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(54) **Title:** METHODS, APPARATUSES AND SYSTEMS DIRECTED TO INITIAL SYNCHRONIZATION AND/OR INITIAL ACQUISITION FOR HIGHLY DIRECTIONAL SYSTEMS

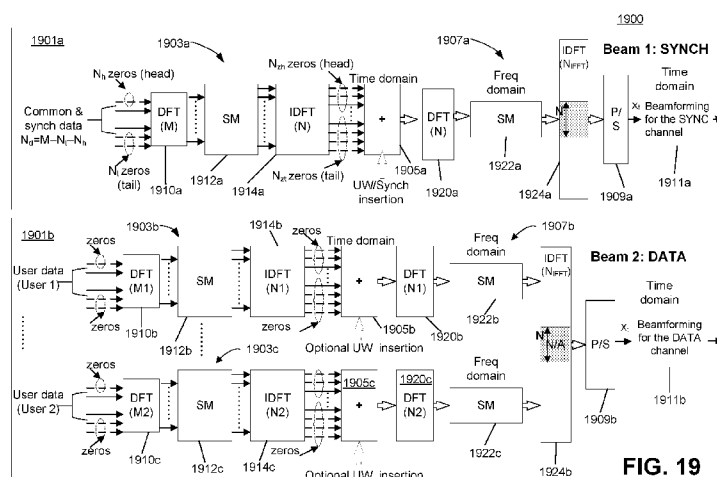


FIG. 19

(57) **Abstract:** Methods, apparatuses, systems, devices, and computer program products directed to highly directional systems for millimeter wave communications above 6 GHz, and to initial synchronization in the highly directional systems. In an embodiment, a high efficiency OFDM based ("he-OFDM-based") waveform may be leveraged (adapted) for initial synchronization using Unique Word DFT-spread-OFDM where both the Unique Word and useful portion of the symbol are synchronization signals. Synchronization signals are arranged such as to be orthogonal with synchronization signals of other superimposed beams.

**METHODS, APPARATUSES AND SYSTEMS DIRECTED TO INITIAL
SYNCHRONIZATION AND/OR INITIAL ACQUISITION FOR HIGHLY
DIRECTIONAL SYSTEMS**

CROSS REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/263,592, filed 4-Dec-2015, which is incorporated herein by reference.

BACKGROUND

[0002] **Field**

[0003] This application is related to wireless communications.

[0004] **Related Art**

[0005] To meet the high data rate required for the next generation of cellular communication systems, the wireless industry and academia have been exploring ways to leverage large bandwidths available at frequencies above 6 gigahertz (GHz), e.g., centimeter wave (cmW) and millimeter wave (mmW) frequencies. The large bandwidths available at these frequencies may provide enormous capacity for user-specific data transmission.

[0006] One challenge of using the above-6 GHz frequencies may be characteristics related to their propagation that may be unfavorable for wireless communication, especially in an outdoor environment. For example, higher frequency transmissions may experience higher free space path loss. Rainfall and atmospheric gasses, e.g., oxygen, may add further attenuation, and foliage may cause attenuation and depolarization. Narrow beam patterns, although a useful technique for countering such losses, pose challenges for delivering cell-specific and/or broadcast information.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] A more detailed understanding may be had from the detailed description below, given by way of example in conjunction with drawings appended hereto. Figures in such drawings, like the detailed description, are examples. As such, the Figures and the detailed description are not to be considered limiting, and other equally effective examples are possible and likely. Furthermore, like reference numerals ("ref.") in the Figures indicate like elements, and wherein:

[0008] FIG. 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented;

[0009] 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;

[0010] FIGs. 1C, 1D and 1E are system diagrams of example radio access networks and example core networks that may be used within the communications system illustrated in FIG. 1A;

[0011] FIG. 2 illustrates an example communications system in which embodiments may be practiced or implemented;

[0012] FIGs. 3A-3B illustrate an example orthogonal frequency division multiplexing (OFDM) based frame structure;

[0013] FIG. 4 illustrates an example mapping of downlink logical, transport and physical channels;

[0014] FIG. 5 illustrates an example transceiver configured for fully digitized beamforming;

[0015] FIG. 6 illustrates an example transceiver configured for analogue beamforming;

[0016] FIG. 7 illustrates an example transceiver configured for analogue beamforming;

[0017] FIG. 8 illustrates an example transceiver configured for analogue beamforming;

[0018] FIG. 9 illustrates an example transceiver configured for analogue beamforming;

[0019] FIG. 10 is a block diagram illustrating an example pulse shaping unit of a transmitter configured to generate a ZT DFT-s-OFDM waveform;

[0020] FIG. 11 is a block diagram illustrating an example a transmitter configured to generate a unique word OFDM (UW-OFDM) waveform;

[0021] FIG. 12 illustrates an example universal mobile telecommunications system (UMTS) signaling structure for a primary synchronization channel (P-SCH), a secondary synchronization channel (S-SCH), and a common pilot channel (CPICH);

[0022] FIG. 13 illustrates an example long term evolution (LTE) signaling structure for a primary synchronization signal (PSS), a secondary synchronization signal (SSS), and a physical broadcast channel (PBCH);

[0023] FIG 14 illustrates an example OFDM signal generated using an *he*-OFDM-based waveform;

[0024] FIG. 15. Illustrates an example OFDM signal resulting from transmission of synchronization information and data channel information on separate beams;

[0025] FIG. 16 illustrates an example OFDM signal resulting from transmission of synchronization information and data channel information on separate beams;

[0026] FIG. 17. Illustrates an example OFDM signal resulting from transmission of synchronization information and data channel information on separate beams;

[0027] FIG. 18 illustrates an example OFDM signal resulting from transmission of synchronization information on a synchronization beam;

[0028] FIG. 19 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0029] FIG. 20 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0030] FIG. 21 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0031] FIG. 22 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0032] FIG. 23 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0033] FIG. 24 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0034] FIG. 25 illustrates an example transmitter configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams;

[0035] FIG. 26 is a flow diagram illustrating an example flow for supporting communications on separate transmit beams;

[0036] FIG. 27 is a flow diagram illustrating an example flow for supporting communications on separate transmit beams;

[0037] FIG. 28 illustrates an example SYNCH and PBCH frame structure;

[0038] FIG. 29 illustrates an example SYNCH and PBCH frame structure;

[0039] FIG. 30 illustrates an example SYNCH and PBCH frame structure;

[0040] FIG. 31 illustrates an example of a basic two partition coordination for SYNCH and PBCH among neighbor cells; and

[0041] FIG. 32 is a flow diagram illustrating an example network-assisted handover procedure.

DETAILED DESCRIPTION

[0042] In the following detailed description, numerous specific details are set forth to provide a thorough understanding of embodiments and/or examples disclosed herein. However, it will be understood that such embodiments and examples may be practiced without some or all of the specific details set forth herein. In other instances, well-known methods, procedures, components and circuits have not been described in detail, so as not to obscure the following description. Further, embodiments and examples not specifically described herein may be practiced in lieu of, or in combination with, the embodiments and other examples described,

disclosed or otherwise provided explicitly, implicitly and/or inherently (collectively "provided") herein.

[0043] Example Communications System

[0044] The methods, apparatuses and systems provided herein are well-suited for communications involving both wired and wireless networks. Wired networks are well-known. An overview of various types of wireless devices and infrastructure is provided with respect to FIGs. 1A-1E, where various elements of the network may utilize, perform, be arranged in accordance with and/or be adapted and/or configured for the methods, apparatuses and systems provided herein.

[0045] FIG. 1A is a diagram of an example communications system 100 in which one or more disclosed embodiments may be implemented. Example communications system 100 is provided for the purpose of illustration only and is not limiting of the disclosed embodiments. 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.

[0046] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104, a core network 106, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d may be configured to transmit and/or receive wireless signals and may include user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, and the like.

[0047] 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.

[0048] 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.

[0049] 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).

[0050] 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).

[0051] 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).

[0052] 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.

[0053] The base station 114b in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In another embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, etc.) to establish a picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the core network 106.

[0054] The RAN 104 may be in communication with the core network 106, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. For example, the core network 106 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104 and/or the core network 106 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104 or a different RAT. For example, in addition to being connected to the RAN 104, which may be utilizing an E-UTRA radio technology, the core network 106 may also be in communication with another RAN (not shown) employing a GSM radio technology.

[0055] 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.

[0056] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities, i.e., the WTRUs 102a, 102b, 102c, 102d may include multiple transceivers for communicating with different wireless networks over different wireless links. For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0057] FIG. 1B is a system diagram of an example WTRU 102. Example WTRU 102 is provided for the purpose of illustration only and is not limiting of the disclosed embodiments. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 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.

[0058] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Array (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0059] 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.

[0060] In addition, although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one embodiment, the WTRU 102 may include two or more transmit/receive elements 122 (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface 116.

[0061] 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.

[0062] 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).

[0063] 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.

[0064] 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.

[0065] 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.

[0066] FIG. 1C is a system diagram of the RAN 104 and the core network 106 according to an embodiment. As noted above, the RAN 104 may employ a UTRA radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 116. The RAN 104 may also be in communication with the core network 106. As shown in FIG. 1C, the RAN 104 may include Node-Bs 140a, 140b, 140c, which may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. The Node-Bs 140a, 140b, 140c may each be associated with a particular cell (not shown) within the RAN 104. The RAN 104 may also include RNCs 142a, 142b. It will be appreciated that the RAN 104 may include any number of Node-Bs and RNCs while remaining consistent with an embodiment.

[0067] As shown in FIG. 1C, the Node-Bs 140a, 140b may be in communication with the RNC 142a. Additionally, the Node-B 140c may be in communication with the RNC 142b. The Node-Bs 140a, 140b, 140c may communicate with the respective RNCs 142a, 142b via an Iub interface. The RNCs 142a, 142b may be in communication with one another via an Iur interface. Each of the RNCs 142a, 142b may be configured to control the respective Node-Bs 140a, 140b, 140c to which it is connected. In addition, each of the RNCs 142a, 142b may be configured to carry out or support other functionality, such as outer loop power control, load control, admission control, packet scheduling, handover control, macrodiversity, security functions, data encryption, and the like.

[0068] The core network 106 shown in FIG. 1C may include a media gateway (MGW) 144, a mobile switching center (MSC) 146, a serving GPRS support node (SGSN) 148, and/or a gateway GPRS support node (GGSN) 150. 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.

[0069] The RNC 142a in the RAN 104 may be connected to the MSC 146 in the core network 106 via an IuCS interface. The MSC 146 may be connected to the MGW 144. The MSC 146 and the MGW 144 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.

[0070] The RNC 142a in the RAN 104 may also be connected to the SGSN 148 in the core network 106 via an IuPS interface. The SGSN 148 may be connected to the GGSN 150. The SGSN 148 and the GGSN 150 may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between and the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0071] As noted above, the core network 106 may also be connected to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0072] FIG. 1D is a system diagram of the RAN 104 and the core network 106 according to another embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 116. The RAN 104 may also be in communication with the core network 106.

[0073] The RAN 104 may include eNode-Bs 160a, 160b, 160c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 160a, 160b, 160c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the eNode-Bs 160a, 160b, 160c may implement MIMO technology. Thus, the eNode-B 160a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0074] Each of the eNode-Bs 160a, 160b, and 160c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink and/or downlink, and the like. As shown in FIG. 1D, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0075] The core network 106 shown in FIG. 1D may include a mobility management gateway (MME) 162, a serving gateway 164, and a packet data network (PDN) gateway 166. 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.

[0076] The MME 162 may be connected to each of the eNode-Bs 160a, 160b, and 160c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 162 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The MME 162 may also provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM or WCDMA.

[0077] The serving gateway 164 may be connected to each of the eNode Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The serving gateway 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The serving gateway 164 may also perform other functions, such as anchoring user planes during inter-eNode B handovers, triggering paging when downlink data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0078] The serving gateway 164 may also be connected to the PDN gateway 166, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0079] The core network 106 may facilitate communications with other networks. For example, the core network 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the core network 106 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the core network 106 and the PSTN 108. In addition, the core network 106 may provide the WTRUs 102a, 102b, 102c with access to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0080] FIG. 1E is a system diagram of the RAN 104 and the core network 106 according to another 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, and 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.

[0081] As shown in FIG. 1E, the RAN 104 may include base stations 170a, 170b, 170c, and an ASN gateway 172, 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 170a, 170b, 170c 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 170a, 170b, 170c may implement MIMO technology. Thus, the base station 170a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a. The base stations 170a, 170b, 170c 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 172 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.

[0082] 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, and 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.

[0083] The communication link between each of the base stations 170a, 170b, and 170c 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 170a, 170b, 170c and the ASN gateway 172 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, 102c.

[0084] As shown in FIG. 1E, 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) 174, an authentication, authorization, accounting (AAA) server 176, and a gateway 178. 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.

[0085] The MIP-HA 174 may be responsible for IP address management, and may enable the WTRUs 102a, 102b, and 102c to roam between different ASNs and/or different core networks. The MIP-HA 174 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 176 may be responsible for user authentication and for supporting user services. The gateway 178 may facilitate interworking with other networks. For example, the gateway 178 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 178 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.

[0086] Although not shown in FIG. 1E, 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.

[0087] FIG. 2 illustrates an example communications system 200 in which embodiments may be practiced or implemented. The communications system 200 is provided for the purpose of illustration only and is not limiting of disclosed embodiments. As shown in FIG. 2, the communications system 200 includes a base station 202 and WTRUs 204a, 204b. As would be understood by a person of skill in the art, the communications system 200 may include additional elements not shown in FIG. 2.

[0088] The base station 202 may be any of the base stations 114 (FIG. 1A), Node-Bs 140 (FIG. 1C), eNode-Bs 160 (FIG. 1D) and base stations 170 (FIG. 1E), for example. The base station 202 may include functionality similar to, and/or different from, the base stations 114, Node-Bs 140, eNode-Bs 160 and base stations 170, as well. For example, the base station 202 may include functionality to support features of 5G and to implement the procedures, techniques, etc. included herein.

[0089] The base station 202 may be configured for small cell operation and/or deployment. The base station 202 may be configured to support any of centimeter wave (cmW) and

millimeter wave (mmW) operation. For simplicity of exposition, the term "xmW" may be used herein to refer to any of cmW and mmW. The base station 202 may be additionally and/or alternatively configured to support various (e.g., all or some) functionality and/or features for small cell operation and/or deployment as specified in 3GPP Release 12. In this regard, the base station 202 may be capable of operating an xmW air interface in parallel, simultaneously and/or otherwise in connection with an LTE, LTE-A or like-type (collectively "LTE") air interface. The base station 202 may be equipped with at least one of various advanced antenna configurations and beamforming techniques, such as those that may allow the base station 202 to simultaneously transmit LTE downlink channels in a wide beam pattern and xmW channels in one or more narrow beam patterns. The base station 202 may also be configured to utilize an LTE uplink configuration adapted with features and procedures (e.g., those detailed herein) to support WTRUs that lack, or do not use their, xmW uplink transmission capabilities.

[0090] Each of the WTRUs 204a, 204b may be any of the WTRUs 102 (FIGs. 1A-1E), for example. Each of the WTRUs 204a, 204b may include functionality similar to, and/or different from, the WTRUs 102, as well. The WTRUs 204a, 204b may include functionality to support features of 5G and to implement the procedures, techniques, etc. included herein. For simplicity of exposition, when "WTRU 204" is used herein, it may refer to any of the WTRUs 204a, 204b.

[0091] Each of the WTRUs 204a, 204b may be configured to support xmW operation. The WTRUs 204a, 204b may be further configured to support various (e.g., all or some) functionality and/or features for user equipment operation and/or deployment as specified in 3GPP Release 12. Each of the WTRUs 204a, 204b may be capable of operating LTE and xmW air interfaces in parallel, simultaneously and/or otherwise in connection with each other. Each of the WTRUs 204a, 204b may have two sets of antennas and accompanying RF chains; one configured for operating in a LTE band and the other configured for operating in a xmW frequency band. However, the present disclosure is not limited thereto, and a WTRU may have any number of sets of antennas and accompanying RF chains. Each of the WTRUs 204a, 204b may include one or more baseband processors, and the baseband processors may include separate, or at least partially combined, functionality for baseband processing of the LTE frequency band and the xmW frequency band. The baseband processing functions may share hardware blocks for the xmW and LTE air interfaces, for example.

[0092] Initial xmW access link system design may focus on cellular system procedures that enable add-on xmW data transmission for example, at least downlink transmission, to an existing network, such as a small cell LTE network. xmW channels may be deployed as an extension of LTE carrier aggregation. A new carrier type in the xmW frequency band, and/or

an air interface different from the LTE air interface may be used, for instance. The xmW channels may lend themselves to opportunistic use for high-throughput and/or low-latency traffic data application.

[0093] Control signaling may be carried in the LTE channels and/or the xmW channels. System information, paging, radio resource control (RRC), network access stratum (NAS) signaling (signaling radio bearers) and multicast traffic may be carried in the LTE channels, for example. Physical layer (PHY) or "L1" control signaling for xmW operation may be carried in the LTE channels and/or the xmW channels.

[0094] Due to the high propagation loss, especially in non-line of sight (NLOS) environments at an xmW frequency band, the base station 202 and/or the WTRUs 204 may employ narrow beamforming, for example to ensure sufficient link budget for high-throughput and low-latency data transmission.

[0095] Transmit and receive narrow beam pairing may be used, and may be well suited for any number of environments. As an example, when operating at any of 28 gigahertz (GHz) and 38 GHz in an urban area, consistent coverage within a cell-radius of up to 200 meters may be achieved by the transmitter of the base station 202 (WTRU 204) and the receiver of the WTRU 204 (base station 202) using respective steerable 10°-beamwidth and 24.5-dBi horn antennas. In an embodiment, the receive beamforming may be regarded as narrow spatial filtering.

[0096] A broad beam pattern may be used in addition the narrow beams employed by the base station 202 and/or the WTRUs 204. The broad beam pattern may be applied for (e.g., traditional) LTE operation, including any of cell search, random access, cell selection/reselection, etc.

