



- (51) International Patent Classification: Not classified
- (21) International Application Number: PCT/US2014/048737
- (22) International Filing Date: 29 July 2014 (29.07.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 61/859,684 29 July 2013 (29.07.2013) US
- (71) Applicant: **INTERDIGITAL PATENT HOLDINGS, INC.** [US/US]; 200 Bellevue Parkway, Suite 300, Wilmington, Delaware 19809 (US).
- (72) Inventors: **CHINCHOLL, Amith V.**; 880 E. Fremont Avenue, Unit 407, Sunnyvale, California 94087 (US). **DAI, Yuying**; 9061 Croissant Rimouski, Brossard, Québec J4X 2S3 (CA). **LAUGHLIN, Scott**; 152 Ballantyne North, Montreal, Québec H4X 2C1 (CA). **LIN, Zinan**; 74 Liberty Ridge Road, Basking Ridge, New Jersey 07920 (US). **DEMIR, Alpaslan**; 1714 Coral Road, East Meadow, New York 11554 (US). **GAUVREAU, Jean-Louis**; 115 Paradis, La Prairie, Québec J5R 6G7 (CA). **LE, Tan B.**; 611 W. 171st Street, Apartment 33B, New York, New York 10032 (US).

(74) Agent: **DUNSAY, Jonathan M.**; Volpe & Koenig, P.C., 30 South 17th Street, United Plaza, Suite 1800, Philadelphia, Pennsylvania 19103 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: METHOD AND APPARATUS FOR SHARED SPECTRUM ACCESS BY IEEE 802.11 SYSTEMS WITH DYNAMIC SPECTRUM AVAILABILITY

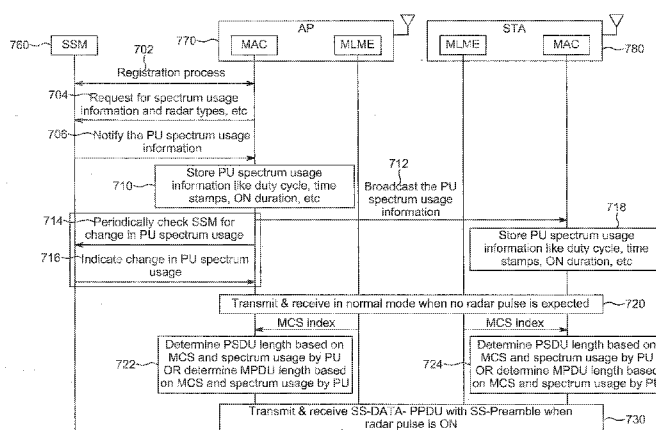


FIG. 7

(57) Abstract: A method and apparatus for operation in a shared spectrum (SS) among a primary user (PU) and other users are disclosed. An access point (AP) or station (STA) may determine that a primary user is using SS frequency and only a portion of an (802.11) channel is available for AP/STA use. The AP may receive spectrum usage information of a PU from a database and transmit this information to a STA. The AP and STA may determine PU usage based on the information and change to a fractional spectrum mode. Based on PU usage, the AP and STA may adjust transmissions to suppress subcarriers used by the PU, including subcarriers in an SS-preamble, an SS short orthogonal frequency division multiplexing (OFDM) training field (SS-STF) symbol and an SS long OFDM training field (SS-LTF) symbol, and may reduce the physical (PHY) Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size.

METHOD AND APPARATUS FOR SHARED SPECTRUM ACCESS BY IEEE 802.11 SYSTEMS WITH DYNAMIC SPECTRUM AVAILABILITY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/859,684 filed July 29, 2013 the contents of which is hereby incorporated by reference herein.

BACKGROUND

[0002] The Federal Communications Commission (FCC) released a memorandum in December 2012 on notice of proposed rulemaking and an order to address commercial operations in the 3550-3650 MHz Band. The memo proposes to create a new Citizens Broadband Service in the 3550-3650 MHz band (3.5 GHz Band), currently utilized for military and satellite operations, which will promote two major advances that may enable more efficient use of radio spectrum: small cells and spectrum sharing.

[0003] The proposal in the memo builds on experience with spectrum sharing in the television white spaces (TVWS). The memo proposes ideas teed up in the recent Notice of Inquiry on Dynamic Spectrum Access technologies, and broadly reflects recommendations made in a recent report by the President's Council of Advisors on Science and Technology (PCAST). The memo also seeks comment on whether to include the neighboring 3650-3700 MHz band, which is already used for commercial broadband services, under the new and flexible rules. The document cites the rapidly increasing need for wireless broadband capacity and also spectrum crunch as a limitation going forward. The document also cites the PCAST report and emphasizes that two technological advances, such as small cells and spectrum sharing, may hold great promise in solving the spectrum crunch. It provides a brief overview of small-cells and spectrum sharing concepts and introduces the 3.5 GHz band as an ideal band to use both technological concepts. The memo cites the fact that the commercial wireless industry found the 3.5 GHz band unsuitable for

macro-cell deployment with some suggesting that it might be more appropriate for fixed wireless or unlicensed use.

SUMMARY

[0004] A method and apparatus may be used for operation in a shared spectrum (SS) among a primary user (PU) and other users. The SS may be used by three tiers of users and the PU may be a tier I user, the other users may include a licensed user, that may be a tier II user, and a secondary user, that may be a tier III user. An access point (AP) or station (STA) may determine that a primary user is using SS frequency within the operating band of the AP or STA. As a result, only a portion of a channel may available for the use of the AP or STA. The channel may include an 802.11 channel. The AP and STA may detect spectrum usage by the PU or may receive information regarding spectrum usage by the PU.

[0005] The AP may register with a database, such as a shared spectrum manager (SSM), which contains information regarding spectrum usage by the PU. The AP may transmit or broadcast this information to one more STAs. The AP and STA may receive an indication, from the SSM, of a change in the spectrum usage of the PU. The SSM may send this information autonomously when it receives notification of such a change. The AP may periodically check with the SSM to ensure that there are no changes in the information regarding spectrum usage by the PU. Further, the AP may receive, as a response to the periodic check, an indication from the SSM of a change in the information regarding spectrum usage by the PU.

[0006] The AP and STA may determine PU usage based on the information regarding spectrum usage by the PU and, as a result, may change to restricted operation mode. Based on PU usage, the AP and STA may adjust transmissions to suppress subcarriers used by the PU, including subcarriers in an SS-preamble. Within the SS-preamble, the AP and STA may suppress the subcarriers in an SS short orthogonal frequency division multiplexing (OFDM) training field (SS-STF) symbol and an SS long OFDM training field

(SS-LTF) symbol. Further, the AP and STA may reduce the physical (PHY) Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size.

[0007] The SS-preamble may have a multiplication factor that reflects the total number of subcarriers in the preamble and the number of subcarriers which are non-zero, and not suppressed. The multiplication factor may be $\sqrt{L/(2K)}$; wherein L may be a total number of subcarriers in the preamble; and wherein K may be a number of subcarriers which are non-zero. The AP and STA may also use a parameter, such as a SUBCARRIER_LIST parameter, to indicate the list of active (non-zero) or suppressed (zero) carriers.

[0008] The AP and STA may also use an SS-Null-PPDU containing the SS-preamble and a null PSDU with no data in it and without a medium access control (MAC) frame. The AP and STA may also use an SS-Null-PPDU/SS-DATA-PPDU Announcement information element in the PPDU before a spectrum use by the PU, such as a radar pulse. The SS-Null-PDDU/SS-DATA-PPDU Announcement may also carry information about whether the SS-Null-PPDU/SS-DATA-PPDU may occur immediately after the PPDU carrying the announcement or be delayed to occur after T seconds or be delayed to occur after N PPDU's.

[0009] The AP and STA may also operate in a regular operation mode during the quiet phase of a radar pulse and a restricted operation mode during the pulse resting times within a radar pulse. The AP and STAs may use timers to switch between modes. The AP and STA may also use a high priority management frame to indicate the change in operation mode due to PU spectrum use, such as a radar pulse.

[0010] The AP and STA may also modify the Power Save Multi-Poll (PSMP) frame and use an enhanced Power Save Multi-Poll (ePSMP) frame, in which the AP may indicate the operation mode as well as the scheduled PSMP downlink transmission time (PSMP-DTT) and PSMP uplink transmission time (PSMP-UTT). The AP may schedule the PSMP-DTT and PSMP-UTT in different opportunity times to save overhead.

[0011] The AP and STA may also use spectrum nulling to use portions of the spectrum when PU users use another spectrum portion. In this way, the AP and STA may not cause interference to the PU users. Various spectrum nulling options may be used depending upon channelization and waveform.

[0012] To operate in the SS without causing interference to the PU, the AP and STA may also use protocol stack modifications. These protocol stack modifications regarding operating in the SS may include a policy driven adaptive RF end with cross-layer signaling from the MAC layer and a tunable notch filter, modified sensing capability with radar pulse detection, radar database equipped in the AP, and agile carrier sense multiple access with collision avoidance (CSMA/CA) with policy enabled adaptive Channel Clear Assessment (CCA) thresholds.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

[0014] FIG. 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented;

[0015] 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;

[0016] 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;

[0017] FIG. 2 is a diagram of an example radar pulse transmission;

[0018] FIG. 3 is a diagram of an example of satellites in the 1675-1710 band;

[0019] FIG. 4 is a diagram of an example Wi-Fi small cell system;

[0020] FIG. 5 is a diagram of an example of the IEEE 802.11 protocol stack architecture;

- [0021] FIG. 6 is a diagram of an example Physical (PHY) Layer Convergence Protocol (PLCP) Protocol Data Unit (PPDU) frame format;
- [0022] FIG. 7 is a diagram of an example signal call flow for adaptive PLCP Service Data Unit (PSDU) size adjustment;
- [0023] FIG. 8 is a diagram of an example call flow showing modification to a PHY service specification;
- [0024] FIG. 9 is a diagram of an example frame format of an SS-Null-PPDU with an SS-Preamble;
- [0025] FIG. 10 is a diagram of an example SS-Null-PPDU use during radar pulse occurrence;
- [0026] FIG. 11 is a diagram of an example SS-Null-PPDU/SS-DATA-PPDU Announcement information element;
- [0027] FIG. 12 is a diagram of an example call flow to schedule SS-Null-PPDU/SS-DATA-PPDU transmission when a radar pulse is ON;
- [0028] FIG. 13 is a diagram of an example of macro/rotation cycles and micro/pulse cycles for opportunistic General Authorized Access (GAA) users operating at a given geo-location;
- [0029] FIG. 14 is a diagram of an example procedure of radar dependent configuration;
- [0030] FIG. 15 is a diagram of an example call flow of the timer enabled operation for the radar dependent configuration;
- [0031] FIG. 16 is a diagram of an example operation of the high priority management frame;
- [0032] FIG. 17 is a diagram of an example of a modified Power Save Multi-Poll (PSMP) sequence with scheduled PSMP downlink transmission time (PSMP-DTT) and PSMP uplink transmission time (PSMP-UTT);
- [0033] FIG. 18 is a diagram of an example operation of spectrum nulling with fixed channelization;
- [0034] FIG. 19 is a diagram of an example operation of adaptive spectrum shifting;

[0035] FIG. 20 is a diagram of an example operation of adaptive spectrum nulling;

[0036] FIG. 21 is a diagram of an example operation procedure of a policy driven RF end and policy based tunable notch filter;

[0037] FIG. 22 is a diagram of an example operation procedure of policy driven RF end;

[0038] FIG. 23 is a diagram of an example call flow of the access point (AP) detecting and broadcasting radar information; and

[0039] FIG. 24 is a diagram of an example operation period of GAA users in a shared spectrum.

DETAILED DESCRIPTION

[0040] Figure 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.

[0041] As shown in Figure 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.

[0042] 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 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.

[0043] 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.

[0044] 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).

[0045] 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).

[0046] 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).

[0047] 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.

[0048] The base station 114b in Figure 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 Figure 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.

[0049] 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 Figure 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.

[0050] 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.

[0051] 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 Figure 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.

[0052] Figure 1B is a system diagram of an example WTRU 102. As shown in Figure 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 106, 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.

[0053] 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 Figure 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.

[0054] 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.

[0055] In addition, although the transmit/receive element 122 is depicted in Figure 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.

[0056] 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.

[0057] 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 106 and/or the removable memory 132. The non-removable memory 106 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).

[0058] 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.

[0059] 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.

[0060] 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.

[0061] Figure 1C is a system diagram of the RAN 104 and the core network 106 according to an embodiment. The RAN 104 may be an access service network (ASN) that employs IEEE 802.16 radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. As will be further discussed below, the communication links between the different functional entities of the WTRUs 102a, 102b, 102c, the RAN 104, and the core network 106 may be defined as reference points.

[0062] As shown in Figure 1C, the RAN 104 may include base stations 140a, 140b, 140c, and an ASN gateway 142, though it will be appreciated that the RAN 104 may include any number of base stations and ASN gateways while remaining consistent with an embodiment. The base stations 140a, 140b, 140c may each be associated with a particular cell (not shown) in the RAN 104 and may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the base stations 140a, 140b, 140c may implement MIMO technology. Thus, the base station 140a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a. The base stations 140a, 140b, 140c may also provide mobility management functions, such as handoff triggering, tunnel establishment, radio resource management, traffic classification, quality of service (QoS) policy enforcement, and the like. The ASN gateway 142 may serve as a traffic aggregation point and may be responsible for paging, caching of subscriber profiles, routing to the core network 106, and the like.

[0063] The air interface 116 between the WTRUs 102a, 102b, 102c and the RAN 104 may be defined as an R1 reference point that implements the IEEE 802.16 specification. In addition, each of the WTRUs 102a, 102b, 102c may establish a logical interface (not shown) with the core network 106. The

logical interface between the WTRUs 102a, 102b, 102c and the core network 106 may be defined as an R2 reference point, which may be used for authentication, authorization, IP host configuration management, and/or mobility management.

[0064] The communication link between each of the base stations 140a, 140b, 140c may be defined as an R8 reference point that includes protocols for facilitating WTRU handovers and the transfer of data between base stations. The communication link between the base stations 140a, 140b, 140c and the ASN gateway 215 may be defined as an R6 reference point. The R6 reference point may include protocols for facilitating mobility management based on mobility events associated with each of the WTRUs 102a, 102b, 100c.

[0065] As shown in Figure 1C, the RAN 104 may be connected to the core network 106. The communication link between the RAN 104 and the core network 106 may be defined as an R3 reference point that includes protocols for facilitating data transfer and mobility management capabilities, for example. The core network 106 may include a mobile IP home agent (MIP-HA) 144, an authentication, authorization, accounting (AAA) server 146, and a gateway 148. 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.

[0066] The MIP-HA may be responsible for IP address management, and may enable the WTRUs 102a, 102b, 102c to roam between different ASNs and/or different core networks. The MIP-HA 144 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. The AAA server 146 may be responsible for user authentication and for supporting user services. The gateway 148 may facilitate interworking with other networks. For example, the gateway 148 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.

In addition, the gateway 148 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.

[0067] Although not shown in Figure 1C, it will be appreciated that the RAN 104 may be connected to other ASNs and the core network 106 may be connected to other core networks. The communication link between the RAN 104 the other ASNs may be defined as an R4 reference point, which may include protocols for coordinating the mobility of the WTRUs 102a, 102b, 102c between the RAN 104 and the other ASNs. The communication link between the core network 106 and the other core networks may be defined as an R5 reference, which may include protocols for facilitating interworking between home core networks and visited core networks.

[0068] 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.

[0069] As used herein, station (STA) may also be referred to as a serving STA, WTRU or UE and such terms may be used interchangeably. As used herein, access point (AP) may also be referred to as a base station, Node-B or eNode-B and such terms may be used interchangeably. The embodiments disclosed herein are equally applicable to tier I and tier II users coexisting with tier III users as they are with tier I users coexisting with tier II and tier III users. As used herein, a multi-tiered communication system may refer to a system that includes at least two tiers of users.

[0070] Spectrum bandwidth may need to be shared by different types of users, organized into tiers of users. A lower tier user may not use the any part of the bandwidth allocated to a higher tier user when it is used by a higher

tier user. If the higher tier user only uses a small part of the allocated bandwidth during the active use of the higher tier user, a more efficient approach may be for the lower tier user or users to use a portion of the allocated bandwidth not being used by the higher tier user. This portion may be indicated in signal transmissions by the lower tier users. This portion may be detected by the lower tier users or information about the portion may be stored in a database available to the lower tier users. Lower tier users may use the allocated bandwidth by co-existing with the higher tier users in frequency domain, time domain or both.

[0071] As used herein, a part of bandwidth, a portion of bandwidth, a fraction of bandwidth, a part of spectrum, a portion of spectrum, a fraction of spectrum, a part of frequency, a portion of frequency, a fraction of frequency, a part of a channel, a portion of a channel, and a fraction of a channel may be used interchangeably. For example, a portion of the bandwidth of a primary user (PU) and a portion of a channel used by a PU may be used interchangeably.

[0072] The Federal Communications Commission's (FCC) December 2012 memorandum proposes to structure the Citizens Broadband Service according to a multi-tiered shared access model that reflects recommendations made in a July 2012 report by the President's Council of Advisors on Science and Technology (PCAST), described further below. The three tiers of service proposed are (1) Incumbent Access; (2) Priority Access; and (3) General Authorized Access (GAA). The memo also states that Qualcomm's Authorized Shared Access model is similar to the proposed multi-tiered framework.

[0073] The Incumbent Access tier may consist solely of authorized federal and grandfathered licensed Fixed Satellite Service (FSS) 3.5 GHz Band users. The Priority Access tier may consist of a portion of the 3.5 GHz Band designated for small cell use by certain critical, quality-of-service dependent users at specific, targeted locations. The GAA tier may be assigned for use by the general public on an opportunistic, non-interfering basis within designated geographic areas.

[0074] Users in the Priority Access and GAA tiers may be licensed by rule as Citizens Broadband Service users under Part 95 of the Commission's rules. A license-by-rule approach may provide individuals, organizations, and service providers with "automatic" authorization to deploy small cell systems, for example, in much the same way that Part 15 unlicensed rules have allowed widespread deployment of Wi-Fi access points. The memo may offer a supplemental proposal to integrate the 3650-3700 MHz band within the proposed Citizens Broadband Service, thereby encompassing an additional 50 megahertz of contiguous spectrum.

[0075] PCAST released a report in July 2012 entitled "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth." The report recommended that the President issue a new memorandum that states it is the policy of the U.S. government to share underutilized Federal spectrum to the maximum extent possible that is consistent with the Federal mission, and may require the Secretary of Commerce to identify 1000 MHz of Federal spectrum in which to implement the new architecture and thereby create the first shared-use spectrum superhighways.

[0076] One of the key recommendations in this report is a three-tier hierarchy for access to federal spectrum: Federal primary systems may receive the highest priority and protection from harmful interference; secondary licensees may register deployments and use in a database and may receive some quality of service protections, possibly in exchange for fees; and General Authorized Access (GAA) users may be allowed opportunistic access to unoccupied spectrum to the extent that no Federal Primary or Secondary Access users are actually using a given frequency band in a specific geographical area or time period.

[0077] The report also states that the National Telecommunications and Information Administration (NTIA) has identified the 3550-3650 MHz radar band as one that may be shared outside of specified exclusion zones, the size of which may vary dramatically depending on the power levels and antenna heights of the secondary and tertiary users. The 3500-3650 MHz band may be

used by Department of Defense radar systems with installations on land, on ships and on aircraft. In general, the predominant use in the band by mobile radars is on ships and aircraft. Most of the aircraft and fixed, land-based systems are operated at military training areas and test ranges, and it is recognized that tactical necessities ultimately determine operational requirements.

[0078] The term radar is an acronym derived from the phrase Radio Detection And Ranging and may apply to electronic equipment designed for detecting and tracking objects or targets at considerable distances. Radar may use extremely short bursts of radio energy traveling at the speed of light. The radio energy may be transmitted, reflected off a target and returned as an echo.

[0079] An example requirement of marine radar may be that of directional transmission and reception, which may be achieved by producing a narrow horizontal beam. In order to focus the radio energy into a narrow beam, the wavelength may be within a few centimeters range.

[0080] Figure 2 is a diagram of an example of radar pulse transmission. The radio-frequency energy transmitted by pulse-modulated radars may include a series of equally spaced pulses 210, 220 and 230, frequently having durations of about 1 microsecond or less, separated by relatively long periods during which no energy is transmitted, which may be known as resting times 215 and 225. Resting times may last approximately 1-3 milliseconds. For example, radar pulse 210 is followed by resting time 215, which is in turn followed by radar pulse 220 and then resting time 225. The time of the radar pulse combined with the pulse resting time may be referred to as the pulse repetition time (PRT). The radar pulse length may be referred to as Pw. Pw divided by PRT may be referred to as the duty cycle. The peak power multiplied by the duty cycle may be referred to as the average power.

[0081] The time that an antenna beam spends on a target may be referred to as *dwell time* T_D . The dwell time of two-dimensional (2D) search radar may depend predominantly on the horizontal beam width of the

antenna Θ_{AZ} and the turn speed of the antenna. The turn speed of the antenna may be referred to as Rotations per Minute (RPM). The dwell time may be calculated and using the following equation:

$$T_D = \frac{\Theta_{AZ}}{360^\circ} \frac{60}{RPM} \text{ in seconds} \quad \text{Equation 1}$$

[0082] On the other hand, the dwell time may be the interference time from the radar to other receivers that stay on the same direction of the target. Table 1 is an example of radar transmission power. The transmission power and duty cycle of radars operated in 3.5-3.7 GHz bands are summarized in Table 1.

Table 1

Radar Type	Peak Transmit Power (dBm)	Average Transmit Power (dBm)	Mainbeam Antenna Gain (dBi)	Duty Cycle
Ground-based radar 1	75	65	36	10%
Ground-based radar 2	53	14.6	8	0.01%
Ground-based radar -3	78	70	39.7	16%
Airborne radar -1	60	29.5	17	0.09%
Airborne radar-2	53	23	17	0.09%
Shipborne radar -1	90	60	32	0.1%
Shipborne radar-2	83	75	47	15%
Shipborne radar-3	98	80	41.8	1.6%
Shipborne radar-4	84		38.9	
Shipborne radar-5	93.3		45.3	

[0083] The 3500-3650 MHz band may be allocated to space-to-Earth Meteorological-Satellite (MetSat) and Meteorological aids (MetAids)

(Radiosondes) services. Radiosonde is an expendable electronic sensing and data transmission probe. The probe may be carried aloft by a balloon to collect atmospheric data like temperature, pressure, and humidity. It may be used for shared use by Federal and non-Federal entities. The band may be divided into two parts: 1675-1700 MHz and 1700-1710 MHz bands. The Geostationary Operational Environmental Satellite (GOES) may use the 1675-1700 MHz part and it may be used for rapid real time observations of hurricanes, severe weather and short-range warning. The band may be used in the downlink direction only and may be used for different applications like Automatic Picture Transmission Application, Satellite Operations and Control Center (SOCC) Application, and Command Data Acquisition (CDA) Application.

