further comprising:
scheduling, by the radio resource scheduler, transmission of queued data from the buffers of the first STA and the second STA in previously unscheduled radio resources of the one or more LIs.

11. A station (STA) for use in a mesh network, the STA comprising:
a receiver circuit configured to receive scheduling information from a controller for a scheduling interval (SI) of a mesh super-frame, wherein the SI comprises a semi-static (SS) period in which data transmissions are interference protected by constraining them to one or more link intervals (LIs) and a dynamic (Dyn) period in which data transmissions are not constrained to the one or more LIs; and

a transmitter circuit configured to transmit data to a peer STA during the one or more LIs based on the received scheduling information.

12. The STA of claim 11, wherein the one or more LIs comprise a channel time when the STA, the peer STA, or the STA and the peer STA are permitted to transmit without suffering or posing interference.

13. The STA of claim 11, wherein the one or more LIs are uni-directional and defined on a per link direction basis.

14. The STA of claim 11, wherein the one or more LIs are bi-directional and defined for both a transmit direction and a receive direction of a link.

15. The STA of claim 11, wherein the scheduling information for the SI comprises a length of the SI, a length of the one or more LIs, a length of the SS period, and a length of the Dyn period.

16. The STA of claim 11, wherein the scheduling information for the SI is calculated by the central controller based on service requirements from users at the STA and the peer STA, an interference matrix, and signal strength measurements.

17. The STA of claim 11, wherein the scheduling information for the SI is dynamically adjusted by the central controller to allow for additional data transmissions based on one or more usage criteria.

18. The STA of claim 11, wherein one or more LIs that extend from the SS period into the Dyn period are interference protected in the Dyn period.

19. The STA of claim 11, wherein the SI further comprises a Poll-Service Period Request (Poll-SPR) period during which Poll-SPR information is exchanged using the one or more LIs to receive periodic buffer status updates for the STA and the peer STA.

20. The STA of claim 19, wherein the transmitter circuit is further configured to transmit queued data from the buffer of the STA in previously unscheduled radio resources of the one or more LIs.