[0097] Disclosed in Table 1 below are example parameters of, and/or assumptions regarding, a representative mmW system in which embodiments may be practiced or implemented. The representative mmW system may be implemented in the communications system 200, and for simplicity of exposition, may be described with reference to the example communications system 200. The parameters of, and/or assumptions regarding, the representative mmW system are provided for the purpose of illustration only and is not limiting of disclosed embodiments.

Parameter	Assumption
Carrier Frequency	28 GHz – selected for example system numerology (embodiments herein may be extended to other mmW frequencies, such as 38 GHz, 60 GHz, 72 GHz, etc.)
System Bandwidth	variable up to 1 GHz with aggregation to a higher bandwidth

Estimated Root Mean Square (RMS) Delay Spread	100-200 nanoseconds (<i>ns</i>) with narrow beam pattern
Required Latency	1 millisecond (<i>ms</i>).
Waveform	OFDM-based or broad-band-single-carrier-based
Connectivity	LTE Small Cell adapted with mmW channels and two separate antennas; RF chains connected to two different antenna solutions
Data Rates	DL minimum of 30 megabit (Mbit)/s for at least 95% of WTRUs
Mobility	Optimized data connection at 3 kilometer per hour (km/h); Maintain connection at 30 km/h
Coverage	Satisfy data rate and mobility assumptions within a cell radius of 100 meters

Table 1

[0098] Any of various transmission time intervals (TTIs) and various system bandwidths may be supported by the representative mmW system. Among the TTIs supported are those that have a duration of 100 microseconds (*us*) or other value for achieving low latency. Among the system bandwidths supported are those in the range of 50 megahertz (MHz) to 2 GHz or other value for achieving high data rates.

[0099] A frame structure of an applied waveform may be used in the representative mmW system. Various other frame structures may be used as well. The frame structure of an OFDM-based waveform ("OFDM-based frame structure") may offer flexibility in coordination between the LTE and mmW channels and/or may enable common functional block sharing in the WTRUs 204. A basis for using the OFDM-based frame structure is provided herein below.

[0100] A mmW sampling frequency may be set as an integer multiple of the LTE minimum sampling frequency of 1.92 MHz. In turn, a mmW OFDM sub-carrier spacing, Δf , may be set as an integer multiple, K , of the LTE sub-carrier spacing of 15 kilohertz (kHz), i.e., $\Delta f = 15 * K$ kHz. The setting of the integer multiple, K , and the resulting mmW OFDM sub-carrier spacing, Δf , may take into consideration sensitivity to Doppler shift, different types of frequency errors and ability to remove channel time dispersion.

[0101] The orthogonality between sub-carriers may deteriorate and inter-sub-carrier interference may increase when the Doppler shift increases in proportion to the sub-carrier spacing. For example, the maximum Doppler shift at 30 km/h and 28 GHz is 778 Hz. And a recent 28 GHz channel time dispersion measurement in dense urban area made by New York University (NYU) Polytechnic indicates the RMS delay spread, σ , is between 100 and 200 *ns* up to 200 meter (*m*) cell radius. The 90% coherence bandwidth may be estimated at $1/50\sigma$ of 100 kHz and the 50% coherence bandwidth at $1/5\sigma$ of 1 MHz. A sub-carrier spacing Δf between

100 kHz and 1 MHz may thus be reasonable. A sub-carrier spacing of 300 kHz ($K=20$) may be robust against Doppler shift and other types of frequency error and reduce considerably the implementation complexity. The corresponding symbol length ($1/\Delta f$) is $3.33 \mu s$.

[0102] A cyclic prefix (CP) length is normally required to span over the entire length of the channel time dispersion to eliminate the inter-symbol interference (ISI). However, because the CP does not carry useful data, a long duration CP can result in excessive CP overhead. In consideration of ISI elimination and excessive CP overhead avoidance for a T_{symbol} of $3.33 \mu s$, the CP length, T_{CP} , may be $1/14$ of T_{symbol} , $0.24 \mu s$. In this case, the corresponding CP overhead is 7% as calculated by $T_{\text{CP}} / (T_{\text{CP}} + T_{\text{symbol}})$.

[0103] In order to achieve low latency, the TTI length of the mmW transmission may be significantly less than the $1 ms$ TTI length of the LTE system. It may be beneficial to have a mmW sub-frame length of $1 ms$ to align with the LTE $1 ms$ sub-frame timing. The mmW sub-frame may contain multiple mmW TTIs whose lengths are tied to other parameters such as sub-carrier spacing, symbol length, CP length, fast Fourier transform (FFT) size, etc.

[0104] With the above considerations taken into account, an example with a conservative CP length using a 4x channel delay spread is summarized in Table 2. It should be noted the CP length selection is based on the assumption that the delay spread over all potential mmW frequency bands is lower than $200 ns$.

OFDM Numerology Parameters				
System bandwidth (MHz)	125	250	500	1000
Sampling rate (MHz)	153.6	307.2	614.4	1228.8
Sub-carrier spacing (kHz)	300	300	300	300
Number of sub-carrier per RB	12	12	12	12
RB bandwidth (MHz)	3.6	3.6	3.6	3.6
Number of assignable RBs	32	64	128	256
Number of occupied sub-carriers	384	768	1536	3072
Occupied bandwidth (MHz)	115.2	230.4	460.8	921.6
IDFT(Tx)/DFT(Rx) size	512	1024	2048	4096
OFDM symbol duration (μs)	3.333	3.333	3.333	3.333
CP length (ratio to symbol length)	1/4	1/4	1/4	1/4
CP length (μs)	0.833	0.833	0.833	0.833
Number of symbols per slot	24	24	24	24
Slot duration (TTI) (μs)	100	100	100	100
Sub-frame duration (ms)	1	1	1	1
Number of slots per sub-frame	10	10	10	10
Frame duration (ms)	10	10	10	10
Number of sub-frames per frame	10	10	10	10

Number of symbols per TTI per RB	288	288	288	288
Number of symbols per TTI using all RBs	9216	18432	36864	73728
Signaling overhead	20%	20%	20%	20%
Data rate using uncoded 64QAM (Mbps)	442.368	884.736	1769.472	3538.944
Spectral efficiency	3.538944	3.538944	3.538944	3.538944

Table 2
(Example mmW Downlink OFDM Numerology)

[0105] FIGs. 3A-3B illustrate an example OFDM-based frame structure 300. As shown, the OFDM-based frame structure 300 may be used in the representative mmW system, where, for example, the system bandwidth is 1 GHz, the sub-carrier spacing is 300 kHz, the symbol length is $3.33 \mu s$ and the CP length is $1/4$ of T_{symbol} (or $0.833 \mu s$).

[0106] The OFDM-based frame structure 300 assumes an OFDM-based mmW waveform, which may be readily incorporated into the OFDM-based LTE (e.g., small cell) network. However, the OFDM-based frame structure 300 is provided for the purpose of illustration only and is not limiting of disclosed embodiments. For example, the system procedures disclosed herein are not bound by this specific frame structure and may be applied to other waveforms, as well.

[0107] New reference signals, PHY channels and/or higher layer (e.g., transport layer) channels for mmW operation may be employed in the representative mmW system. The mmW reference signals, PHY channels and/or higher layer channels may be employed in addition to the existing LTE reference signals, PHY channels and/or higher layer channels. The mmW reference signals may include any of a beam-specific reference signal (BSRS), an adaptive antenna reference signal (AARS) and a demodulation reference signal (DMRS). The mmW PHY channels may include any of a physical downlink directional control channel (PDDCCH) and a physical downlink directional data channel (PDDDCH). The mmW higher layer channels may include a downlink directional data channel (DL-DDCH). An example channel mapping with mmW channels is illustrated in FIG. 4.

[0108] The BSRS may be a unique sequence transmitted per transmit beam, and may be used for any of beam acquisition, timing/frequency synchronization, channel estimation for the PDDCCH, beam tracking and measurement, etc. The BSRS may carry (e.g., implicitly) beam identity information. The beam identity information may include a BSRS sequence index. Different types of BSRSs may be used. The resources (e.g., time and frequency resources) that may be used to transmit BSRSs may be pre-defined and known to the devices..

[0109] The AARS may be a unique sequence scheduled and transmitted dynamically, and may be used for beam pair measurement specific to an antenna port. The AARS may embed (e.g., implicitly) the beam identity information in the sequence index and/or carry a small payload including the same information.

[0110] The PDDCCH may carry (e.g., all) data related control information for a WTRU to identify, demodulate and decode the associated PDDCH correctly. The PDDCCH may be carried in a mmW narrow beam or broad beam, and may apply different multiple accesses (e.g., TDD, FDD, etc.). For example, when WTRU-specific data transmission is on-going, there may be a common PDDCCH transmitted in a downlink mmW broad beam covering a sector or cell and a dedicated PDDCCH only transmitted in a narrow beam pair. The dedicated PDDCCH may carry scheduling information for its associated PDDCH on a per-TTI basis and may not carry beam specific information. A common PDDCCH may include cell-specific information including sector/segment identity or beam identity. In addition, a WTRU may read the common PDDCCH to determine if it is scheduled for a narrow beam pairing procedure in order to begin (e.g., perform) narrow beam data transmission.

[0111] The PDDCH may carry payload information received in the form of a MAC PDU from a mmW medium access control (MAC) layer. The complete resource allocation of this channel is determined by the downlink scheduling information carried in PDDCCH. The PDDCH intended for a WTRU may be transmitted in a narrow transmit (Tx) beam and received in a properly paired narrow receive (Rx) beam, for example a narrow beam pair. Due to this spatial isolation between the narrow Tx and Rx beams, PDDCHs for different WTRUs in different beam pairs may reuse any of a time, a frequency and a code resource. Multiple PDDCHs may also operate in one beam pair using multiple access in a time, frequency, or code domain. In addition, a common PDDCH may be used to carry data in broad mmW antenna pattern associated with the common PDDCCH.

[0112] The DMRS may include symbols embedded in the transmission for channel estimation for PDDCH. They may be placed in both time and frequency domains according to a (pre-)defined pattern to ensure correct interpolation and reconstruction of the channel.

[0113] All channels and reference signals in a narrow beam (or narrow beam pair) may be beamformed identically and may be considered to be transmitted via one physical antenna port. Given directivity of the transmission, carrying broadcast or multicast information on the narrow beam might not be optimal.

[0114] Various beamforming techniques and/or architectures may be implemented by/at a WTRU 204 and/or a base station 202 in the representative mmW system. The WTRU 204 may

use a phased antenna array (PAA). The PAA may provide a beamforming gain for compensating high path loss at mmW frequencies; the short wavelengths of which allow a compact form factor to be used for the PAA. Spacing between elements of the PAA may be 0.5λ (as is typically used in theoretical performance analysis), or larger, e.g., 0.7λ , where λ is the wavelength corresponding to the carrier/center frequency of the mmW band. The PAA may be implemented in various ways, such as shown in FIGs. 5-9.

[0115] Referring to FIG. 5, an example PAA 502 implemented in a transceiver 500 using a fully digitized beamforming approach is shown. The transceiver 500 may include a dedicated RF chain 506 for each antenna element 504 of the PAA 502. Each dedicated RF chain 506 may include an RF processing element 508 and an analogue-to-digital converter (ADC) 510. Signals processed by each of the antenna elements 504 may be controlled independently in phase and amplitude to optimize the channel capacity.

[0116] FIG. 6 illustrates an example PAA 602 implemented in a transceiver 600 using an analogue beamforming approach. The transceiver 600 may include a single RF chain 606 for the entire PAA 602. Each antenna element 604 of the PAA 502 is communicatively coupled to a phase shifter 612. Each phase shifter 612 may be used to set weights for beamforming and/or steering. As compared to the fully digitized beamforming approach of the transceiver 500 (FIG. 5), the analogue beamforming approach of the transceiver 600 may be less costly and complex, and may have lower energy consumption in operation, due in part to the lesser number of RF chains.

[0117] In the example shown, a phase of a signal at each antenna element is adjusted (e.g., shifted) in the beamforming. The phase shifting and combining may be implemented in different stages, including any of RF, baseband (BB) analogue and local oscillator (LO).

[0118] FIG. 7 illustrates an example PAA 702 implemented in a transceiver 700 using an analogue beamforming approach. The analogue beamforming approach of the transceiver 700 is similar to the analogue beamforming approach of the transceiver 600, except that it includes two RF chains 706A-B communicatively coupled to the single PAA 702. FIG. 8 illustrates example PAAs 802A-B implemented in a transceiver 800 using an analogue beamforming approach. The analogue beamforming approach of the transceiver 800 is similar to the analogue beamforming approach of the transceiver 700 in that the PAAs 802A-B have respective dedicated RF chains 806A-B. FIG. 9 illustrates an example of multiple PAAs 802A-N implemented in a transceiver 900 using an analogue beamforming approach. The analogue beamforming approach of the transceiver 900 is similar to the analogue beamforming approach of the transceiver 600 in that the multiple PAAs 802A-B have a single RF chain 906.

[0119] Analogue beamforming algorithms may include fixed codebook-based beamforming and continuous phase shifting beamforming. Using fixed codebook-based beamforming, a grid or fixed set of beams may be generated. Each beam is formed by applying a beamforming weight vector v chosen from a pre-defined codebook $v \in \{v_1, v_2, v_3 \dots v_N\}$ where N denotes the number of fixed beams. Each vector may include pre-calibrated phase shifts for all phase shifters, and may represent a unique analogue beam direction, i.e. "beam". The number of beams may depend on a half-power-beam-width (HPBW) of the beamforming and desired coverage.

[0120] Using continuous phase shifting beamforming, the desired weight for each phase shifter may be calculated based on estimated short-term channel information and converted using a high resolution digital-to-analogue converter (DAC) in order to apply to the phase shifter. Continuous phase shifting beamforming may provide a continuous and adaptive beamforming to track the channel conditions. Continuous phase shifting beamforming may perform well in scenarios with increased multipath, high angular spread and low WTRU mobility.

[0121] Although not shown, a hybrid beamforming approach may be employed. The hybrid approach may combine some elements of digital and analogue beamforming approaches. This hybrid beamforming approach may include analogue beamforming performed over PAA antenna elements associated with respective phase shifters, and all PAA antenna elements and associated phase shifters may be communicatively coupled to one or more RF chain. This approach may further include digital precoding applied on the baseband signal of each of the RF chains when there is more than one RF chain. MIMO embodiments may be implemented using digital precoding, for example.

[0122] Basic system parameters of hybrid beamforming may include any of a number of data streams, N_{DATA} , a number of RF chains (TRX), N_{TRX} , a number of antenna ports (AP), N_{AP} , a number of antenna elements (AE), N_{AE} , and a number of PAAs, N_{PAA} . Configuration of these parameters may impact system functions and performance, e.g., as disclosed herein.

[0123] In an embodiment, the $N_{PAA} \leq N_{AP} \leq N_{TRX} \leq N_{AE}$.

[0124] One PAA may include multiple antenna elements, for example a PAA of size 4x4 has 16 antenna elements. An antenna port may be defined such that the channel over which a symbol on the antenna port is conveyed may be inferred from the channel over which another symbol on the same antenna port is conveyed. There may be one resource grid per antenna port. Cell-specific reference signals may support a configuration of one, two, or four antenna ports and may be transmitted on antenna ports $p = 0$, $p \in \{0,1\}$ and $p \in \{0,1,2,3\}$, respectively. MBSFN

reference signals may be transmitted on antenna port $p = 4$. WTRU-specific reference signals associated with PDSCH may be transmitted on antenna port(s) $p = 5, p = 7, p = 8$, or one or several of $p \in \{7,8,9,10,11,12,13,14\}$. Demodulation reference signals associated with EPDCCH may be transmitted on one or several of $p \in \{107,108,109,110\}$. Positioning reference signals may be transmitted on antenna port $p = 6$. CSI reference signals may support a configuration of one, two, four or eight antenna ports and may be transmitted on antenna ports $p = 15, p \in \{15,16\}, p \in \{15,16,17,18\}$, and $p \in \{15,16,17,18,19,20,21,22\}$, respectively. Each antenna port may carry a beamformed reference signal uniquely associated with that antenna port. The beamformed reference signal may be used to identify the antenna port. When the number of TRX equals the number of antenna elements, for example, one RF chain per antenna element, the antenna configuration becomes a fully digitized solution (e.g., as shown in FIG. 5).

[0125] One PAA may be connected to one RF chain in accordance with FIG. 6, or to multiple RF chains depending on the system requirement and configuration. In accordance with FIG. 7, for example, one PAA of size 4×4 may be connected to two RF chains and each RF chain has a set of 16 phase shifters. The PAA may form two narrow beam patterns within a $+45^\circ$ and -45° coverage in azimuth plane. In this configuration, $N_{PAA} < N_{AP} = N_{TRX} < N_{AE}$.

[0126] In accordance with FIG. 8, each of two PAAs may be communicatively coupled to a dedicated RF chain, for example $N_{PAA} = N_{AP} = N_{TRX} \leq N_{AE}$. This configuration may allow for spatial independence between the two simultaneous beams by placing the PAAs at different orientations, for example in an azimuth plane. An aligned PAA arrangement may provide an aggregated larger coverage compared to the configuration in FIG. 7. The configurations with two RF chains may apply MIMO with two data streams.

[0127] In an embodiment, $N_{AE} > N_{PAA} > N_{AP} = N_{TRX}$. Multiple PAAs may be communicatively coupled to a single RF chain by using a switch in accordance with FIG. 9. Each PAA may form a narrow beam pattern covering from $+45^\circ$ to -45° in an azimuth plane. Each PAA may be oriented separately so a single-beam solution may also provide a good coverage by using a narrow beam at different direction at different time instances.

[0128] In an embodiment, $N_{DATA} \leq N_{TRX} \leq N_{AE}$. When $N_{DATA} = N_{TRX} = 1$, a single-beam configuration is employed and operation may be carried out using one beam at a time. The beamforming may form a narrow beam pattern at the strongest angular direction, for example, a line-of-sight (LOS) path obtained from beam measurement. Alternatively, the beamforming

may form a broad beam pattern, for example, a wide main lobe to cover a range of continuous angular directions including both strong and weak ones in-between.

[0129] When $N_{DATA} = 1 < N_{TRX}$, for example when $N_{TRX} = 2$, two simultaneous beam patterns may be employed and the beam patterns may be different and/or used for different applications. Two narrow beam patterns may be formed at different angular incoming directions to receive one data stream. Coherent beam combining, for example, may be used to utilize spatial diversity and mitigate the blockage effect and/or weak LOS condition. Alternatively, one narrow beam and one broad beam may be formed. The narrow beam may be used for data transmission and the broad beam for control signaling, for example.