[0084] The Polar-Orbiting Environmental Satellites (POES) may use the 1700-1710 part and it may be used for high resolution real time hazard observations and weather forecast models. It may operate in the 1675-1683 MHz band and may be used by Department of Energy (DOE), and National Aeronautics and Space Administration (NASA). These agencies may operate Radiosonde systems for MetAids service.

[0085] The GOES Data Collection System Service may use near real-time data transmission. The National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites may operate in real-time during satellite contact, with two contacts a day and a 12 to 15 minute contact duration for each contact. The Radiosonde transmitters are launched at least twice per day and each transmits for approximately 2.5 hours per flight.

[0086] The emission bandwidth of each of these satellites and Radiosonde may only be a small fraction of the total 35 MHz band. For example, the GOES-N satellite may be used for sensor data link and uses 5.2 MHz of bandwidth at 1676 MHz center frequency. GOES-R satellite may be used for command and data acquisition telemetry uses only 8 KHz of bandwidth at 1696.3 MHz center frequency. In each case, the exact geo-location of the satellite receiver is known a priori.

[0087] Figure 3 is a diagram of an example of satellites in the 1675-1710 band. Several satellites, including satellites 310, 320 and 330, may operate in the 1675-1710 band. Satellite 330 is an example of a satellite that performs two contacts a day with a 12 to 15 minute contact duration for each contact.

[0088] To enable dynamic shared spectrum access, the bands of interest may be 3.55 GHz - 3.65 GHz occupied by radar as incumbents as proposed in the PCAST proposal and 1675-1710 band occupied by satellites as incumbents. The total bandwidth available for use may be 100 MHz in the 3.55 GHz - 3.65 GHz band and 35MHz in the 1675-1710 band, although the channelization for use by Tier II/III access systems is not yet defined. In another example, the total bandwidth available for use may be 150 MHz in the 3.50 GHz - 3.65 GHz band. In general, three different types of users may access this spectrum, a Tier I user that may be a PU, for example, RADAR in the case of the 3.5 GHz band; a Tier II user that may be a Licensed User; and a Tier III user that may be a Secondary User. Example uses of this band may include Small Cell Home/Enterprise/Hotspot deployment. Non-primary users may be considered Tier II users, Tier III users, or both. Small Cells may be served by low-powered APs that operate in licensed and unlicensed spectrum and have a range of 10 m to 1 or 2 km. Small Cell Home systems may be used in a residential setting. Small Cell Enterprise systems may be used in a business setting. Small Cell Hotspots systems may be used in public areas. Example uses of RAT for this band may be based on IEEE 802.11n, IEEE 802.11ac or both. The max allowed Transmit Power at APs and stations (STA) are not yet regulated.

[0089] Figure 4 is a diagram of an example of a Wi-Fi small cell system. The system may include an AP 410 and at least one STA 420. A primary user 430, such as a satellite or radar system, may use the same spectrum as the small cell system. The maximum transmit (Tx) power at the AP may determine the cell radius and power amplifier (PA) linearity.

[0090] Figure 5 is a diagram of an example of the IEEE 802.11 protocol stack architecture. The 802.11 protocol stack architecture may include a

Physical (PHY) layer 510 and a data link layer 520 separated vertically. Each layer may have a management sub-layer and a data sub-layer separated horizontally. The PHY layer 510 may have a management layer 550, including the PHY Sub-Layer Management Entity, and data layer 530, including PMD Sub-layer 533 and PLCP Sub-Layer PMD_SAP 536. The data link layer 520 may have management layer 560, including the MAC Sub-Layer Management Entity, and data layer 540, including the MAC Sub-Layer. Several service access points (SAPs) between sub-layers have been defined in the standard. For example, MLME_PLME_SAP 555 is an SAP between the MAC Sub-Layer Management Entity and the PHY Sub-Layer Management Entity. Also, the management sub-layer may interface with the data sub-layer. For example, in the data link layer 520, the MAC Sub-Layer Management Entity may interface 565 with the MAC Sub-Layer.

[0091] Figure 6 is a diagram of an example of a PHY Layer Convergence Protocol (PLCP) Protocol Data Unit (PPDU) frame format. The PPDU frame format of the base band signal at the transmitter may include a PLCP preamble 610, a SIGNAL field 620 and DATA field 630. The DATA field 630 may include a PLCP Service Data Unit (PSDU) 635, SERVICE field 633, tail bits 637 and pad bits 639. The SIGNAL field 620 may be different on all channels since the RATE 621 and LENGTH 625 parameters may be dependent on the channel parameters and the number of octets in the PSDU 635 respectively.

[0092] In an example wireless system, a large bandwidth, for example, 100 MHz of spectrum around the carrier, for example, a carrier at 3.5 GHz, may be used on a shared basis. The use of this bandwidth in a wireless system may be achieved by using a single radio unit, for example, a single RF Chain where one analog filter may span the whole band. This band, however, may also include at least one primary user, for example, radar or satellite, operating simultaneously with the secondary user system. Moreover, the primary user may be expected to use only a fraction of the spectrum and may also be expected to be used sporadically and not continuously.

[0093] This dynamic nature of spectrum usage may impact the amount of spectral resources available to transmit data over the air. The amount of spectral resources available may directly determine the amount of medium access control (MAC) data bits that may be transmitted in each sub frame over the air. In a Wi-Fi system, the PSDU size may determine the number of payload bits that will be encoded, modulated, and transmitted over the air.

[0094] In legacy Wi-Fi systems, the spectral resources may not change on-the-fly and the PSDU size may depend on the modulation and coding scheme (MCS) index for the link and also the IP packet size. However, in the system described above, the spectral resources may change over time based on the spectrum occupancy pattern of the primary user and thus the PSDU size may also depend on available number of orthogonal frequency division multiplexing (OFDM) subcarriers at any given time. A PSDU size which fits the amount of spectral resources when the whole spectrum is available will be too much when only a fraction of the whole spectrum is used (to allow coexistence with primary user). Similarly, a PSDU size which fits the amount of spectral resources when only a fraction of the whole spectrum is used will be too small (wasting precious spectral resources) when the whole spectrum is available.

[0095] The PLCP preamble in the PPDU frame format shown in Figure 6 may be used for synchronization, channel estimation, and frequency offset estimation purposes and may be made of 12 symbols. The training sequences may be specified in the frequency domain as a vector of complex numbers with a scaling factor for normalization. The preamble sequences defined in the standard may be fixed and may be designed to maintain a predefined periodic pattern in time domain, such as the 12 symbols of PLCP preamble which may consist of 10 repetitions of the short training sequence symbols and 2 repetitions of the long training sequence symbols. But in the case when the system operates on shared spectrum where a fraction of the spectrum becomes unavailable, no transmissions may be scheduled on the sub-carriers corresponding to the unavailable portion of spectrum. When some sub-carriers

become unavailable, the training sequence elements originally mapped on to those sub-carriers may not be mapped to them anymore which in turn may disrupt the periodic pattern in the time domain. Thus a new set of PLCP preambles may be designed taking into account the spectral occupancy pattern on the shared spectrum.

[0096] In general, given the multi-tiered shared spectrum framework, and high-powered transmission characteristics by incumbents like radar operating on such spectrum, the following issue may arise when operating secondary access systems. Interference from primary users/incumbents like radar may be much higher than the desired maximum received power of access systems. This may cause the Low-Noise-Amplifier (LNA) of an access system's receiver to operate out of its linear range and may lead to significant performance degradation in the access system. Moreover, the frequency fragments with high interference presence may be variable with time and geo-location, and in some cases like defense radars, the operating parameters may be unknown (due to classified information) which may pose a challenge in terms of interference mitigation.

[0097] In bands like the 1675-1710 MHz band where satellites operate, the transmission from the satellite has a very large footprint on earth covering hundreds of miles around the satellite's receiver location. Based on free-space path loss analysis, this received power may not cause any performance degradation in commercial wireless radios if they operate in this band. But the regulators (like the FCC) releasing such spectrum for Tier II/III use may want to ensure that satellite receivers are immune to any interference from such commercial wireless systems operating as Tier II/III users. To ensure that immunity, exclusion zones around the satellite receivers may be defined where Tier II/III users may not operate on this band and thus prevent unwanted interference from the Tier II/III users onto the satellite receivers. But wireless network operators who would like to use this spectrum for Tier II/III use may not like such large exclusions zones since the commercial

wireless systems are unusable over large areas, at least when the satellite is transmitting based on transmission patterns described above.

[0098] Modifications to the 802.11 frames and protocol and the mechanisms and procedures to support coexistence with radar may be defined. The following new modifications to the Wi-Fi protocol stack may be disclosed herein: enable fractional use of spectrum by a Wi-Fi Tier II/III user, adaptive PPDU duration, shared spectrum (SS) preamble design, SS data PPDU frame, SS null PPDU frame, and SS null PPDU/SS data PPDU announcement.

[0099] For enabling fractional use of spectrum by Wi-Fi Tier II/III user, Wi-Fi a Tier II/III user may operate on the shared band by leaving the primary user spectrum fragments unused (assuming the primary user occupies only a fraction of the band). Since the presence of the primary user may be sporadic and not continuous, the secondary user Wi-Fi system may continue using the whole band when the primary user is absent, and may use only a portion of the band excluding the primary user's channel when the primary user is present.

[0100] For adaptive PPDU duration, one PSDU/MAC protocol data unit (MPDU) size may be used when using all 100 MHz and different PSDU/MPDU size(s) may be used when using part(s) of the spectrum. The impact to PHY service primitives may be that a LENGTH parameter element in TXVECTOR and RXVECTOR parameters may be adjusted when radar is ON or OFF and that a parameter called SUBCARRIER_LIST may be inserted in TXVECTOR and RXVECTOR parameters to indicate active/suppressed sub-carriers.

[0101] The SS-Preamble design, may maintain periodicity of short and long training sequences when part of spectrum is unavailable.

[0102] For an SS-Data-PPDU Frame, when the primary user's transmission is about to occur (based on a priori knowledge from the shared spectrum manager (SSM)/geo-location database), the Wi-Fi system may schedule one or more SS-Data-PPDU(s) with certain sub-carriers suppressed. The frame format may contain SS-Preamble field, Length field and Data payload of size specified by length field.

[0103] For an SS-Null-PPDU Frame, when the primary user's transmission is about to occur (based on a priori knowledge from the SSM/geo-location database), the Wi-Fi system may schedule one or more SS-Null-PPDU(s). The frame format may contain SS-Preamble field, Length field and Null payload of size specified by length field.

[0104] For an SS-Null-PPDU/SS-Data-PPDU Announcement, the previous PPDU before the radar pulse arrives may carry an SS-Null-PPDU/SS-Data-PPDU announcement either in the PPDU header (for example, a "Reserved bit" in the Signal field) or in the PSDU by piggybacking with the payload. The SS-Null-PDDU/ SS-Data-PPDU Announcement may be 1 octet in length and may carry 4 elements including announce, length, offset Type, and offset.

[0105] The announce element, which may be 2 bits, may indicate whether SS-Null-PPDU is present, SS-Data-PPDU is present or both are absent. The length element, which may be 3 bits, may indicate the length of the Null/Data PSDU in octets. The offset type element, which may be 1 bit, may indicate the offset is the number of PPDU's or the number of microseconds, if the announcement is delayed and not immediate. The offset element, which may be 2 bits, may indicate the number of PPDU's or the number of microseconds that the SS-Null-PPDU/SS-Data-PPDU is offset by.

[0106] The following coexistence mechanisms may be disclosed herein: policy enabled opportunistic transmission strategy for Wi-Fi systems, high priority management frame, waveform generation mechanisms to access the wide band (some of which may be occupied by the radar transmission), and AP/STA protocol stack modifications operating in shared spectrum. The coexistence mechanisms may share the spectrum with high-powered incumbent users, like radar in the 3.5-3.65 GHz band to mitigate radio saturation in the access system as well as coexistence mechanisms to share the spectrum with incumbents like Satellites in the 1675-1710 MHz bands to ensure drastic reduction in exclusion zones as specified by the regulatory bodies.

[0107] For a policy enabled opportunistic transmission strategy for Wi-Fi systems, AP signals may be associated with STAs to adjust the transmission mode based on the time length with no radar interference. The decision of the transmission mode is made by the AP per the information from the database/shared spectrum manager, and/or, sensing results from the AP and STAs.

[0108] The High Priority Management Frame may notify all associated STAs to take immediate action in the shared spectrum band. This action may be, for example, change to the new operation mode or stop operation due to the detected radar transmission. The High Priority Management Frame may have higher priority than other types of management frames. The High Priority Management Frame may contain multiple elements, including, for example, the new operation, the starting time of the new operation, the duration of new operation mode, transmission pattern, and the like.

[0109] The AP/STA protocol stack modifications operating in shared spectrum may have a policy driven adaptive RF end with cross-layer signaling from the MAC layer, modified sensing capability with radar pulse detection, radar database equipped in the AP, and agile carrier sense multiple access with collision avoidance (CSMA/CA) with policy enabled adaptive Channel Clear Assessment (CCA) thresholds.

[0110] Dynamic Spectrum Sharing by Wi-Fi Systems operating with Tier II/III access systems frame and protocol modifications may be described herein. Completely shutting down the secondary user operation across the whole band to enable coexistence with the primary user or to sense the primary user may not be the most efficient use of spectrum. Enabling fractional use of the spectrum by a Wi-Fi Tier II/III user may be utilized. A Wi-Fi Tier II/III user may operate on the shared band by leaving the primary user spectrum fragments unused (assuming the primary user occupies only a fraction of the band). Since the presence of the primary user may be sporadic and not continuous, the secondary user Wi-Fi system may continue using the whole band when the primary user is absent, and may use only a portion of

the band excluding the primary user's channel when the primary user is present.

[0111] The PLCP preamble in the legacy PPDU frame format shown in Figure 6 may be used for synchronization, channel estimation, and frequency offset estimation purposes and may be made of 12 symbols which may consist of 10 repetitions of the short training sequence symbols and 2 repetitions of the long training sequence symbols. The PLCP preamble may be followed by the SIGNAL field and DATA field. The total training length may be 16 μ s. The repetitions in the short training sequence and the long training sequence may be due to the periodicity of the inverse Fourier transform.

[0112] A short OFDM training field (STF) symbol consists of 12 subcarriers, which may be modulated by the elements of the sequence S, given by:

$$S_{-26, 26} = \sqrt{13/6} \times \{0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0\}$$

Equation 2

The multiplication by a factor of $\sqrt{13/6}$ is in order to normalize the average power of the resulting OFDM symbol, which utilizes 12 out of 52 subcarriers.

[0113] Similarly, a long OFDM training field (LTF) symbol consists of 53 subcarriers (including the value 0 at dc), which may be modulated by the elements of the sequence L, given by:

$$L_{-26, 26} = \{1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1\}$$

Equation 3

[0114] In an example, an SS-STF may be used. In an example, the SS-Preamble may have a multiplication factor which is $\sqrt{L/2K}$ where "L" may be the total number of sub-carriers in the preamble (L=52 in the unmodified preamble shown above) and "K" may be the number of sub-carriers which are non-zero (K=12 in the unmodified STF of the preamble shown above). The frequency spacing between two consecutive non-zero elements between

subcarrier indices $-(L/2)$ and 0 and between sub-carrier indices 0 and $(L/2)$ in the preamble sequence may determine the periodicity in the time domain, for example, 10 repetitions of the STF.

[0115] In order to keep the number of repetitions “R” in time domain the same as in the unmodified STF (for example, $R=10$ repetitions for the unmodified STF), the frequency spacing between two consecutive non-zero elements between subcarrier indices $-(L/2)$ and 0 and between sub-carrier indices 0 and $(L/2)$ in the preamble sequence may not be changed. Instead, the non-zero subcarrier(s) which are most likely to overlap the primary user’s frequency location, may be set to zero. If the primary user has a bandwidth of “ B_{PU} ” and its center frequency location is around the dc sub-carrier, in other words, around the pass-band center frequency of the Tier-II/III access system, care may be taken to ensure that the non-zero sub-carrier(s) falling within a bandwidth of “ B_{PU} ” on the either side of the dc sub-carrier may be set to zero. “K” in the scale factor may reflect the number of non-zero sub-carriers after this process of suppressing subcarriers falling on the primary user’s channel.

[0116] If the primary user has a bandwidth of “ B_{PU} ” and its center frequency location is either to the low band edge or the high band edge of the Tier-II/III access system’s channel, care may be taken to ensure that the non-zero sub-carrier(s) falling within a bandwidth of “ B_{PU} ” on the left band edge and “ B_{PU} ” on the right band edge may be set to zero. Again, “K” in the scale factor may reflect the number of non-zero sub-carriers after this process of suppressing subcarriers falling on the primary user’s channel.

[0117] In a further example, an SS-LTF may be used. The SS-LTF may be defined by suppressing sub-carrier elements in the sequence which may overlap with the primary user’s spectrum occupancy. Additional sub-carriers around the PU’s spectrum occupancy may be suppressed to provide a guard band in order to avoid spectral leakage from the Tier II/III user on to the PU’s spectrum.

[0118] Shared spectrum PPDU Design may be described herein. In a dynamic spectrum sharing system with fractional use of channels, the spectral

resources may change over time based on the spectrum occupancy pattern of the primary user and thus a single fixed PSDU size may not be the most efficient way to utilize the spectrum. A fixed PSDU size which fits the amount of spectral resources when the whole spectrum is available may be too much when only a fraction of the whole spectrum is used (to allow coexistence with primary user). Similarly, a fixed PSDU size which fits the amount of spectral resources when only a fraction of the whole spectrum is used may be too small (wasting precious spectral resources) when the whole spectrum is available. In an example, a dynamic adaptation of PSDU size may be based not only on the link quality (or MCS) as it is done today but also on the instantaneous channel availability based on a primary user's spectrum occupancy. The number of sub-carriers available to be used for Tier-II/III access may be signaled instantaneously to the MAC during transmission so that the PSDU inside the PPDU may be accommodated exactly and is neither too little nor too much.

[0119] The length of the PSDU, which is specified in octets, may map to the number of OFDM symbols G carrying the PSDU payload. When all sub-carriers are enabled, the PSDU length may be dependent on the MCS and the MPDU length. But for the same MCS and MPDU length, when the number of available sub-carriers decrease due to the presence of a primary user, the number of OFDM symbols used to carry the PSDU payload may have to increase. If the number of sub-carriers used to accommodate/coexist with a primary user is P , and the modulation order used has M bits/subcarrier, the number of coded bits that may have mapped to the sub-carriers occupied by the primary user may be $P*M$. If each OFDM symbol has S sub-carriers in total, it may carry $S*M$ bits in total when a primary user is absent. Thus when the primary user is active, $G*P*M$ bits may remain unscheduled and may need $Z=\text{ceil}[(G*P)/S]$ additional OFDM symbols in the PSDU.

[0120] If the PSDU length needs to be fixed, the length of the MPDU/Aggregated MPDUs (AMPDU) which forms the PSDU may be reduced by $Y=G*P*M*C$ bits where 'C' is the coding rate used in the PSDU.

[0121] Figure 7 is an example of a signal call flow for adaptive PSDU size adjustment. The initial steps involve communication between an AP and an SSM, where the AP may register with the SSM 702, request for a PU's spectrum usage information 704, and receive information from the SSM regarding primary user's spectrum usage information 706. The AP may store PU spectrum usage information, such as duty cycle, time stamps, duration of a pulse and similar information 710. The AP may broadcast the PU spectrum usage information to all STAs that it serves 712. The AP may periodically check with the SSM to ensure that there are no changes in PU spectrum usage pattern 714. The SSM may indicate any change in PU spectrum usage pattern 716, either as a response to the periodic check or autonomously when it gets notified of such a change. The STA may store PU spectrum usage information 718. The AP and STA may communicate in the normal mode during the time when the primary user, for example, radar pulse, is not operating on the spectrum 720. When the radar pulse is about to occur, the AP 722 and STA 724 may readjust their transmission/reception to suppress sub-carriers around the PU's spectrum and correspondingly reduce the PSDU/MPDU size, as described below, and use the shared spectrum preamble. When the radar pulse is OFF, the AP and STA may switch back to normal mode. The PPDU with suppressed sub-carriers may be referred to as Shared Spectrum Data PPDU (SS-DATA-PPDU) and may be transmitted when the radar pulse is ON 730.

[0122] Figure 8 is a diagram of an example call flow showing modification to a PHY service specification. Figure 8 shows the PHY service specification may change to reflect adaptive PSDU/MPDU size adaptation when certain sub-carriers are dynamically suppressed. The PHY service may be provided to the MAC entity 873 at the AP 870, to the MAC entity 887 at the STA 880, or both, through a service access point (SAP), called the PHY-SAP, using a set of primitives. The PHY service to the MAC entity 873 at the AP 870 may be provided through the PHY-SAP 875. The PHY service to the MAC entity 887 at the STA 880 may be provided through the PHY-SAP 885. The

specific PHY-SAP sublayer-to-sublayer service primitives, which are impacted by the adaptive PSDU/MPDU size adjustment, may be PHY_TXSTART 805, PHY-TXEND on the transmit side and PHY-RXSTART 820 and PHY-RXEND 830 on the receive side. The TXVECTOR parameter 815 on the transmit side may carry information about the length of the PSDU that indicates the number of octets to be transferred between PHY and MAC. Similarly, the RXVECTOR 825 parameter on the receive side may carry information about the length of the PSDU that indicates the number of octets to be transferred between PHY and MAC. Additionally, a new parameter called SUBCARRIER_LIST 840 may be added to the TXVECTOR 815 and RXVECTOR 825 parameters to indicate the list of sub-carriers which are active or which are suppressed.

[0123] In the case of bands where the primary user has transmission pattern like a radar, the Wi-Fi system may schedule normal transmission when the primary user is absent but when the primary user's transmission is about to occur (based on apriori knowledge from the SSM/geo-location database). The Wi-Fi system may schedule one or more SS-Null-PPDU containing an SS-Preamble.

[0124] Figure 9 is diagram of an example frame format of an SS-Null-PPDU with an SS-Preamble. It may include an SS-Preamble 910 with subcarriers occupied by the primary user being suppressed, a length field 920 that may indicate the length of the Null PSDU 930 in octets, followed by a Null PSDU 930 with no data in it and may not contain any MAC frame.