100

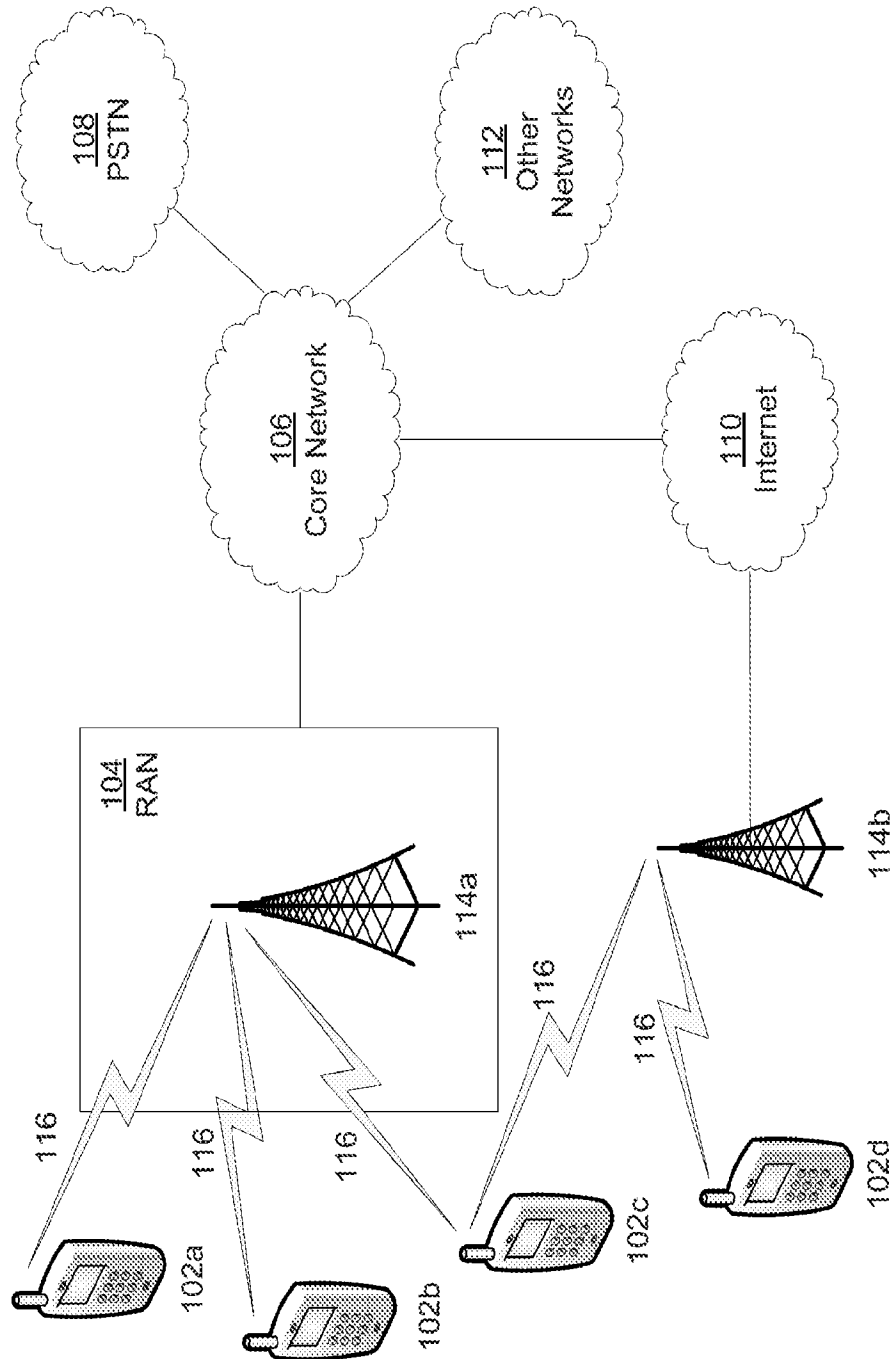


FIG. 1A

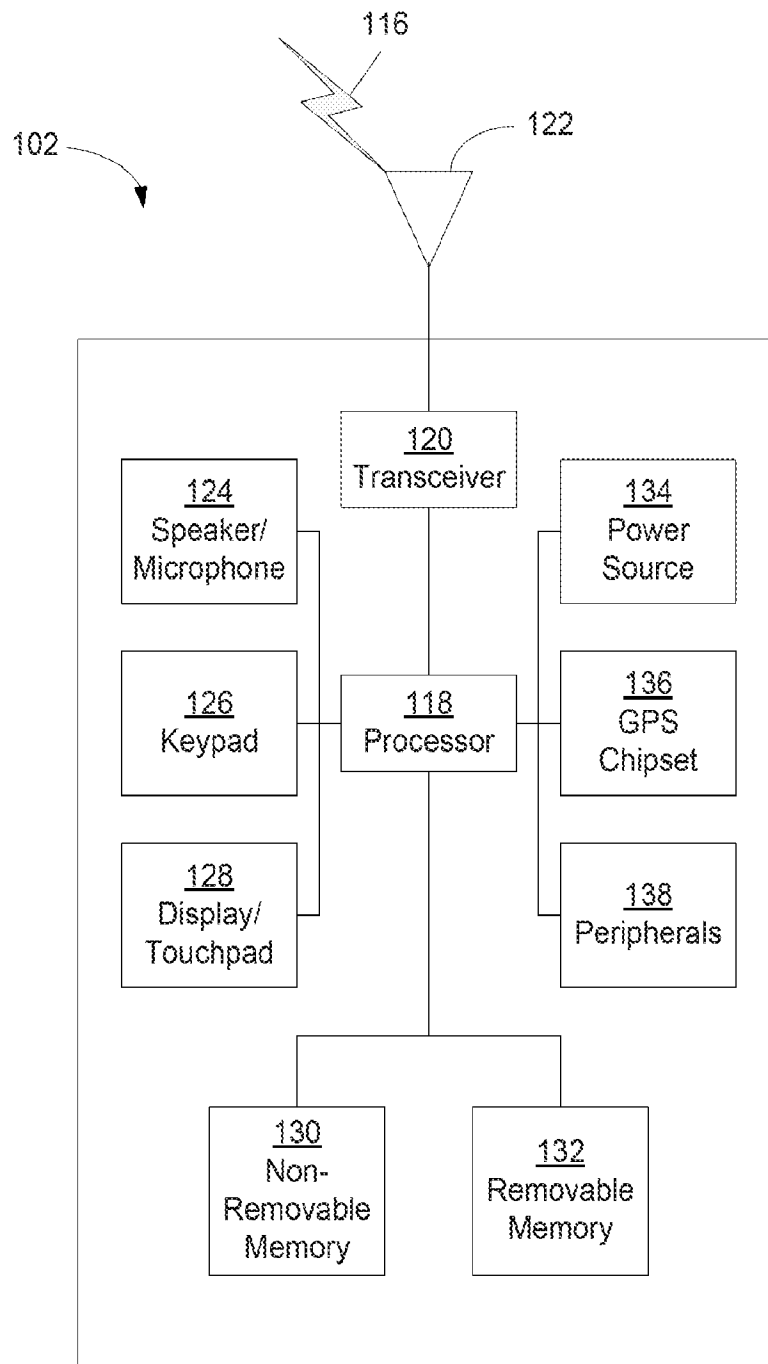


FIG. 1B

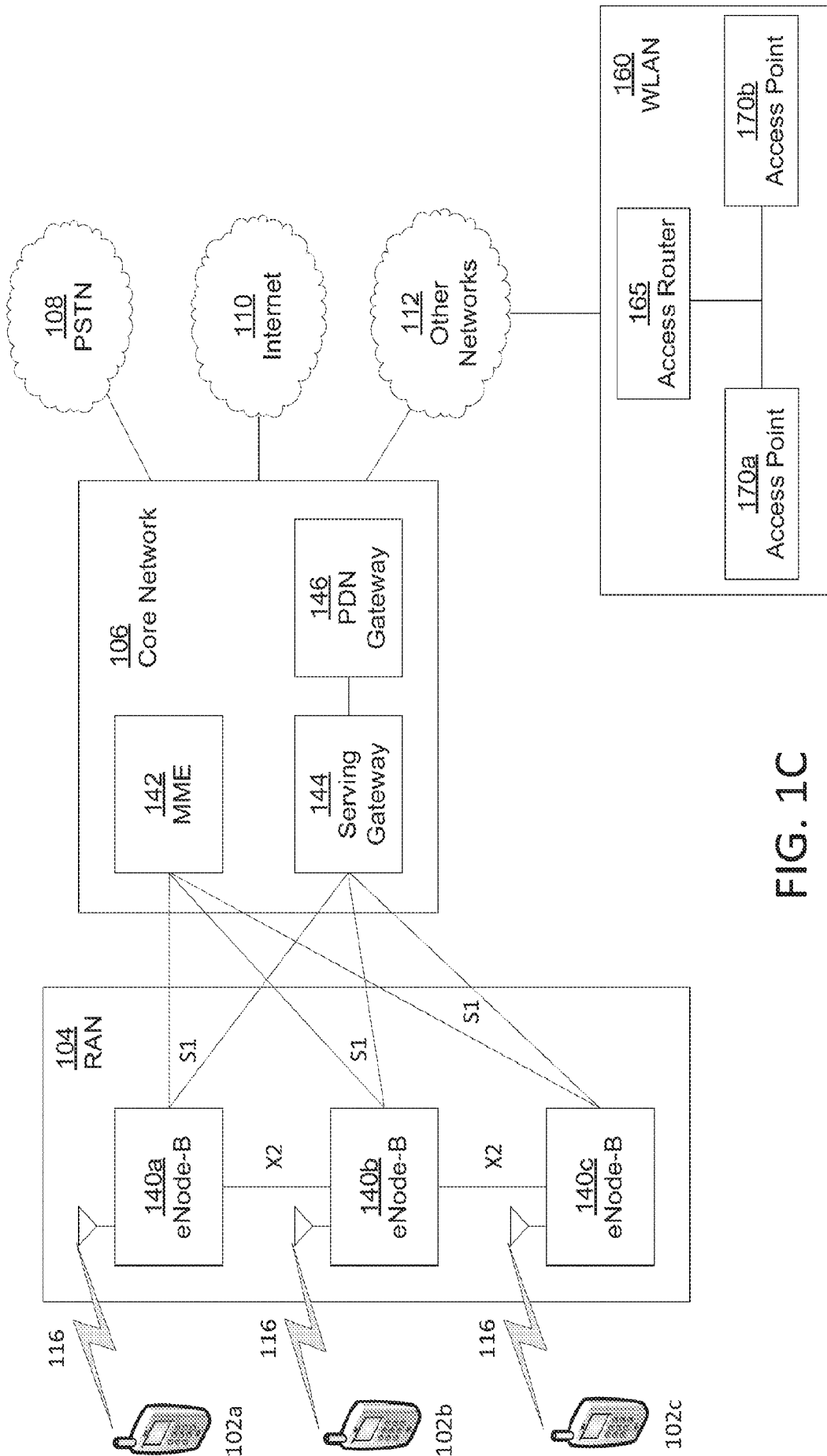