[0130] When $1 < N_{DATA} = N_{TRX}$, for example, the transmission may apply MIMO to increase the capacity, for example in high SNR channel condition. Two narrow beam patterns may be formed at different angular incoming directions to receive two data streams in parallel.

[0131] Although described with reference to a WTRU, the example beamforming approaches may be carried out by a base station. The base station beamforming embodiments may also include fixed beam, adaptive beamforming, for example codebook-based and non-codebook-based, and classical beamforming, for example direction-of-arrival (DoA) estimation. Each embodiment may require different procedures and work well in certain scenarios. For example the DoA estimation may require smaller angular spread and a WTRU may need to transmit a LTE uplink reference signal to ensure DoA accuracy. The fixed beam system may require beam cycling and switch procedures.

[0132] The antenna configuration and beamforming in the description that follows are based on a single beam antenna configuration with analogue beamforming, such as illustrated in FIG. 6.

[0133] As used herein the term "beam" may refer to one of the lobes, for example, main/side/grating lobes of a transmit radiation pattern and/or receive gain pattern of an antenna array. The term "beam" may denote a spatial direction that may be represented with a set beamforming weights. A beam may be identified and/or associated with a reference signal, an antenna port, a beam identity (ID), a scrambling sequence number and may be transmitted and/or received at a specific time and/or frequency and/or code and/or spatial resources. A beam may be formed digitally, in an analogue manner or both (hybrid beamforming). The analogue beamforming may be based on fixed code-book or continuous phase shifting.

[0134] A data channel beam may be used to transmit any of a data channel, data channel beam, PDSCH, , mmW PDSCH (mPDSCH), mmW data channel, directional PDSCH, beamformed data channel, spatial data channel, data channel slice or high frequency data channel. A data

channel beam may be identified or associated with any of a reference signal, an antenna port, a beam identity (ID), a scrambling sequence number and may be transmitted and/or received at a specific time and/or frequency and/or code and/or spatial resources.

[0135] A control channel beam may be used to transmit any of a control channel, control channel beam, PDCCH, mPDCCH, mmW PDCCH, mmW control channel, directional PDCCH, beamformed control channel, spatial control channel, control channel slice or high frequency control channel. A control channel beam may be identified or associated with a reference signal, an antenna port, a beam identity (ID), a scrambling sequence number and may be transmitted and/or received at a specific time and/or frequency and/or code and/or spatial resources.

[0136] A control channel beam duration may be a number of OFDM symbols in a TTI occupied by one control channel beam.

[0137] A control region may be the number of OFDM symbols in a TTI occupied by all the control channel beams transmitted in the TTI.

[0138] A measurement beam may be used to transmit a signal or channel for beam measurement including any of a beam reference signal, beam measurement reference signal, CRS, CSI-RS, CSI-IM, etc. A measurement beam may be identified or associated with a reference signal, an antenna port, a beam identity (ID), a scrambling sequence number and may be transmitted and/or received at a specific time and/or frequency and/or code and/or spatial resources.

[0139] In embodiments described herein, base station, eNB, mmW base station/eNB (mB), cell, small cell, PCell, SCell may be used interchangeably. The term "operate" may be used interchangeably with transmit and/or receive. The terms "component carrier" and/or the terms "mmW carrier" may be used interchangeably with serving cell.

[0140] In some embodiments, the term WTRU may be substituted for eNB and/or vice versa and still be consistent with this disclosure. In some embodiments UL may be substituted for DL and/or vice versa and still be consistent with this disclosure.

[0141] The term "channel" may refer to a frequency band which may have a center or carrier frequency and a bandwidth. Spectrum may include one or more channels which may or may not overlap. Channel, frequency channel, wireless channel, and mmW channel may be used interchangeably. Accessing a channel may be the same as using, for example, transmitting and/or receiving on or using the channel.

[0142] The term "channel" may refer to a mmW channel and/or signal, such as an uplink channel and/or signal and/or downlink channel or signal. Downlink channels and signals may

include one or more of a mmW synchronization signal, mmW broadcast channel, mmW cell reference signal, mmW beam reference signal, mmW beam control channel, mmW beam data channel, mmW hybrid ARQ indicator channel, mmW demodulation reference signal, PSS, SSS, DMRS, CRS, CSI-RS, PBCH, PDCCH, PHICH, EPDCCH, and PDSCH. Uplink channels and signals may include one or more of a mmW PRACH, mmW control channel, mmW data channel, mmW beam reference signal, mmW demodulation reference signal, PRACH, PUCCH, SRS, DMRS and PUSCH. Channel and mmW channel may be used interchangeably. Channels and signals may be used interchangeably. PRACH and preamble may be used interchangeably.

[0143] The terms "data/control" may refer to data and/or control signals and/or channels. Control may include synchronization. The data/control may be mmW data/control. Data/control and data/control channels and/or signals may be used interchangeably. Channels and signals may be used interchangeably. The terms control channel, control channel beam, PDCCH, mPDCCH, mmW PDCCH, mmW control channel, directional PDCCH, beamformed control channel, spatial control channel, control channel slice, high frequency control channel may be used interchangeably. The terms data channel, data channel beam, PDSCH, mPDSCH, mmW PDSCH, mmW data channel, directional PDSCH, beamformed data channel, spatial data channel, data channel slice, high frequency data channel may be used interchangeably.

[0144] The terms "channel resources" may refer to any of time, frequency, code and/or spatial resources (e.g., 3GPP LTE or LTE-A resources). The channel resources may carry one or more channels and/or signals. The terms "channel resources" may be used interchangeably with channels and/or signals.

[0145] The terms mmW beam reference signal, mmW reference resource for beam measurement, mmW measurement reference signal, mmW channel state measurement reference signal, mmW demodulation reference signal, mmW sounding reference signal, reference signal, CSI-RS, CRS, DM-RS, DRS, measurement reference signal, reference resource for measurement, CSI-IM, and measurement RS may be used interchangeably. mmW cell, mmW small cell, SCell, secondary cell, license-assisted cell, unlicensed cell, and LAA cell may be used interchangeably. mmW cell, mmW small cell, PCell, primary cell, LTE cell, and licensed cell may be used interchangeably.

[0146] The terms interference and interference plus noise may be used interchangeably.

[0147] A WTRU may determine the UL and/or DL directions of one or more subframes according to one or more received and/or configured TDD UL/DL configurations. UL/DL and UL-DL may be used interchangeably.

[0148] The terms transmit power, power, antenna array transmit power may be used interchangeably. The terms μ W, mW and mmW may be used interchangeably.

[0149] By way of background, the throughput of wireless communication systems has increased significantly by new technologies introduced in LTE and Wi-Fi. These technologies, however, are not sufficient to meet the demands of future applications which will require Gbits/sec of throughput and latencies of 1 ms. Therefore, research on a new RAT, known as 5G, has already started.

[0150] One of the critical components of the 5G RAT will be the radio waveform. OFDM has been and is currently used for LTE and Wi-Fi. Benefits of OFDM include its simplicity in converting a frequency selective channel into smaller flat fading sub channels, allowing one-tap equalization per sub-channel. Discrete Fourier transform spread OFDM (DFT-s-OFDM) improves peak-to-average power ratio (PAPR) of OFDM by spreading a data sequence with DFT before loading the spread signal onto sub-channels.

[0151] Both OFDM and DFT-s-OFDM append a CP to each OFDM symbol. The CP may operate as a guard against inter-symbol interference (ISI) that may occur due to delay spread of a channel, and to ensure cyclicity. The CP length is typically fixed and dimensioned for a maximum delay spread of the channel. Loss of spectral efficiency occurs, however, when the actual delay spread of the channel is less than the CP length. The loss may be significant when the variance of the RMS delay spread of the channel is large. For example, in mmW channels, the delay spread may be below 4 ns for indoor channels in LOS conditions, and up to 70 ns for indoor channels in non-LOS (NLOS) conditions. Since changing the CP length would change the number of OFDM symbols in a subframe, configuring many different CP sizes is generally not feasible for a fixed sub-frame duration.

[0152] Zero tail (ZT) OFDM based waveforms may be used as an alternative to CP-appended OFDM based waveforms. The ZT OFDM based waveforms decouple numerology from channel characteristics. In a ZT OFDM based waveform, each OFDM symbol has a zero tail of a given duration. The zero tail duration may be dynamically adapted to the channel delay spread, without changing the OFDM symbol duration. In addition, the zero tail may be used as a gap for beam switching, DL/UL switching, and interference measurement in mmW channels.

[0153] FIG. 10 is a block diagram illustrating an example pulse shaping unit 1000 of a transmitter configured to generate a ZT DFT-s-OFDM waveform. The pulse shaping unit 1000 may include a M-point DFT unit 1010, a subcarrier mapping (SM) unit 1012 and an N-point inverse fast Fourier transform (IFFT) unit 1014. An OFDM symbol with a zero tail and/or a zero head output from the N_{IFFT} -point IFFT unit 1014 may include M data symbol samples and

($N_{\text{IFFT}}\text{-point}/M-1$) interpolated samples between each of the M data symbols. The samples forming the OFDM symbol output from the $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014 may be generated by feeding N_h and N_t zeros into inputs at the head and tail of the $M\text{-point}$ DFT unit 1010 and by feeding N_d data symbols into inputs between the head and tail of the $M\text{-point}$ DFT unit 1010.

[0154] The N_h and N_t zeros fed to the inputs to the $M\text{-point}$ DFT unit 1010 may result in samples of zero values, almost zero values or a combination of both values (collectively " $\sim$ zero valued samples") on the head and/or tail of the $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014 by the combined operation of the $M\text{-point}$ DFT unit 1010, SM unit 1012 and $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014. In general, the output of the $M\text{-point}$ DFT unit 1010 fed to the SM unit 1012 is mapped to a subset of subcarriers and output from the SM unit 1012 to a continuous set of inputs of $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014 corresponding to the subset of subcarriers. The $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014 processes the set of inputs and passes the processed inputs to its outputs.

[0155] The N_h zeros fed into the inputs at the head of the $M\text{-point}$ DFT unit 1010 may result in N_{zh} $\sim$ zero valued samples output at the head of the $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014. The N_t zeros fed into the inputs at the tail of the $M\text{-point}$ DFT unit 1010 may result in N_{zt} $\sim$ zero valued samples output at the tail of the $N_{\text{IFFT}}\text{-size}$ IFFT unit 1014. Although the OFDM symbol output from $N_{\text{IFFT}}\text{-point}$ IFFT unit 1014 includes the N_{zh} $\sim$ zero valued samples and N_{zt} $\sim$ zero valued samples corresponding to the N_h zeros and N_t zeros fed into the $M\text{-point}$ DFT unit 1010, the tail/head of the OFDM symbol might not be exactly zero due to (at least some of) the interpolated samples being data dependent. In addition, since the interpolated samples are data dependent, the zero tail/head may be different from one DFT-s symbol to the next. One shortcoming of the ZT DFT-s OFDM signal is that the non-perfect zero tail breaks the cyclic property of the OFDM signal and creates ISI. This results in a bit-error-rate (BER) floor at high SNR in high delay spread channels.

[0156] Although the zero tail/head generation mechanism shown in FIG. 10 is for DFT-s OFDM waveforms, modifications to other high complexity solutions for zero tail/head generation of other OFDM waveforms will be apparent to those skilled in the art from the foregoing descriptions.

[0157] FIG. 11 is a block diagram illustrating an example a transmitter 1100 configured to generate a unique word OFDM (UW-OFDM) waveform. An OFDM symbol generated by the transmitter 1100 includes a fixed pilot, referred to as the "unique word". The unique word may be used for synchronization, channel estimation and phase tracking purposes. The unique word may operate as a guard interval against ISI and may maintain cyclicity obviating a need for a CP.

[0158] The transmitter 1100 may include a redundant data generation unit 1108, a permutation unit 1110, a B unit 1112, an N_{IFFT} -point IFFT unit 1114, a unique word insertion (UW-insertion) unit 1116, and a parallel to serial converter 1118. The redundant data generation unit 1108 may receive N_d modulation data symbols, d . The redundant data generation unit 1108 may output N_r redundant data signals, r , to the permutation unit 1110. The redundant data generation unit 1108 may generate the N_r redundant data signals by precoding the N_d modulation data symbols.

[0159] The permutation unit 1110 may receive the N_d modulation data symbols and the N_r redundant data signals. The permutation unit 1110 may apply a permutation matrix to map the N_d modulation data symbols and N_r redundant data signals to appropriate subcarriers. The subcarriers to which the N_r redundant data signals are mapped may be selected so that a power of the redundant data does not become excessive.

[0160] The B unit 1112 may receive the subcarrier mapped N_d modulation data symbols and N_r redundant data signals. The B unit 1112 may insert one or more null valued subcarriers for guard bands. The B unit 1112 may output to the N_{IFFT} -point IFFT unit 1114 a signal, N_{IFFT} , including the subcarrier mapped N_d modulation data symbols, N_r redundant data signals and null values. The N_{IFFT} -point IFFT unit 1114 may receive the signal, N_{IFFT} , and may generate samples corresponding to the signal, N_{IFFT} . The samples generated from the null values may be forced to zero and may be output from the tail of the N_{IFFT} -point IFFT unit 1114 to form the tail of the OFDM symbol. The UW-insertion unit 1116 may receive the outputs from the N_{IFFT} -point IFFT unit 1114. The UW-insertion unit 1116 may insert a deterministic unique sequence (unique word) into the zeroed tail of the OFDM symbol. The deterministic unique sequence may be used to facilitate tasks, such as synchronization, channel estimation, etc.

[0161] The transmitted signal with zero tail may be written as $F_{N_{\text{IFFT}}}^H B P \begin{bmatrix} d \\ r \end{bmatrix} = \begin{bmatrix} x_d \\ 0 \end{bmatrix}$ where B inserts the zero subcarriers for the guard bands. Writing, $M = F_{N_{\text{IFFT}}}^H B P = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$, the redundant data may be computed as $r = T d$ where $T = -M_{22}^{-1} M_{21}$.

[0162] The shortcomings of the UW OFDM signal include: (i) high Tx and Rx complexity; (ii) for each resource allocation, the permutation matrix P needs to be optimized to minimize the power of the redundant subcarriers (this results in both computational complexity at the transmitter, and in signaling overhead, as knowledge of the permutation matrix is required at the receiver, in order to decode the data); and (iii) due to the need to optimize the permutation matrix for each resource allocation, support of frequency domain scheduling and multi-user is very difficult with UW-OFDM.

[0163] Initial Cell Synchronization Overview

[0164] Initial cell synchronization (ICS) may be defined as determining downlink timing and the identity of a cell. ICS may be performed when a WTRU is turned-on to search for a suitable cell to camp on. The cell search may provide functionality to determine signal power level for a specific channel, such as PCPICH in UMTS and CRS in LTE, and to determine the received signal strength indicator (RSSI) level in order to help trigger events such as handover and cell reselection.

[0165] FIG. 12 illustrates an example UMTS signaling structure 1200 for a primary synchronization channel (P-SCH), a secondary synchronization channel (S-SCH), and a common pilot channel (CPICH). As shown in FIG. 12, SYNCH (P-SCH and S-SCH) and PBCH channels utilize separate resources.

[0166] Synchronization may be carried out in three phases. The first phase may include performing slot offset detection on the P-SCH, The second phase may include performing group number detection on the S-SCH (64 groups with 16 codes in each, that constructs 512 Primary Cell IDs), and performing frame timing detection on the S-SCH. The third phase may include performing Cell ID detection using the P-CPICH. After the third phase, the master information block (MIB) and system information blocks (SIBs) may be read. Detectible cells include those with P-SCH and S-SCH SNIR > -20 dB and P-CPICH SNIR > -20 dB. Initial synchronization time is < 5s in a known channel, and encompasses the periods for performing the three synchronization phases, reading the MIB and SIBs and performing RACH preamble transmission.

[0167] FIG. 13 illustrates an example LTE signaling structure 1300 for a primary synchronization signal (PSS), a secondary synchronization signal (SSS), and a physical broadcast channel (PBCH). As shown in FIG. 13, the SYNCH (PSS and SSS) and PBCH channels may utilize separate resources and may be spread over 6 resource blocks (RBs), and 62 center subcarriers.

[0168] Synchronization may be carried out in three phases. The first phase may include performing symbol timing offset detection using the PSS and determining whether $N_{id}(2) = \{0, 1, 2\}$. The second phase may include performing frame timing detection using the SSS, determining whether the CP length = {normal, extended, determining whether $N_{id}(1) = \{0, 1, \dots, 168\}$ and determining whether the $Cell_ID = f(N_{id}(1), N_{id}(2))$. The third phase may include reading the MIB and SIBs along with determining the bandwidth, number of antennas, etc. Detectible cells include those with PSS and SSS SNIR > -3 dB. Initial synchronization time is

< 5s in a known channel, and encompasses the periods for performing the three synchronization phases, reading the MIB and SIBs and performing RACH preamble transmission.

[0169] Example High Efficiency OFDM based Waveforms

[0170] Zero tail based waveforms and other high efficiency OFDM based waveforms (collectively "*he*-OFDM-based waveforms") may decouple numerology from channel characteristics. The zero tail duration may be dynamically adapted to the channel delay spread, without changing the OFDM symbol duration. In addition, the zero tail may be used as a gap for beam switching, DL/UL switching, and interference measurement in mmW channels.

[0171] In order to increase resource allocation efficiency, *he*-OFDM-based waveforms, such as ZT DFT-s OFDM, UW OFDM and their variants, are proposed to enable variable cyclic-prefix lengths within an OFDM symbol. In today's communication standards, such as UMTS and LTE, independent resources are allocated for the transmission of SYNCH and PBCH channels. By leveraging the proposed waveforms, the simultaneous transmission of SYNCH and PBCH channels over the same symbols is desirable in order to increase resource utilization efficiency.