[0125] Figure 10 is a diagram of an example of SS-Null-PPDU use during radar pulse occurrence. Figure 10 shows the use of SS-Null-PPDUs 1010, 1030, 1050 and 1070 during micro/pulse cycles for opportunistic Tier II/III operations at a given geo-location.

[0126] The previous PPDU before the radar pulse, such as one of the radar pulses 1020, 1040, 1060 and 1080 shown, arrives may carry an SS-Null-PPDU/SS-DATA-PPDU announcement either in the PPDU header (example 'Reserved bit' in Signal field) or in the PSDU by piggybacking with the

payload. Control Information, such as those in the MAC header, may be obtained from the previous PPDU. The SS-Null-PDDU/SS-DATA-PPDU Announcement may also carry information about whether the SS-Null-PPDU/SS-DATA-PPDU may occur immediately after the PPDU carrying the announcement or be delayed to occur after T seconds or be delayed to occur after N PPDU's.

[0127] Figure 11 is an example of a SS-Null-PPDU/SS-DATA-PPDU Announcement information element. The SS-Null-PDDU/ SS-Data-PPDU Announcement 1110 may be 1 octet in length and carries 4 elements including announce 1111, length 1113, offset type 1115, and offset 1117.

[0128] The announce element 1111, which may be 2 bits, may indicate whether SS-Null-PPDU 1120 is present, SS-Data-PPDU is present or both are absent. The length element 1113, which may be 3 bits may indicate the length of the Null/Data PSDU in octets. The offset type element 1115, which may be 1 bit, may indicate offset in the number of PPDU's or the number of microseconds, if the announcement is delayed and not immediate. The offset element 1117, which may be 2 bits, may indicate the number of PPDU's or microseconds that the SS-Null-PPDU/SS-Data-PPDU is offset by.

[0129] Figure 12 is a diagram of an example call flow to schedule SS-Null-PPDU/SS-DATA-PPDU transmission when a radar pulse is ON. The initial steps may be the same as those in Figure 7 and involve communication between the AP 1270 and the SSM 1260, where the AP 1270 may register with the SSM 1260, request for a primary user's spectrum usage information (this is not shown in Figure 12), and receive information from the SSM 1260 regarding primary user's spectrum usage information 1206. The AP 1270 may broadcast PU spectrum usage information 1212 to all STAs that it serves, such as STA 1280. The AP 1270 may periodically check with the SSM 1260 to ensure that there are no changes in PU spectrum usage pattern 1214. The SSM 1260 may indicate any change in PU spectrum usage pattern 1216 either as a response to the periodic check or autonomously when it gets notified of such a change. The AP 1270 and STA 1280 may communicate in the normal

mode during the time when the primary user, for example, radar pulse, may not be operating on the spectrum 1220. The AP 1270 sends SS-NULL-PPDU/SS-DATA-PPDU announcement 1225 in all 'K' PPDU's before a radar pulse is going to occur and STA 1280 may prepare to receive SS-NULL-PPDU or SS-DATA-PPDU after "K" PPDU's 1227, as described above, and use the shared spectrum preamble. After the readjustment and preparation, the AP 1270 and STA 1280 may transmit/receive the SS-Null-PPDU/SS-DATA-PPDU when the radar pulse is ON 1230. When the radar pulse is OFF, the AP 1270 and STA 1280 may switch back to normal mode.

[0130] Coexistence Mechanisms Between Tier I and Tier II/III Access Systems may be described herein. A modified Wi-Fi system to opportunistically use the available spectrum and time slots which are not used by the incumbent users, for example, radar, may be used. Modified functions for the AP and STAs to cognitively avoid/suppress the high interference (for example, radar transmission and priority access users) experienced in shared spectrum, such as 3.5GHz band may be used. The primary focus may be: a transmission strategy with high powered cycled transmission; spectrum utilization in wide band spectrum access; and modified AP/STA functions in shared spectrum.

[0131] An independent entity, called a SSM may be assumed to coordinate the shared spectrum usage. This SSM may have a direct contact to the database containing the usage information of the shared band.

[0132] In the band co-shared by radar and GAA users, when there is no radar energy towards GAA users (for example, the resting time between equally space pulses and the quiet phase between two series of pulses), GAA users may explore such opportunities for transmission. Transmission strategies of GAA users in a shared band may be used, such as how WiFi enabled GAA users cooperate with the SSM to use the quiet phase and the resting time for packet delivery.

[0133] Given the characteristics of pulsed radar transmission, policy based transmissions for GAA users operating in radar band, for example,

3.5GHz, may be used. This strategy may enable the AP, which is registered to the database before its operation, to contact the SSM periodically or triggered by the special event (for example, traffic load change, QoS change) for necessary information, such as radar types, radar operation characteristics and operational channels, the availability of the spectrum. If for any reason the tier I user needs to use the spectrum occupied by the tier III users, the tier III users may immediately stop any operation on the spectrum and free up the spectrum.

[0134] The issue regarding how the GAA users may avoid pulsed radar transmission and adaptively change the operation strategy in the time or frequency domain may be addressed herein. In particular, a radar-dependent-configuration may be employed to have the AP perform different operation modes in different time periods.

[0135] Figure 13 is a diagram of an example of macro/rotation cycles and micro/pulse cycles for opportunistic GAA users operating at a given geo-location. There may be two type of time periods in which no pulse is transmitted. The AP and STAs may use this time periods for opportunistic transmission. One may be the period between two pulse-phases, such as 1310 and 1330, which may be called the quiet phase 1320. In this period, the GAA users at the specific geo-location may be not impacted by the radar transmission as the radar main beam is pointed toward other locations. Depending on the radar types, the quiet phase 1320 may be different, for example, varying from 3.95 s to 9.87 s in the 3.5 GHz radar band. The other period may be the one between two pulses, such as 1311 and 1313, which may be called the pulse resting time 1312. This period may be much shorter than the quiet phase 1320. Similar to the quiet phase 1320, the length of the resting time 1312 may vary from radar to radar, for example, 0.16 ms to 6.52 ms in the 3.5 GHz radar band. In this relatively short period, a fewer number of frames or shorter frames may be transmitted. Therefore, given the special transmission characteristics of the radar, the AP may enable different

transmission strategies in the different opportunity phases. For example, the AP may enable different strategies in quiet phase 1320 and resting time 1312.

[0136] Figure 14 is a diagram of an example procedure of radar dependent configuration. Before the AP 1470 starts to operate in the shared spectrum, the AP 1470 may register to the SSM 1460, providing the required information, for example, geo-location, RAT, potential usage time length, traffic load, and (highest or average) QoS requirements of its communications, geo-location, and the like 1402. Once the registration procedures are completed, the SSM 1460 may provide the necessary information to the AP 1470, for example, types of radar impacting the AP 1470, radar transmission characteristics, available spectrum at the AP 1470 location, and the like 1409. Then the AP 1470 may use the obtained information and collect the sensing information 1407 from STAs 1480, to determine which operation mode may be used by its network 1423 and broadcast the message to STAs 1429. For example, as shown in Figure 13, during the quiet phase period which has little or no interference to GAA users, regular operation mode (similar to the ISM band operation) may be applied. During the resting time period, which is shorter than the quiet phase, restricted operation mode may be enabled. Also, the AP 1470 may also periodically check the SSM 1460 for the available spectrum or an event triggered contact, for example, a change or traffic load, change of QoS requirements or other event 1434. The AP 1470 may receive from the SSM 1460 an emergent notification of spectrum availability or change or radar type 1436. The AP 1470 may then decide to take immediate action on the affected spectrum 1440 and notify the STAs 1480 of the corresponding change, for example, the change in operational channel, operation mode and other changes 1450.

[0137] The rules for restricted operation mode may include: no transmission opportunity (TXOP) contention for high priority access category, such as voice (VO) or video (VI); only high priority data/management frames allowed; transmission of data/management frames using Distributed Coordination Function (DCF); and transmission of data/management frames

with the length shorter than a threshold (for example, the threshold may be determined by the channel condition, available time length, and the like). The performing rules and the periodicity of restricted mode (for example, how long the restricted mode lasts and when the restricted mode completes) may be changed per radar type. All this information may be AP configured, whereby the rules, periodicity or both of the restricted mode may be pre-defined per SSM information (such as, for example, radar pulse width, resting time, pulse phase length, and the like) and embedded in the beacon frame, or adaptively changed per the AP notification, for example, through beacon or management frames. Alternatively, the information may be STA configured, whereby STAs may base on the radar type information to determine the performing rules in the restricted mode and periodicity of restricted mode.

[0138] The indication of operation mode may only use small number of bits, for example, 1 bit. There may be different options to carry the mode change indication and the new operation mode starting time, such as, for example: regular/ restricted mode embedding the regular beacon; timer enabled operation of regular/restricted model; and delivery through a high priority management frame. These options are explained in more detail, as follows.

[0139] For regular/restricted mode embedded in the regular beacon, a new element may be included in the frame body of the beacon to show the next operation mode, either regular operation or restricted operation, and the transmission periodicity. STAs may start the new operation mode upon the receipt of the operation mode indication. One of the advantages of this scheme may be its simplicity. The system may start the new operation mode triggered by the receipt of the indication. However, this simplicity may lead to some inefficiency. For example, at some time before the pulse phase starts, the beacon may be transmitted to enable the restricted mode. Then all STAs and the AP may have to switch to the restricted mode although there may still be some time remained before the pulse phase, which may be used for regular operation.

[0140] For time enabled operation of regular/restricted mode, the AP and STAs may need to be synchronized and installed with timers. The AP may transmit the beacon or other management frames which shows the timing to start the new operation mode and the transmission pattern of the new mode. Once the STAs receive this message, they may set the timer and start to count backward. When the timer reaches zero, the new operation may take effect. When the restricted mode starts, two timers may be set. One timer may control the total operation length of the restricted mode, for example, the time length equal or larger than phase length. The other time may control the periodic operation length during the pulse resting time, for example, the time length equal to or less than the resting time.

[0141] Figure 15 is a diagram of an example call flow of the timer enabled operation for the radar dependent configuration. During regular operation mode 1510, the STAs may receive a notification that restricted mode may start 1520. The AP and STAs may then set a Timer1 1530, which will expire at the end of normal mode operation and the start of restricted mode operation. When Timer1 reaches 0 1540, the AP and STAs may then set a Timer2 to the pulse resting time and Timer1 to the total operation length of the restricted mode 1545. Restricted mode operation may then begin 1550 and the AP and STAs may communicate during the pulse resting time. When Timer2 reaches 0 1560 but Timer1 continues 1570, the AP and STAs may stop communicating during the time of the radar pulse 1575 and may reset Timer2 to the pulse resting time. After the pulse, the AP and STAs may again communicate during any remaining pulse resting time 1550. When Timer2 reaches 0 1560 and Timer1 reaches 0 1570, the STAs may check if they have received notification of the resumption of the regular mode of operation 1580. If not, the AP and STAs may continue to operate in restricted mode 1585. If the notification is received, the AP and STAs may resume regular operation mode 1590.

[0142] For delivery through a high priority management frame, a modified management frame may be employed. This management frame may

have higher priority than other types of management frames. It may contain multiple elements, for example, the new operation mode, the starting time of the new operation mode, the duration of new operation mode, transmission pattern, and the like. Once the high priority management frame is received, the STAs may need to switch to the new operation mode as indicated in the management frame, for example, immediately or some time later. To make sure all STAs switch to the new operation mode with the least delay, the AP may use a shorter waiting time, for example, for example less than or equal to the point (coordination function) interframe space (PIFS), to gain the access to the medium and transmit this frame. No back-off may be required for the transmission of this high priority management frame. This transmission solution of the indication message may be particularly good in the scenarios where the radar transmission pattern is not fixed or pseudo-random or the AP may not get the latest information of the radar type. For example, in the case where the radar type is not disclosed due to some security reason and the type of radar does not follow a certain transmission pattern, the AP may enable its sensing scheme, collect all the sensing information from the STAs and determine when the pulse comes and when the pulse resting time starts. Once the AP concludes that the next time period, for example, the next few microseconds, may be the pulse resting time, the AP may need to transmit the high priority management frame and notify all STAs to start the operation mode immediately.

[0143] All of the options mentioned above may be either used together or independently. For example, when the radar transmission pattern is known and deterministic, the option of the change mode indication embedded in the beacon and/or the option of timer enabled operation may be used. Further, when the radar transmission is random, the option of delivery through a high priority management frame and the option of the change mode indication embedded in the beacon may be used together.

[0144] To avoid getting interference from the radar, the AP may also need to obtain the available spectrum information from the SSM periodically

or by event-trigger. For example, any change of its traffic load or highest/average QoS requirement may trigger the AP to contact the SSM and look for any new available spectrum if its system so requires. Depending on the needs of the radar operation, the SSM may also contact the AP to free up, the whole or part of, the spectrum the AP is occupying or notify the STAs of any change of radar operation. Once the AP obtains such a request from the SSM, the AP may take the necessary action, for example, broadcast the notice to all STAs to stop the operation on the requested spectrum or broadcast the change of operation mode.

[0145] Figure 16 is a diagram of an example operation of the high priority management frame. The main purpose of the high priority management frame may be to notify all the associated STAs to take an immediate action in the shared spectrum band, for example, change to the new operation mode or stop operation due to the detected radar transmission. Several main characteristics of the high priority management frame may be summarized as follows.

[0146] The high priority management frame body may include an action, for example, change to a new operation mode 1650 or stop transmission 1630; one or more affected operational channels; a new operation mode pattern, for example, length of transmission and length of silence for restricted mode; the next time of beacon frame, a service set identifier (SSID), and the like.

[0147] The high priority management frame may wait for the shorter time to gain the channel access with no back-off, for example, a time less than or equal to the PIFS. For example, shorter waiting times 1620 or 1640 may apply. This property may guarantee that the AP accesses the channel with the highest priority. This property may also assist the AP with gaining the channel access over the stations occupying the channel via TXOP.

[0148] The high priority management frame may be event triggered. This type of frame may be independently used. If the transmission time is conflicted with the regular beacon, such as beacon 1610, then the regular beacon may get the higher priority to be delivered.

[0149] The high priority management frame may be broadcasted by the AP and no acknowledgment (ACK) may be required. The high priority management frame may be transmitted a couple of times or on multiple channels to increase the robustness of the transmission. Upon the receipt of this high priority management frames, all STAs may immediately take the actions indicated by this frame.

[0150] The way STAs in power save mode are notified of any emergent operation change, for example, radar type change, operation mode change, operation frequency change, and the like, may be disclosed herein. Using a beacon to broadcast the operation change (for example, new operation mode, operation mode rules, starting time, and the like) may be applied to the STAs in power save mode. However, it may lead to certain delay in some urgent conditions, for example, missing the utilization of the radar resting time. Therefore, a way to modify the existing Power Save Multi-Poll (PSMP) may be employed to notify the STAs in power save mode. In an enhanced Power Save Multi-Poll (ePSMP) frame, the AP may indicate the operation mode as well as the scheduled PSMP downlink transmission time (PSMP-DTT) and PSMP uplink transmission time (PSMP-UTT).

[0151] Figure 17 is a diagram of an example of a modified PSMP sequence with scheduled PSMP-DTT and PSMP-UTT. As an example, if the available transmission time is very short, such as during the radar pulse resting time, 1770, then the AP may specify the operation mode (including the radar pulse width and periodicity, operation rules for the restricted mode, and the like) and the scheduled PSMP-DTT/PSMP-UTT in the ePSMP 1710. To save the overhead, the AP 1760 may schedule the PSMP-DTT and PSMP-UTT in different opportunity times. Therefore, to be co-existing with radar transmissions, the consecutive PSMP-UTTs or PSMP-DTTs, such as for example PSMP-DTT1 1720, PSMP-DTT2 1730, PSMP-UTT1 1740, PSMP-UTT1 1750, may occur in neighboring resting times, such as resting time 1780 and resting time 1790, but not separated by a short interface space (SIFS) or reduced interface space (RIFS).

[0152] In further examples, high interference may affect wide band access, as discussed in the following. The way the GAA users may utilize the wide band spectrum when the high priority users are present on certain parts of the shared spectrum may be disclosed herein. As the shared spectrum may have a larger bandwidth, for example, 100 MHz at 3.5 GHz and may be up to 1000 MHz at 3.5 GHz in the future, and in further examples the GAA users, such as WiFi enabled devices, may opportunistically use the available frequency portion which is unused by the tier I/tier II users without generating the interference to the higher tier users. Several options may be used for the opportunistic wide band access affected by high interference, such as, for example: spectrum nulling with fixed channelization; adaptive spectrum shifting; and adaptive spectrum nulling.

[0153] Figure 18 is a diagram of an example operation of spectrum nulling with fixed channelization. For spectrum nulling with fixed channelization, channelization of the shared spectrum may be pre-performed, for example, 5 channels are present in the 100 MHz shared spectrum 1810 with each channel containing 20 MHz. For example, channel 1811, channel 1813, channel 1815, channel 1817 and channel 1819 may each contain 20 MHz. As a result, separated waveforms may be generated on different segments. The AP/STA may access all available spectrums through certain type of channel aggregation, for example, MAC layer aggregation or PHY layer bonding. There may be no waveform generated on the spectrum occupied by high priority users, for example, radar 1830. For example, channel 1815 and channel 1817 may contain no waveform. The advantages of this solution may be backward compatibility and easy implementation. It may reuse the existing 802.11ac technology to occupy the multiple non-contiguous channels, such as channel 1811, channel 1813 and channel 1819. However, it may require at least 5 RF ends and may result in low spectrum usage efficiency. For example, the worst case may be that the spectrum used by the radar 1830 is in-between two channels, such as channel 1815 and channel

1817. Then both channels may not be usable, which may cost the spectrum waste.

[0154] Adaptive spectrum shifting may be used to improve the spectrum usage efficiency. Figure 19 is diagram of an example operation of adaptive spectrum shifting. In this solution, no waveform may be generated on the spectrum occupied by high priority users, for example, radar 1930. A single waveform may be generated on the contiguous available portion. Depending on the number of unavailable spectrum pieces, the AP/STAs may generate different number of waveforms. For example, when there is only one radar transmission present on one piece of spectrum, then two separate waveforms, such as waveform 1912 and waveform 1914, may be generated. One benefit of this solution may be highly efficient spectrum usage. One issue with this solution may be the complexity of scheme, which may require adaptive RF design to generate separate waveforms with different bandwidths. The cost of such an RF platform may be relatively high.

[0155] Figure 20 is a diagram of an example operation of adaptive spectrum nulling. Adaptive spectrum nulling may enable the generation of a single waveform 2030, which may occupy the whole shared spectrum 2010, for example, 100 MHz. To avoid using the spectrum used by the high priority users, for example, radar 2030 or tier II users, the transmitter may null the data transmission on the subcarriers corresponding to such spectrum. This solution may result in an efficient spectrum usage and only one RF end required. However, it may also require advanced receiver technology to remove the high interfered part, which may lead to a high cost of RF end.

[0156] As a further example, the modified functions of the AP that may assist the AP to operate in the shared spectrum with high interference from incumbent users, for example, radar. Figure 21 is a diagram of example protocol stack of the modified AP and STA operating in the shared spectrum. The main modified functionalities may include: a policy driven adaptive RF end 2110 with a tunable notch filter 2115; a modified sensing capability with radar pulse detection in the sensing board 2160; a radar database 2140

connected to the sensing toolbox 2150 and MAC 2122 layer of the AP; and agile CSMA/CA with adaptive CCA. Another example modified functionality in the AP may be policy driven signaling 2132 between the MAC layer 2122 and the adaptive RF end 2112. Another example modified functionality in the STA may be policy driven signaling 2134 between the MAC layer 2124 and the adaptive RF end 2114.

[0157] GAA users may get interference from co-channel radar operation even when GAA users are out of exclusion zones. The interference level may be out of the linear operation range of receiver LNA. In such a case, it may need some technology to suppress the interference and bring the received energy level to within the linear operation range. As a further example, a policy enabled tunable notch filter equipped in the analog RF end of the modified AP/STA may be used.

[0158] Figure 22 is a diagram of an example operation procedure of a policy driven RF end and policy based tunable notch filter. There may be a direct link between the AP 2270 and the SSM 2260. After the AP 2270 registration process 2202 with the SSM 2260, the AP may request spectrum usage information, radar types and other information 2204 from the SSM 2260. Further, the AP 2270 may obtain notification from the SSM 2260 of non-accessible frequency portion or the portion with high interference 2206. Then the AP may broadcast the information to the associated STAs indicating the spectrum piece with high interference. Upon receipt of the spectrum available information, the AP MAC layer 2272 may signal it to the AP RF layer 2274, which may be equipped with a single or multiple notch filters. The AP RF layer 2274 may then tune its notch to the spectrum piece with high interference. One notch filter may only remove certain amount of interference, for example, 12 dB. More notch filters may be good for removing interference presented on multiple pieces of spectrum, but this approach may be costly and generate high noise. Therefore, an optimization between cost and number of notch filters may be required. For simplicity, it may be assumed that only one tunable notch filter is employed. If the number of

spectrum pieces with high interference is more than one, then the MAC layer may decide which spectrum the interference may be suppressed on.

[0159] Accordingly, the AP MAC layer 2272 may determine the spectrum piece or pieces the notch filter should be tuned to 2210. After the decision is made, the AP MAC layer 2272 may indicate to the AP RF layer 2274 the spectrum piece the notch filter may be tuned to 2211. The AP 2270 may then broadcast the spectrum piece for the notch 2212 to the STA 2280. The STA MAC layer 2282 may indicate the targeted notch frequency 2218 to the STA RF layer 2284. The STA RF layer 2284 may confirm 2219 with the STA MAC layer 2282 and the AP RF layer 2274 may confirm 2213 with the AP MAC layer 2272.

[0160] During the operation of GAA users, the SSM 2260 may contact the AP 2270 with any change of the frequency pieces with high interference 2240. The AP 2270 may then make a corresponding decision on the new notch frequency and notify the STAs 2242, such as STA 2280, of such a change. Also, the AP MAC layer 2272 may indicate to the AP RF layer 2274 the spectrum piece the notch filter may be tuned to 2241. The STA MAC layer 2282 may indicate the targeted notch frequency 2248 to the STA RF layer 2284. The STA RF layer 2284 may confirm 2249 with the STA MAC layer 2282 and the AP RF layer 2274 may confirm 2243 with the AP MAC layer 2272. Depending on the capability of the notch filter, the interference may be suppressed to different levels. If the interference levels are still high, it may require other baseband techniques to further remove the interference level if there is a need.