FIG. 1C

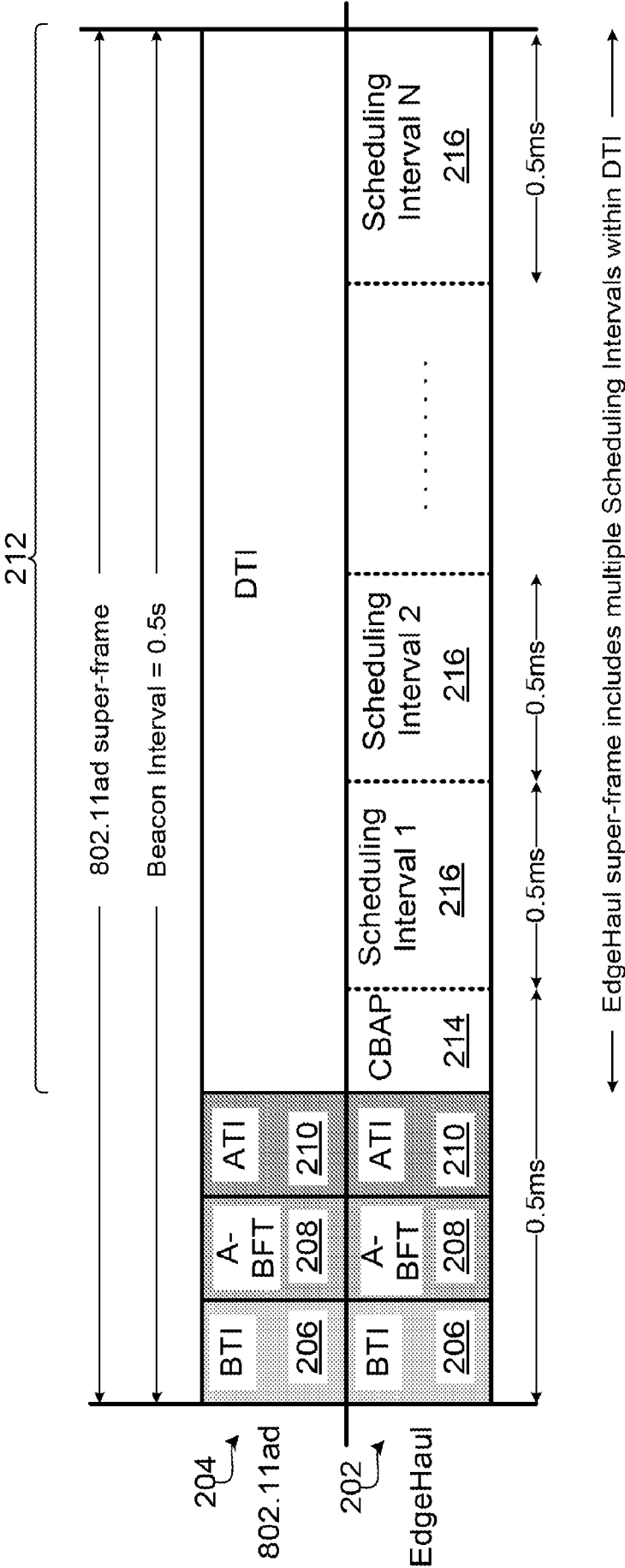


FIG. 2

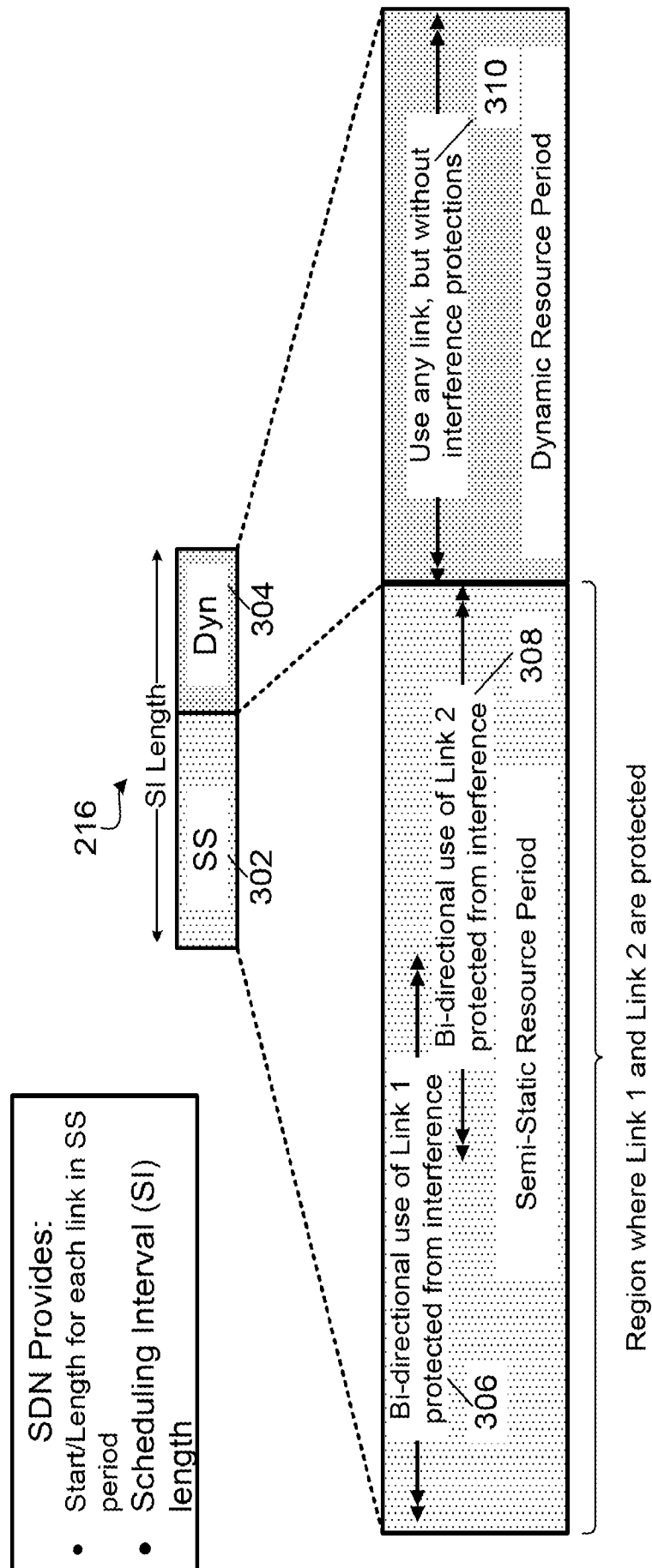


FIG. 3