[0172] In highly directional antenna beamforming based cellular systems designed for cmW and mmW bands, a coverage mismatch may happen between initial system acquisition (ICA) and regular (e.g., post-ICA) operations of user data exchange due to beamforming gains. Extending ICA coverage area by leveraging wide beams may require very long synchronization sequences and heavy coding on system information (SI) bits. That, in turn, may reduce initial acquisition time (IAT), but may reduce resource utilization efficiency. Utilization of narrow beams may increase cell radius for control plane channels, such as SYNCH and PBCH, and might reduce the need for long synchronization sequences and heavy coding on SI bits. But with such narrow beam usage, search space may be comparably larger than with wide beams, and targets can be missed. In this case, the impact of utilization of narrow beams becomes the overall IAT increase. Therefore, there may be a need to design the system optimally and adaptively for initial synchronization.

[0173] This disclosure is drawn, *inter alia*, to methods, apparatuses, systems, devices, and computer program products directed to highly directional systems, and to initial synchronization in the highly directional systems. In an embodiment, a *he*-OFDM-based waveform may be leveraged (adapted) for initial synchronization. Such *he*-OFDM-based waveform may be, for example, any of a zero-tail (ZT) discrete Fourier transform (DFT) spread OFDM ("ZT DFT-s-OFDM") waveform; a unique word (UW) DFT-s-OFDM waveform; an enhanced ZT (eZT) DFT-s-OFDM waveform; a eZT OFDM based waveform; a variant of any

of the ZT DFT-s-OFDM, UW DFT-s-OFDM, eZT DFT-s-OFDM and eZT OFDM based waveforms; and another like-type waveform.

[0174] In an embodiment, initial synchronization may be carried out using an OFDM signal that carries synchronization information in at least a tail portion of one or more modulation symbols of each OFDM symbol. The modulation symbol(s) may be concentrated within a single sub-band (i.e., in a single subcarrier or in multiple consecutive subcarriers), for example. This single sub-band may map to a particular sub-band of the available channel, such as, for example, a center sub-band of the available channel. Alternatively, the modulation symbols may be dispersed among multiple sub-bands, and such multiple sub-bands may map to, for example, the center sub-band and other sub-bands. The other sub-bands may be selected to avoid the power of modulated symbols becoming excessive.

[0175] In an embodiment, the synchronization information carried in the tail portions of the modulation symbols may include symbol timing synchronization information. In an embodiment, the synchronization information carried in non-tail portions of the modulation symbols may include a sequence for identifying a cell identity (ID) and/or a physical broadcast channel (PBCH).

[0176] Pursuant to new methodologies and/or technologies provided herein, the OFDM signal may be generated by leveraging (adapting) a *he*-OFDM-based waveform generated signal. As an example, a time domain signal having a zero tail ("zero-tail time domain signal") may be generated using (i) a *he*-OFDM-based waveform generator, and (ii) synchronization information and/or data along with zeros as inputs to such generator. Thereafter, synchronization information, such as symbol timing synchronization information, may be inserted into the zero tail of the zero-tail time domain signal so as to adapt the zero-tail time domain signal into a time domain signal having a tail with the inserted synchronization information ("synch-tail time domain signal"). The synch-tail time domain signal may be converted to a frequency domain, then mapped to a set of subcarriers, and then converted back to the time domain. Thereafter, the synch-tail time domain signal may undergo parallel-serial-conversion and/or other processes to form an OFDM symbol. The OFDM symbol may be transmitted on a beamformed beam.

[0177] Pursuant to new methodologies and/or technologies provided herein, multiple types of synchronization information may be transmitted in the same OFDM symbol. As an example, the OFDM symbol may have a tail and at least one other portion. The tail may carry symbol timing synchronization information pursuant to time domain insertion of such symbol timing synchronization information into the OFDM symbol tail (e.g., as above). The other portion may

carry, pursuant to frequency domain insertion, a physical broadcast channel (PBCH) and/or synchronization information, such as, a sequence for identifying a cell identity (ID). The frequency domain insertion may be carried out as a function of using such information as inputs for generation of the zero-tail time domain signal.

[0178] Pursuant to new methodologies and/or technologies provided herein, separate beams may be used for synchronization information and data channel transmissions. In an embodiment, a wide beam may be used for synchronization information transmissions, and a narrow beam may be used for data channel transmission. The synchronization information transmissions carried over the wide beam may be mapped on a central sub-band of the available channel. The data channel carried over the narrow beam may be mapped on sub-bands orthogonal to the central sub-band (e.g., sub-bands not used by the synch beam).

[0179] Pursuant to new methodologies and/or technologies provided herein, coordination among neighboring cells may be carried out in connection with synchronization information transmissions. In an embodiment, synchronization channel ("SYNCH") and PBCH transmission multiplexing may be carried out over multiple partitions, and may increase a likelihood of SYNCH detection and PBCH decoding.

[0180] Pursuant to new methodologies and/or technologies provided herein, target cell assisted handover may be carried out. In an embodiment, a directed area focus and SYNCH power boost may be used.

[0181] As used herein, the term "SYNCH" may refer to a synchronization signal and/or synchronization information, including two different types of sequences, namely, S1 and S2. The S1 may be used for time domain initial acquisition. The S1 may be used for symbol and/or slot timing establishment. The S1 may be used mainly in time domain processing. The S1 may identify a start of one or more S2s.

[0182] The S2 may be used to identify cell ID. The S2 may be used for frame timing establishment. The S2 may identify a start of a PBCH. The S2 may be inserted in data and time domains, and may be coded sufficiently to meet detection needs.

[0183] A PBCH may carry a MIB, and may carry additional parameters from SIBs.

[0184] As used herein, the terms "SYNCH beam" and "synchronization beam" may refer to a beam used for the transmission of a SYNCH, including any of an S1, an S2, a PBCH and one or more SIBs. As used herein, the terms "non-synchronization beam" may refer to a beam used for transmission of information other than a SYNCH (e.g., data and/or control channels). As used herein the term "sector" may refer to an angular portion of an omnidirectional coverage

area. Each sector may represent a unique cell. As used herein, the term "partition" may refer to an angular portion of a sector.

[0185] Example Transmissions In Highly Directional Systems

[0186] The methodologies and/or technologies provided herein may allow for transmission of synchronization signals in highly directional systems. The methodologies and/or technologies provided herein may enable matching coverages for synchronization channels and data channels.

[0187] FIG. 14 illustrates an example of an OFDM signal 1400 generated using a *he*-OFDM-based waveform. The OFDM signal 1400 includes two OFDM symbols 1402a, 1402b, each with respective data portions 1404a, 1404b and tail portions 1406a, 1406b. The tail portions 1406a, 1406b may be zero tails, unique words or a combination thereof. The *he*-OFDM-based waveform may be leveraged for efficient synchronization, by using the tail portions 1406a, 1406b for the transmission of synchronization signals.

[0188] The tail portions 1406a, 1406b may be configured to carry synchronization information, such as S1, that facilitates symbol timing acquisition. One or both of the data portions 1404a, 1404b may carry synchronization information, such as S2, so as to facilitate acquisition of frame/sub-frame timing, and/or some other information, such as a cell ID.

[0189] FIG. 15 illustrates an example OFDM signal 1500 resulting from transmission of synchronization information and data channel information on separate beams 1502a, 1502b. The separate beams 1502a, 1502b may be generated by, and transmitted from, a base station capable of generating at least two Tx beams simultaneously. The base station may be equipped with multiple RF chains to generate the Tx beams simultaneously.

[0190] As shown, the synchronization information (e.g. S1/S2/PBCH) may be carried on beam 1502a, and data channel transmissions may be carried on beam 1502b. Beam 1502a may have a wide beam width. Beam 1502b may have a narrow beam width (at least compared to beam 1502a).

[0191] The base station may sweep beam 1502a (synchronization beam) periodically within a partition (FIG. 31, e.g.). Sweeping beam 1502a may allow for cell-wide coverage for the synchronization signals. The base station may point beam 1502b (data beam) to specific areas, e.g., as needed for data channel transmissions to scheduled WTRUs.

[0192] Because the two beams 1502a, 1502b may overlap in the space domain, the synchronization signal transmitted on the (swept/sweeping) beam 1502a and the data/control signals transmitted on the narrow beam 1502b may be kept separate using frequency domain processing. As an example, signals transmitted on synchronization beam 1502a may be limited

in the frequency domain, such as to a set of sub-carriers or sub-channels. The set of sub-carriers/sub-channels may be pre-defined and/or specified. One example of the set of sub-carriers/sub-channels is n center sub-carriers. Signals transmitted on the non-synchronization beam 1502b (which may include data, control, etc.) may be mapped to one or more sub-carriers not assigned to/or used by the synchronization beam 1502a.

[0193] FIG. 16 illustrates an example OFDM signal 1600 resulting from transmission of synchronization information and data channel information on synchronization and non-synchronization beams 1602a, 1602b. As shown, signals transmitted on synchronization beam 1602a may map to a center sub-carrier, and signals transmitted on non-synchronization beam 1602b may map to sub-carriers other than the center subcarrier (or otherwise not assigned to/used by the synchronization beam).

[0194] FIG. 17 illustrates an example OFDM signal 1700 resulting from transmission of synchronization information and data channel information on separate beams 1702a, 1702b. As shown, the synchronization beam (beam 1702a) may carry data, including user data, in OFDM symbols not used for carrying synchronization information. Doing so may allow for efficient use of resources corresponding to the synchronization beam 1702a. In the example shown, in time domain, the first x OFDM symbols of the TTI carry synch (denoted "s") and the next y OFDM symbols of the TTI carry data (denoted "sd"), where $x+y$ = the total number of OFDM symbols per TTI.

[0195] FIG. 18 illustrates an example OFDM signal 1800 resulting from transmission of synchronization information on a synchronization beam. Each synch symbol, s , and data symbol, sd , transmitted on the synchronization beam may use the same UW, $syUW$. As shown, each synch symbol, s , may include synchronization information, $sync-ch$, and the UW, $syUW$; and each of data symbols, sd , may include data channel information, $data-ch$, and the UW, $syUW$. The data channel information may be common or dedicated data channels mapped in frequency domain and transmitted over the data portion of the OFDM symbol. The UW, $syUW$, may be synchronization information transmitted over the tail portion of the OFDM symbol.

[0196] Example Synchronization Procedures and/or Techniques

[0197] In the description that follows, transmissions of synchronization information and data channel information may be carried on separate beams. For simplicity of exposition, one beam may be used for synchronization purposes, and any number of other beams are used for transmissions of data channels to one or multiple users (any of the other beams may be a narrow beam – e.g., to provide high gain). The beams may be generated by, and transmitted from, a base station capable of generating at least two Tx beams simultaneously, e.g., by using hybrid

beamforming. The base station may be equipped with multiple RF chains to generate such Tx beams simultaneously.

[0198] Also for simplicity of exposition, OFDM signals carried on the synchronization beam may include (i) symbol timing synchronization information (e.g., S1) inserted in time domain at a tail of an OFDM symbol, and (ii) TTI/frame timing information, and/or other synchronization information inserted in frequency domain on one or more data sub-carriers.

[0199] FIG. 19 illustrates an example transmitter 1900 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 1900 may include first and second waveform generators 1901a, 1901b. The first waveform generator 1901a may generate the OFDM signals that may be transmitted on a synchronization beam. The second waveform generator 1901b may generate the OFDM signals that may be transmitted on a data beam.

[0200] The first waveform generator 1901a may include a pulse shaping unit 1903a, a time-domain insertion unit 1905a, a sub-channel mapping unit 1907a, a parallel-to-serial converter 1909a and a beamforming unit 1911a. The pulse shaping unit 1903a may be configured as a ZT DFT-s-OFDM waveform generator, and may include an M-point DFT unit 1910a, a subcarrier mapping (SM) unit 1912a and an N-point inverse DFT (IDFT) unit 1914a. The sub-channel mapping unit 1907a may include an N-point DFT unit 1920a, a subcarrier mapping (SM) unit 1922a and an N_{IFFT} -point IFFT unit 1924a.

[0201] A zero tail (or approximate zero tail) time domain OFDM signal may be generated using the pulse shaping unit 1903a on a symbol-by-symbol basis. As shown, N_t and N_h zero samples may be fed to tail and head inputs, respectively, of the M-point DFT unit 1910a. Common and/or synchronization information, such as, S2 and/or PBCH, may be fed to one or more of the remaining inputs of the M-point DFT unit 1910a. The output of the M-point DFT unit 1910a may be mapped to the N-point IDFT unit 1914a, where $N > M$ may be an integer multiple of M. A resulting output of the N-point IDFT unit 1914a may be a time domain OFDM symbol that has N_{zt} ~zero valued samples in the tail and N_{zh} ~zero valued samples in the head, where:

$$N_{zt} = N_t \frac{N}{M} \quad \text{Eq. (1)}$$

$$\dots N_{zh} = N_h \frac{N}{M} \quad \text{Eq. (2)}$$

[0202] Each time domain OFDM symbol output from the N-point IDFT unit 1914a may be fed to inputs of the time-domain insertion unit 1905a. The time-domain insertion unit 1905a may insert (add) a symbol level synchronization sequence (e.g., S1) to the time domain OFDM

symbol replacing the N_{zt} ~zero valued samples in the tail and/or the N_{zh} ~zero valued samples in the head; the result of which may be a time domain OFDM symbol carrying multiple types of synchronization information ("SYNC-type OFDM symbol). The synchronization sequence may be a fixed sequence and have a pre-defined length. Alternatively, the synchronization sequence may be dynamically or semi-statically configured and/or its length may be configurable. Once a desired length of the synchronization sequence is determined, the pulse shaping unit 1903a may set the required number of zero tail samples (N_t) to be fed at the input of the M-point DFT unit 1910a as calculated using equation (1) and/or equation (2), where N and M are known, for any given resource assignment.

[0203] The time-domain insertion unit 1905a may feed the resulting SYNC-type OFDM symbol to sub-channel mapping unit 1907a. The sub-channel mapping unit 1907a, may map the SYNC-type OFDM symbol to a center sub-band and/or other sub-band of the available channel and orthogonal to other subcarriers used for the data channel transmission on the data beam. The SYNC-type OFDM symbol may be mapped to, for example, the center N subcarriers (e.g., one or more sub-bands) out of the total N_{IFFT} subcarriers (where the total N_{IFFT} subcarriers may include the used subcarriers and the guard subcarriers). The sub-channel mapping unit 1907a may use, for example, frequency domain guard band insertion at the N_{IFFT} -point IFFT unit 1924a to mask off all of the N_{IFFT} subcarriers orthogonal to the center N sub-carriers (and/or other desired sub-band(s)). The N_{IFFT} -point IFFT unit 1924a may feed the sub-band mapped SYNC-type OFDM symbol to the parallel-to-serial converter 1909a for conversion and output to the beamforming unit 1911a, which performs beamforming for transmission on the synchronization beam.

[0204] The second waveform generator 1901b may include pulse shaping units 1903b, 1903c, time-domain insertion units 1905b, 1905c, sub-channel mapping units 1907b, 1907c, a parallel-to-serial converter 1909b and a beamforming unit 1911b. The pulse shaping units 1903b, 1903c may include respective M-point DFT units 1910b, 1910c, subcarrier mapping (SM) units 1912b, 1912c and N-point IDFT units 1914b, 1914c. The sub-channel mapping units 1907b, 1907c may include respective N-point DFT unit 1920b, 1920c and subcarrier mapping (SM) units 1922b, 1922c along with a common N_{IFFT} -point IFFT unit 1924b. Although not shown, the sub-channel mapping units 1907b, 1907c may include respective N_{IFFT} -point IFFT units as an alternative to the common N_{IFFT} -point IFFT unit 1924b. For simplicity of exposition, the terms "M1-point" and "N1-point" may be used instead of "M-point" and "N-point" to denote an association to user data for user 1. Similarly, the terms "M2-point" and "N2-point" may be used instead of "M-point" and "N-point" to denote an association to user data for user 2.

Notwithstanding the different designations, one or more of the "M", "M1" and "M2" may be the same number, and/or one or more of the "N", "N1" and "N2" may be the same number.

[0205] Akin to the first waveform generator 1901a, a zero tail (or approximate zero tail) time domain OFDM signal may be generated using the pulse shaping unit 1903b on a symbol-by-symbol basis. N_t and N_h zero samples may be fed to tail and head inputs, respectively, of an M1-point DFT unit 1910b. Data of user 1 may be fed to one or more of the remaining inputs of the M1-point DFT unit 1910b. The output of the M1-point DFT unit 1910b may be mapped to the N1-point IDFT unit 1914b, where $N1 > M1$ may be an integer multiple of M1. A resulting output of the N1-point IDFT unit 1914a may be a time domain OFDM symbol that has N_{zt} ~zero valued samples in the tail and N_{zh} ~zero valued samples in the head, in accordance with the equations (1) and/or (2).

[0206] Each time domain OFDM symbol output from the N1-point IDFT unit 1914b may be fed to inputs of the time-domain insertion unit 1905b. The time-domain insertion unit 1905b may insert (add) a symbol level synchronization sequence (e.g., S1) to the time domain OFDM symbol replacing the N_{zt} ~zero valued samples in the tail and/or the N_{zh} ~zero valued samples in the head; the result of which may be a time domain OFDM symbol carrying the data of user 1 along with synchronization information ("SYNC-tail OFDM symbol"). The synchronization sequence may be a fixed sequence and have a pre-defined length. Alternatively, the synchronization sequence may be dynamically or semi-statically configured and/or its length may be configurable. Once a desired length of the synchronization sequence is determined, the pulse shaping unit 1903b may set the required number of zero tail samples (N_t) to be fed at the input of the M1-point DFT unit 1910b as calculated using equation (1) and/or equation (2), where $N=N1$ and $M=M1$, N1 and M1 are known, for any given resource assignment.

[0207] The time-domain insertion unit 1905b may feed the resulting SYNC-tail OFDM symbol to the sub-channel mapping unit 1907b. The sub-channel mapping unit 1907b, by the combined operation of the N1-point DFT unit 1920b, SM unit 1922b and N_{IFFT} -point IFFT unit 1924b, may map the SYNC-tail OFDM symbol to one or more sub-bands of the available channel. The SM unit 1922b at the input of the N_{IFFT} -point IDFT unit 1924b may be used to enable mapping of the data symbols on orthogonal sub-carriers not used for the synchronization symbols. User 1 may be assigned M1 resources in frequency domain (including the zero tail and head, if used). The M1 resources may be spread using the M1-size DFT unit 1910b, and may be converted to time domain using the N1-point IDFT unit 1914b, where N1 may be an integer multiple of M1. The SYNC-tail OFDM generated for user 1 may be mapped to the assigned frequency resources (N1 sub-carriers) not overlapping the N sub-carriers used for

synchronization symbols. The N_{IFFT} -point IFFT unit 1924b may feed the N_1 sub-band mapped SYNC-tail OFDM symbol to the parallel-to-serial converter 1909b for conversion and output to the beamforming unit 1911b, which performs beamforming for transmission on the (narrow) data beam.