[0161] As previously discussed, the AP may directly obtain the radar information from the SSM. However, there may be a scenario where the radar type is not disclosed due to some security reason or for certain reason the AP loses the connection to the SSM such that the latest radar information is unable to obtain. Therefore, how the AP/STAs detect the radar pulse using sensing assisted techniques may be disclosed herein.

[0162] Figure 23 is a diagram of an example call flow of the AP detecting and broadcasting radar information. At the beginning of the operation in shared spectrum, the AP may need to obtain the operation information of incumbent users, for example, radar, from the SSM 2310. If the detailed operation information 2325 is available, then the AP may directly relay all the information to STA 2380. If only partial information (such as radar operational frequency or radar operation time) is available, then the AP may need to enable its sensing algorithm to detect the radar operation pattern at the suspicious frequency pieces 2325, record the time when the detected energy is hitting the saturate region of LNA and set such a time as pulse transmission time 2340, as well as to request the STAs with sensing capability to start the sensing algorithm for radar operation pattern detection at suspicious frequencies 2350. If no radar information is available at the SSM, then the blind detection may be enabled in the WiFi systems 2330. That is the AP may scan all the channels in the shared spectrum 2333, for example, 100 MHz, to detect the channels (or frequency pieces) with high interference levels 2336.

[0163] In the blind detection approach, to distinguish the radar transmission and other types of transmission, the AP may first determine if the interference pattern is the same kind of the WiFi transmission, if it is not, then the AP may determine if the interference level is larger than a certain threshold. If the interference level is larger than the pre-defined threshold and the interference pattern may be similar to the radar transmission pattern, then the AP may determine the potential frequency locations where such transmission occurred. After that, the AP may start to record the pulse transmission time on these frequency locations 2340. One of the solutions to determine the pulse transmission for the AP/STA may be monitoring the LNA saturating time. When the LNA of the AP (or STA) hits the saturation region, the AP (or STA) may record such a time as a suspicious pulse transmission time. To avoid the confusion between the radar transmission and the nearby high level interference transmission, the AP may need to wait for a certain

time to collect the LNA saturating time as well as collect corresponding information from STAs to make a final decision.

[0164] As illustrated in Figure 21, the AP operating in the shared spectrum may be equipped with a radar database 2140, which may store the transmission patterns of different types of radars potentially occurring in the shared spectrum and may help the AP correctly identify the radar transmission pattern. As illustrated in Figure 23, using the mapping results between the transmission pattern presented by the sensing results 2350 and the pattern stored in the database 2360, the AP may be able to determine if the suspicious pulse transmission pattern is a real radar transmission and what the complete transmission pattern is 2370, for example, pulse width, pulse resting time, pulse phase length, quiet phase length, and the like. The AP may then broadcast radar information, such as, for example, transmission time, frequency, pattern and the like, to the STAs 2380. The main functions of radar database in the AP may include, but are not limited to: storing and collecting the information of potential radars operating in the shared spectrum, for example, radar type, radar transmission characteristics (pulse periodicity, pulse width, pulse phase, radar rotation rate, and the like), radar distance, radar operational frequencies, and the like; collecting sensing information from the sensing toolbox; and providing the information to the MAC, for example, radar information, mapping results.

[0165] As a further example, an agile CSMA/CA with policy enabled adaptive CCA threshold for GAA WiFi users may be used. The determination of CCA threshold may be determined by the incumbent users (for example, radar) operation time and relative operational frequency between radar and GAA users in the shared spectrum. The AP may contact the SSM to get the related information and combine the sensing results to make a determination on the appropriate CCA threshold.

[0166] There is a scenario where the AP may detect the high energy level on the available spectrums which are indicated by the SSM. This high energy level may be due to the significant out-of-band emissions and

electromagnetic interference (EMI) from the incumbent users, for example, radar. Because of the presence of the high energy levels, the AP/STAs may not correctly evaluate the channel and may be unable to gain channel access, which may cause an inefficient usage of the shared spectrum. Therefore, as an example, the AP may be able to adjust the CCA threshold and enable interference mitigation mechanisms accordingly, per the SSM information and the sensing results.

[0167] The operation areas (in both time and frequency domains) of GAA users, for example, WiFi enabled devices, may be classified into three categories: “free” transmission area, GAA impacted areas, and radar protection areas. “Free” transmission areas may be where no tier I or tier II transmissions are on the band and no high interference is received from high priority users. The AP and STAs may use available frequencies to transmit with regular CCA. For example, CCA may indicate busy with a sensitivity of at least $\Gamma_1 = -82$ dBm to a valid 20 MHz PPDU transmission (this may be referred to as signal detect CCA). CCA may indicate busy with a sensitivity of at least $\Gamma_2 = -62$ dBm to any signal in the 20 MHz channel (this may be referred to as energy detect CCA).

[0168] GAA impacted areas may be where radar (and or tier II) transmissions are presented on some frequency portions for some time. The AP and STAs may use only the available spectrum indicated by the SMS. To avoid the interference/leakage caused by the incumbent user transmission, for example, radar transmission, the interference avoidance/mitigation mechanisms may be enabled. Also, the energy detect threshold and signal detect CCA threshold, Γ_1 and Γ_2 , may need to be increased to improve the probability of AP/STAs gaining channel access. For example, $\Gamma_1 = -82$ dBm, $\Gamma_2 = -60$ dBm. With the improved threshold, the “clear” channel condition may be too poor to make a successful transmission. In an example, the transmitter may need to have sufficient path loss information to estimate the received signal to interference plus noise ratio (SINR) on the receiver side. If the

received SINR is higher than a threshold, then the transmission may start as usual. Otherwise, the transmission may be stopped.

[0169] Radar protection areas may be where radar pulse is transmitting and no other “official” allowable bands transmit per SSM information. In this area, the AP/STA may not be allowed to transmit signals. Alternatively, the AP/STA may start to sense the channel and perform opportunistic transmission under certain conditions. For example, to avoid generating interference to tier I users, the AP/STA may transmit only when the distance to the tier-1 user is larger than a required threshold. The AP may need to guide all STAs to increase the CCA thresholds, Γ_1 and Γ_2 . Meanwhile, the interference avoidance/mitigation mechanisms may be enabled by the WiFi systems to suppress the interference from the tier I/tier II users.

[0170] Figure 24 is an example operation period of GAA users in a shared spectrum. For different geo-locations of AP/STAs, the distribution of free transmission areas, such as free transmission area 2410, GAA impacted areas, such as GAA impacted area 2420, and radar protection areas, such as radar protection area 2430, may be different. For example, the AP/STAs, which are located far from the radar, may operate on all shared spectrum and time slots without impacting radar. In other words, they may have all free transmission areas in both time and frequency dimensions. The radar protection areas may be located around radar pulses, such as radar pulse 2440.

[0171] 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.

[0172] Embodiments.

[0173] 1. A method for use in a wireless communication system, the method comprising:

[0174] accessing a shared spectrum (SS) by Wi-Fi systems with dynamic spectrum availability.

[0175] 2. The method as in embodiment 1, further comprising:

[0176] enabling fractional use of the shared spectrum by a Wi-Fi tier II/III user.

[0177] 3. The method as in any one of the preceding embodiments, wherein the Wi-Fi tier II/III user operates on a shared band by leaving a primary user spectrum fragments unused.

[0178] 4. The method as in any one of the preceding embodiments, wherein a secondary user Wi-Fi system continues using the whole band with the primary user is absent.

[0179] 5. The method as in any one of the preceding embodiments, wherein the secondary user Wi-Fi system uses only a portion of the band, excluding the primary user's channel when the primary user is present.

[0180] 6. The method as in any one of the preceding embodiments, wherein a PLCP preamble in a legacy PPDU frame is used.

[0181] 7. The method as in any one of the preceding embodiments, wherein the PLCP preamble is followed by a signal field and data.

[0182] 8. The method as in any one of the preceding embodiments, wherein a short OFDM training symbol is used.

[0183] 9. The method as in any one of the preceding embodiments, wherein a long OFDM training symbol is used.

- [0184] 10. The method as in any one of the preceding embodiments, wherein a new SS-preamble has a multiplication factor of $\sqrt{L/(2K)}$.
- [0185] 11. The method as in any one of the preceding embodiments, wherein L is the total number of subcarriers in the preamble.
- [0186] 12. The method as in any one of the preceding embodiments, wherein K is the number of subcarriers which are non-zero.
- [0187] 13. The method as in any one of the preceding embodiments, wherein a new SS LTF is defined by suppressing sub carrier elements in the sequence which overlap with the primary user's spectrum occupancy.
- [0188] 14. The method as in any one of the preceding embodiments, wherein a dynamic adaptation of PSDU size based on a link quality and an instantaneous channel availability based on the primary user's spectrum occupancy is used.
- [0189] 15. The method as in any one of the preceding embodiments, wherein an access point (AP) registers with a shared spectrum manager (SSM).
- [0190] 16. The method as in any one of the preceding embodiments, wherein the AP requests spectrum usage information from the SSM.
- [0191] 17. The method as in any one of the preceding embodiments, wherein the SSM notifies the AP of the primary user (PU) spectrum usage information.
- [0192] 18. The method as in any one of the preceding embodiments, wherein the AP broadcasts the PU spectrum usage information.
- [0193] 19. The method as in any one of the preceding embodiments, wherein the AP periodically checks with the SM to ensure that there are no changes in the PU spectrum usage pattern.
- [0194] 20. The method as in any one of the preceding embodiments, wherein the SSM indicates any change in the PU spectrum usage pattern as a response to the periodic check.

[0195] 21. The method as in any one of the preceding embodiments, wherein the SSM indicates any change in the PU spectrum usage pattern autonomously when it gets notified of such a change.

[0196] 22. The method as in any one of the preceding embodiments, wherein the AP and a station (STA) communicate in a normal mode during a time when the PU is not operating in the spectrum.

[0197] 23. The method as in any one of the preceding embodiments, wherein the AP and STA readjust the communication to suppress subcarriers around the spectrum of the PU and reduce the PSDU/MPDU size when a radar pulse is about to occur.

[0198] 24. The method as in any one of the preceding embodiments, wherein the AP and STA switch back to the normal mode when the radar pulse is off.

[0199] 25. The method as in any one of the preceding embodiments, wherein a PPDU with suppressed subcarriers is referred to as a SS data PPDU.

[0200] 26. The method as in any one of the preceding embodiments, wherein a physical (PHY) service is provided to a Medium Access Control (MAC) entity at the AP/STA through a SAP.

[0201] 27. The method as in any one of the preceding embodiments, wherein the SAP is called a PHY-SAP using a set of primitives.

[0202] 28. The method as in any one of the preceding embodiments, wherein the PHY-SAP sublayer-to-sublayer service primitives impacted by the adaptive PSDU/MPDU size adjustment are PHY_TXSTART, PHY-TXEND, PHY_RXSTART, and PHY-RXEND.

[0203] 29. The method as in any one of the preceding embodiments, wherein a TXVECTOR parameter on the transmit side carries information about length of the PSDU indicating the number of octets to be transferred between the PHY and the MAC.

[0204] 30. The method as in any one of the preceding embodiments, wherein an RXVECTOR on the receive side carries information about length

of the PSDU indicating the number of octets to be transferred between the PHY and the MAC.

[0205] 31. The method as in any one of the preceding embodiments, wherein a SUBCARRIER_LIST is added to the TXVECTOR and RXVECTOR to indicate the list of sub carriers which are active or suppressed.

[0206] 32. The method as in any one of the preceding embodiments, wherein the Wi-Fi system schedules normal transmission when the primary user is absent.

[0207] 33. The method as in any one of the preceding embodiments, wherein the Wi-Fi system schedules one or more SS-Null-PPDUs containing an SS preamble when the primary user's transmission is about to occur.

[0208] 34. The method as in any one of the preceding embodiments, wherein the PPDU that arrives before the radar pulse carries an SS-Null-PPDU/SS-DATA-PPDU announcement in the PPDU header.

[0209] 35. The method as in any one of the preceding embodiments, wherein control information in the MAC header is obtained from a previous PPDU.

[0210] 36. The method as in any one of the preceding embodiments, wherein the SS-Null-PPDU/SS-DATA-PPDU announcement is a 1 octet length and carries an announcement, a length, an offset type, and an offset.

[0211] 37. The method as in any one of the preceding embodiments, wherein the AP broadcasts PU spectrum usage information to all the STAs it serves.

[0212] 38. The method as in any one of the preceding embodiments, wherein an enhanced Wi-Fi system uses available spectrum and time slot which are not used by the incumbent users.

[0213] 39. The method as in any one of the preceding embodiments, wherein the SSM has direct contact with a database containing the usage information of a shared band.

[0214] 40. The method as in any one of the preceding embodiments, wherein the radar database in the AP includes storing and collecting information of potential radars operating in the shared spectrum.

[0215] 41. The method as in any one of the preceding embodiments, wherein the radar database in the AP includes collecting sensing information from a sensing toolbox.

[0216] 42. The method as in any one of the preceding embodiments, wherein the radar database in the AP includes providing information to the MAC.

[0217] 43. The method as in any one of the preceding embodiments, wherein an agile CSMA/CA with policy enabled adaptive clear channel assessment (CCA) threshold for GAA WiFi users.

[0218] 44. The method as in any one of the preceding embodiments, wherein a determination of the CCA threshold is determined by the incumbent user's operation time and relative operational frequency between radar and FAA users in the SS.

[0219] 45. The method as in any one of the preceding embodiments, wherein the AP contacts the SSM to obtain related information and combine the sensing results to make a determination on the appropriate CCA threshold.

[0220] 46. The method as in any one of the preceding embodiments, wherein the AP adjusts the CCA threshold and enables interference mitigation mechanisms according to the SSM information and the sensing results.

[0221] 47. The method as in any one of the preceding embodiments, wherein the AP/STAs operate on all shared spectrum and time slots without impacting radar.

[0222] 48. The method as in any one of the preceding embodiments, wherein transmission strategies with pulsed radar transmission are used.

[0223] 49. The method as in any one of the preceding embodiments, wherein a policy based transmission for GAA users operating in the radar band is used.

[0224] 50. The method as in any one of the preceding embodiments, wherein the AP contacts the SSM periodically or triggered by a special event for information.

[0225] 51. The method as in any one of the preceding embodiments, wherein the GAA users avoid pulsed radar transmission and adaptively change operation strategy in time or frequency domain.

[0226] 52. The method as in any one of the preceding embodiments, wherein a quiet phase is a period between two pulse phases.

[0227] 53. The method as in any one of the preceding embodiments, wherein a pulse resting time is a period between two pulses.

[0228] 54. The method as in any one of the preceding embodiments, wherein the AP uses information obtained from the SSM and collects sensing information from the STAs to determine which operation mode should be used by its network and broadcast the message to the STAs.

[0229] 55. The method as in any one of the preceding embodiments, wherein rules for performing and periodicity of restricted mode are changed per radar type.

[0230] 56. The method as in any one of the preceding embodiments, wherein the STAs determine performing rules in a restricted mode and periodicity of restricted mode based on the radar type information.

[0231] 57. The method as in any one of the preceding embodiments, wherein a new element is included in a frame body of the beacon indicating the next operation mode and transmission periodicity.

[0232] 58. The method as in any one of the preceding embodiments, wherein the STAs begin the new operation mode upon receipt of the operation mode indication.

[0233] 59. The method as in any one of the preceding embodiments, wherein the AP and STAs are synchronized and installed with timers.

[0234] 60. The method as in any one of the preceding embodiments, wherein the AP transmits the beacon indicating the timing to start the new operation mode and transmission pattern of the new mode.

[0235] 61. The method as in any one of the preceding embodiments, wherein the STAs set the timer and begin to count backward upon receipt of the beacon.

[0236] 62. The method as in any one of the preceding embodiments, wherein the new operation takes effect when the timer reaches zero

[0237] 63. The method as in any one of the preceding embodiments, wherein two timers are set when restricted mode is started.

[0238] 64. The method as in any one of the preceding embodiments, wherein one timer controls a total operation length of the restricted mode and the other timer controls the periodic operation length during the pulse resting time.

[0239] 65. The method as in any one of the preceding embodiments, wherein a new management frame has a higher priority than other types of management frames.

[0240] 66. The method as in any one of the preceding embodiments, wherein the STAs switch to the new operation mode once the high priority management frame is received.

[0241] 67. The method as in any one of the preceding embodiments, wherein the high priority management frame notifies all associated STAs to take an immediate action in the shared spectrum band.

[0242] 68. The method as in any one of the preceding embodiments, wherein in the high priority management frame body action, affected operational channels, new operation mode pattern, next time of beacon frame, and SSID are included.

[0243] 69. The method as in any one of the preceding embodiments, wherein the high priority management frame waits for a shorter time to gain channel access with no back-off.

[0244] 70. The method as in any one of the preceding embodiments, wherein the high priority management frame is event triggered.

[0245] 71 The method as in any one of the preceding embodiments, wherein the high priority management frame is broadcasted by the AP and no ACK is required.

[0246] 72. The method as in any one of the preceding embodiments, wherein the high priority management frame is transmitted for a couple of time or on multiple channels to increase the robustness of the transmission.

[0247] 73. The method as in any one of the preceding embodiments, wherein an enhanced power save multi-poll (ePSMP) is used.

[0248] 74. The method as in any one of the preceding embodiments, wherein the AP indicates operation mode and a scheduled PSMP downlink transmission time and PSMP uplink transmission time in the ePSMP frame.

[0249] 75. The method as in any one of the preceding embodiments, wherein the AP schedules the PSMP downlink transmission time and the PSMP uplink transmission time in different opportunity times.

[0250] 76. The method as in any one of the preceding embodiments, wherein channelization of the SS is pre-performed.

[0251] 77. The method as in any one of the preceding embodiments, wherein the AP/STA accesses all available spectrums through channel aggregation.

[0252] 78. The method as in any one of the preceding embodiments, wherein adaptive spectrum shifting is used.

[0253] 79. The method as in any one of the preceding embodiments, wherein no waveform is generated on the spectrum occupied by high priority users for adaptive spectrum shifting.

[0254] 80. The method as in any one of the preceding embodiments, wherein the AP/STAs generate a different number of waveforms.

[0255] 81. The method as in any one of the preceding embodiments, wherein adaptive spectrum nulling is used.

[0256] 82. The method as in any one of the preceding embodiments, wherein a single waveform that occupies the whole shared spectrum is used in adaptive spectrum nulling.

[0257] 83. The method as in any one of the preceding embodiments, wherein a policy enabled tunable notch filter equipped in the analog RF end of the enhanced AP/STA is used.

[0258] 84. The method as in any one of the preceding embodiments, wherein the AP obtains notification from the SSM of the non-accessible frequency portion.

[0259] 85. The method as in any one of the preceding embodiments, wherein the AP broadcasts the information to the associated STAs indicating the spectrum piece with high interference.

[0260] 86. The method as in any one of the preceding embodiments, wherein the MAC layer signals spectrum availability information to the RF layer upon receipt of the information.

[0261] 87. The method as in any one of the preceding embodiments, wherein the RF layer tunes its notch to the spectrum piece with high interference.

[0262] 88. The method as in any one of the preceding embodiments, wherein one notch filter removes a certain amount of interference.

[0263] 89. The method as in any one of the preceding embodiments, wherein the MAC layer determines which spectrum the interference should be suppressed on.

[0264] 90. The method as in any one of the preceding embodiments, wherein the MAC layer indicates to the RF layer which spectrum piece the notch filter should be turned to.

[0265] 91. The method as in any one of the preceding embodiments, wherein the SSM indicates to the AP any change of the frequency pieces with high interference.

[0266] 92. The method as in any one of the preceding embodiments, wherein the AP makes a corresponding decision on the new notch frequency and notifies the STAs of the change.

[0267] 93. The method as in any one of the preceding embodiments, wherein the AP obtains operation information of incumbent users.

[0268] 94. The method as in any one of the preceding embodiments, wherein the AP relays the information to the STA if the detailed information is available.

[0269] 95. The method as in any one of the preceding embodiments, wherein the AP enables a sensing algorithm to detect radar operation pattern at suspicious frequency pieces if only partial information is available.

[0270] 96. The method as in any one of the preceding embodiments, wherein the AP requests the STAs with sensing capability to begin the sensing algorithm for radar operation pattern detection at suspicious frequencies.

[0271] 97. The method as in any one of the preceding embodiments, wherein blind detection is enabled if no radar information is available at the SSM.

[0272] 98. The method as in any one of the preceding embodiments, wherein the AP determines if the interference pattern is the same kind of the WiFi transmission in blind detection.

[0273] 99. The method as in any one of the preceding embodiments, wherein the AP determine if the interference level is larger than a certain threshold if the interference pattern is not the same kind of the WiFi transmission in blind detection.

[0274] 100. The method as in any one of the preceding embodiments, wherein if the interference level is larger than a pre-defined threshold and similar to the radar transmission pattern, the AP determines the potential frequency locations with such transmission occurred.

[0275] 101. The method as in any one of the preceding embodiments, wherein the AP begins to record the pulse transmission time on these frequency locations.

[0276] 102. The method as in any one of the preceding embodiments, wherein the AP/STA monitors a low-noise amplifier (LNA) saturating time.

[0277] 103. The method as in any one of the preceding embodiments, wherein the AP records a time as a suspicious pulse transmission time when the LNA of the AP hits the saturation region.

[0278] 104. The method as in any one of the preceding embodiments, wherein the AP determines if a suspicious pulse transmission pattern is a real radar transmission.

[0279] 105. A WTRU configured to perform a method as in any preceding embodiments comprising:

a receiver;

a transmitter; and

a processor in communication with the transmitter and the receiver.

[0280] 106. A base station configured to perform a method as in any of embodiments 1-104.

[0281] 107. An integrated circuit configured to perform a method as in any of embodiments 1-104.

[0282] 108. A method for enabling adaptive PHY Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size adjustment in an access point (AP), the method comprising:

registering with a shared spectrum manager (SSM);

requesting a spectrum usage information of a primary user (PU) from the SSM;

receiving the spectrum usage information of the PU from the SSM;

broadcasting the spectrum usage information of the PU to a serving station (STA);

receiving an indication, from the SSM, of a change in the spectrum usage of the PU;

adjusting a transmission with the STA to suppress subcarriers based on the change in the spectrum usage of the PU; and

reducing the PSDU size based on the change in the spectrum usage of the PU.