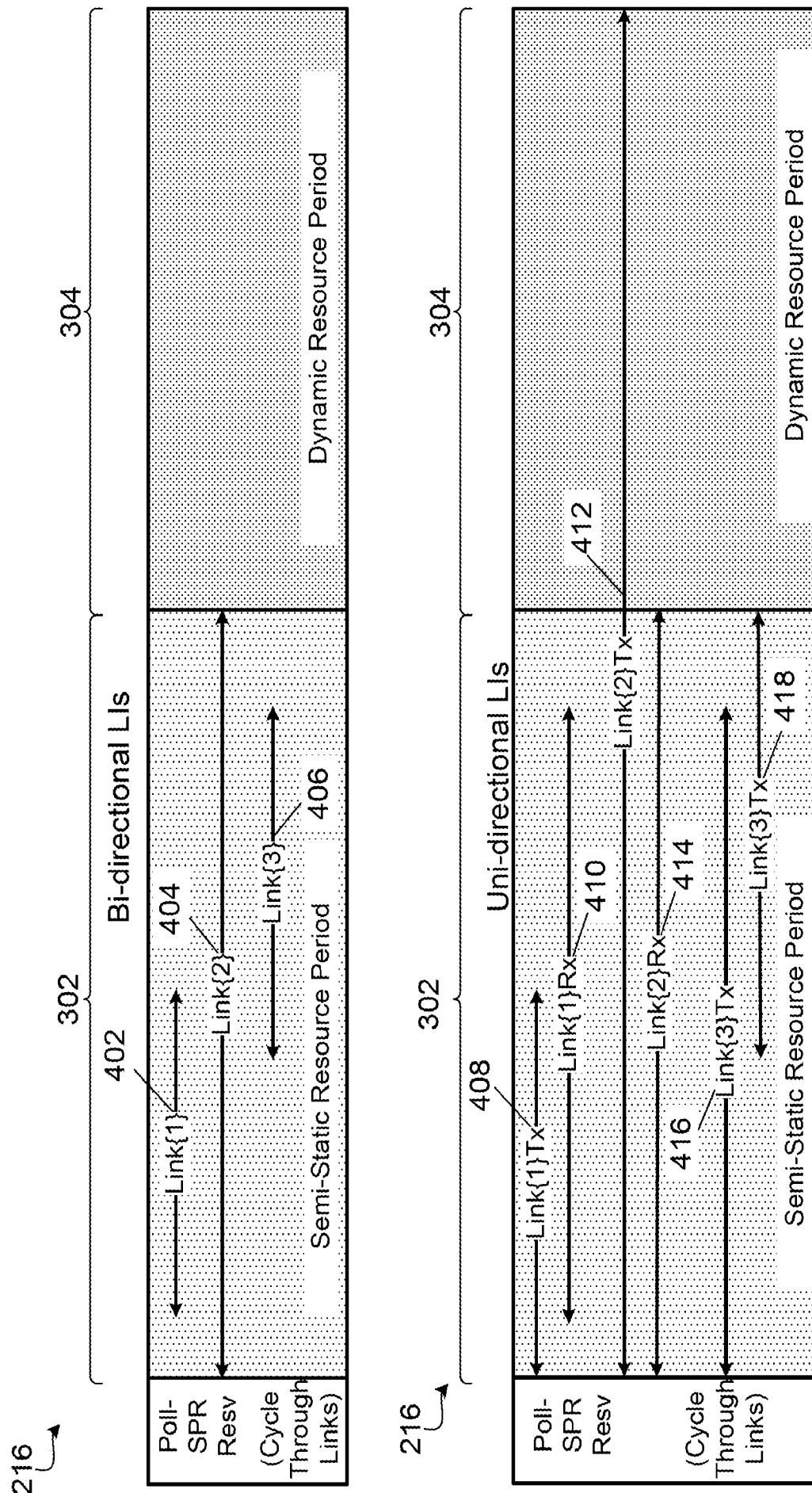


FIG. 4

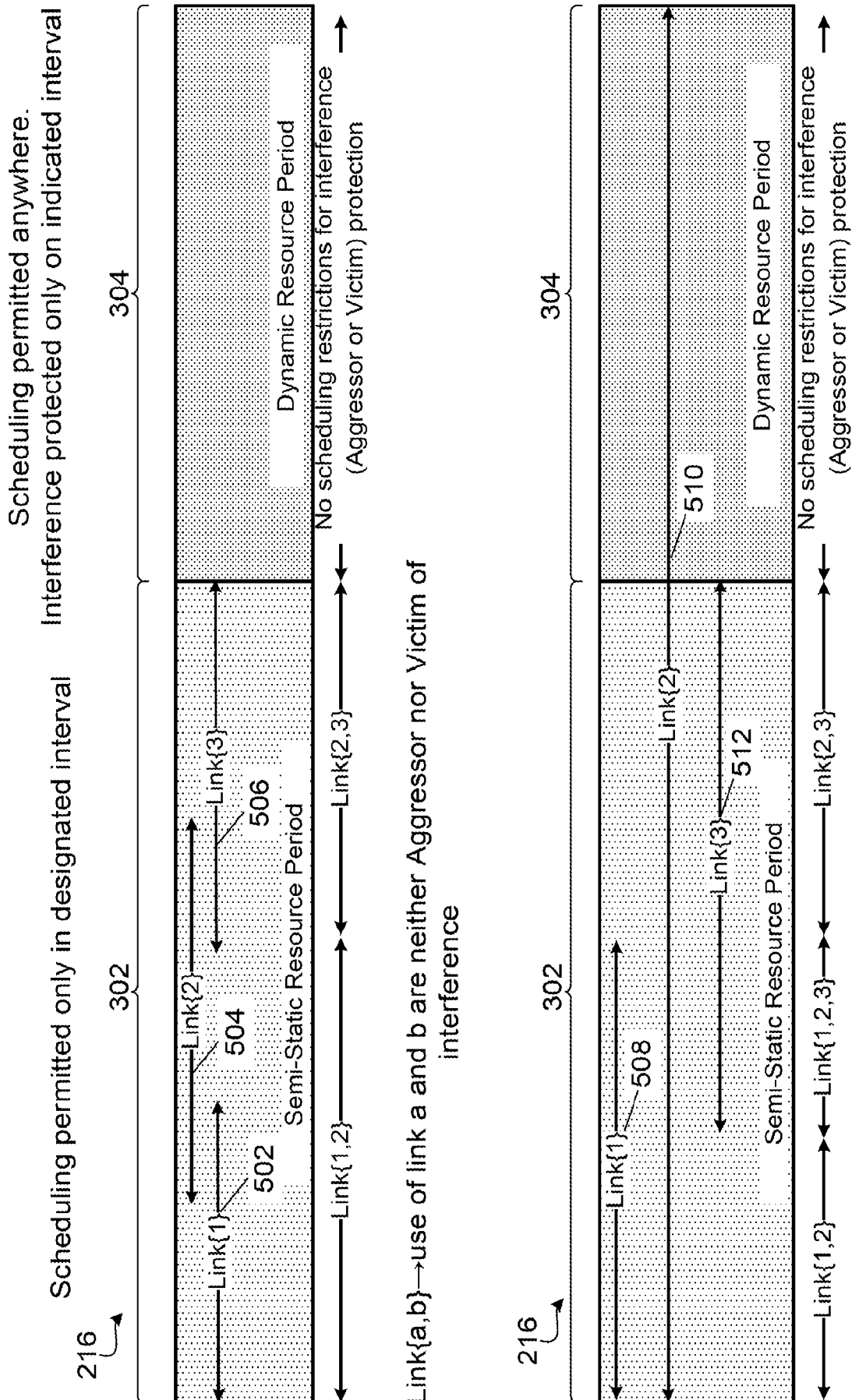


FIG. 5

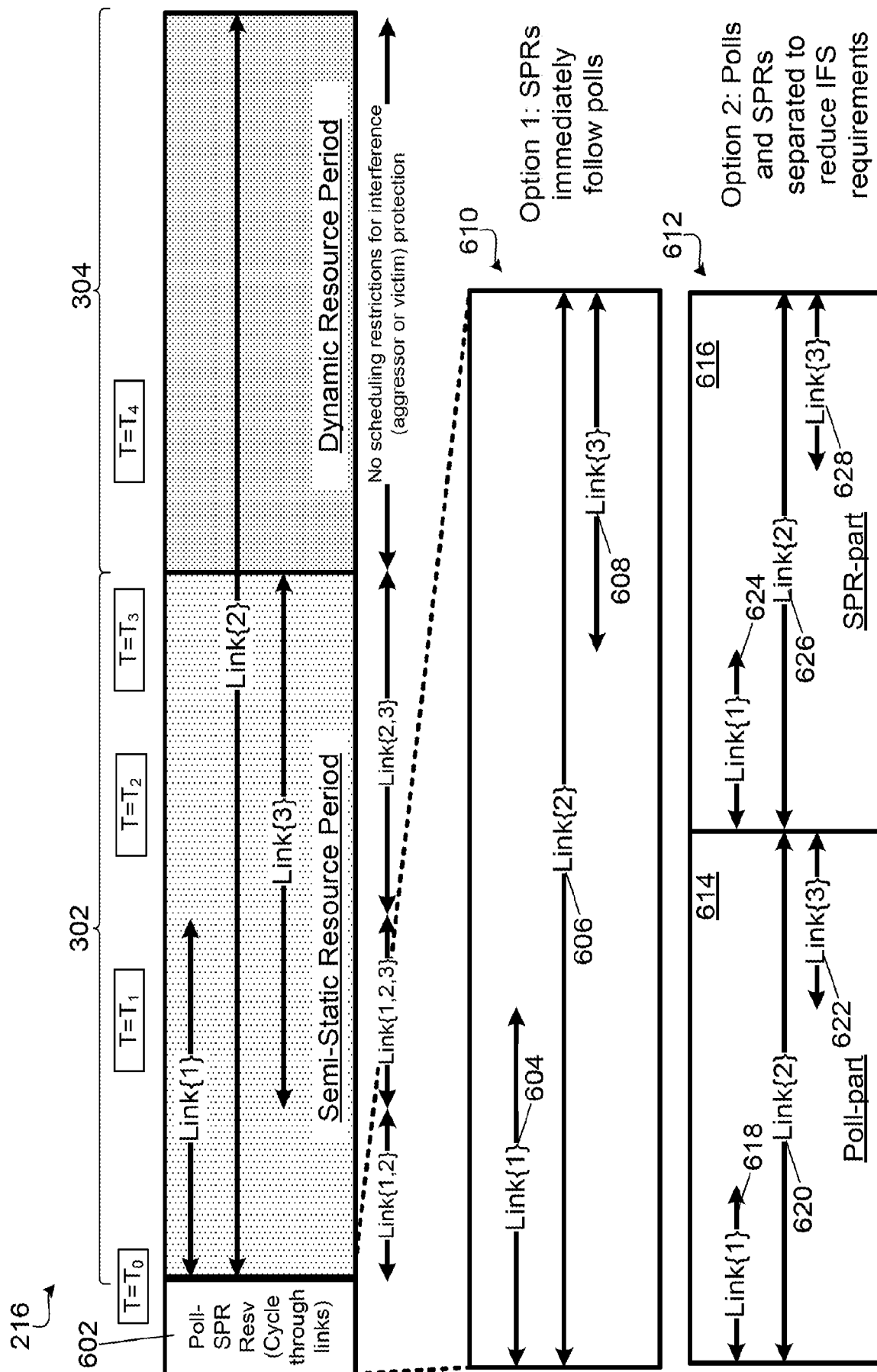


FIG. 6