[0208] A SYNC-tail OFDM symbol carrying data of user 2 may be generated in the same way as the SYNC-tail OFDM symbol carrying data of user 1 using the pulse shaping unit 1903c and the time-domain insertion unit 1905c. The sub-channel mapping unit 1907c may map the SYNC-tail OFDM symbol to assigned frequency resources (N_2 sub-carriers) not overlapping the N sub-carriers used for synchronization symbols and the N_1 sub-carriers used for the SYNC-tail OFDM symbol carrying data of user 1. The N_{IFFT} -point IFFT unit 1924b may feed the N_2 sub-carriers (e.g., sub-bands) mapped SYNC-tail OFDM symbol to the parallel-to-serial converter 1909b for conversion and output to the beamforming unit 1911b, which performs beamforming for transmission on the (narrow) data beam.

[0209] Table 3 below lists examples of possible sizes for resource allocation to data and synchronization information.

Resource Allocation	Value
N_{IFFT}	2048 points
Synch	$M=32$ or 64 , $N=256$
Data	$N_1=1024$, $M_1=256$ or 512 $N_2=512$, $M_2=128$ or 256

Table 3

[0210] FIG. 20 illustrates an example transmitter 2000 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2000 may include first and second waveform generators 2001a, 2001b. The first waveform generator 2001a may generate the OFDM signals that may be transmitted on a synchronization beam. The second waveform generator 2001b may generate the OFDM signals that may be transmitted on a data beam.

[0211] The first waveform generator 2001a is similar to the first waveform generator 1901a of FIG. 19, except that the first waveform generator 2001a may include a pulse shaping unit 2003a configured as an eZT DFT-s-OFDM waveform generator instead of a ZT DFT-s-OFDM waveform generator. The pulse shaping unit 2003a may include an M -point DFT unit 2010a, a SM unit 2012a, an N -point IDFT unit 2014a and a time domain tail cancellation unit 2016a at the output of the N -point IDFT unit 2014a. The time domain tail cancellation unit 2016a may be fed a time domain OFDM symbol output from the N -point IDFT unit 2014a. The time domain tail cancellation unit 2016a may cancel (e.g., set to zero) samples in the tail and/or head

of the time domain OFDM symbol, and may feed the tail-cancelled OFDM symbol to a time-domain insertion unit 2005a. The rest of the processing may be similar to the processing carried out by the first waveform generator 1901a of FIG. 19.

[0212] The second waveform generator 2001b is similar to the second waveform generator 1901b of FIG. 19, except that the second waveform generator 2001b may include pulse shaping units 2003b, 2003c that are configured as eZT DFT-s-OFDM waveform generators instead of ZT DFT-s-OFDM waveform generators. The pulse shaping units 2003b, 2003c may include M1/M2-point DFT units 2010b, 2010c, SM units 2012b, 2012c, N1/N2-point IDFT units 2014b, 2014c and time domain tail cancellation units 2016b, 2016c at the outputs of the N1/N2-point IDFT units 2014b, 2014c, respectively. The time domain tail cancellation unit 2016b (2016c) may be fed a time domain OFDM symbol output from the IDFT unit 2014b (2014c). The time domain tail cancellation unit 2016b (2016c) may cancel samples in the tail and/or head of the time domain OFDM symbol, and may feed the tail-cancelled OFDM symbol to a time-domain insertion unit 2005b (2005c). The rest of the processing may be similar to the processing carried out by the second waveform generator 1901b of FIG. 19.

[0213] FIG. 21 illustrates an example transmitter 2100 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2100 may include first and second UW DFT-s OFDM waveform generators 2101a, 2101b. The first UW DFT-s OFDM waveform generator 2101a may include a redundant data generation unit 2108a, an M-point DFT unit 2110a, a SM unit 2122a, an N_{IFFT} -point IFFT unit 2124a, a parallel to serial converter 2109a, and a beamforming unit 2111a.

[0214] The SYNCH channel may be generated using a set of M subcarriers out of the N_{IFFT} subcarriers. These subcarriers may be at a center of the system band. Common data may be fed into the redundant data generation unit 2108a. The common data along with redundant data output from the redundant data generation unit 2108a may be fed into the M-point DFT unit 2110a. The redundant data may be fed into tail and head portions of the M-point DFT unit 2110a, and the remaining samples input to the M-point DFT unit 2110a may be taken from the common data. The redundant data generation unit 2108a may compute the redundant data from the common data using precoding. The precoding allows for a unique word to be generated at the tail of the output of the M-point DFT unit 2110a. The data may be used for synchronization purposes and/or to for carrying broadcast information. For example, the common data may include a PBCH, a secondary synchronization sequence, etc.

[0215] A resulting OFDM symbol (e.g., a SYNC-type OFDM symbol) may be mapped to a center sub-band and/or other sub-band of the available channel by combined operation of the

M-point DFT unit 2110a, SM unit 2122a and N_{IFFT} -point IFFT unit 2124a. The OFDM symbol may be mapped to, for example, the center N sub-carriers out of the total N_{IFFT} subcarriers (where the total N_{IFFT} subcarriers may include the used subcarriers and subcarriers around the synchronization channel reserved as guard subcarriers and not used for data transmission). The N_{IFFT} -point IFFT unit 2124a may use frequency domain guard band insertion to mask off all of the N_{IFFT} subcarriers orthogonal to the center N sub-carriers (and/or other desired sub-band(s)). The N_{IFFT} -point IFFT unit 2124a may feed the sub-band mapped OFDM symbol to the parallel-to-serial converter 2109a for conversion and output to the beamforming unit 2111a, which performs beamforming for transmission on the synchronization beam.

[0216] The subcarriers not allocated to the synchronization channel and guard subcarriers, if any, may be used for data transmission. The data signal may be generated using the second UW DFT-s-OFDM waveform generator 2101b. The second UW DFT-s OFDM waveform generator 2101b may include redundant data generation units 2108b, 2108c, $K1/K2$ -point DFT units 2110b, 2110c, SM units 2122a, 2122b, an N_{IFFT} -point IFFT unit 2124b, a parallel to serial converter 2109b, and a beamforming unit 2111b.

[0217] Data of user 1 may be fed into the redundant data generation unit 2108a. The data of user 1 along with redundant data output from redundant data generation unit 2108a may be fed into the $K1$ -point DFT unit 2110b. The redundant data may be fed into tail and head portions of the $K1$ -point DFT unit 2110b, and the remaining samples input to the $K1$ -point DFT unit 2110b may be taken from the data of user 1. The redundant data generation unit 2108b may compute the redundant data from the common data using precoding. The precoding allows for a unique word to be generated at the tail of the output of the M-point DFT unit 2110b.

[0218] A resulting OFDM symbol (e.g., a SYNC-tail OFDM symbol) may be mapped to one or more sub-bands of the available channel by combined operation of the $K1$ -point DFT unit 2110b, SM unit 2122b and N_{IFFT} -point IFFT unit 2124a. The SM unit 2122b at the input of the N_{IFFT} -point IDFT unit 2124b may be used to enable mapping of the data symbols on orthogonal sub-carriers not used for the synchronization channel and/or guard subcarriers. User 1 may be assigned $K1$ resources in frequency domain (including the zero tail and head, if used). The OFDM symbol generated for user 1 may be mapped to the assigned frequency resources ($K1$ sub-carriers) not overlapping the N sub-carriers used for synchronization symbols. The N_{IFFT} -point IFFT unit 2124b may feed the $K1$ sub-band mapped SYNC-tail OFDM symbol to the parallel-to-serial converter 2109b for conversion and output to the beamforming unit 2111b, which performs beamforming for transmission on the (narrow) data beam.

[0219] An OFDM symbol (e.g., a SYNC-tail OFDM symbol) carrying data of user 2 may be generated in the same way as the OFDM symbol carrying data of user 1 using the redundant data generation unit 2108c and the K2-point DFT unit 2110c. The SM unit 2122c at the input of the N_{IFFT} -point IDFT unit 2124b may be used to enable mapping of the OFDM symbol carrying data of user 2 to assigned frequency resources (N_2 sub-carriers) not overlapping the N sub-carriers used for synchronization symbols and the N_1 sub-carriers used for the OFDM symbol carrying data of user 1. The N_{IFFT} -point IFFT unit 2124b may feed the N_2 sub-band mapped OFDM symbol to the parallel-to-serial converter 2109b for conversion and output to the beamforming unit 2111b, which performs beamforming for transmission on the (narrow) data beam.

[0220] At a receiver side, a WTRU that is attempting to achieve initial synchronization may filter the incoming signal to discriminate the sub-band carrying the synchronization information. A low-pass filter may be used by the WTRU, for example, if the synchronization channel uses the N subcarriers in the center of the band (e.g., as illustrated in FIG. 21). The WTRU may use the unique words of OFDM symbols carried on a synchronization channel for initial synchronization. The WTRU may use the unique words of SYNC-tail OFDM symbols carried on a data channel, if any, for initial synchronization, as well.

[0221] FIG. 22 illustrates an example transmitter 2200 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2200 may include first and second ZT DFT-s OFDM waveform generators 2201a, 2201b. The first ZT DFT-s OFDM waveform generator 2201a may include an M-point DFT unit 2210a, a SM unit 2212a, an N_{IFFT} -point IFFT unit 2224a, a time domain insertion unit 2205a, a parallel to serial converter 2209a, and a beamforming unit 2211a.

[0222] A zero tail (or approximate zero tail) time domain OFDM signal may be generated on a symbol-by-symbol basis using the M-point DFT unit 2210a, SM unit 2212a, and N_{IFFT} -point IFFT unit 2224a. N_t and N_h zero samples may be fed to tail and head inputs, respectively, of the M-point DFT unit 2210a. Common and synchronization information, such as S_2 and/or PBCH, may be fed to one or more of the remaining inputs of the M-point DFT unit 2210a. The output of the M-point DFT unit 2210a may be mapped to the N_{IFFT} -point IFFT unit 2224a, where $N > M$ and N may be an integer multiple of M . The N_{IFFT} -point IFFT unit 2224a may span the entire channel bandwidth, including guard sub-carriers, if any.

[0223] A resulting output of the N_{IFFT} -point IFFT unit 2224a may be a time domain OFDM symbol that has N_{zt} ~zero valued samples in the tail and N_{zh} ~zero valued samples in the head, and that is mapped to a center sub-band and/or other sub-band of the available channel and

orthogonal to other subcarriers used for the data channel transmission on the data beam. The OFDM symbol may be mapped to, for example, the center N sub-carriers out of the total N_{IFFT} subcarriers. The sub-band mapped OFDM symbol may be fed to the time domain insertion unit 2205a. The time domain insertion unit 2205a may insert (add) a synchronization signal (e.g., S1) in the time domain, directly to the zero-tail of the time domain OFDM symbol replacing the N_{zt} ~zero valued samples in the tail and/or the N_{zh} ~zero valued samples in the head; the result of which may be a sub-band mapped SYNC-type OFDM symbol. The synchronization signal may be a fixed sequence and have a pre-defined length. Alternatively, the synchronization signal may be dynamically or semi-statically configured and/or its length may be configurable. The synchronization signal (e.g., unique word/synchronization sequence) may be designed and/or configured such that it is contained in frequency domain to the sub-band used for synchronization purposes (e.g., the center subcarriers), while maintaining good cross-correlation properties. Once a desired length of the synchronization sequence is determined, the number of zero tail samples (N_t) to be fed at the inputs of the M -point DFT unit 2210a may be configured in accordance with equation (1) and/or equation (2).

[0224] The sub-band mapped SYNC-type OFDM symbol may be fed from the time domain insertion unit 2205a to the parallel-to-serial converter 2209a for conversion and output to the beamforming unit 2211a, which performs beamforming for transmission on the synchronization beam.

[0225] The second ZT DFT-s OFDM waveform generator 2201b may include M_1/M_2 -point DFT units 2210b, 2210c, SM units 2212b, 2212c, an N_{IFFT} -point IFFT unit 2224b, a time domain insertion unit 2205b, a parallel to serial converter 2209b, and a beamforming unit 2211b. A zero tail (or approximate zero tail) time domain OFDM signal may be generated on a symbol-by-symbol basis using the M_1/M_2 -point DFT units 2210b, 2210c, SM units 2212b, 2212c and N_{IFFT} -point IFFT unit 2224b. N_t and N_h zero samples may be fed to tail and head inputs, respectively, of each of the M_1 -point DFT unit 2210b and the M_2 -point DFT unit 2210c. Data of user 1 may be fed to one or more of the remaining inputs of the M_1 -point DFT unit 2210b, and data of user 2 may be fed to one or more of the remaining inputs of the M_2 -point DFT unit 2210c. The outputs of the M_1/M_2 -point DFT units 2210b, 2210c may be mapped to the N_{IFFT} -point IFFT unit 2224b, where $N > M_1 + M_2$ and N may be an integer multiple of M . The N_{IFFT} -point IFFT unit 2224b may span the entire channel bandwidth, including guard subcarriers, if any.

[0226] A resulting output of the N_{IFFT} -point IFFT unit 2224a may be first and second time domain OFDM symbols. The first time domain OFDM symbol may include the data of user 1

and N_{zt} ~zero valued samples in the tail and N_{zh} ~zero valued samples in the head, and may be mapped to assigned frequency resources (N_1 sub-carriers). The second time domain OFDM symbol may include the data of user 2 and N_{zt} ~zero valued samples in the tail and N_{zh} ~zero valued samples in the head, and may be mapped to assigned frequency resources (N_2 sub-carriers). The N_1/N_2 sub-band mapped OFDM symbols may be fed to the time domain insertion unit 2205a. The time domain insertion unit 2205a may insert (add) a synchronization signal (e.g., S_1) in the time domain, directly to one or both of the zero-tails of the N_1/N_2 sub-band mapped OFDM symbols; the result of which may be a N_1/N_2 sub-band mapped SYNC-tail OFDM symbols. The synchronization signal may be a fixed sequence and have a pre-defined length. Alternatively, the synchronization signal may be dynamically or semi-statically configured and/or its length may be configurable. Once a desired length of the synchronization sequence is determined, the number of zero tail samples (N_t) to be fed at the inputs of each of the N_1/N_2 -point DFT units 2210b, 2210c may be configured in accordance with equation (1) and/or equation (2).

[0227] The sub-band mapped SYNC-tail OFDM symbols may be fed from the time domain insertion unit 2205b to the parallel-to-serial converter 2209b for conversion and output to the beamforming unit 2211b, which performs beamforming for transmission on the data beam.

[0228] FIG. 23 illustrates an example transmitter 2300 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2300 may include first and second eZT OFDM based waveform generators 2301a, 2301b. The first eZT OFDM based waveform generator 2301a may include a SM unit 2312a, an M-point IDFT unit 2314a, a time domain tail cancellation unit 2316a at the output of the M-point IDFT unit 2314a, a circular shift unit 2318a, a time domain insertion unit 2305, a sub-channel mapping unit 2307a, a parallel to serial converter 2309a, and a beamforming unit 2311a.

[0229] The synchronization channel may be generated using a set of M subcarriers out of the N_{IFFT} subcarriers. These subcarriers may be at a center of the system band. To generate the synchronization channel, M inputs consisting of zeros and data fed to the SM unit 2312a may be mapped to the M-point IDFT unit 2314a, where the zeros may be mapped to uniformly interleaved sub-carriers. The data may be used for synchronization purposes and/or for carrying broadcast information. For example, the common data may contain PBCH, secondary synchronization sequence, etc.

[0230] After the time-domain tail cancellation by the time domain tail cancellation unit 2316a and circular shifting of N_h samples by the circular shift unit 2318a, time domain insertion unit

2305 may insert (add) a unique word (e.g., a deterministic sequence) into all or part of a zero tail portion of the signal; the result of which may be a SYNC-type OFDM symbol. The sub-channel mapping unit 2307a may transform the SYNC-type OFDM symbol to the frequency domain, and may map the transformed SYNC-type OFDM symbol to a set of subcarriers, e.g., a set of subcarriers located at the center of the band. The N_{IFFT} -point IFFT unit 2324a may feed the sub-band mapped SYNC-type OFDM symbol to the parallel-to-serial converter 2309a for conversion and output to the beamforming unit 2311a, which performs beamforming for transmission on the synchronization beam.

[0231] The subcarriers not allocated to the synchronization channel and/or guard bands, if any, may be used for data transmission. The second eZT OFDM based waveform generator 2301b may include SM units 2312b, 2312c, K_1/K_2 -point IDFT units 2314b, 2314c, time domain tail cancellation units 2316b, 2316c, circular shift units 2318b, 2318c, sub-channel mapping units 2307b, 2307c, a parallel to serial converter 2309a, and a beamforming unit 2311a. The data signal may be generated using second eZT OFDM based waveform generator 2301b and elements thereof configured for a conventional eZT OFDM waveform approach.

[0232] At the receiver side, a WTRU that is attempting to achieve initial synchronization may filter the incoming signal to discriminate the sub-band carrying the synchronization information. A low-pass filter may be used by the WTRU, for example, if the synchronization channel uses the N subcarriers in the center of the band (e.g., as illustrated in FIG. 23). The WTRU may use the unique words of OFDM symbols carried on synchronization channel for initial synchronization.

[0233] FIG. 24 illustrates an example transmitter 2400 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2400 may include first and second UW OFDM waveform generators 2401a, 2401b. The first UW OFDM based waveform generator 2401a may include a redundant data generation unit 2408a, a permutation unit 2410a, an SM unit 2412a, an M -point IDFT unit 2414a, a time domain insertion unit 2405a, a sub-channel mapping unit 2407a, a parallel to serial converter 2409a, and a beamforming unit 2411a.