*

*

*

CLAIMS

What is claimed:

1. A method for use in an IEEE 802.11 station (STA), operating in a multi-tiered communication system having a primary user (PU) and a non-primary user, wherein the STA is a non-primary user, the method comprising:

determining, by the STA, usage by a PU in a first portion of an IEEE 802.11 channel shared by at least the PU and the STA; and

on a condition that the PU is determined to be using the first portion of the IEEE 802.11 channel, operating, by the STA, in a fractional spectrum mode wherein a second, unused portion of the IEEE 802.11 channel is utilized by the STA.

2. The method of claim 1, further comprising:

sensing, by the STA, usage of a first portion of the IEEE 802.11 channel by the PU.

3. The method of claim 2, wherein the determining usage is based upon the sensed usage of a first portion of the IEEE 802.11 channel by the PU.

4. The method of claim 1, further comprising:

receiving, by the STA, information regarding usage of a first portion of the IEEE 802.11 channel by the PU, from a database, via an access point (AP).

5. The method of claim 4, wherein the determining usage is based upon the received information regarding usage of a first portion of the IEEE 802.11 channel by the PU.

6. The method of claim 1, wherein the operating in a fractional spectrum mode includes adaptively sizing a physical (PHY) Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size based on the first portion of the IEEE 802.11 channel used by the PU.

7. The method of claim 1, wherein the operating in a fractional spectrum mode includes transmitting a shared spectrum (SS) preamble, including an SS short orthogonal frequency division multiplexing (OFDM) training field (SS-STF) symbol, wherein the SS-STF symbol is defined by suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

8. The method of claim 7, wherein the SS-STF symbol has a multiplication factor of $\sqrt{L/2K}$ wherein L is a total number of subcarriers in the preamble; and wherein K is a number of subcarriers which are non-zero.

9. The method of claim 1, wherein the operating in a fractional spectrum mode includes transmitting an SS-preamble, including an SS long OFDM training field (SS-LTF) symbol, wherein the SS-LTF symbol is defined

by suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

10. A station (STA), operating in a multi-tiered communication system having a primary user (PU) and a non-primary user, wherein the STA is a non-primary user, comprising:

circuitry configured to determine usage by a PU in a first portion of an IEEE 802.11 channel shared by at least the PU and the STA; and

circuitry configured to operate in a fractional spectrum mode wherein a second, unused portion of the IEEE 802.11 channel is utilized by the STA, on a condition that the PU is determined to be using the first portion of the IEEE 802.11 channel.

11. The STA of claim 10, further comprising circuitry configured to sense usage of a first portion of the IEEE 802.11 channel by the PU.

12. The STA of claim 11, wherein to determine usage is based upon the the sensed usage of a first portion of the IEEE 802.11 channel by the PU.

13. The STA of claim 10, further comprising:
circuitry configured to receive information regarding usage of a first portion of the IEEE 802.11 channel by the PU, from a database, via an access point (AP).

14. The STA of claim 13, wherein to determine usage is based upon the received information regarding usage of a first portion of the IEEE 802.11 channel by the PU.

15. The STA of claim 10, wherein to operate in a fractional spectrum mode includes adaptively sizing a physical (PHY) Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size based on the first portion of the IEEE 802.11 channel used by the PU.

16. The STA of claim 10, wherein to operate in a fractional spectrum mode includes transmitting a shared spectrum (SS) preamble, including an SS short orthogonal frequency division multiplexing (OFDM) training field (SS-STF) symbol, wherein the SS-STF symbol is defined by suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

17. The STA of claim 16, wherein the the SS-STF symbol has a multiplication factor of $\sqrt{L/2K}$ wherein L is a total number of subcarriers in the preamble; and wherein K is a number of subcarriers which are non-zero.

18. The STA of claim 10, wherein to operate in a fractional spectrum mode includes transmitting an SS-preamble, including an SS long OFDM training field (SS-LTF) symbol, wherein the SS-LTF symbol is defined by

suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

19. A method for use in an access point (AP), operating in a multi-tiered communication system having a primary user (PU) and a non-primary user, wherein the AP is a non-primary user, the method comprising:

determining, by the AP, usage by PU in a first portion of an IEEE 802.11 channel shared by at least the PU and the AP; and

on a condition that a PU is determined to be using the first portion of the IEEE 802.11 channel, operating, by the AP, in a fractional spectrum mode wherein a second, unused portion of the IEEE 802.11 channel is utilized by the AP.

20. The method of claim 19, further comprising:

sensing, by the AP, usage of a first portion of the IEEE 802.11 channel by the PU.

21. The method of claim 20, wherein the determining usage is based upon the sensed usage of a first portion of the IEEE 802.11 channel by the PU.

22. The method of claim 19, further comprising:

receiving, by the AP, information regarding usage of a first portion of the IEEE 802.11 channel by the PU, from a database; and

transmitting, by the AP, the information to one or more stations (STA).

23. The method of claim 22, wherein the determining usage is based upon the received information regarding usage of a first portion of the IEEE 802.11 channel by the PU.

24. The method of claim 19, wherein the operating in a fractional spectrum mode includes adaptively sizing a physical (PHY) Layer Convergence Protocol (PLCP) Service Data Unit (PSDU) size based on the first portion of the IEEE 802.11 channel used by the PU.

25. The method of claim 19, wherein the operating in a fractional spectrum mode includes transmitting a shared spectrum (SS) preamble, including an SS short orthogonal frequency division multiplexing (OFDM) training field (SS-STF) symbol, wherein the SS-STF symbol is defined by suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

26. The method of claim 25, wherein the SS-STF symbol has a multiplication factor of $\sqrt{L/2K}$ wherein L is a total number of subcarriers in the preamble; and wherein K is a number of subcarriers which are non-zero.

27. The method of claim 19, wherein the operating in a fractional spectrum mode includes transmitting an SS-preamble, including an SS long OFDM training field (SS-LTF) symbol, wherein the SS-LTF symbol is defined by suppressing sub-carrier elements in a sequence which overlap with the first portion of the IEEE 802.11 channel used by the PU.

28. The method of claim 22, wherein the database is a shared spectrum manager (SSM).

29. The method of claim 28, further comprising:

the AP registering with the SSM and requesting information regarding usage of a first portion of the IEEE 802.11 channel by the PU; and

the AP receives an indication from the SSM of a change in the information regarding usage of a first portion of the IEEE 802.11 channel by the PU.

30. The method of claim 28, further comprising:

the AP registering with the SSM and requesting information regarding usage of a first portion of the IEEE 802.11 channel by the PU;

the AP periodically checking with the SSM to ensure that there are no changes in the information regarding usage of a first portion of the IEEE 802.11 channel by the PU; and

the AP receives, as a response to the periodic check, an indication from the SSM of a change in the information regarding usage of a first portion of the IEEE 802.11 channel by the PU.

+

100

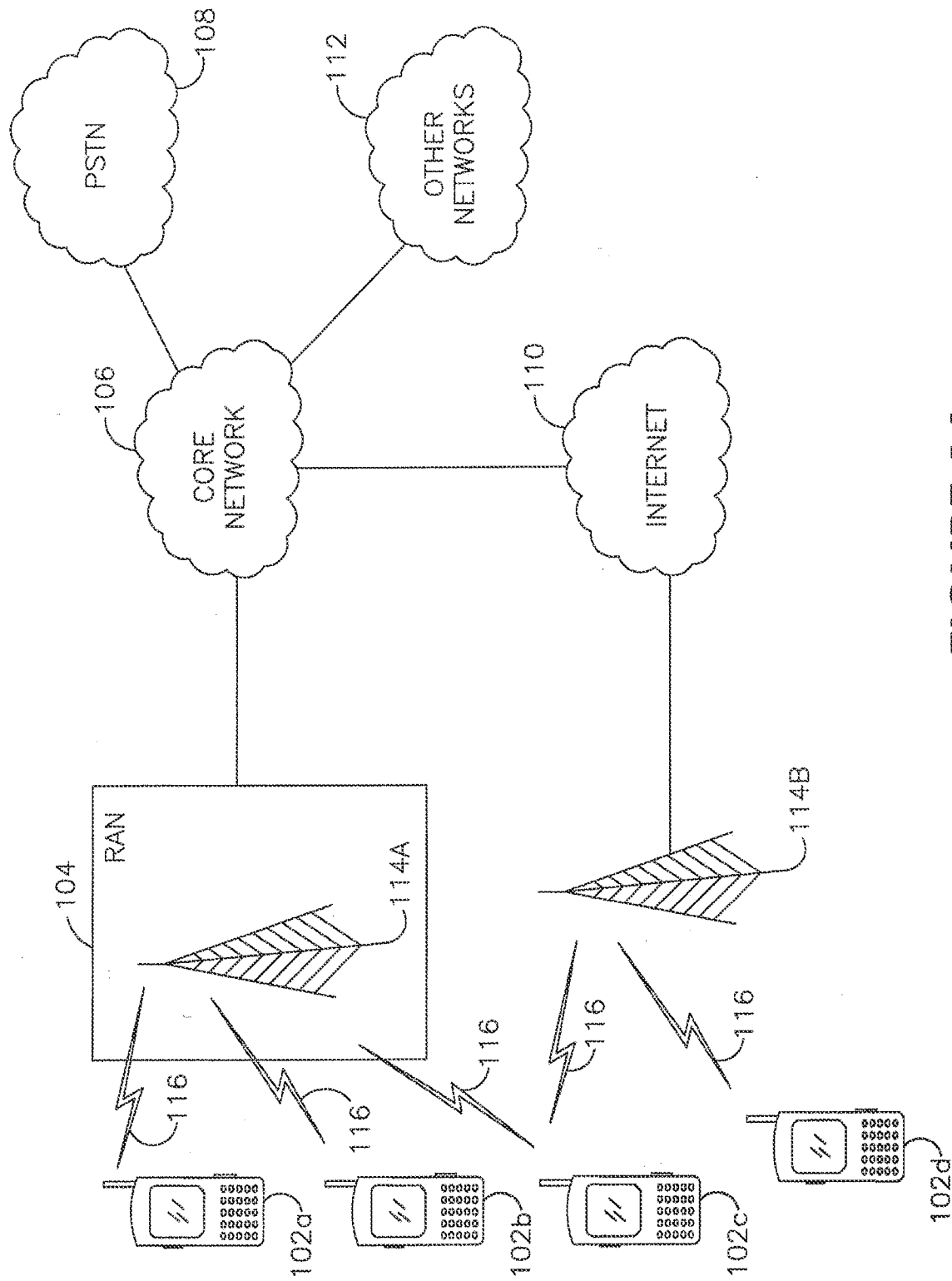
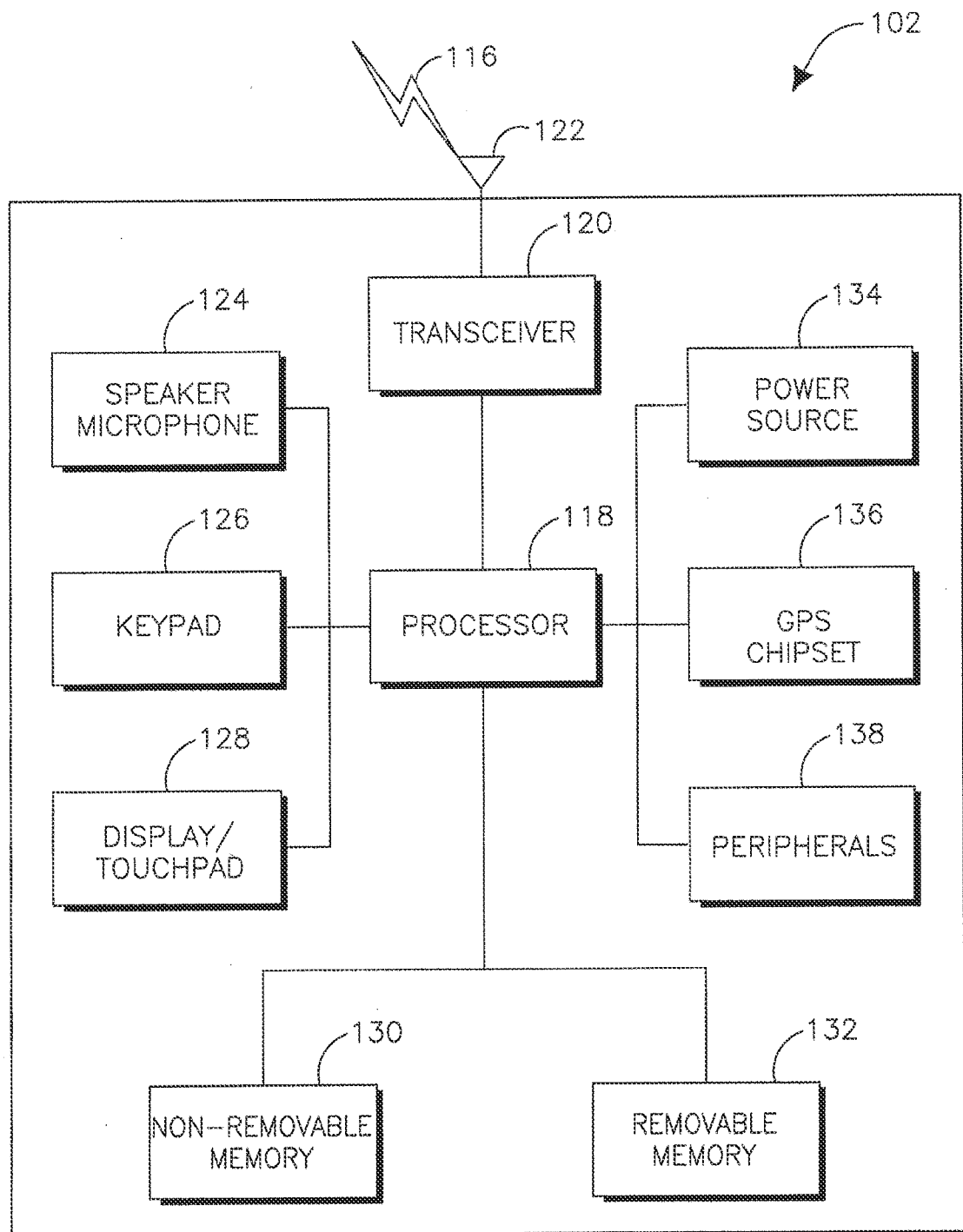