216

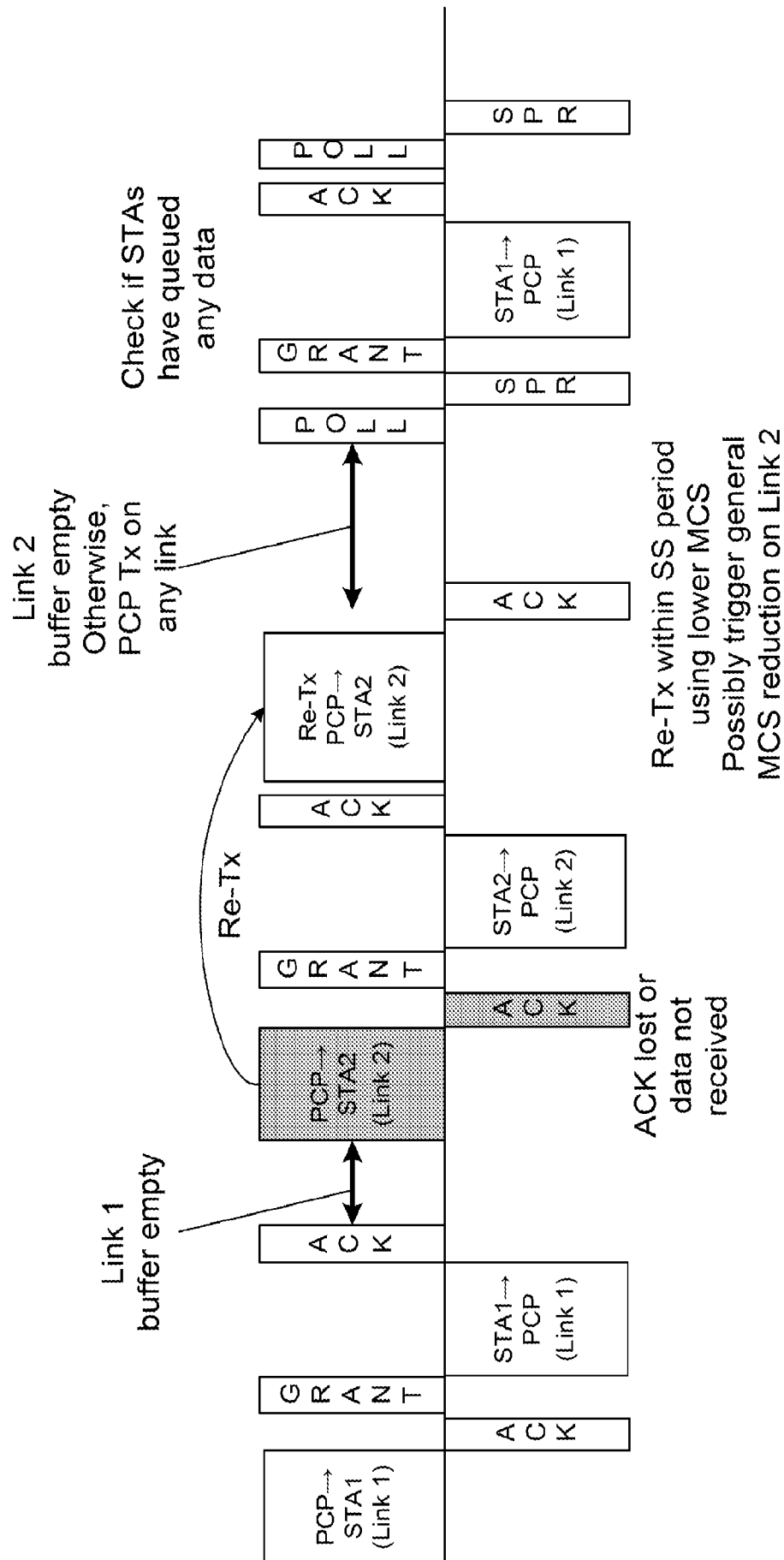


FIG. 7

216

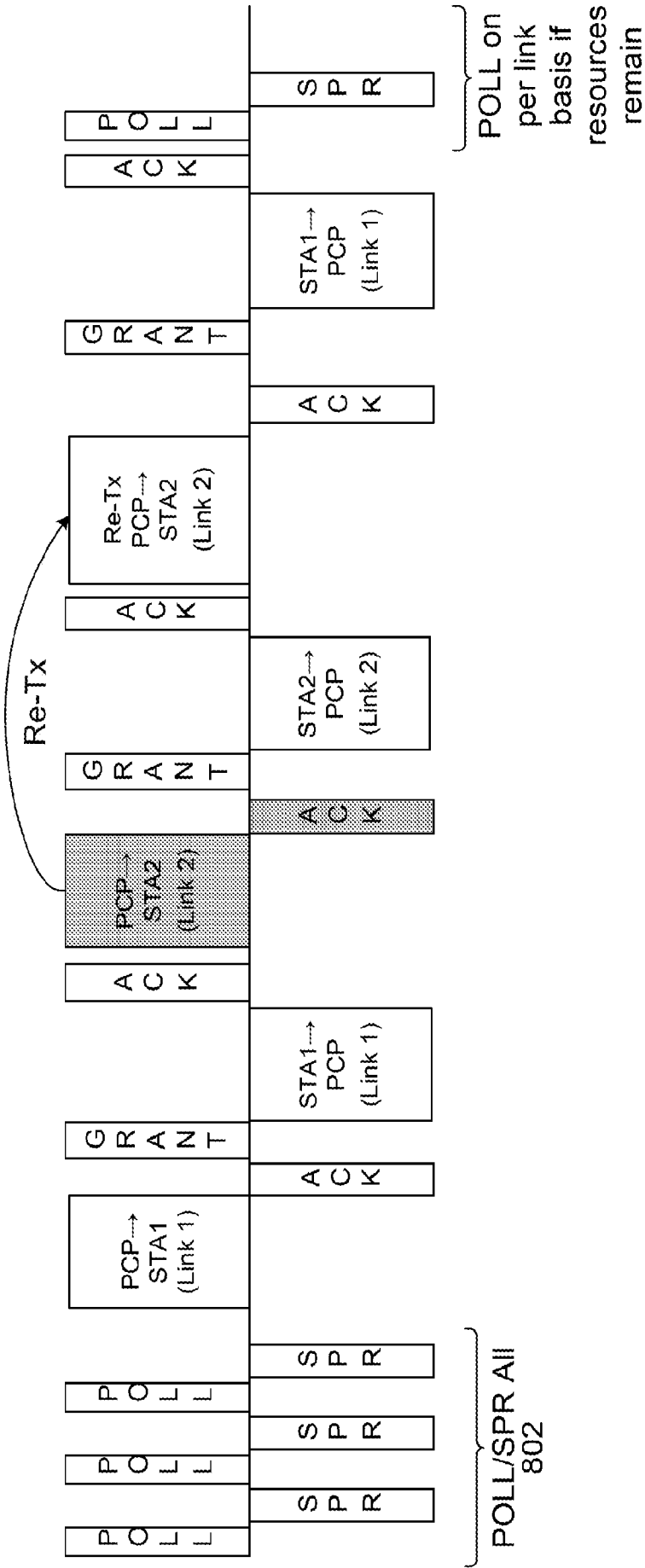


FIG. 8

216