[0234] The synchronization channel may be generated using a set of M subcarriers out of the N_{IFFT} subcarriers. These subcarriers may be at a center of the system band. To generate the synchronization channel, common data and redundant data output from the redundant data generation unit 2408a may be fed into the M -point IDFT unit 2414a. The redundant data generation unit 2408a may compute redundant data from the common data using precoding. The precoding may allow for a zero tail to be generated at the output of the M -point IDFT unit

2414a. The subcarriers to which the common data and the redundant data may be mapped are determined by the permutation unit 2410a. The data may be used for synchronization purposes and/or to for carrying broadcast information. For example, the common data may include PBCH, secondary synchronization sequence, etc.

[0235] The OFDM symbol may be fed to the time domain insertion unit 2405a. The time domain insertion unit 2405a may insert (add) a synchronization signal (e.g., S1) in the time domain, directly to the zero-tail of the time domain OFDM symbol; the result of which may be a SYNC-type OFDM symbol. The synchronization signal may be a fixed sequence and have a pre-defined length. Alternatively, the synchronization signal may be dynamically or semi-statically configured and/or its length may be configurable. The synchronization signal (e.g., unique word/synchronization sequence) may be designed and/or configured such that it is contained (in frequency domain) to the sub-band used for synchronization purposes (e.g., the center subcarriers), while maintaining good cross-correlation properties.

[0236] The SYNC-type OFDM symbol may be mapped to a center sub-band and/or other sub-band of the available channel by the sub-channel mapping unit 2407a. The SYNC-type OFDM symbol may be mapped to, for example, the center N sub-carriers out of the total N_{IFFT} subcarriers (where the total N_{IFFT} subcarriers may include the used subcarriers and subcarriers around the synchronization channel reserved as guard subcarriers and not used for data transmission). The N_{IFFT} -point IFFT unit 2424a may feed the sub-band mapped SYNC-type OFDM symbol to the parallel-to-serial converter 2409a for conversion and output to the beamforming unit 2411a, which performs beamforming for transmission on the synchronization beam.

[0237] The subcarriers not allocated to the synchronization channel and/or guard bands, if any, may be used for data transmission. The second UW OFDM waveform generator 2301b may include redundant data generation units 2408b, 2408c, permutation units 2410b, 2410c, SM units 2412b, 2412c, $K1/K2$ -point IDFT units 2414b, 2414c, time domain insertion units 2405b, 2405c, sub-channel mapping units 2407b, 2407c, a parallel to serial converter 2409b, and a beamforming unit 2411b. Data of user 1 along with redundant data output from the redundant data generation unit 2408b may be fed into the permutation unit 2410b. The redundant data may be fed into tail and head portions of the permutation unit 2410b, and the remaining samples input to the permutation units 2410b may be taken from the data of user 1. The redundant data generation unit 2408b may compute the redundant data from the data of user 1 using precoding. The precoding allows for a unique word to be generated at the tail of the output of the $K1$ -point IDFT unit 2414b.

[0238] Each time domain OFDM symbol output from the $K1$ -point IDFT unit 2414b may be fed to inputs of the time-domain insertion unit 2405b. The time-domain insertion unit 2405b may insert (add) a synchronization sequence to the tail and head of the time domain OFDM symbol; the result of which may be a SYNC-tail OFDM symbol carrying the data of user 1.

[0239] The time-domain insertion unit 2405b may feed the resulting SYNC-tail OFDM symbol to the sub-channel mapping unit 2407b. The sub-channel mapping unit 2407b may map the SYNC-tail OFDM symbol to one or more sub-bands of the available channel corresponding to frequency resources ($K1$ sub-carriers) assigned to user 1. The N_{IFFT} -point IFFT unit 2424b may feed the $K1$ sub-band mapped SYNC-tail OFDM symbol to the parallel-to-serial converter 2409b for conversion and output to the beamforming unit 1911b, which performs beamforming for transmission on the (narrow) data beam.

[0240] A SYNC-tail OFDM symbol carrying data of user 2 may be generated in the same way as the SYNC-tail OFDM symbol carrying data of user 1 using the redundant data generation unit 2408c, permutation unit 2410c, SM unit 2412c, $K2$ -point IDFT unit 2414c and time domain insertion unit 2405c. The sub-channel mapping unit 2407c may map the SYNC-tail OFDM symbol to assigned frequency resources ($K2$ sub-carriers) not overlapping the N sub-carriers used for synchronization symbols and the $K1$ sub-carriers used for the SYNC-tail OFDM symbol carrying data of user 1. The N_{IFFT} -point IFFT unit 2424b may feed the $K2$ sub-band mapped SYNC-tail OFDM symbol to the parallel-to-serial converter 2409b for conversion and output to the beamforming unit 2411b, which performs beamforming for transmission on the (narrow) data beam.

[0241] FIG. 25 illustrates an example transmitter 2500 configured to generate OFDM signals for transmission of synchronization information and data channel information on separate beams. The transmitter 2500 is an alternative to the transmitter 2400 of FIG. 24. The transmitter 2500 may include first and second UW OFDM waveform generators 2501a, 2501b. As illustrated, in the first UW OFDM waveform generator 2501a, common data and corresponding precoded redundant data may be directly mapped to an IFFT block of size N_{IFFT} , and hence, does not include an intermediate IFFT-FFT pair, such as shown in FIG. 24. Similarly, in the second UW OFDM waveform generator 2501b, user data and corresponding precoded redundant data may be directly mapped to an IFFT block of size N_{IFFT} , hence, does not include an intermediate IFFT-FFT pair, such as shown in FIG. 24. The precoded data and respective permutation matrices may be calculated such that a tail of the signal at the output of the size- N_{IFFT} IFFT block is zero. Additionally, the UW may be designed such that it is spectrally

contained (e.g., in the frequency domain) to the sub-band used for that channel. As an example, for the SYNCH channel, the UW may be spectrally contained to the center sub-band.

[0242] FIG. 26 is a flow diagram illustrating an example flow 2600 for supporting communications on separate transmit beams. The flow 2600 may be implemented in a transmitter, those disclosed herein and/or illustrated in FIGs. 19-25.

[0243] Referring to FIG 26, the transmitter may generate a first OFDM symbol including a plurality of types of synchronization information (2610). In an embodiment, the transmitter may generate a first symbol including a first of the plurality of types of synchronization information, perform time domain insertion of a second of the plurality of types of synchronization information into the first symbol, and further process the first symbol to form the first OFDM symbol. The first symbol may include a tail portion and one or more non-tail portions. When generating the first symbol, the transmitter may apportion a duration of the first symbol among a tail portion and non-tail portions. In an embodiment, the transmitter may perform time domain insertion of the second of the plurality of types of synchronization information into the tail portion. In an embodiment, the transmitter may generate the first symbol with the second of the plurality of types of synchronization information carried solely in the tail portion. In an embodiment, the transmitter may generate the first symbol with the first of the plurality of types of synchronization information carried solely in any of the one or more non-tail portions. The first of the plurality of types of synchronization information may include any of a sequence for identifying a cell ID and a PBCH. The second of the plurality of types of synchronization information may include any of symbol timing synchronization information and slot timing synchronization information.

[0244] The transmitter may generate a second OFDM symbol including data channel information (2612). In an embodiment, the transmitter may generate a second symbol including any of data, control or other data channel information, perform time domain insertion of the second of the plurality of types of synchronization information into the first symbol, and further process the second symbol to form the second OFDM symbol. The second symbol may include a tail portion and one or more non-tail portions. When generating the second symbol, the transmitter may apportion a duration of the second symbol among a tail portion and non-tail portions. In an embodiment, the transmitter may perform time domain insertion of the second of the plurality of types of synchronization information into the tail portion. In an embodiment, the transmitter may generate the second symbol with the second of the plurality of types of synchronization information carried solely in the tail portion. In an embodiment, the transmitter

may generate the second symbol with the data channel information carried solely in any of the one or more non-tail portions.

[0245] The transmitter may simultaneously transmit the first and second OFDM symbols on first and second transmit beams, respectively (2614). The first transmit beam may have a wide beam width, and second transmit beam may have a narrow beam width. In an embodiment, the transmitter may simultaneously transmit the first and second OFDM symbols by transmitting them during a common symbol time. In an embodiment, the first and second transmit beams may overlap in a space domain. In an embodiment, the first OFDM symbol may be transmitted on one or more of a first set of subcarriers, and the second OFDM symbol may be transmitted on one or more of a second set of subcarriers. In an embodiment, the first set of subcarriers may map to a center sub-band of an available channel, and the second set of subcarriers may be orthogonal to the first set of subcarriers.

[0246] FIG. 27 is a flow diagram illustrating an example flow 2700 for supporting communications on separate transmit beams. The flow 2700 may be implemented in a transmitter, such as those disclosed herein and/or illustrated in FIGs. 19-25.

[0247] Referring to FIG. 27, the transmitter may generate a first symbol having a zero tail using (i) an OFDM-based waveform generator, and (ii) a first of a plurality of types of synchronization information and zeros as inputs to such generator (2710). The first of the plurality of types of synchronization information may include any of a sequence for identifying a cell ID and a PBCH. In an embodiment, the transmitter may generate the first symbol with the first of the plurality of types of synchronization information carried solely in any of one or more non-tail portions of the first symbol. When generating the first symbol, the transmitter may apportion a duration of the first symbol among the zero tail and non-tail portions.

[0248] The transmitter may perform time domain insertion of a second of the plurality of types of synchronization information into the zero tail of the first symbol (2712). The second of the plurality of types of synchronization information may include any of symbol timing synchronization information and slot timing synchronization information. In an embodiment, the transmitter may generate the first symbol with the second of the plurality of types of synchronization information carried solely in the zero tail.

[0249] The transmitter may map the first symbol to a first set of subcarriers (2714). The transmitter may convert the mapped first symbol to a first OFDM symbol (2716).

[0250] The transmitter may generate a second symbol having a zero tail using (i) a second OFDM-based waveform generator, and (ii) user data and zeros as inputs to such generator (2718). The transmitter may optionally perform time domain insertion of the second of the

plurality of types of synchronization information into the zero tail of the second symbol (2720). The transmitter may map the second symbol to a second set of subcarriers (2722). The transmitter may convert the mapped second symbol to a second OFDM symbol (2724).

[0251] The transmitter may simultaneously transmit the first and second OFDM symbols on first and second transmit beams, respectively (2726). The first transmit beam may have a wide beam width. The second transmit beam may have a narrow beam width. In an embodiment, the transmitter may simultaneously transmit the first and second OFDM symbols by transmitting them during a common symbol time. In an embodiment, the first and second transmit beams may overlap in a space domain. In an embodiment, the first OFDM symbol may be transmitted on one or more of the first set of subcarriers, and the second OFDM symbol may be transmitted on one or more of the second set of subcarriers. In an embodiment, the first set of subcarriers may map to a center sub-band of an available channel, and the second set of subcarriers may be orthogonal to the first set of subcarriers.

[0252] Example SYNCH Design Considerations

[0253] Approaches for a robust system design may allow for smooth transition from initial synchronization (i.e., SYNCH sequence detections) to broadcast channel information decoding, followed by successful RACH processing and authentication procedures.

[0254] The SYNCH design may consider multiple parameters to support various deployment scenarios. One or more of the following may be considered:

- Enabling timing offset detection with respect to a common reference (i.e. free running clock)
 - Symbol and slot timing acquisition, frame timing establishment
 - System Information decoding to prepare the WTRU for the next steps in Initial Access procedures
- Coding design to enable imbedding cell specific information such as group ID, Code index, Cell ID, CP length, symbol, slot, and frame timing
- Allowing Neighbor Search capability
- Achieving required cell coverage by link budget analyses
 - Regulated EIRP limits, beamforming gain considerations
 - Processing gain figures via utilization of long or frequent repetition of short sequences
- Reduced resource utilization for SYNCH and its impact to initial acquisition time

- Deploying multiple narrow beams for a coverage area and simultaneous SYNCH transmission on each narrow beam greatly reduces the IAT in the expense of reduced resource utilization efficiency
- Imposed receiver design complexity
 - SYNCH repetition period impact on non-coherent integration buffer size
 - Long periods (e.g., very long SYNCH periods) may be prohibitive for implementations
 - Algorithm selection impact on hardware
 - Utilization of match filters
 - Initial frequency offset estimation

[0255] Example Detection Criteria

[0256] Detection criteria may enable 95% detection performance at 10^{-3} false-alarm rate, that can be achieved for non-fluctuating target for a single pulse at 13dB minimum SNR. The effective SNR of 13dB can be reached by coherent integration of a single long sequence or coherent integration of a short sequence followed by multiple non-coherent additions. S1 and S2 could be in data and time domains and coded enough to meet the detection requirements. MIB info may be in data domain or carried by coded sequences in time domain.

[0257] Example Case Study for SYNCH and PBCH Frame Timing- Feasibility Study

[0258] A framework is provided below to highlight viability of the waveforms utilized herein for SYNCH and PBCH combining over the same symbols.

[0259] Assumptions:

[0260] Cell planning:

- Sectors: 60 degrees
- Partitions: None

[0261] Channel Parameters:

- BW: 2 GHz
- Number of subcarriers = 2048

[0262] SYNCH and PBCH configurations:

- SYNCH and PBCH channels are transmitted with wide-angle beamforming over the entire sector
- The SYNCH and PBCH repetition period can be set based on the acquisition time constraints. The Synch codes S1 & S2 and MIB information are repeated every 100 μs (assumed) and transmitted over multiple symbols

- BCH, S1 and S2 are using K=256 center subcarriers
- MIB must be heavily protected by coding

[0263] Power and antenna gain limits:

- $P_{tx} = 10$ dBm per antenna
- $N_{tx} = 2$, $N_{rx} = 2$
 - 2-element can create about 60 degree wide beamforming
 - Synch and PBCH utilize 2Tx and 2Rx antennae
- Patch antenna elements with 4.7dBi gain each
- Independent RF chains with 7dB Noise Figure
- Minimum SNR: -10dB
 - Cell boundary is confined to the minimum SNR required level to synchronize and read PBCH(MIB)

[0264] Range Calculations:

- Beamforming gain for Synch and PBCH
 - Total Gain(TG) = array gain($2 \times 10 \log_{10}(2)$) + element gain(2×4.7 dBi) = 15.4 dB
 - Effective bandwidth = $(256/2048) \times 2$ GHz = 250 MHz, Synch and PBCH occupying center 256 subcarriers
 - Effective Noise Floor(ENF) = -80 dBm
 - $-174 + 10 \log_{10}(250 \text{ MHz}) + 7 + 10 \log_{10}(2)$, NF=7 dB per path, $R_x = 2$
- With $P_{tx} = 10$ dBm per antenna and LTE requirements for Synch channel detection,
 - The effective Synch SNR at $R_x \geq -10$ dB
 - Synch channel power(SCP) = -90dBm (ENF + SNR)
 - Tx power aggregate(TPA) = 13 dBm with 2Tx antennae
 - Tolerable pathloss (PL) upper bound = $TPA(13 \text{ dBm}) + TG(15.4 \text{ dB}) - SCP(-90 \text{ dBm})$
= 118.4 dB max.
 - Range = 330 meters for free space model with $n=2$ (n is propagation factor) based on the model $PL = 20 \log_{10}(\text{wave_length}/4\pi) + n \cdot 10 \cdot \log_{10}(\text{distance})$ dB
 - Some other pathloss models severely impact the range, for example, $n=3$, then the range becomes only 48 meters and for $n=2.5$ the range becomes 100 meters.
- Synch Code length calculations:
 - Minimum SNR = -10dB and detection criteria as defined above, the 95% Pd with 10^{-3} pfa requires 13dB effective SNR, also adding implementation margin of 2dB to the calculations, then

- The required Processing Gain(PG) = 25 dB (margin + effective SNR – minimum SNR)
- The length = $10^{(0.1 \times \text{PG})} = 316$ samples

[0265] The design may assume a low SNR level at the receiver for SYNCH detection and PBCH decoding, that resulted in a 316 sample synch code length. Using only 256 center subcarriers to transmit SYNCH and PBCH is assumed, as well as PBCH data and SYNCH sequences being transmitted as part of the waveforms within 256 center subcarriers. Any of the following examples may be used: (Note: The following sample configurations assume usage of the eZT OFDM approach).

[0266] **Example 1**

[0267] The following may be applicable to eZT/UW OFDM waveforms.

- PBCH data: 128 subcarriers
- SYNCH sequence: 128 time domain samples (corresponding to 128 subcarriers)
 - PG over 128 coherent integration = 21dB
 - Required non-coherent integration gain = Required PG – 21dB = 4dB
 - Minimum number of non-coherent integrations required = 3
- S1 and S2 are inserted in time and data domains, respectively. S1 must be transmitted at least 3 times over SYNCH and PBCH repetition period, default to 100us.
 - S1 is repeated for every symbol to enable cyclic redundancy and fast symbol timing acquisition
 - S2 may carry enough number of bits to identify the cell ID and other information. For example, using 9 bits would enable 512 unique cell IDs. Coding and spreading may apply to S2 bits.
- PBCH data can be repeated with enough spreading and coding gains against decoding errors over 100 μ s repetition period
 - Length 24 bits
- Other channels can be transmitted as well
 - Partial SIB1 and SIB2 information may be transmitted with the scheme

[0268] FIG. 28 illustrates an example SYNCH and PBCH frame structure for Example 1.

[0269] **Example 2**

[0270] The following may be applicable to eZT/UW OFDM waveforms.

- PBCH data: 192 subcarriers
- SYNCH sequence: 64 time domain samples (corresponding to 64 subcarriers)
 - PG over 64 coherent integration = 18dB

- Required non-coherent integration gain = Required PG – 18dB = 7dB, then
- Minimum number of non-coherent integrations required = 6
- S1 and S2 are inserted in time and data domains, respectively. S1 must be transmitted at least 6 times over SYNCH and PBCH repetition period, default to 100us.
 - S1 is repeated for every symbol to enable cyclic redundancy and fast symbol timing acquisition
 - S2 may carry enough bits to identify the cell ID and other information. For example, using 9 bits would enable 512 unique cell IDs. Coding and spreading may apply to S2 bits.
- PBCH data can be repeated with enough spreading and coding gains against decoding errors over 100 μ s repetition period
 - Length 24 bits
- Other channels can be transmitted as well
 - Partial SIB1 and SIB2 information may be transmitted with the scheme

[0271] FIG. 29 illustrates an example SYNCH and PBCH frame structure for Example 2.