FIGURE 1A

+

2/23

+

**FIGURE 1B**

+

+

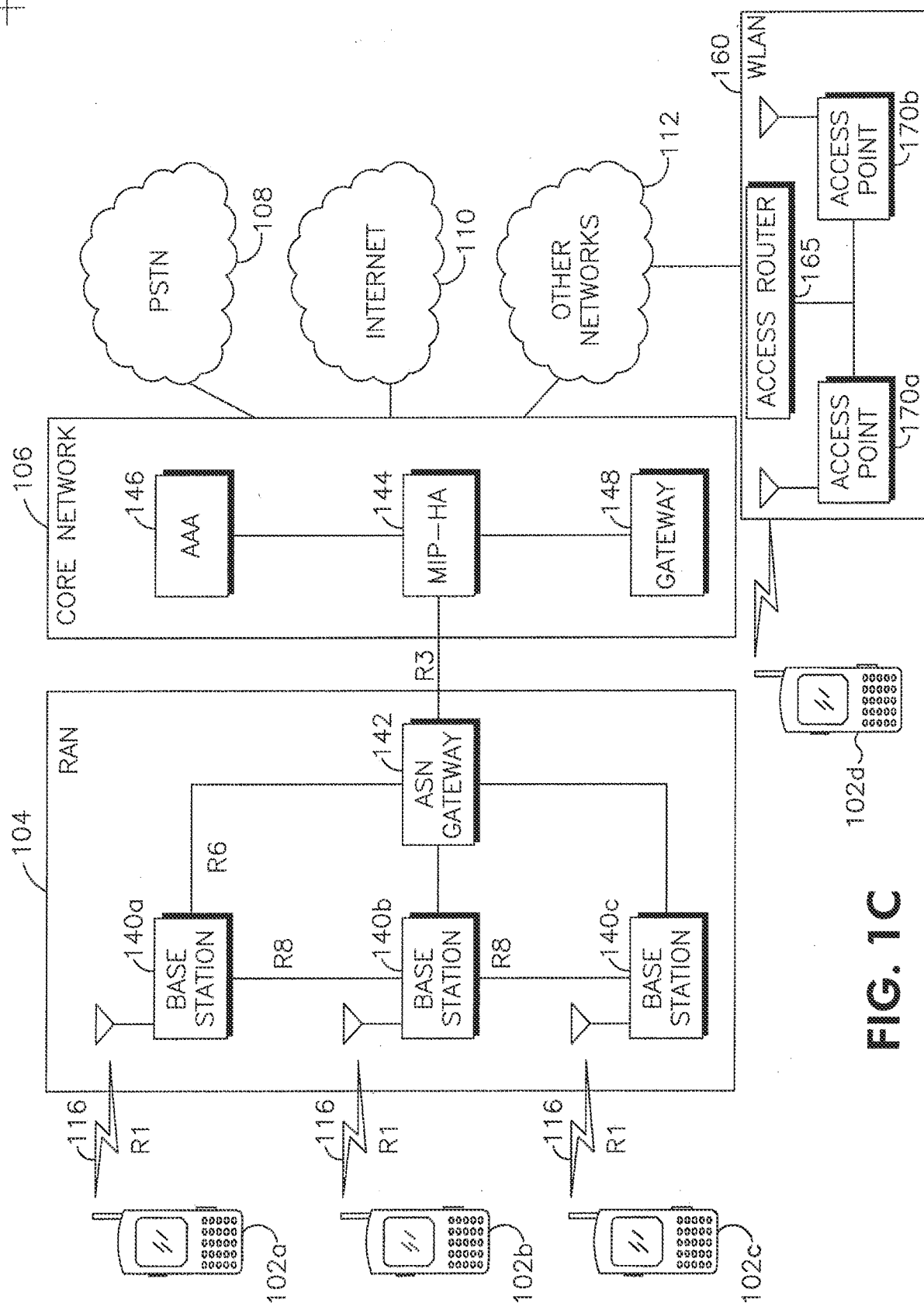


FIG. 1C

+

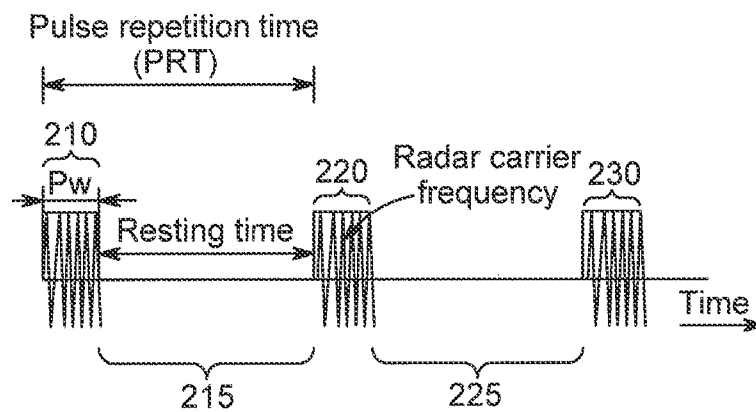


FIG. 2

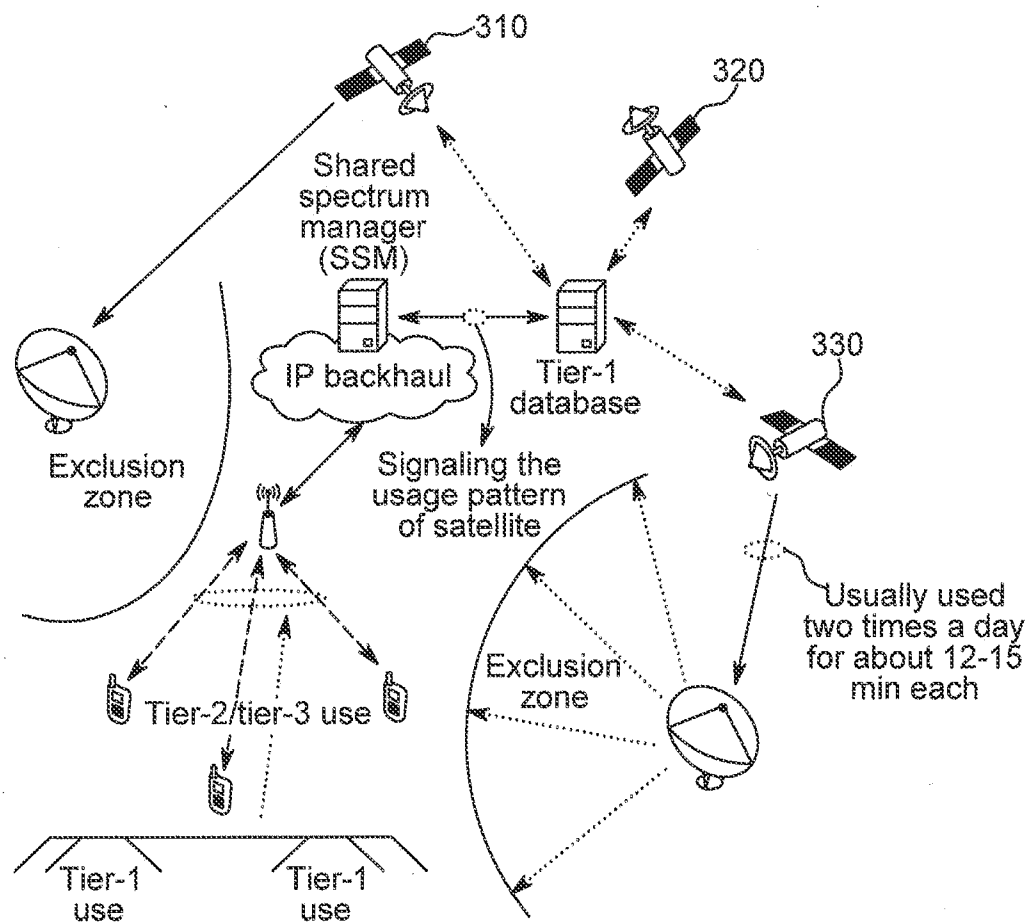


FIG. 3

5/23

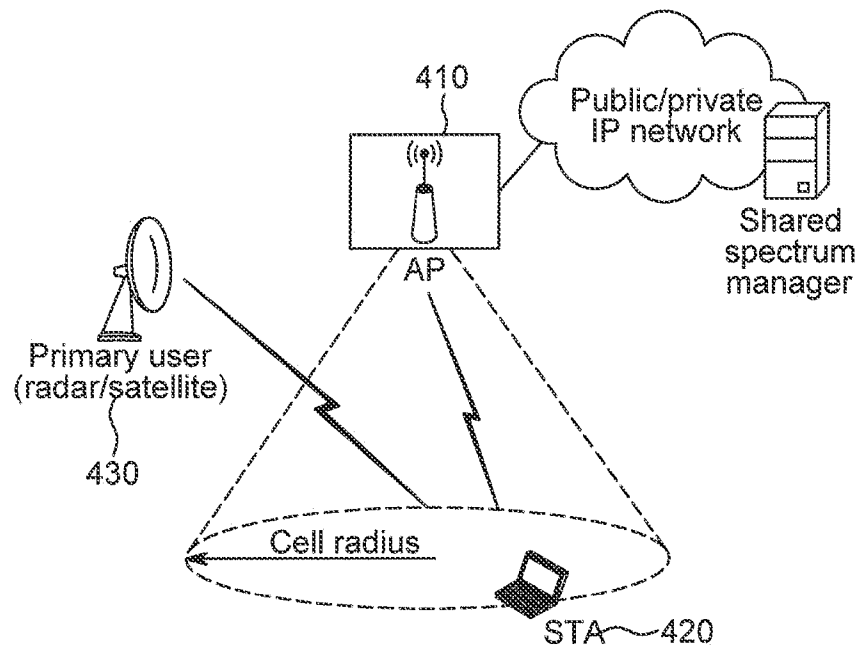


FIG. 4

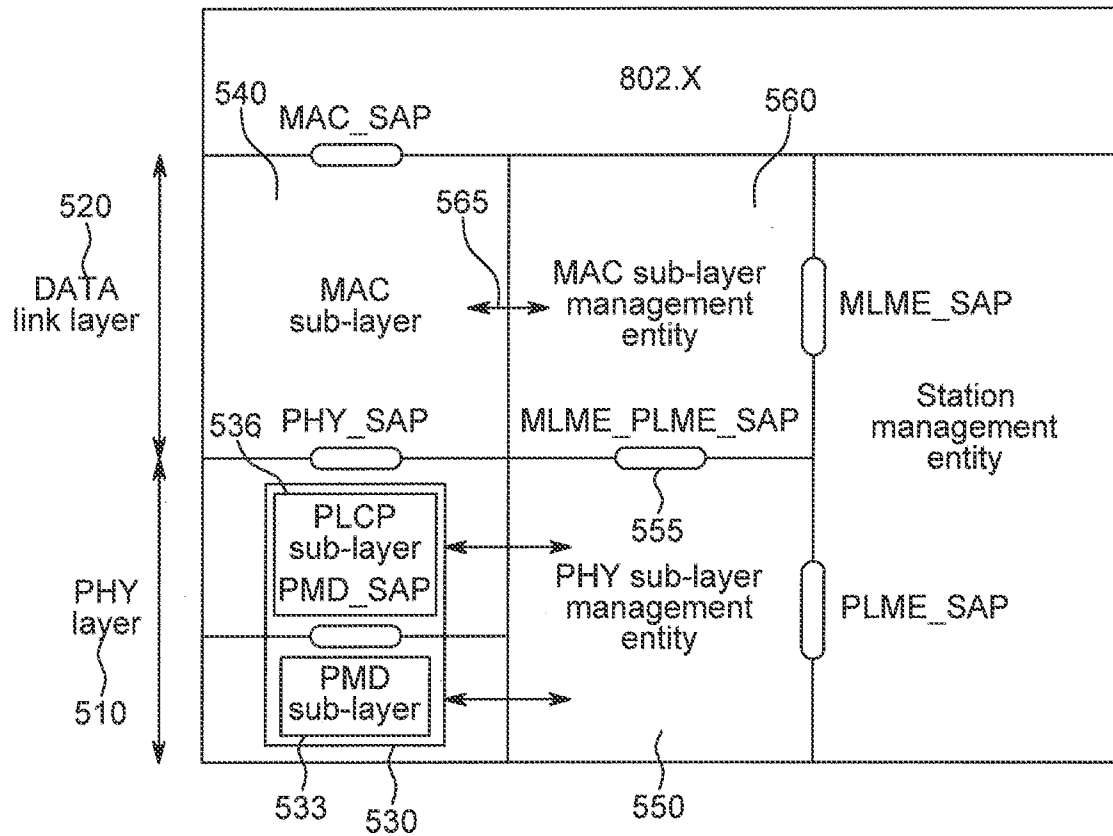


FIG. 5

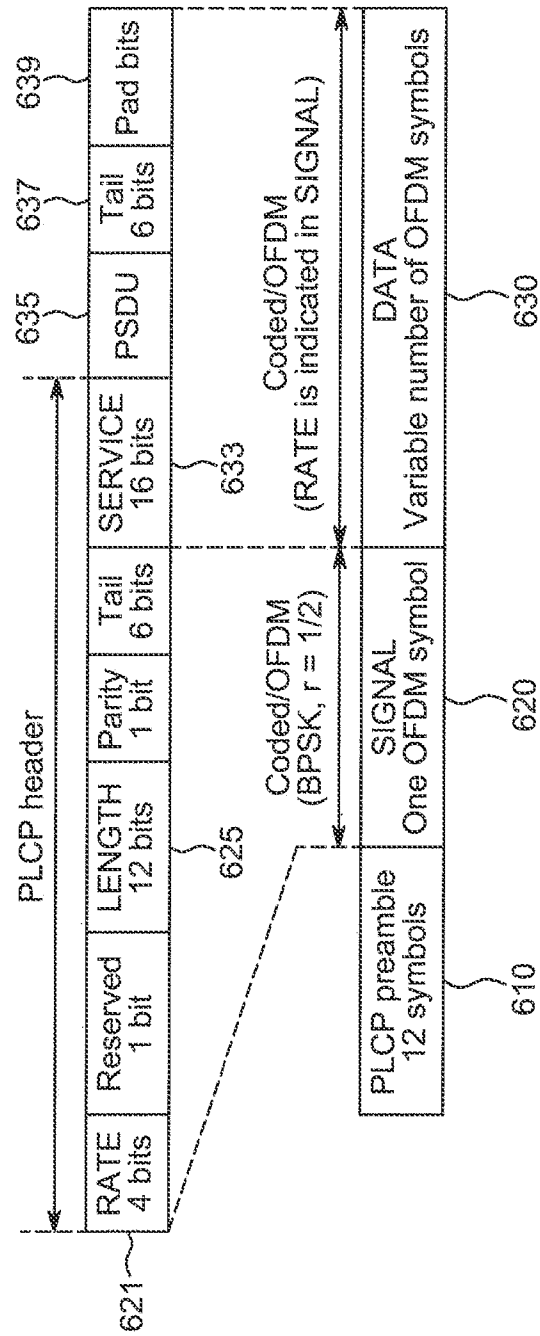


FIG. 6

7/23

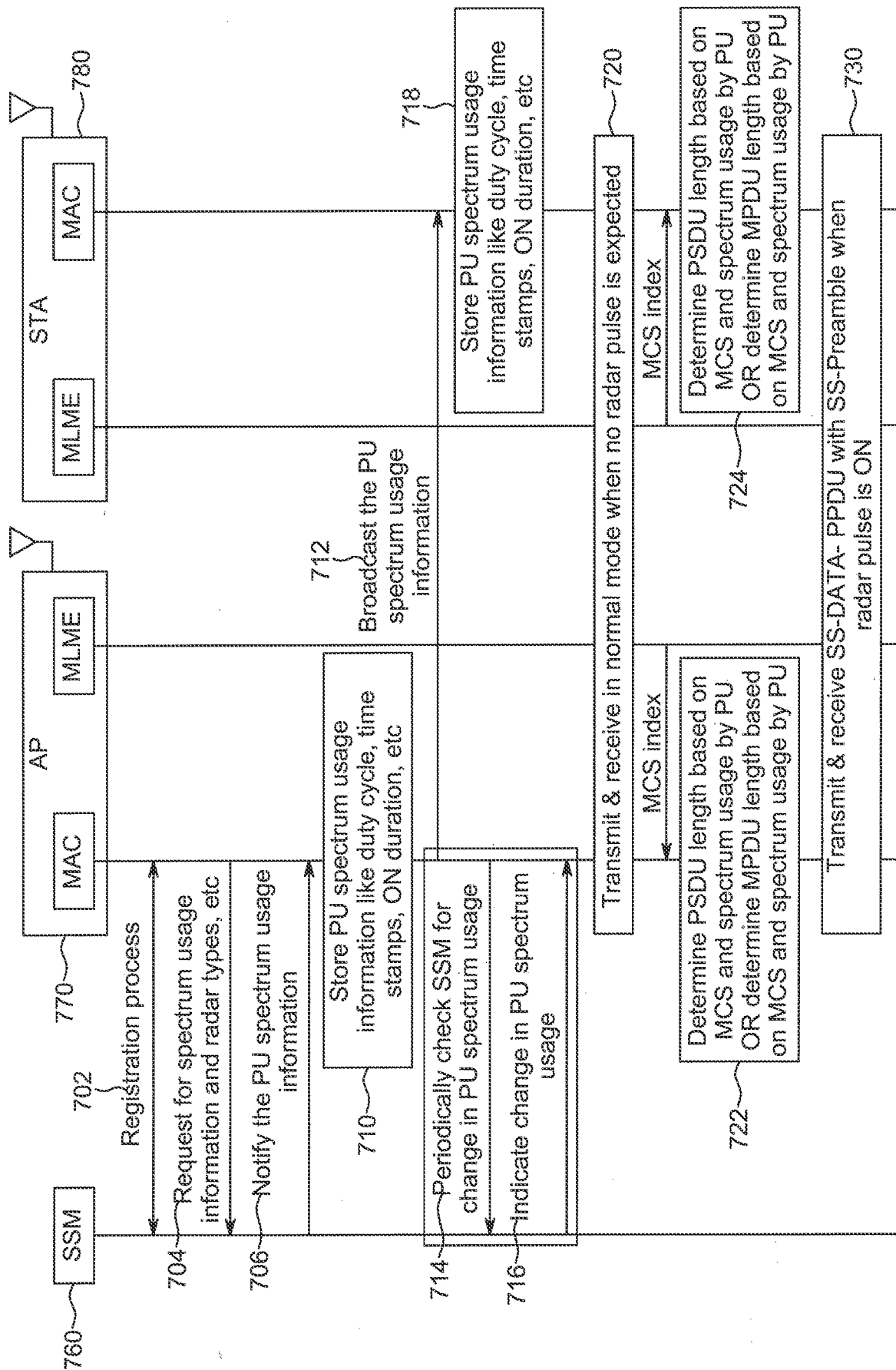


FIG. 7

8/23

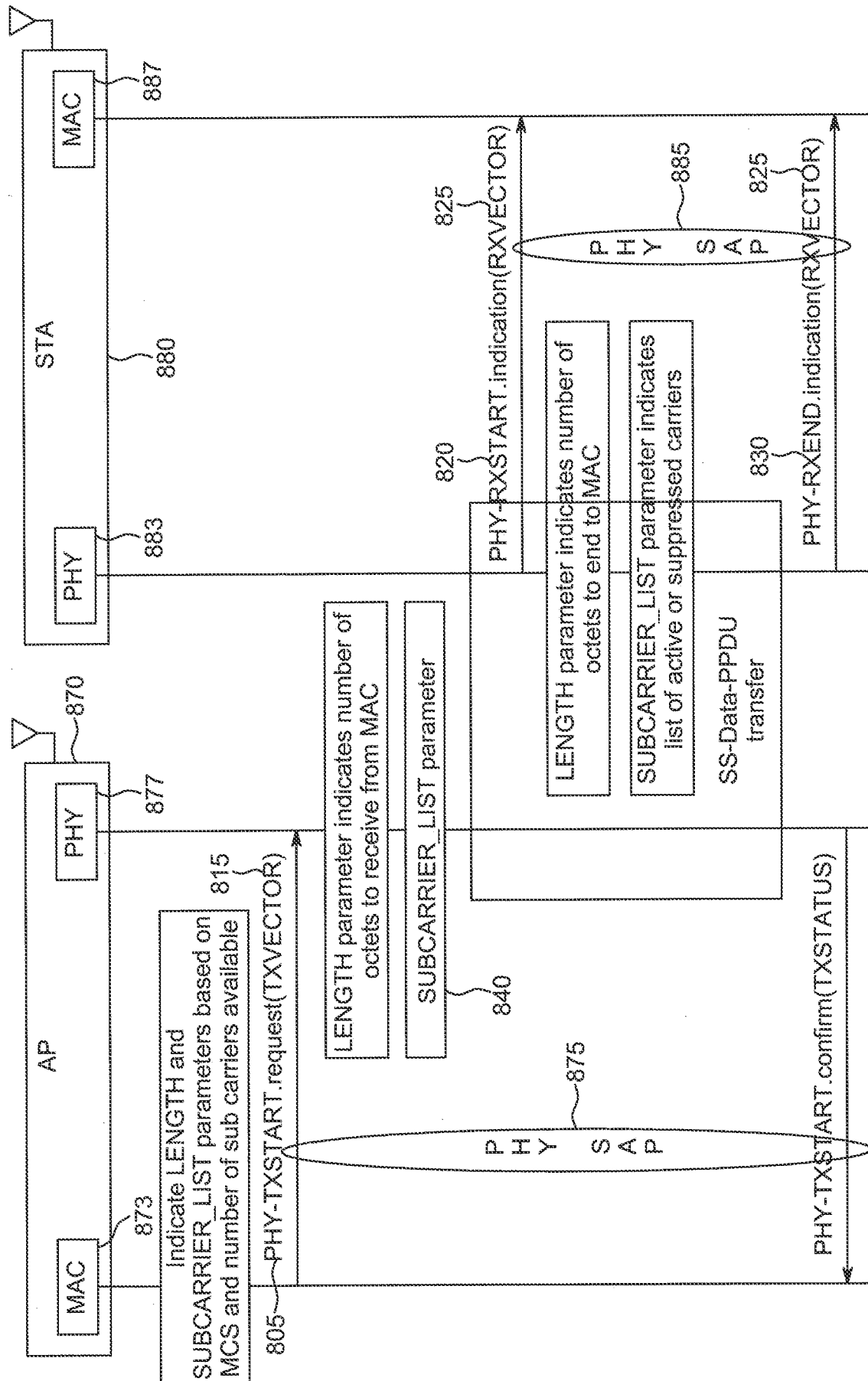