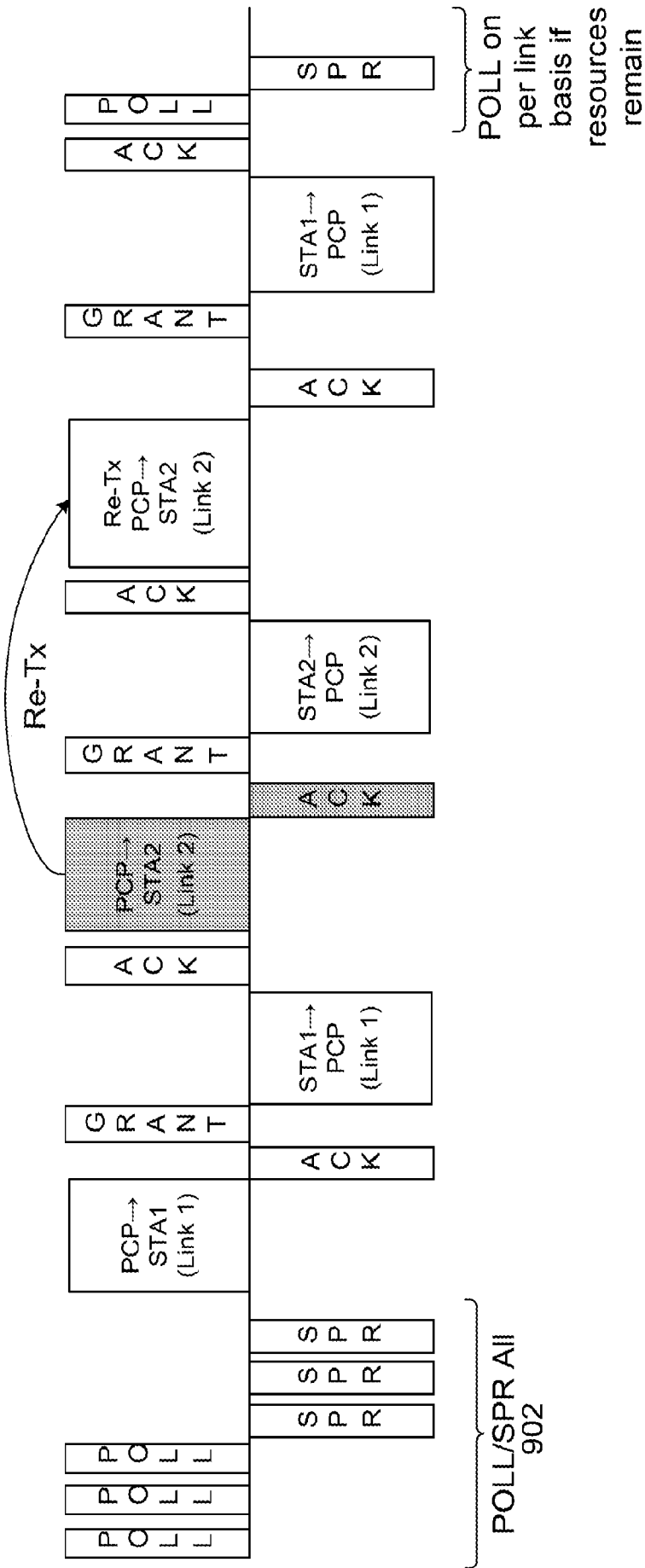


FIG. 9

216

Note that Link2 is always interference free, so scheduler should prefer Link1 and Link3 in SS region