[0272] **Example 3**

[0273] The following may be applicable to eZT/UW OFDM waveforms PBCH data: 224 subcarriers

- SYNCH sequence: 32 time domain samples (corresponding to 32 subcarriers)
 - PG over 32 coherent integration = 15dB
 - Required non-coherent integration gain = Required PG – 15dB = 10dB, then
 - Minimum number of non-coherent integrations required = 14
- S1 and S2 are inserted in time and data domains, respectively. S1 must be transmitted at least 14 times over SYNCH and PBCH repetition period, default to 100us.
 - S1 is repeated for every symbol to enable cyclic redundancy and fast symbol timing acquisition
 - S2 may carry enough number of bits to identify the cell ID and other information. For example, using 9 bits would enable 512 unique cell IDs. Coding and spreading may apply to S2 bits.
- PBCH data can be repeated with enough spreading and coding gains against decoding errors over 100 μ s repetition period
 - Length 24 bits
- Other channels can be transmitted as well

- Partial SIB1 and SIB2 information may be transmitted with the scheme

[0274] Example 4:

- The following may be applicable to ZT/eZT DFT-s OFDM waveforms SYNCH sequence: 32 time domain samples, corresponding to $N_{zt}=32$
 - As shown in Option #3 above, this requires minimum 14 non-coherent integrations.
- As in Options 1 to 3 above, assuming that 256 sub-carriers are used for synchronization purposes, then for the transmitter structure in FIG. 19 and FIG. 20, $N=256$. Moreover, assuming that the DFT size is $M=64$, it follows that the number of zero tail sub-carriers at the input of the DFT is: $N_t=N_{zt} / (N/M) = 8$. Using the minimum number of zero head sub-carriers to help reduce the tail, results in $N_h=1$.
- This gives $N_d=M-N_t-N_h=64-8-1=55$ sub-carriers available for PBCH in each OFDM symbol.
 - As for Options 1 to 3 above, by using multiple OFDM symbols over the $100 \mu s$ repetition period to transmit the PBCH, this allows enough spreading and coding gains to reach the target SNR for PBCH decoding.

[0275] FIG. 30 illustrates an example SYNCH and PBCH frame structure for Example 3.

[0276] Example SYNCH and PBCH Transmission Coordination Among Neighboring Cells

[0277] In the case of sectorized and further partitioned systems, simultaneous transmissions of SYNCH channel and PBCH over multiple partitions may create large overhead that may cause reduction in resource utilization efficiency. If proper sweep timing and neighbor cell coordination are provided, the respective scheduling of SYNCH and PBCH transmissions (e.g., one at a time) for each partition may increase resource allocation efficiency and may enable range extension while reducing initial acquisition time. A simple scheduling scheme with non-overlapping area may help increase detection performance, and thus reduce acquisition time. For instance, the schedule provides the SYNCH channel and PBCH transmissions from neighboring cells so as not to align simultaneously over the same area among neighboring cells. As an example, Sector 1 and 10 are counterparts for a system with 60° sectors and 30° partitions as shown in FIG. 31. The SYNCH and PBCH transmission may alternate between $\{S1P1\}$, $\{S10P1\}$ and $\{S1P2\}$, $\{S10P2\}$ pairs over synchronization periods as shown in FIG. 31 where S_i and P_i represent i^{th} Sector and Partition, respectively. Assume that the SYNCH and PBCH channels may be transmitted over $100 \mu s$ synchronization periods and a WTRU starts scanning in O1 overlap location, if the neighbor cell coordination is present, then the WTRU may get

twice the chance of receiving synchronization bursts within $200\ \mu\text{s}$ with $100\ \mu\text{s}$ intervals. If the neighbor coordination is not present, then the WTRU may receive both transmissions simultaneously once every $200\ \mu\text{s}$. The network coordination under this scenario may reduce initial acquisition time by half. The neighbor cell coordination may also increase cell edge initial synchronization performance for WTRUs located in overlap areas, where the WTRUs are most likely to experience low SNR conditions.

[0278] Assuming that each sector constitutes a cell as shown in FIG. 31, neighboring cells are already synchronized with some tolerance (i.e. $\pm 10\ \mu\text{s}$) and sectors have k partitions, then a head node can start synchronization beam sweep operations over k partitions. Counterpart cells covering the same directions are depicted in FIG. 31; for example, the $\{S1, S10\}$, $\{S6, S15\}$, and $\{S11, S14\}$. A cell may determine its counterpart neighbor's transmission phase among $\{0, 1, \dots, k-1\}$, then may use $(k+1 \bmod N)$ to identify a partition number to transmit its own SYNCH and PBCH channels. For example, if k is chosen to be 3 and the SYNCH and PBCH channels are repeated every $100\ \mu\text{s}$, then the overall sweep may take $300\ \mu\text{s}$ for the sector. The counterpart neighbors may sweep the overlap areas at least once every $300\ \mu\text{s}$ each. The WTRU in the overlap areas may have a higher chance of detecting either counterpart cells.

[0279] Example Assisted Handover

[0280] The next generation wireless communication systems are expected to have two main design parameters, high throughput and low latency. While the next generation systems are intended to operate with very low latency, it is imperative to improve the current handover approaches adopted in current cellular networks by using Targeted Cell assistance. It is assumed that the neighboring cells are connected to each other and capable of exchanging information.

[0281] Utilization of SYNCH and PBCH channels may help expedite handover process. In an embodiment, a target base station (eNodeB) may start transmitting SYNCH and PBCH beams towards the direction and the location of a prospective WTRU; and the target base station (eNodeB) may transmit higher power than normal to increase detection likelihood for the WTRU.

[0282] FIG. 32 is an example control flow for carrying out assisted handover using SYNCH and PBCH channels. A handover (HO) decision may be initiated (3102). Target cell selection and the WTRU-specific information gathering may be carried out (3104). The WTRU-specific information may include location and direction information for the WTRU.

[0283] The current cell may (i) inform the target cell with the WTRU-specific information, HO transition start time, and detection timeout value; and/or (ii) inform the WTRU with the target and other neighboring cell parameters (3106). The target and other neighboring cell

parameters may include location(s), direction(s), a HO transition start time, and a detection timeout value.

[0284] The target cell may (i) start a handover process at the transition start time; (ii) halt regular SYNCH and PBCH transmissions; (iii) beamform at the WTRU direction; and (iv) set a detection timeout timer (" $T_{\text{DETECT_TC}}$ ") (3108). The WTRU may (i) start the handover process at the transition start time, (ii) beamform at the target cell direction; and (iii) set a detection timeout timer (" $T_{\text{DETECT_WTRU}}$ ") (3110).

[0285] The target cell may transmit SYNCH and PBCH signals over a beam with increased power level (3112). The WTRU may perform (e.g., repeatedly perform) a detection process for the SYNCH and PBCH signals (3114). If the WTRU fails to acquire the target cell (3116) prior to expiry of the detection timeout timer, $T_{\text{DETECT_WTRU}}$, then the WTRU may initiate initial cell search procedures with priority on the target cell (3118). If the WTRU acquires the target cell (3116) prior to expiry of the detection timeout timer, $T_{\text{DETECT_WTRU}}$, then the WTRU may inform the target cell of the acquisition (3120).

[0286] If the target cell is informed or otherwise determines that it has been acquired by WTRU (3122) prior to expiry of the detection timeout timer, $T_{\text{DETECT_TC}}$, then the target cell may inform the neighbor cell for successful handover (3124). Thereafter, the target cell may resume normal process for SYNCH and PBCH transmissions (3126).

[0287] If the target cell determines that it has been not been acquired by WTRU (3122) prior to expiry of the detection timeout timer, $T_{\text{DETECT_TC}}$, then the target cell may set an additional timer, $T_{\text{NO_DETECT_TC}}$, (or reset and reuse the detection timeout timer, $T_{\text{DETECT_TC}}$) (3128). Thereafter, the target cell may transmit SYNCH and PBCH over all partitions pointing at locations of the WTRU (3130). If the target cell is informed or otherwise determines that it has been acquired by WTRU (3132) prior to expiry of the additional timer, $T_{\text{NO_DETECT_TC}}$, then the target cell may inform the neighbor cell for successful handover (3124), and may resume normal process for SYNCH and PBCH transmissions (3126). If the target cell determines that it has been not been acquired by WTRU (3132) prior to expiry of the additional timer, $T_{\text{NO_DETECT_TC}}$, then the target cell may inform the neighbor cell for unsuccessful handover (3134).

[0288] Conclusion

[0289] Although features and elements are provided 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. The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as

illustrations of various aspects. Many modifications and variations may be made without departing from its spirit and scope, as will be apparent to those skilled in the art. No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly provided as such. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods or systems.

[0290] It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting. As used herein, the term "video" may mean any of a snapshot, single image and/or multiple images displayed over a time basis. As another example, when referred to herein, the terms "user equipment" and its abbreviation "UE" may mean (i) a wireless transmit and/or receive unit (WTRU), such as described *supra*; (ii) any of a number of embodiments of a WTRU, such as described *supra*; (iii) a wireless-capable and/or wired-capable (e.g., tetherable) device configured with, *inter alia*, some or all structures and functionality of a WTRU, such as described *supra*; (iii) a wireless-capable and/or wired-capable device configured with less than all structures and functionality of a WTRU, such as described *supra*; or (iv) the like. Details of an example WTRU, which may be representative of any WTRU recited herein, are provided herein with respect to FIGs. 1A-1E.

[0291] In addition, the methods provided 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.

[0292] Variations of the method, apparatus and system provided above are possible without departing from the scope of the invention. In view of the wide variety of embodiments that can

be applied, it should be understood that the illustrated embodiments are examples only, and should not be taken as limiting the scope of the following claims. For instance, the embodiments provided herein include handheld devices, which may include or be utilized with any appropriate voltage source, such as a battery and the like, providing any appropriate voltage.

[0293] Moreover, in the embodiments provided above, processing platforms, computing systems, controllers, and other devices containing processors are noted. These devices may contain at least one Central Processing Unit (CPU") and memory. In accordance with the practices of persons skilled in the art of computer programming, reference to acts and symbolic representations of operations or instructions may be performed by the various CPUs and memories. Such acts and operations or instructions may be referred to as being "executed," "computer executed" or "CPU executed."

[0294] One of ordinary skill in the art will appreciate that the acts and symbolically represented operations or instructions include the manipulation of electrical signals by the CPU. An electrical system represents data bits that can cause a resulting transformation or reduction of the electrical signals and the maintenance of data bits at memory locations in a memory system to thereby reconfigure or otherwise alter the CPU's operation, as well as other processing of signals. The memory locations where data bits are maintained are physical locations that have particular electrical, magnetic, optical, or organic properties corresponding to or representative of the data bits. It should be understood that the embodiments are not limited to the above-mentioned platforms or CPUs and that other platforms and CPUs may support the provided methods.

[0295] The data bits may also be maintained on a computer readable medium including magnetic disks, optical disks, and any other volatile (e.g., Random Access Memory (RAM")) or non-volatile (e.g., Read-Only Memory (ROM")) mass storage system readable by the CPU. The computer readable medium may include cooperating or interconnected computer readable medium, which exist exclusively on the processing system or are distributed among multiple interconnected processing systems that may be local or remote to the processing system. It should be understood that the embodiments are not limited to the above-mentioned memories and that other platforms and memories may support the provided methods.

[0296] In an illustrative embodiment, any of the operations, processes, etc. described herein may be implemented as computer-readable instructions stored on a computer-readable medium. The computer-readable instructions may be executed by a processor of a mobile unit, a network element, and/or any other computing device.

[0297] There is little distinction left between hardware and software implementations of aspects of systems. The use of hardware or software is generally (but not always, in that in certain contexts the choice between hardware and software may become significant) a design choice representing cost vs. efficiency tradeoffs. There may be various vehicles by which processes and/or systems and/or other technologies described herein may be effected (e.g., hardware, software, and/or firmware), and the preferred vehicle may vary with the context in which the processes and/or systems and/or other technologies are deployed. For example, if an implementer determines that speed and accuracy are paramount, the implementer may opt for a mainly hardware and/or firmware vehicle. If flexibility is paramount, the implementer may opt for a mainly software implementation. Alternatively, the implementer may opt for some combination of hardware, software, and/or firmware.

[0298] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples may be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In an embodiment, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), and/or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, may be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein may be distributed as a program product in a variety of forms, and that an illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a CD, a DVD, a digital tape, a computer memory, etc., and a transmission type medium such as a digital and/or an analogue

communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

[0299] Those skilled in the art will recognize that it is common within the art to describe devices and/or processes in the fashion set forth herein, and thereafter use engineering practices to integrate such described devices and/or processes into data processing systems. That is, at least a portion of the devices and/or processes described herein may be integrated into a data processing system via a reasonable amount of experimentation. Those having skill in the art will recognize that a typical data processing system may generally include one or more of a system unit housing, a video display device, a memory such as volatile and non-volatile memory, processors such as microprocessors and digital signal processors, computational entities such as operating systems, drivers, graphical user interfaces, and applications programs, one or more interaction devices, such as a touch pad or screen, and/or control systems including feedback loops and control motors (e.g., feedback for sensing position and/or velocity, control motors for moving and/or adjusting components and/or quantities). A typical data processing system may be implemented utilizing any suitable commercially available components, such as those typically found in data computing/communication and/or network computing/communication systems.

[0300] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality may be achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable" to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0301] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to

the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0302] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, where only one item is intended, the term "single" or similar language may be used. As an aid to understanding, the following appended claims and/or the descriptions herein may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should be interpreted to mean "at least one" or "one or more"). The same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of

including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

[0303] Further, the terms "any of" followed by a listing of a plurality of items and/or a plurality of categories of items, as used herein, are intended to include "any of," "any combination of," "any multiple of," and/or "any combination of multiples of" the items and/or the categories of items, individually or in conjunction with other items and/or other categories of items. Moreover, as used herein, the term "set" is intended to include any number of items, including zero. Additionally, as used herein, the term "number" is intended to include any number, including zero.

[0304] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0305] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein may be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as "up to," "at least," "greater than," "less than," and the like includes the number recited and refers to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0306] Moreover, the claims should not be read as limited to the provided order or elements unless stated to that effect. In addition, use of the terms "means for" in any claim is intended to invoke 35 U.S.C. §112, ¶ 6 or means-plus-function claim format, and any claim without the terms "means for" is not so intended.

CLAIMS

What is claimed is:

1. A method, implemented in a transmitter, for supporting communications, the method comprising:
 - generating a first orthogonal frequency division multiplexing (OFDM) symbol including a plurality of types of synchronization information;
 - generating a second OFDM symbol including data; and
 - simultaneously transmitting the first and second OFDM symbols on first and second transmit beams, respectively, wherein the first transmit beam has a wide beam width, and wherein second transmit beam has a narrow beam width.
2. The method of claim 1, wherein the first and second transmit beams overlap in a space domain.
3. The method of any of the claims 1-2, wherein the first OFDM symbol is transmitted on one of a first set of subcarriers, and wherein the second OFDM symbol is transmitted on one of a second set of subcarriers.
4. The method of claim 3, wherein the first set of subcarriers maps to a center sub-band of an available channel, and wherein the second set of subcarriers is orthogonal to the first set of subcarriers.
5. The method of any of the claims 1-4, wherein simultaneously transmitting the first and second OFDM symbols comprises:
 - transmitting the first and second OFDM symbols during a common symbol time period.
6. The method of any of the claims 1-5, wherein generating a first OFDM symbol comprises:
 - generating a first symbol comprising a first of the plurality of types of synchronization information; and
 - performing time domain insertion of a second of the plurality of types of synchronization information into the first symbol.
7. The method of claim 6, wherein the first symbol comprises a tail portion, and wherein performing time domain insertion comprises: performing time domain insertion of the second of the plurality of types of synchronization information into the tail portion of the first symbol.
8. The method of claim 7, wherein generating a first symbol comprises apportioning a duration of the first symbol among the tail portion and non-tail portions of the first symbol.

9. The method of any of the claims 6-7, wherein the second of the plurality of types of synchronization information is carried solely in the tail portion of the first symbol.
10. The method of any of the claims 6-9, wherein the second of the plurality of types of synchronization information comprises any of symbol timing synchronization information and slot timing synchronization information.
11. The method of any of the claims 6-10, wherein the first of the plurality of types of synchronization information comprises any of a sequence for identifying a cell identity (ID) and a physical broadcast channel (PBCH).
12. The method of any of the claims 6-11, wherein the first symbol comprises one or more non-tail portions, and wherein the first of the plurality of types of synchronization information is carried solely in any of the one or more non-tail portions of the first symbol.
13. The method of any of the claims 6-12, wherein generating a second OFDM symbol comprises:
- generating a second symbol comprising any of data and control information; and
 - performing time domain insertion of the second of the plurality of types of synchronization information into the second symbol.
14. A transmitter comprising:
- a first waveform generator configured to generate a first orthogonal frequency division multiplexing (OFDM) symbol including a plurality of types of synchronization information;
 - a second waveform generator configured to generate a second OFDM symbol including data; and
 - a processor and a plurality of phased antenna array elements configured to simultaneously transmit the first and second OFDM symbols on first and second transmit beams, respectively, wherein the first transmit beam has a wide beam width, and wherein second transmit beam has a narrow beam width.
15. The transmitter of claim 14, wherein the processor and the plurality of phased antenna array elements are configured to:
- transmit the first and second OFDM symbols during a common symbol time period.
16. The transmitter of any of the claims 14-15, wherein:
- the first waveform generator is configured to:

generate a first symbol comprising a first of the plurality of types of synchronization information; and
perform time domain insertion of a second of the plurality of types of synchronization information into the first symbol; and
the second waveform generator is configured to:
generate a second symbol comprising any of data and control information; and
perform time domain insertion of the second of the plurality of types of synchronization information into the second symbol.

17. The transmitter of the claims 14-16, wherein the first of the plurality of types of synchronization information comprises any of a sequence for identifying a cell identity (ID) and a physical broadcast channel (PBCH), and wherein the second of the plurality of types of synchronization information comprises any of symbol timing synchronization information and slot timing synchronization information.