FIG. 8

9/23

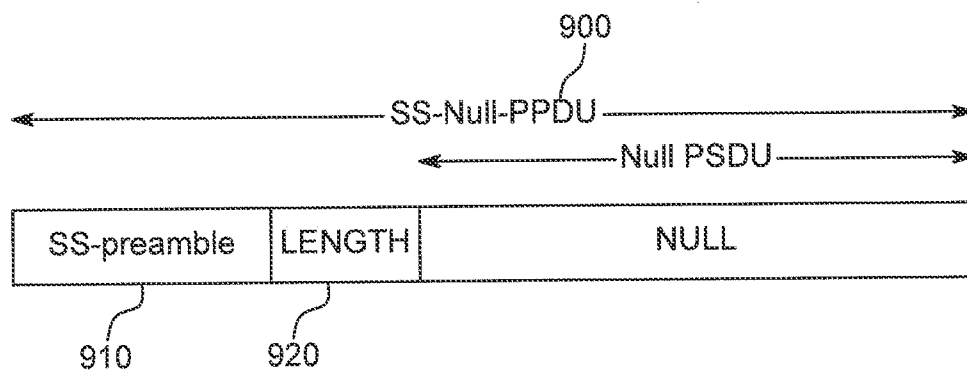


FIG.9

10/23

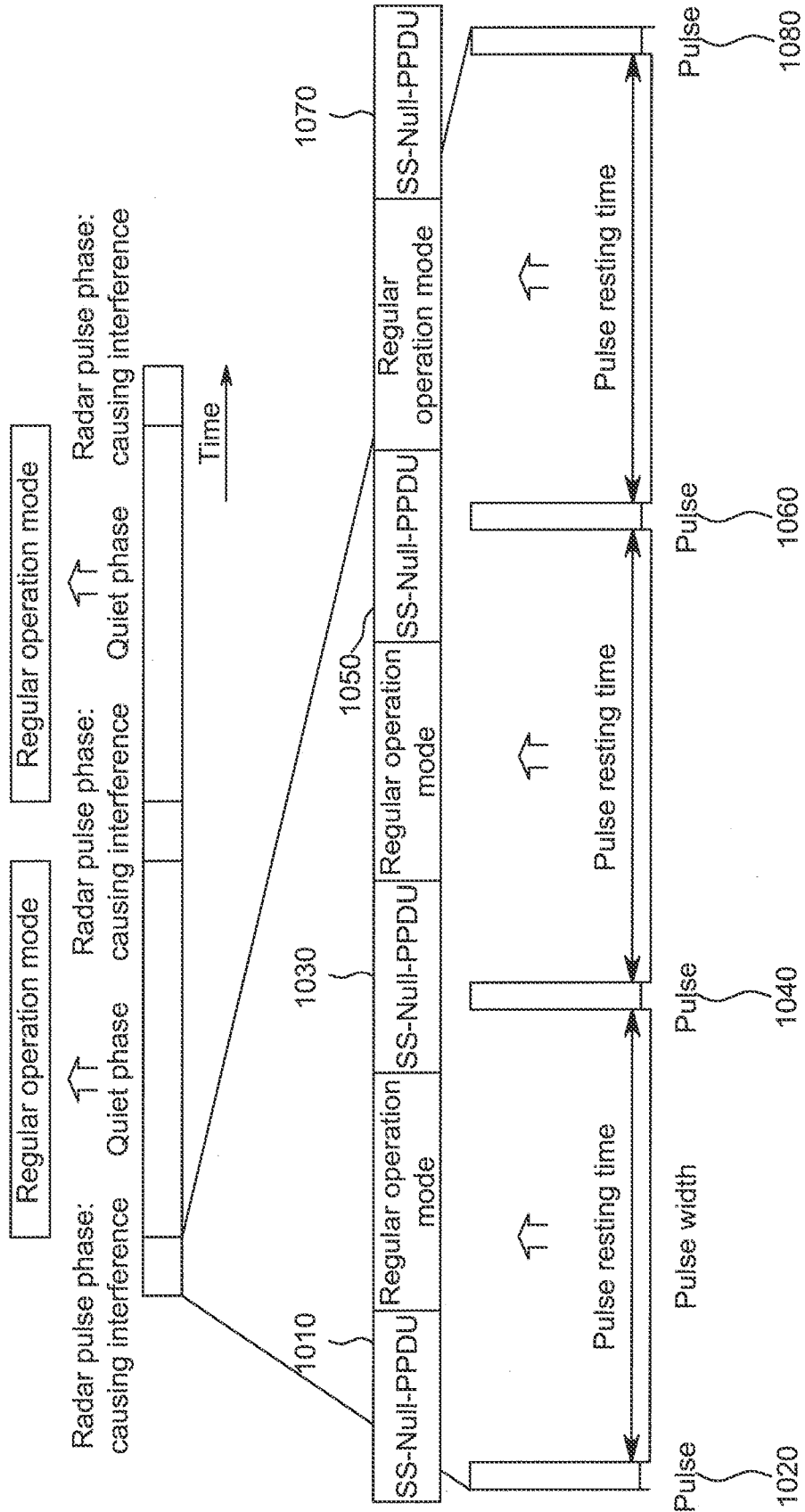


FIG. 10

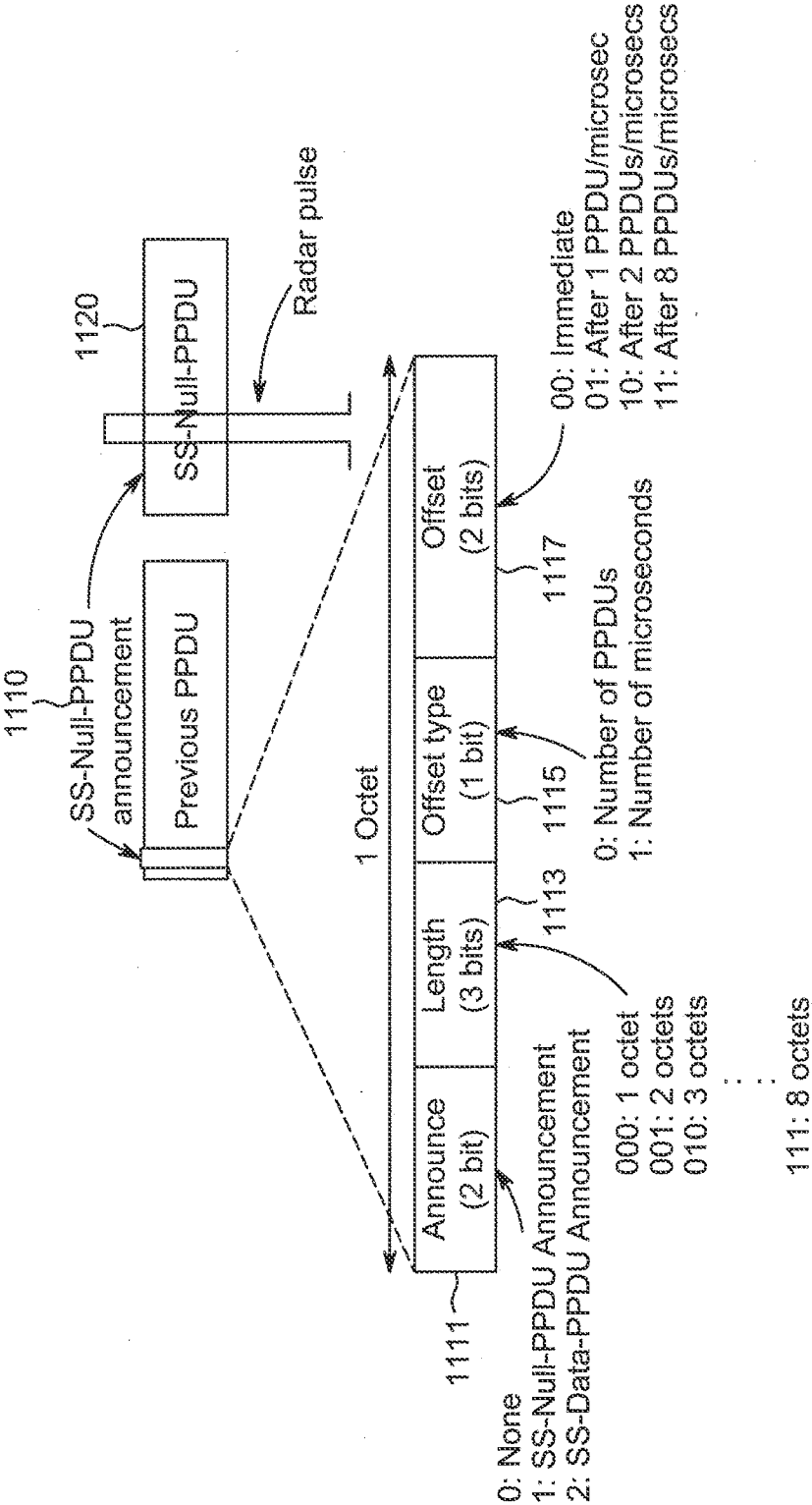


FIG. 11

12/23

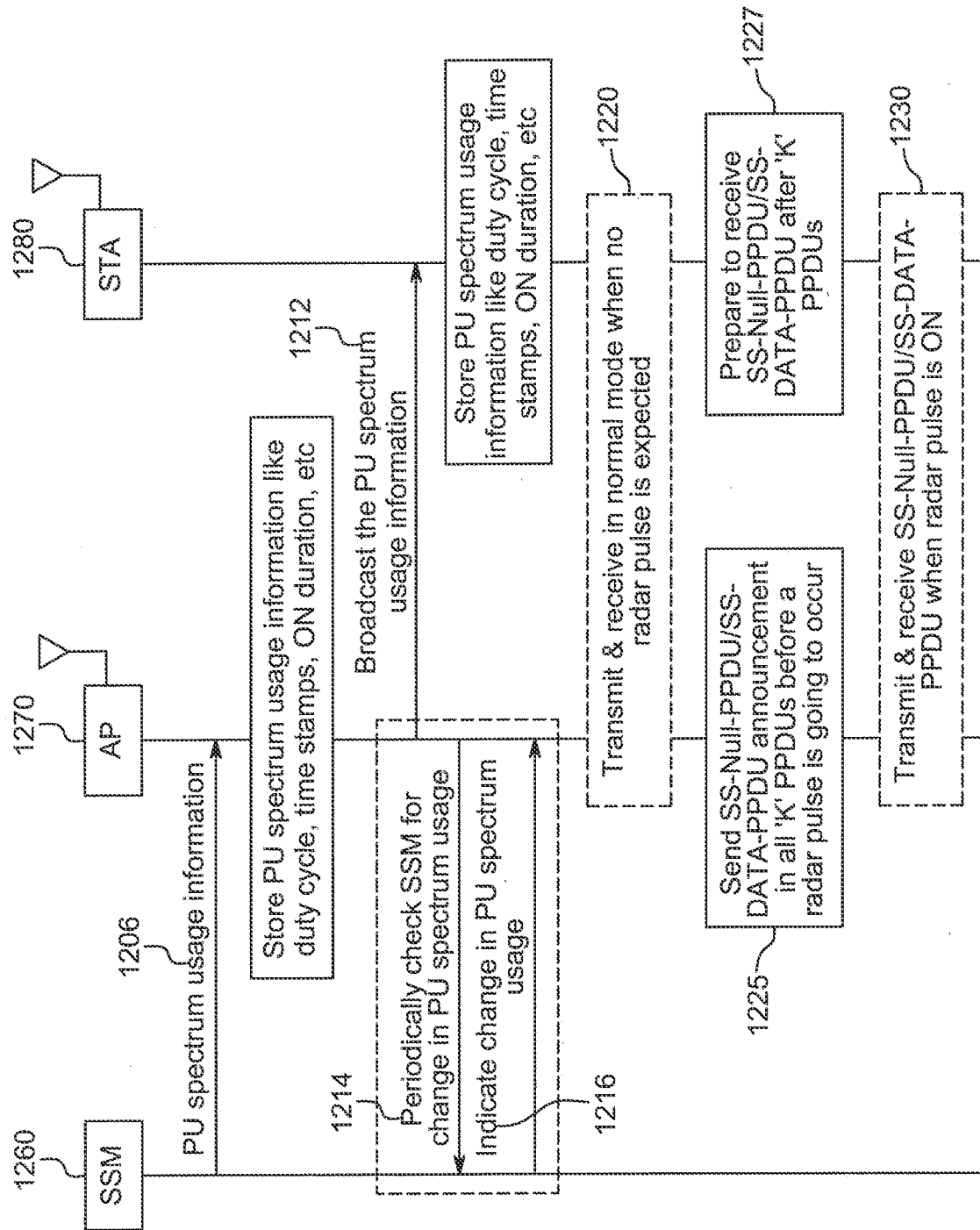


FIG. 12

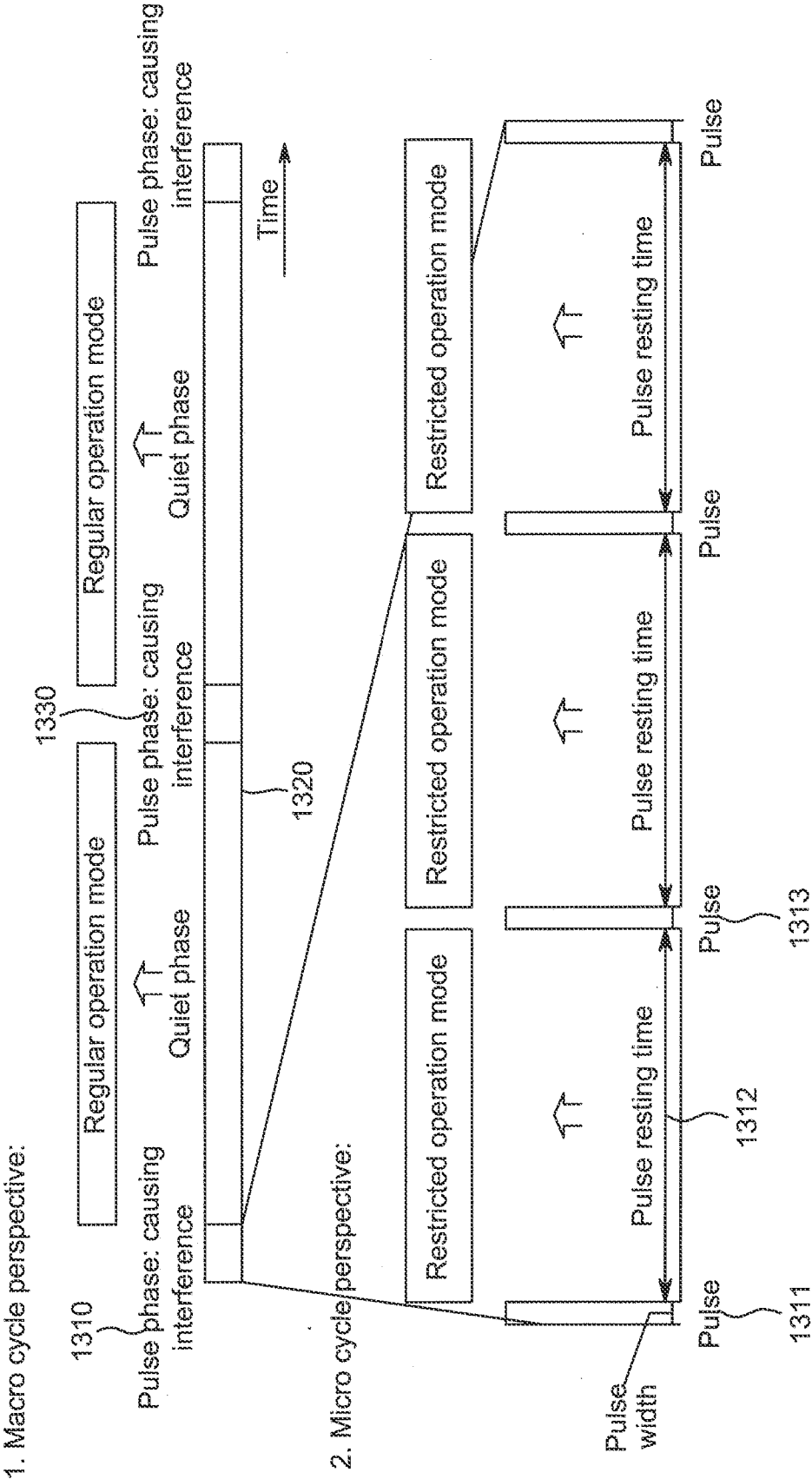


FIG. 13

14/23

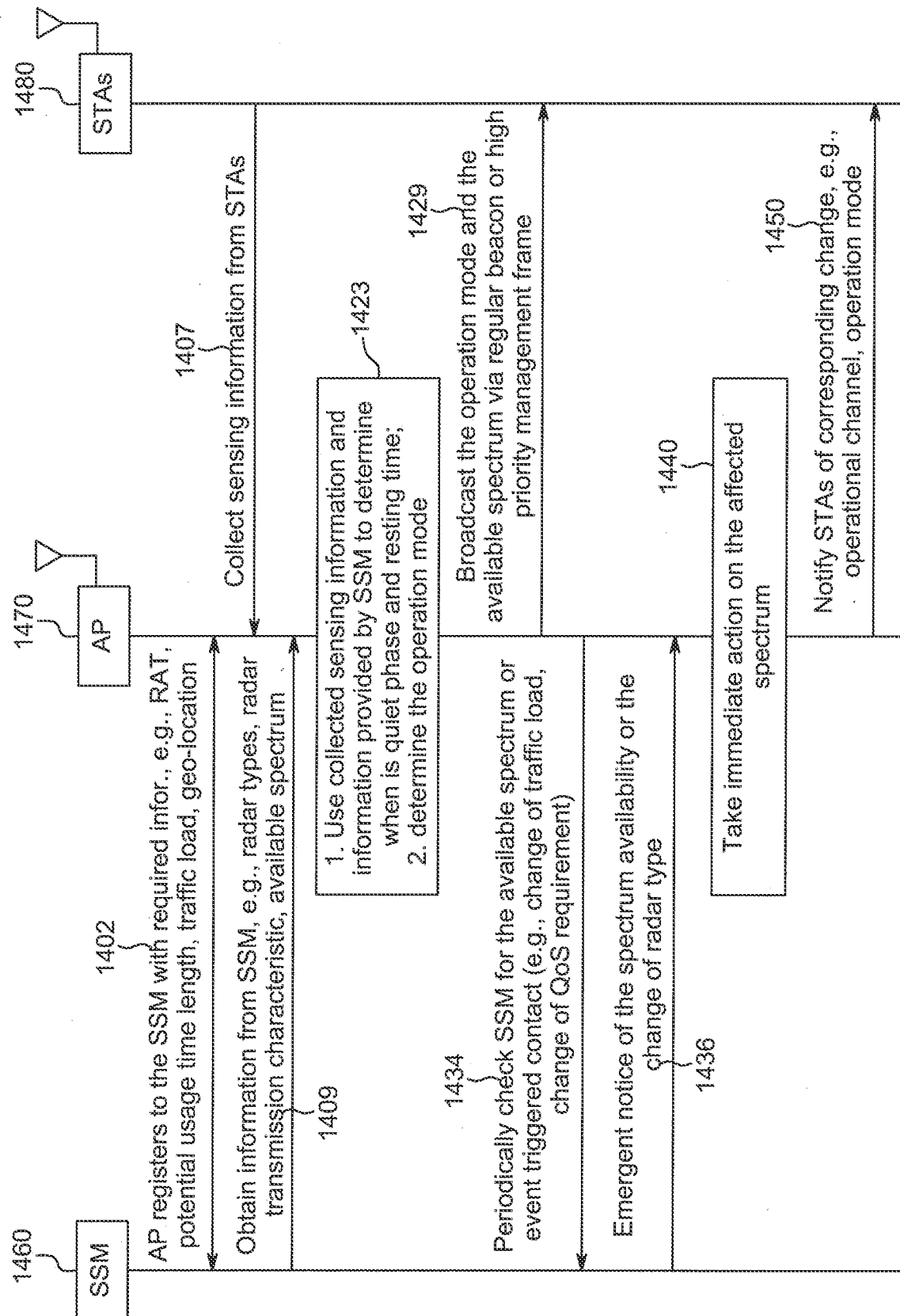


FIG. 14

15/23

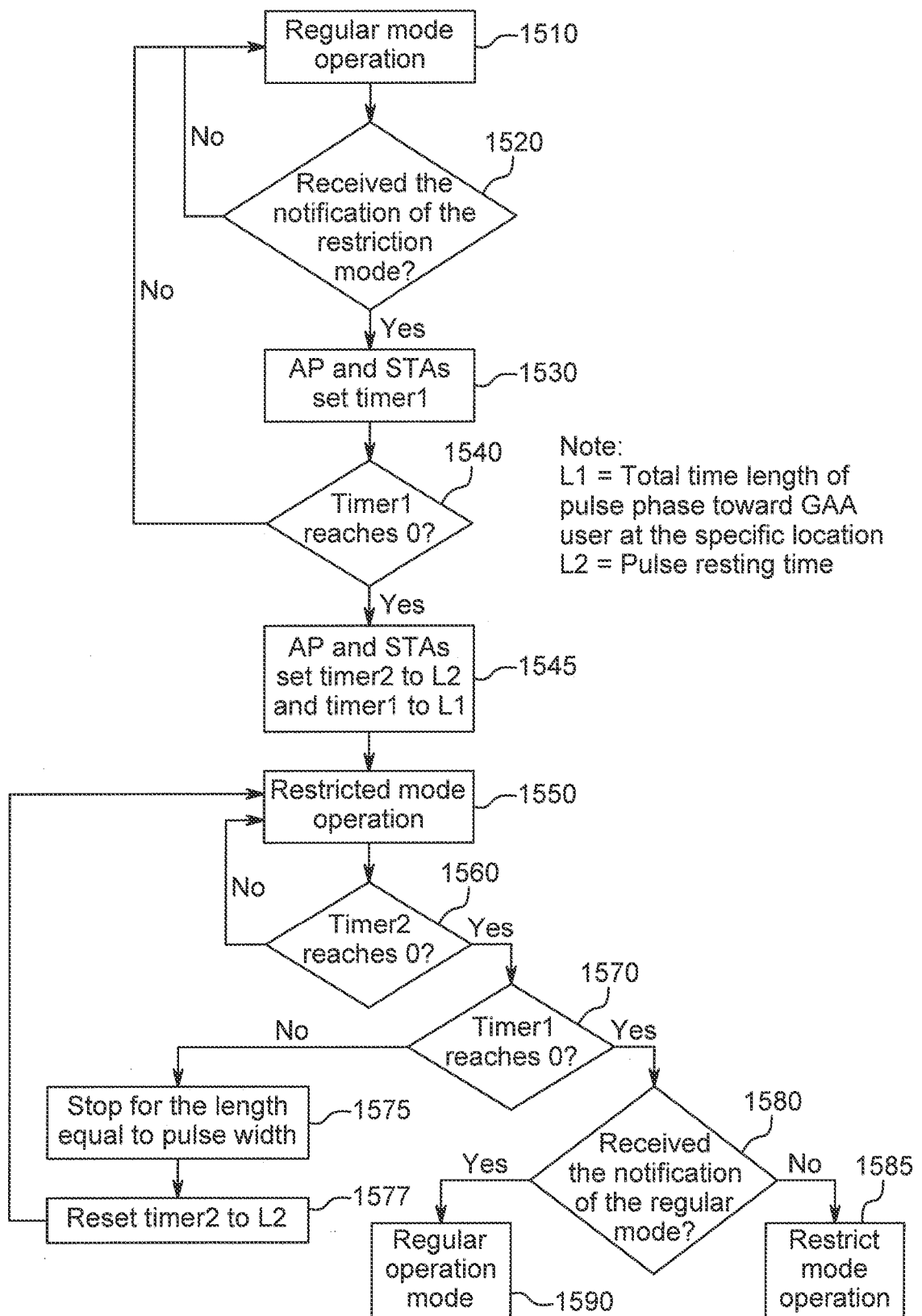


FIG. 15

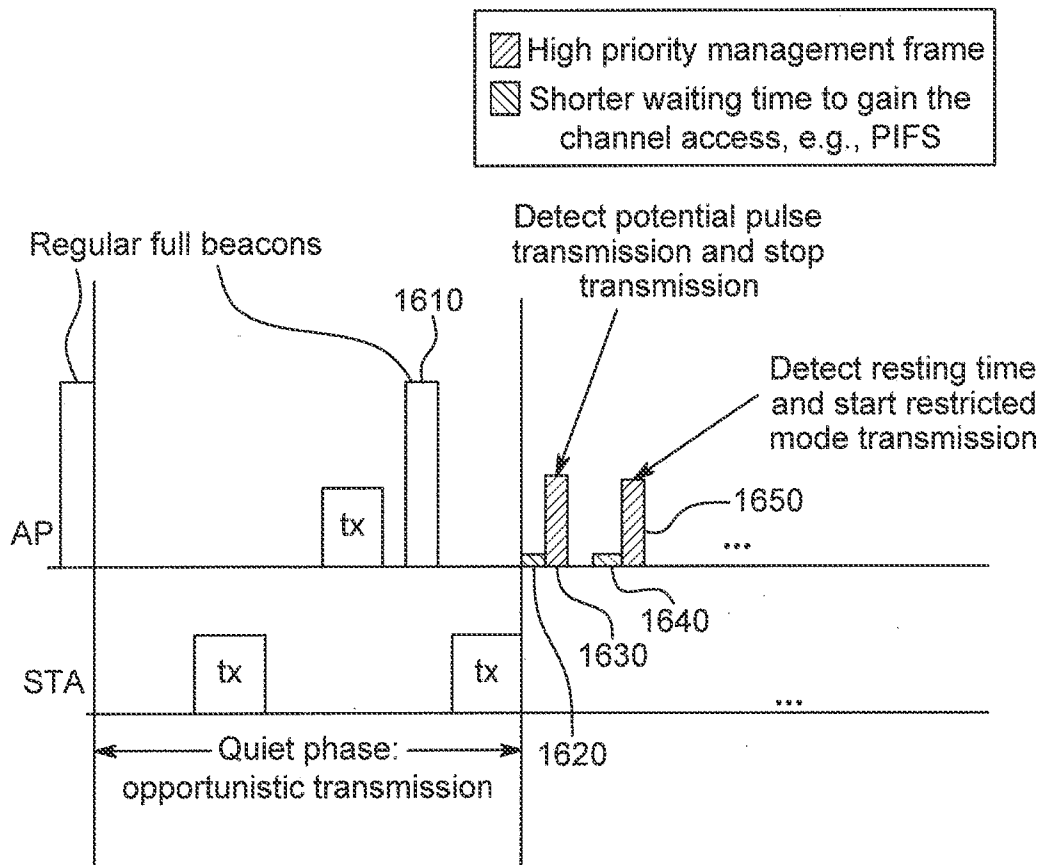


FIG. 16

17/23