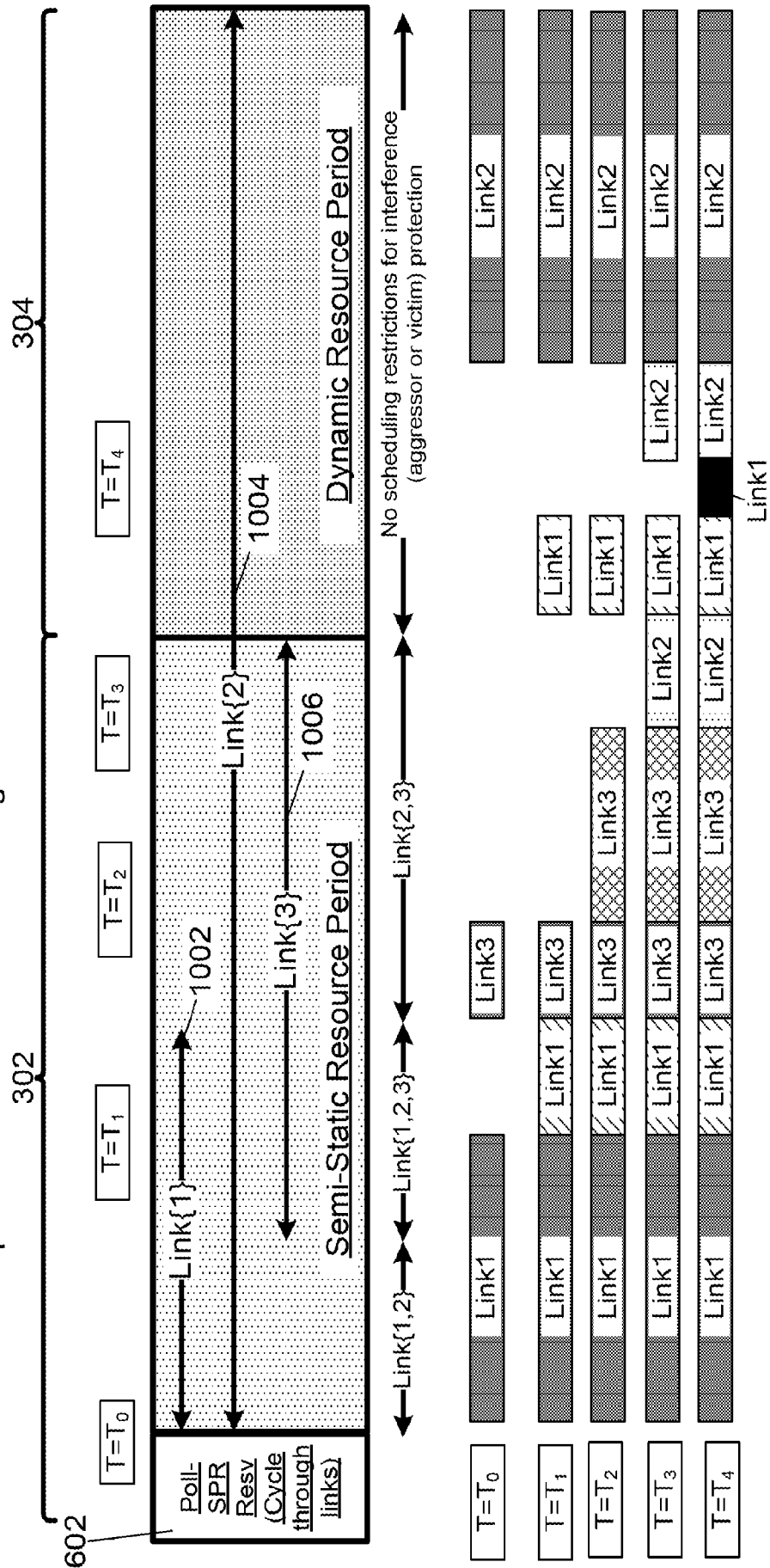


FIG. 10

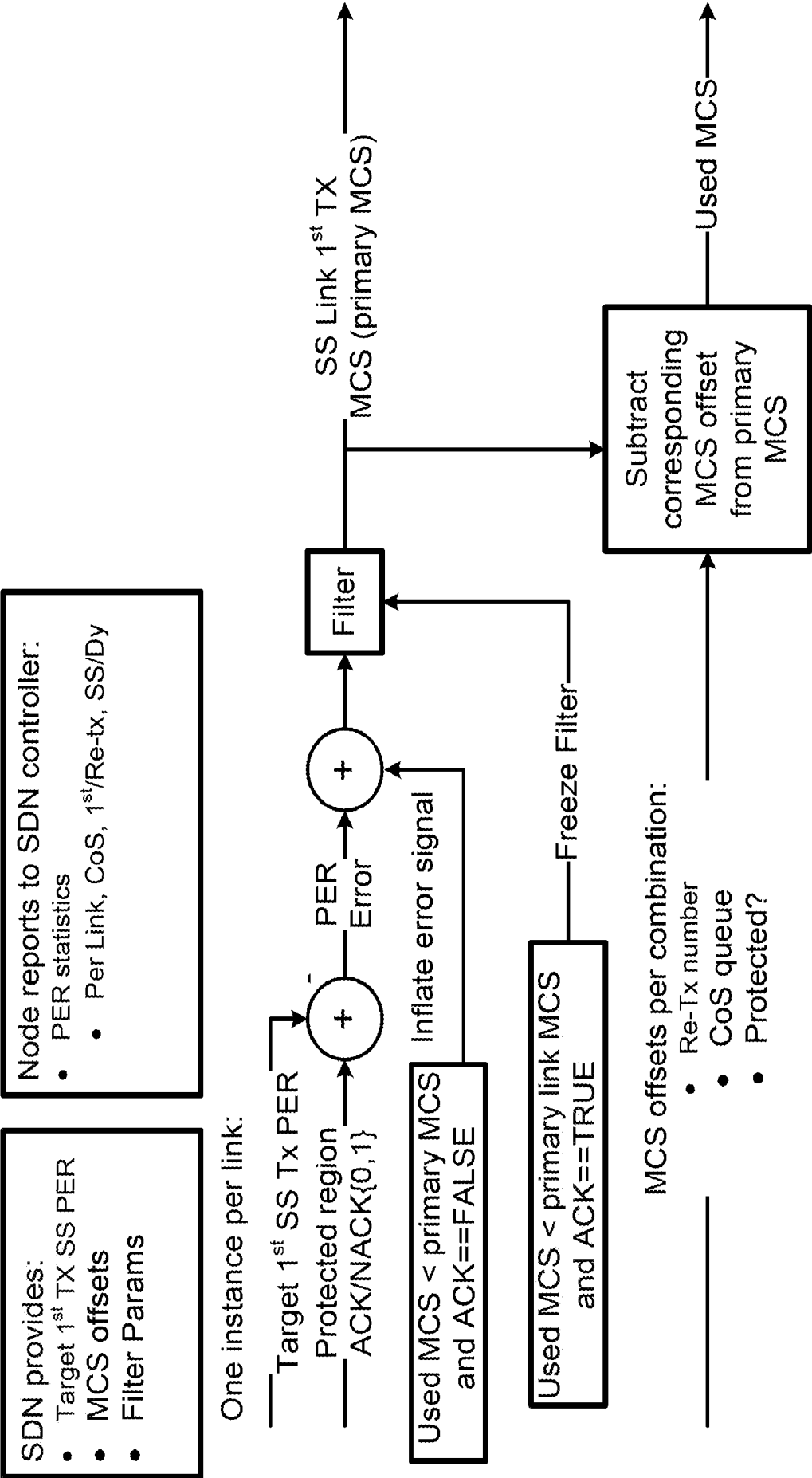
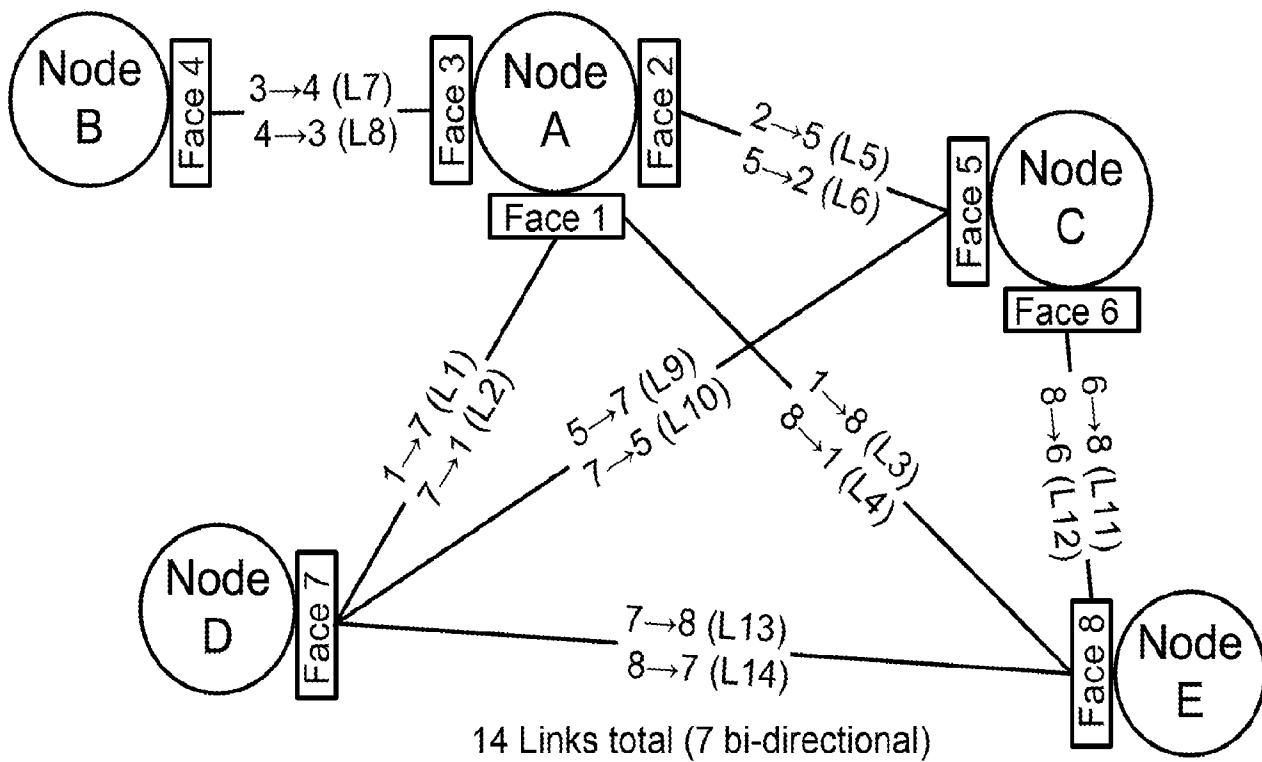


FIG. 11



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	NA	Implies FD	Implies FD	Implies FD					Implies FD	Implies FD			Implies FD	Implies FD
2	Implies FD	NA	Implies FD	Implies FD					Implies FD	Implies FD			Implies FD	Implies FD
3	Implies FD	Implies FD	NA	Implies FD							Implies FD	Implies FD	Implies FD	Implies FD
4	Implies FD	Implies FD	Implies FD	NA							Implies FD	Implies FD	Implies FD	Implies FD
5					NA	Implies FD			Implies FD	Implies FD				
6					Implies FD	NA			Implies FD	Implies FD				
7							NA	Implies FD						
8							Implies FD	NA						
9	Implies FD	Implies FD			Implies FD	Implies FD			NA	Implies FD			Implies FD	Implies FD
10	Implies FD	Implies FD			Implies FD	Implies FD			Implies FD	NA			Implies FD	Implies FD
11			Implies FD	Implies FD							NA	Implies FD	Implies FD	Implies FD
12			Implies FD	Implies FD							Implies FD	NA	Implies FD	Implies FD
13	Implies FD	Implies FD	Implies FD						Implies FD	Implies FD			NA	Implies FD
14	Implies FD	Implies FD	Implies FD	Implies FD					Implies FD	Implies FD	Implies FD	Implies FD	Implies FD	NA

Interference Matrix

Not permitted

Implies FD

NA

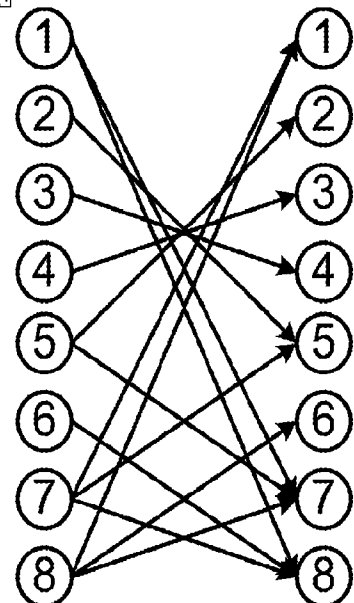


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/030983A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/08
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)
H04W H04B

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.
Y	NITSCHKE THOMAS ET AL: "IEEE 802.11ad: directional 60 GHz communication for multi-Gigabit-per-second Wi-Fi [Invited Paper]", IEEE COMMUNICATIONS MAGAZINE, IEEE SERVICE CENTER, PISCATAWAY, US, vol. 52, no. 12, 1 December 2014 (2014-12-01), pages 132-141, XP011567636, ISSN: 0163-6804, DOI: 10.1109/MCOM.2014.6979964 [retrieved on 2014-12-08] IEEE 802.11ad using dynamic channel time allocation and polling based channel access; superframe structure; page 135 - page 137 ----- -/--	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

25 July 2016

Date of mailing of the international search report

02/08/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Tsapelis, Athanasios

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/030983

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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