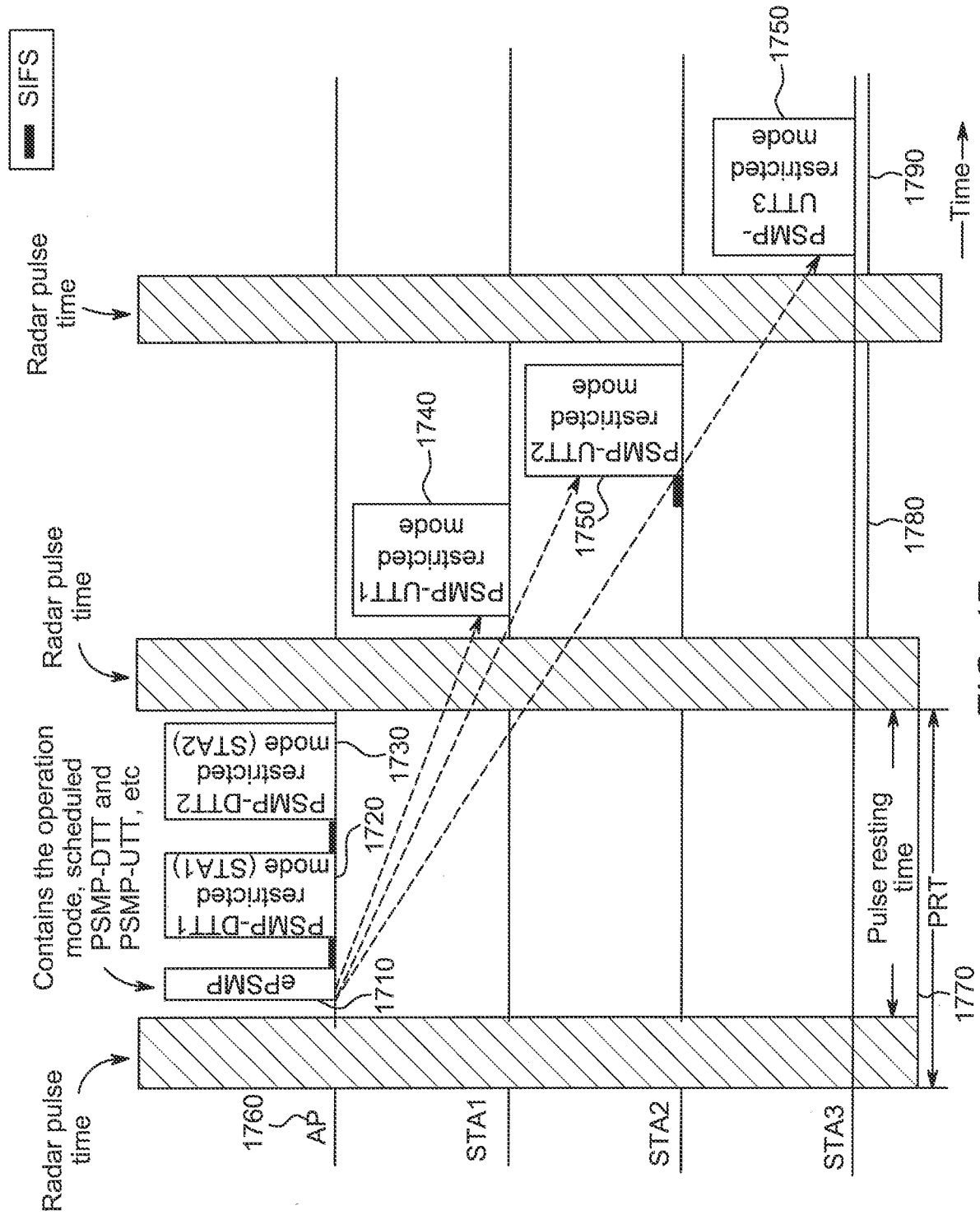


FIG. 17

18/23

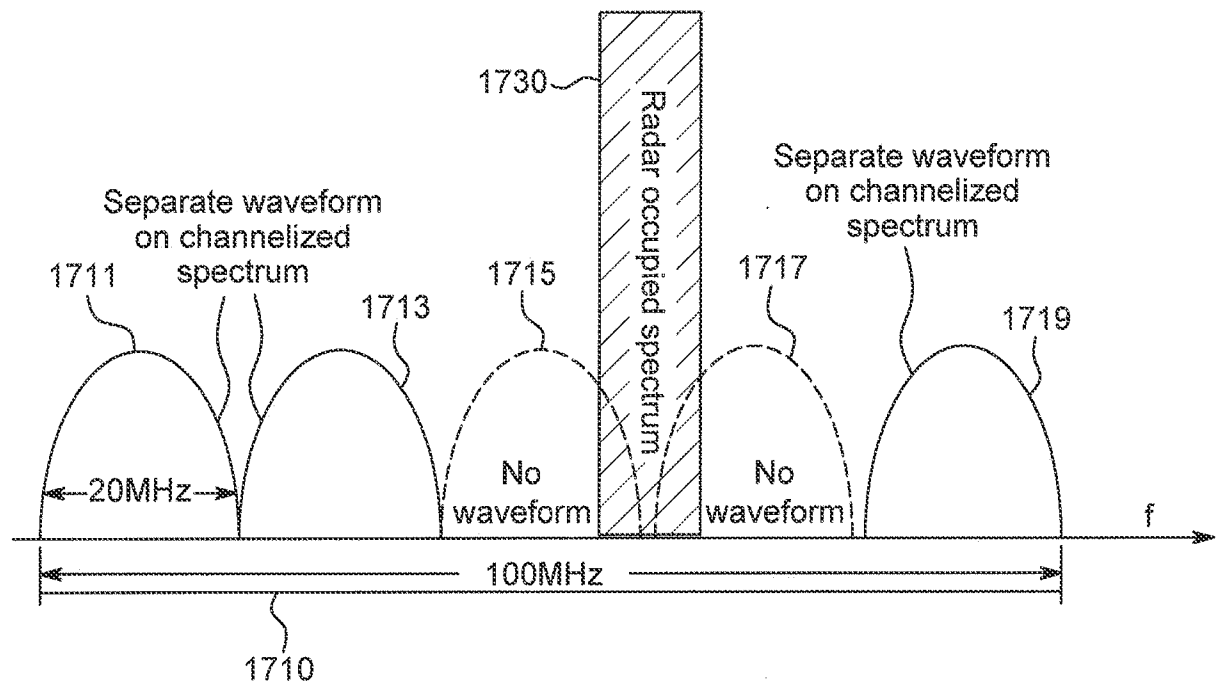


FIG. 18

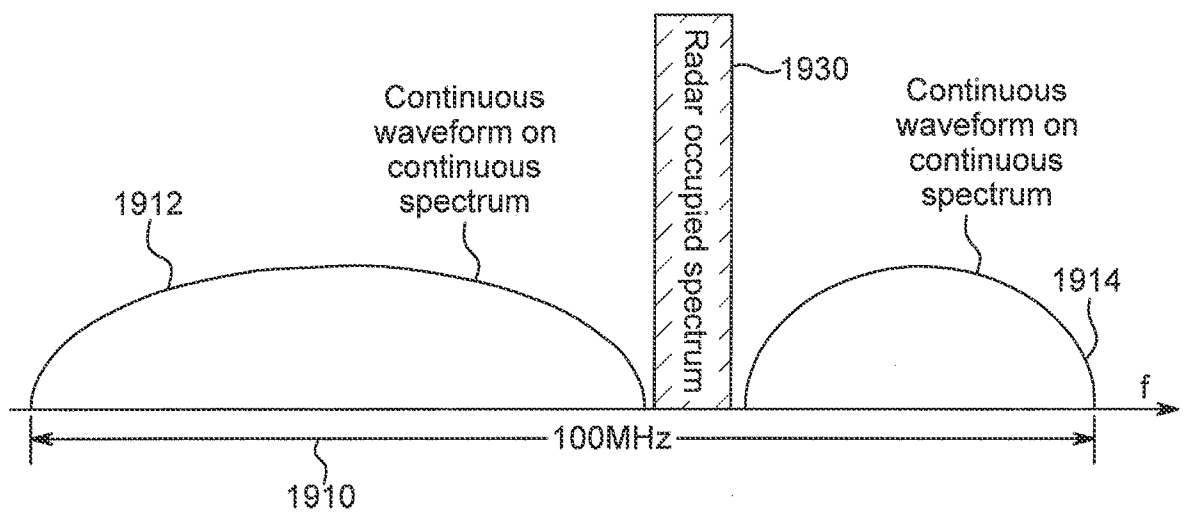


FIG. 19

19/23

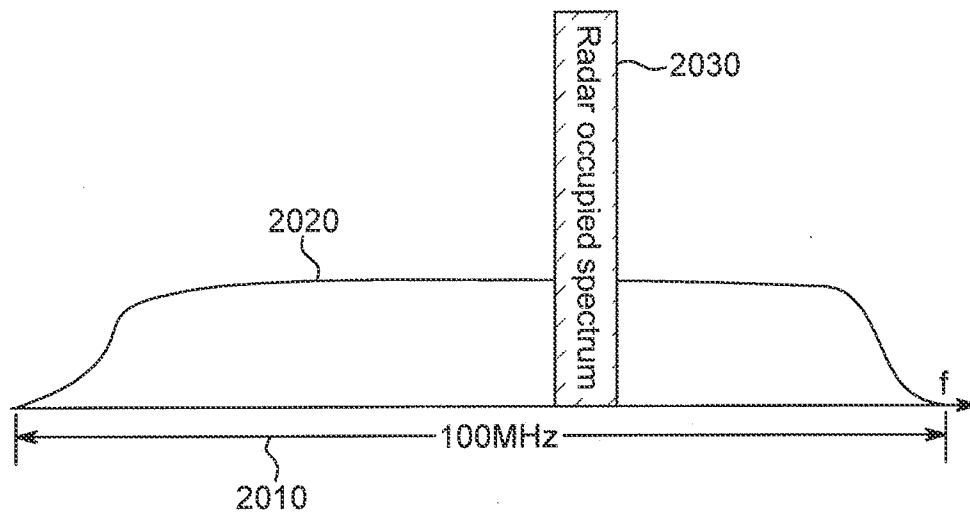


FIG. 20

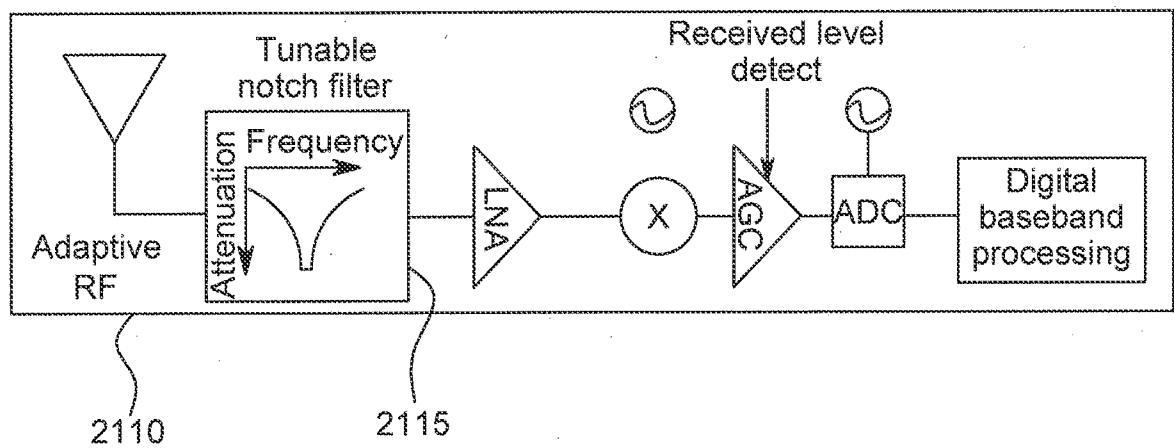
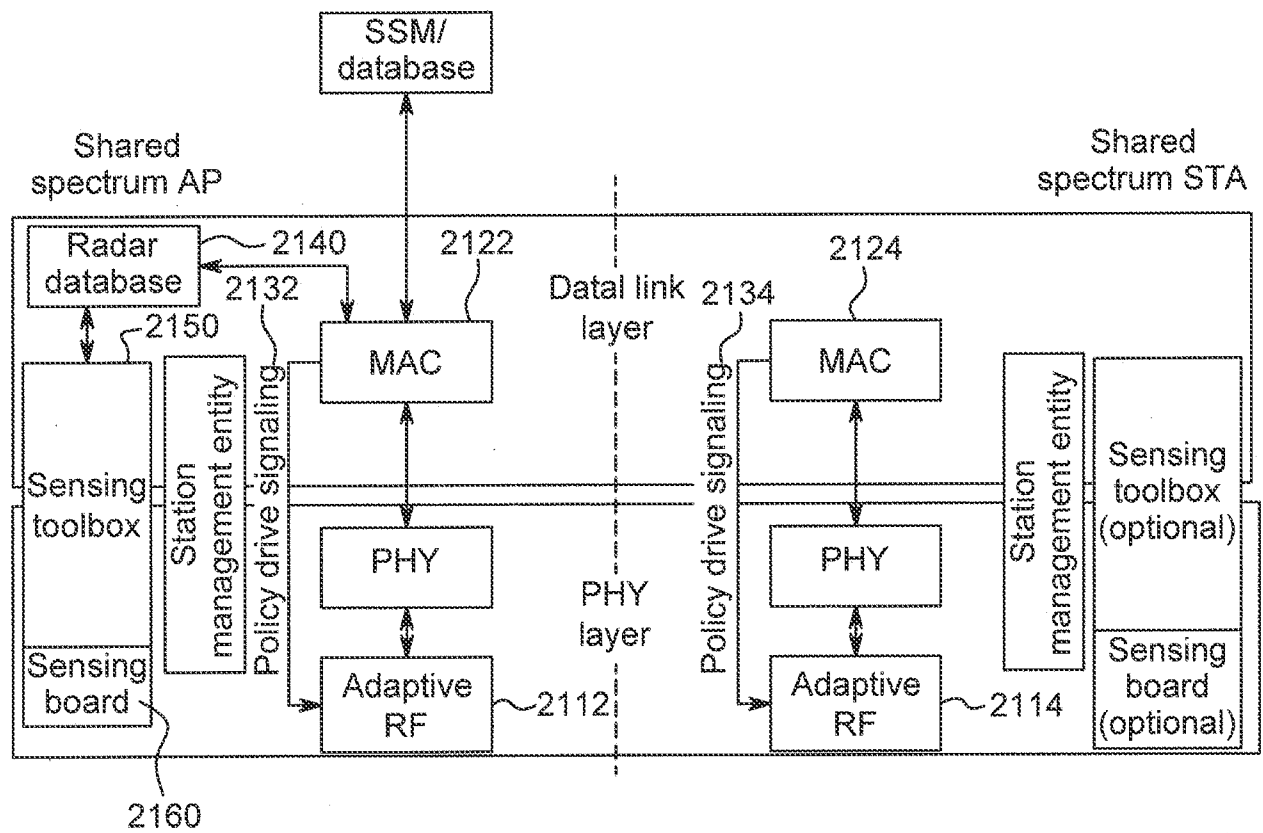


FIG. 21

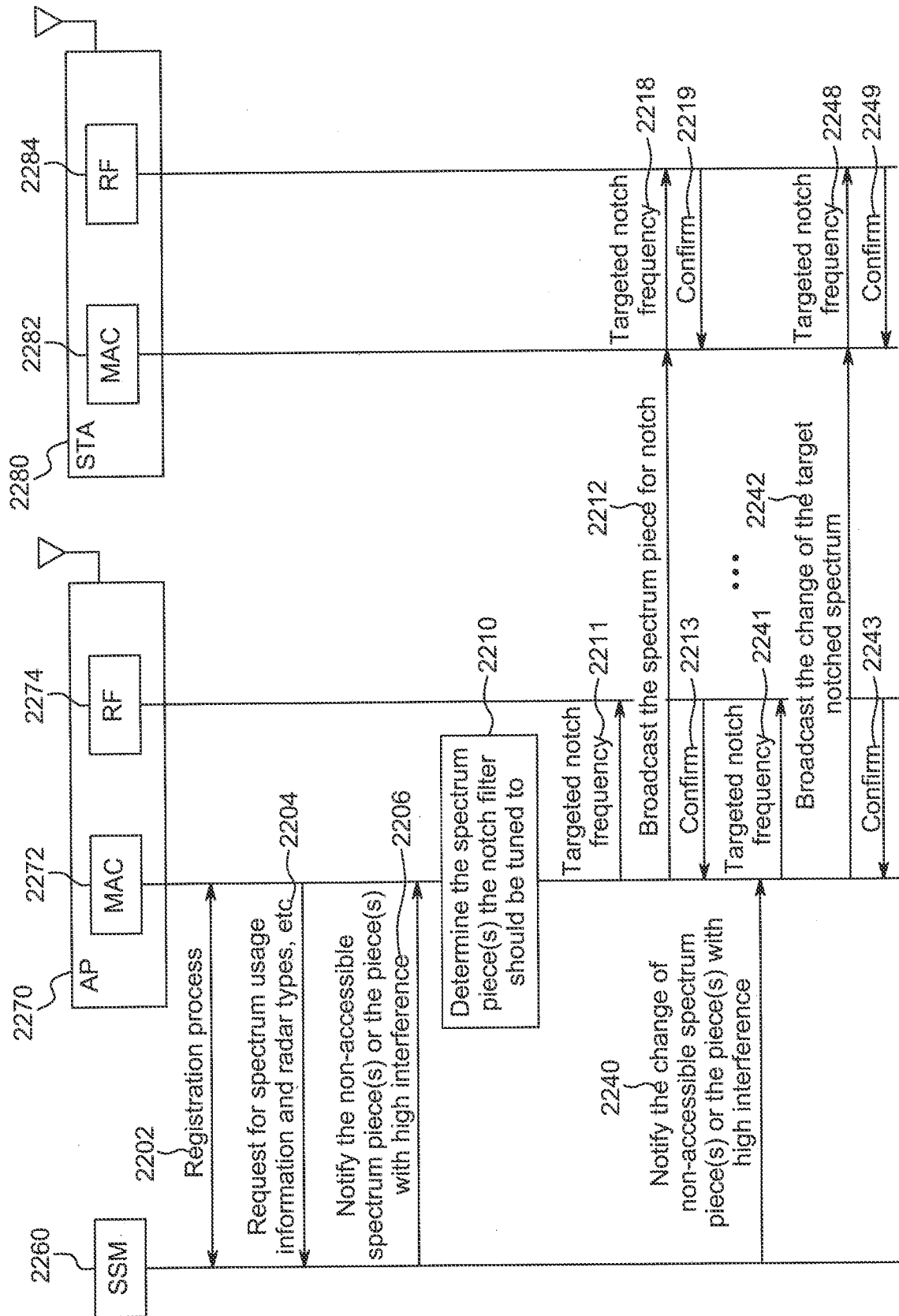


FIG. 22

22/23

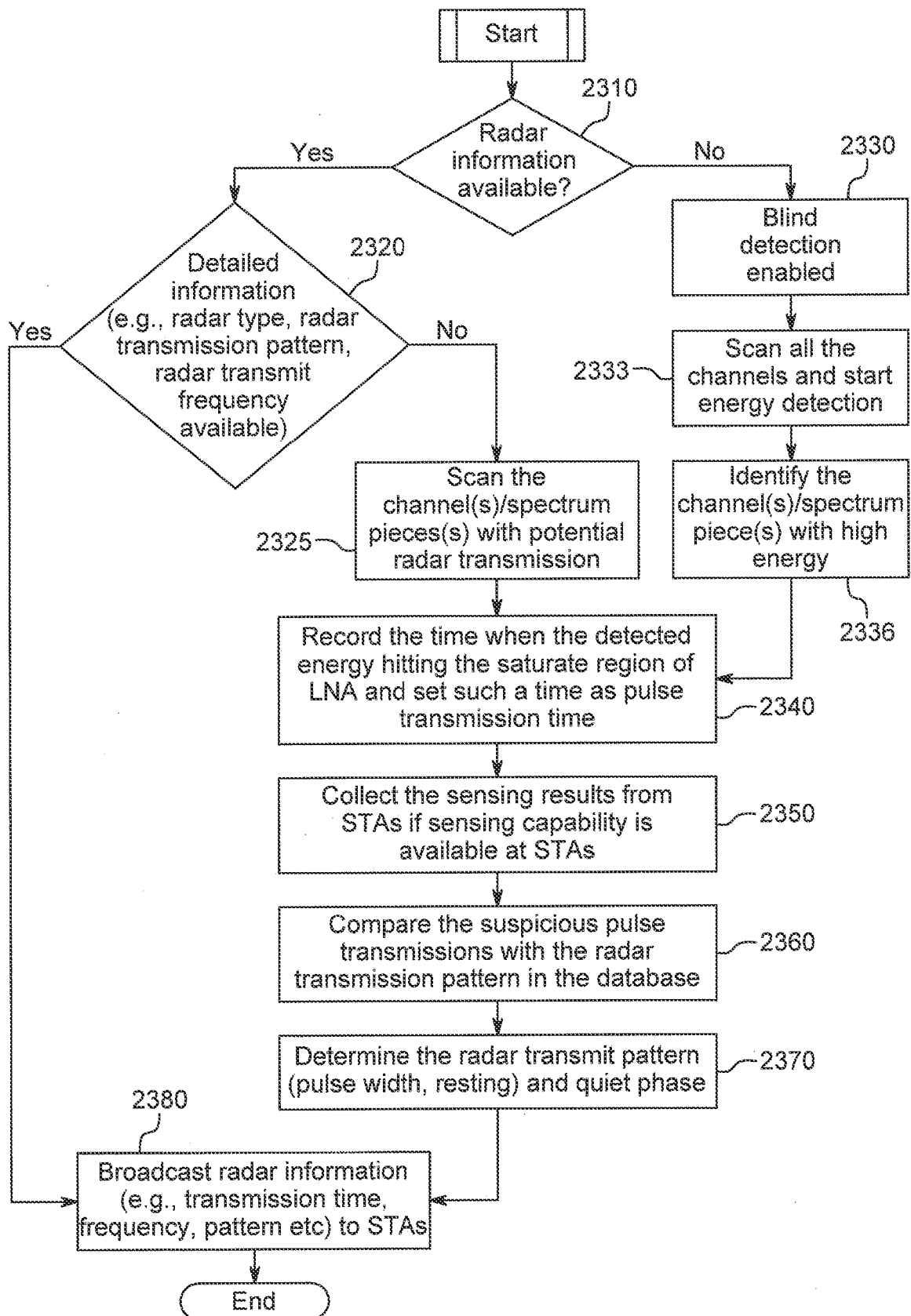


FIG. 23

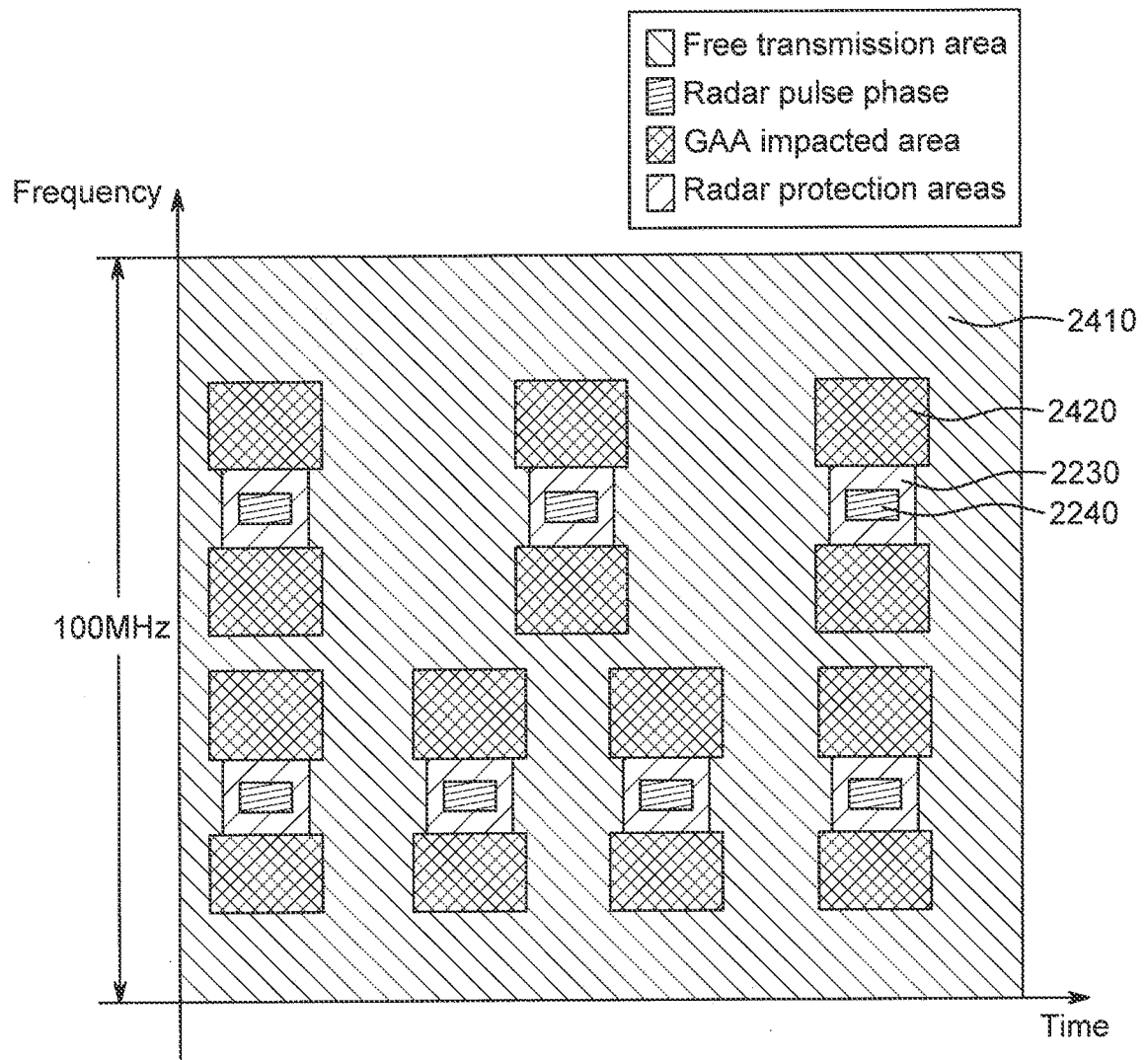


FIG. 24