18. A method, implemented in a transmitter, for supporting communications, the method comprising:

generating a first symbol having a zero tail using (i) a first orthogonal frequency division multiplexing (OFDM)-based waveform generator, and (ii) a first of a plurality of types of synchronization information and zeros as inputs to such generator;
performing time domain insertion of a second of the plurality of types of synchronization information into the zero tail of the first symbol;
mapping the first symbol to a first set of subcarriers;
converting the mapped first symbol to a first OFDM symbol;
generating a second symbol having a zero tail using (i) a second OFDM-based waveform generator, and (ii) user data and zeros as inputs to such generator;
mapping the second symbol to a second set of subcarriers;
converting the mapped second symbol to a second OFDM symbol;
simultaneously transmitting the first and second OFDM symbols on first and second transmit beams, respectively, wherein the first transmit beam has a wide beam width, and wherein second transmit beam has a narrow beam width

19. The method of claim 18, wherein the first and second transmit beams overlap in a space domain.

20. The method of any of the claims 18-19, wherein the first OFDM symbol is transmitted on one of the first set of subcarriers, and wherein the second OFDM symbol the transmitted on one of a second set of subcarriers.
21. The method of claim 20, wherein the first set of subcarriers maps to a center sub-band of an available channel, and wherein the second set of subcarriers is orthogonal to the first set of subcarriers.
22. The method of any of the claims 18-21, wherein simultaneously transmitting the first and second OFDM symbols comprises:
- transmitting the first and second OFDM symbols during a common symbol time period.
23. The method of any of the claims 18-22, wherein generating a first symbol comprises apportioning a duration of the first symbol among the tail portion and non-tail portions of the first symbol.
24. The method of any of the claims 18-23, further comprising:
- performing time domain insertion of the second of the plurality of types of synchronization information into the zero tail of the second symbol.
25. The method of any of the claims 18-24, wherein the second of the plurality of synchronization information comprises any of symbol timing synchronization information and slot timing synchronization information.
26. The method of any of the claims 18-25, wherein the first of the plurality of synchronization information comprises any of a sequence for identifying a cell identity (ID) and a physical broadcast channel (PBCH).
27. A transmitter comprising:
- a first orthogonal frequency division multiplexing (OFDM)-based waveform generator configured to:
 - generate a first symbol having a zero tail using a first of a plurality of types of synchronization information and zeros as inputs;
 - perform time domain insertion of a second of the plurality of types of synchronization information into the zero tail of the first symbol;
 - map the first symbol to a first set of subcarriers; and
 - convert the mapped first symbol to a first OFDM symbol;
 - a second OFDM-based waveform generator configured to:
 - generate a second symbol having a zero tail using user data and zeros as inputs;

map the second symbol to a second set of subcarriers;
convert the mapped second symbol to a second OFDM symbol; and
a processor and a plurality of phased antenna array elements configured to simultaneously transmit the first and second OFDM symbols on first and second transmit beams, respectively, wherein the first transmit beam has a wide beam width, and wherein second transmit beam has a narrow beam width.

28. The transmitter of claim 27, wherein the processor and the plurality of phased antenna array elements are configured to:

transmit the first and second OFDM symbols during a common symbol time period.

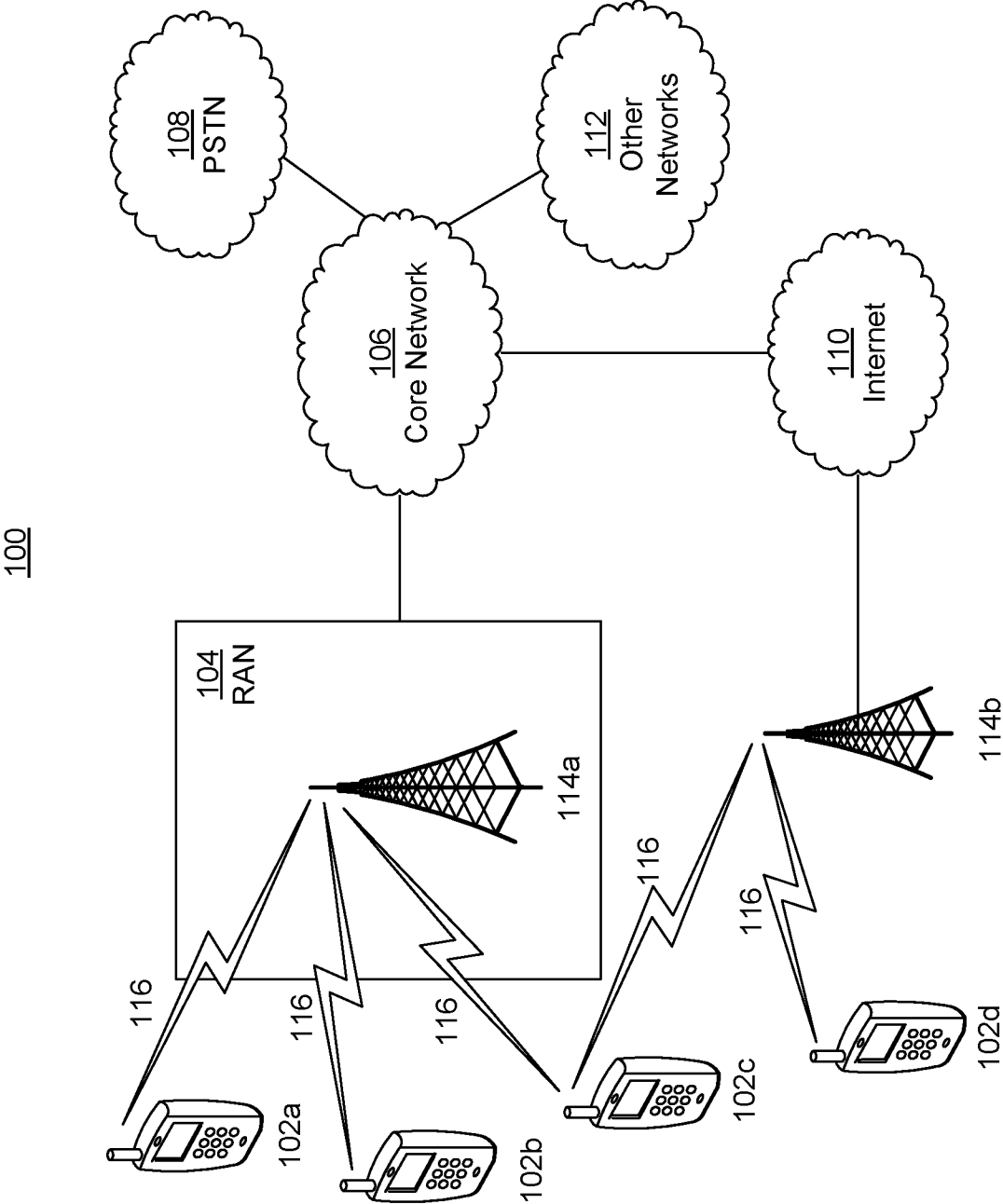
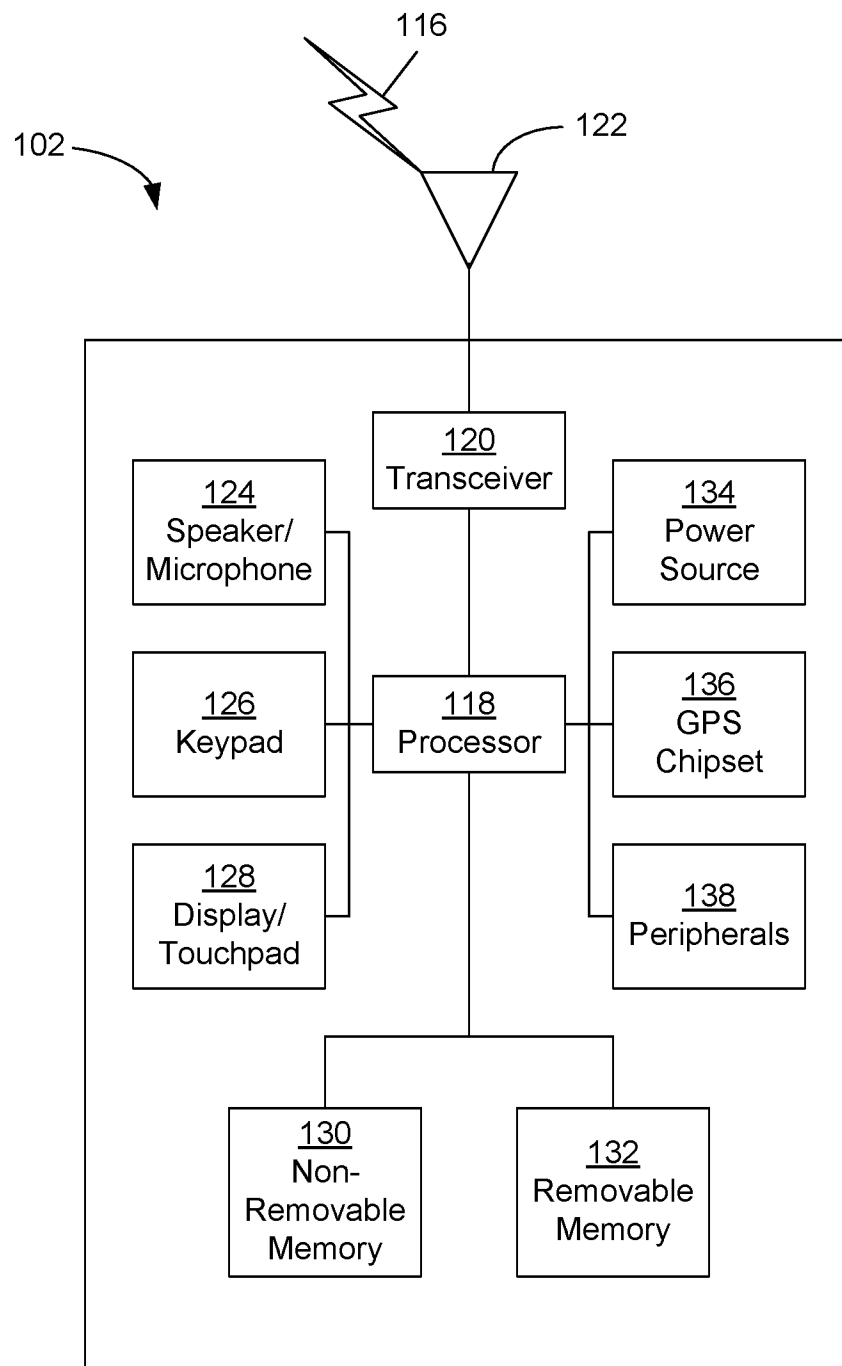


FIG. 1A

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**FIG. 1B**

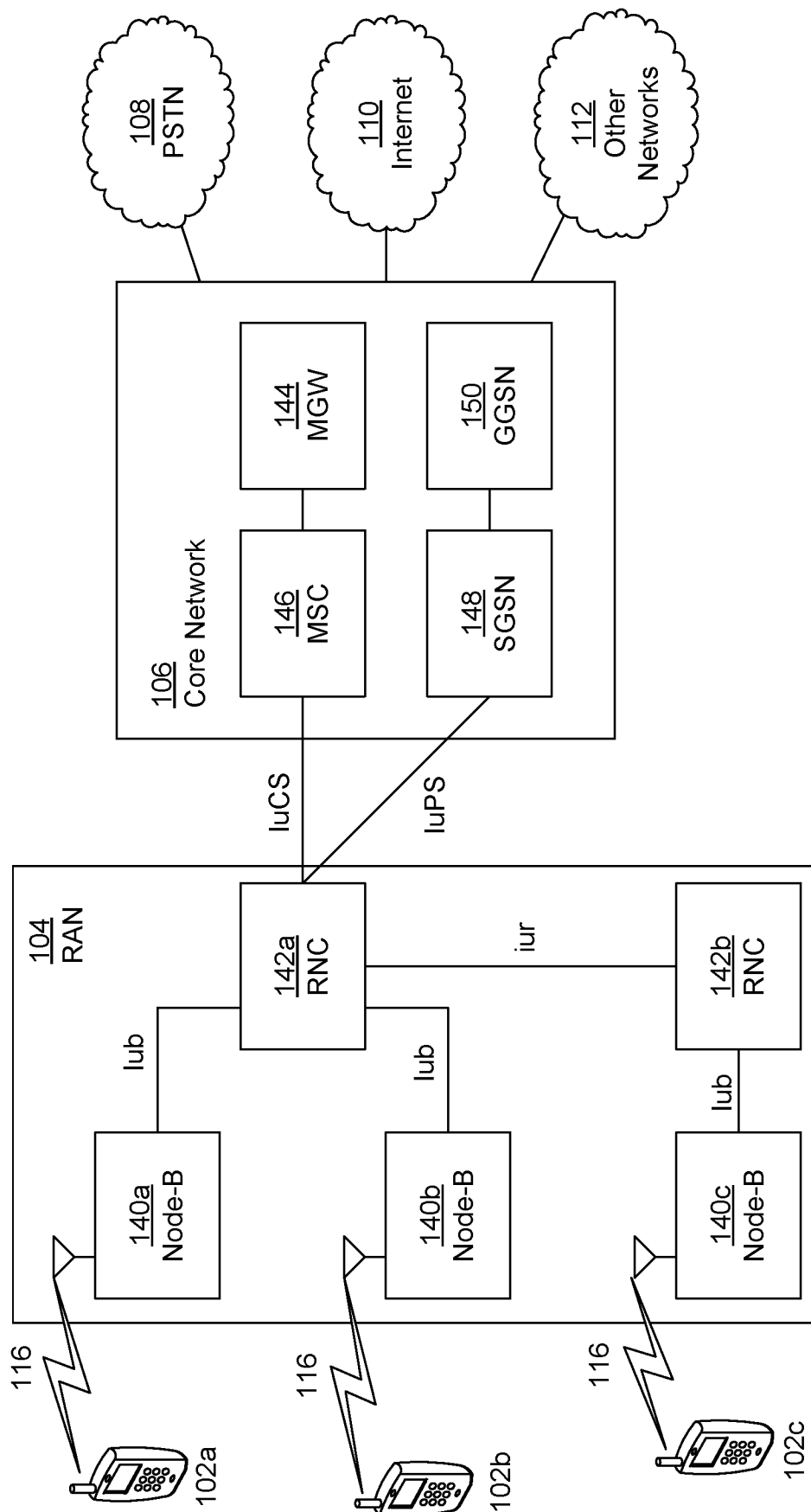


FIG. 1C

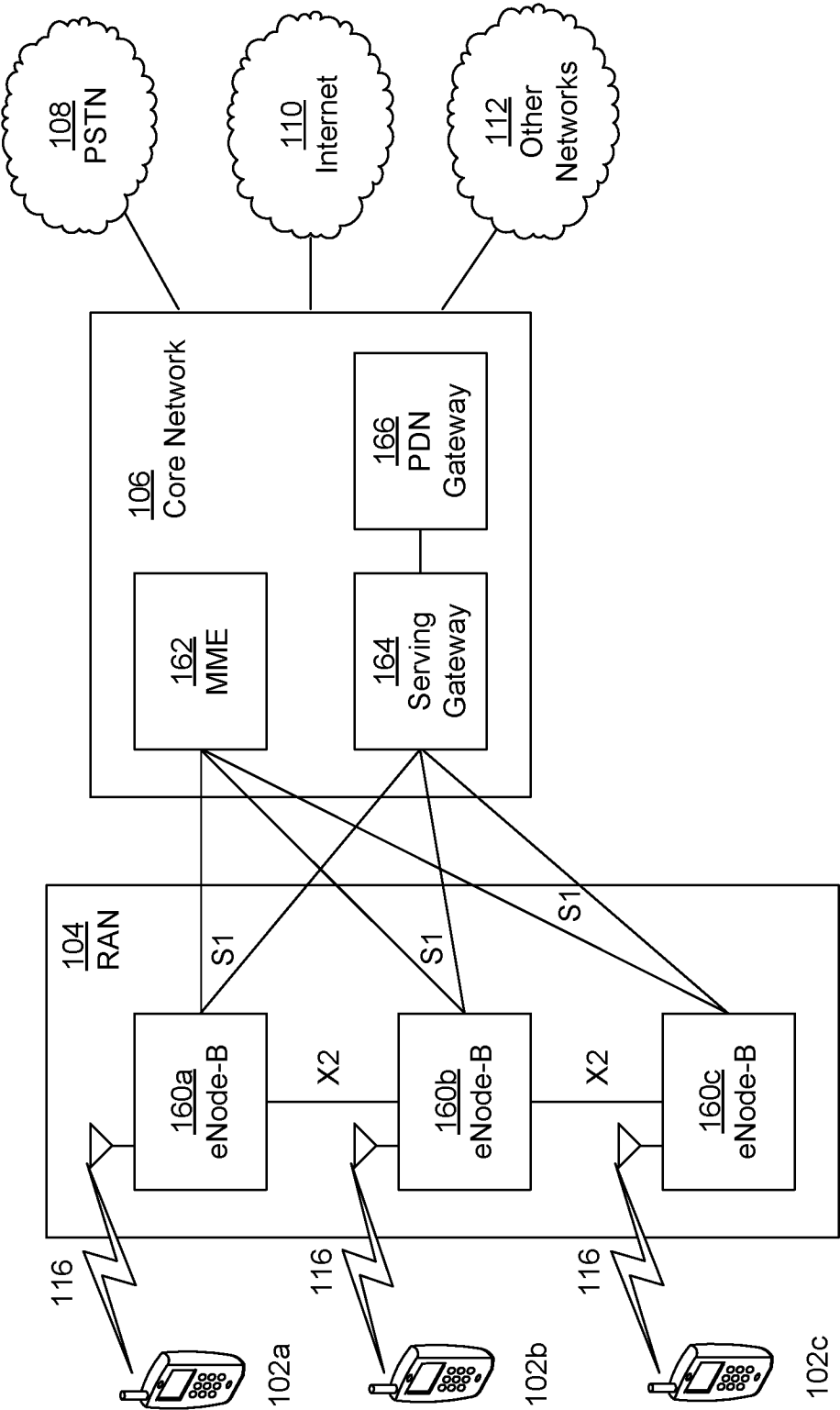


FIG. 1D

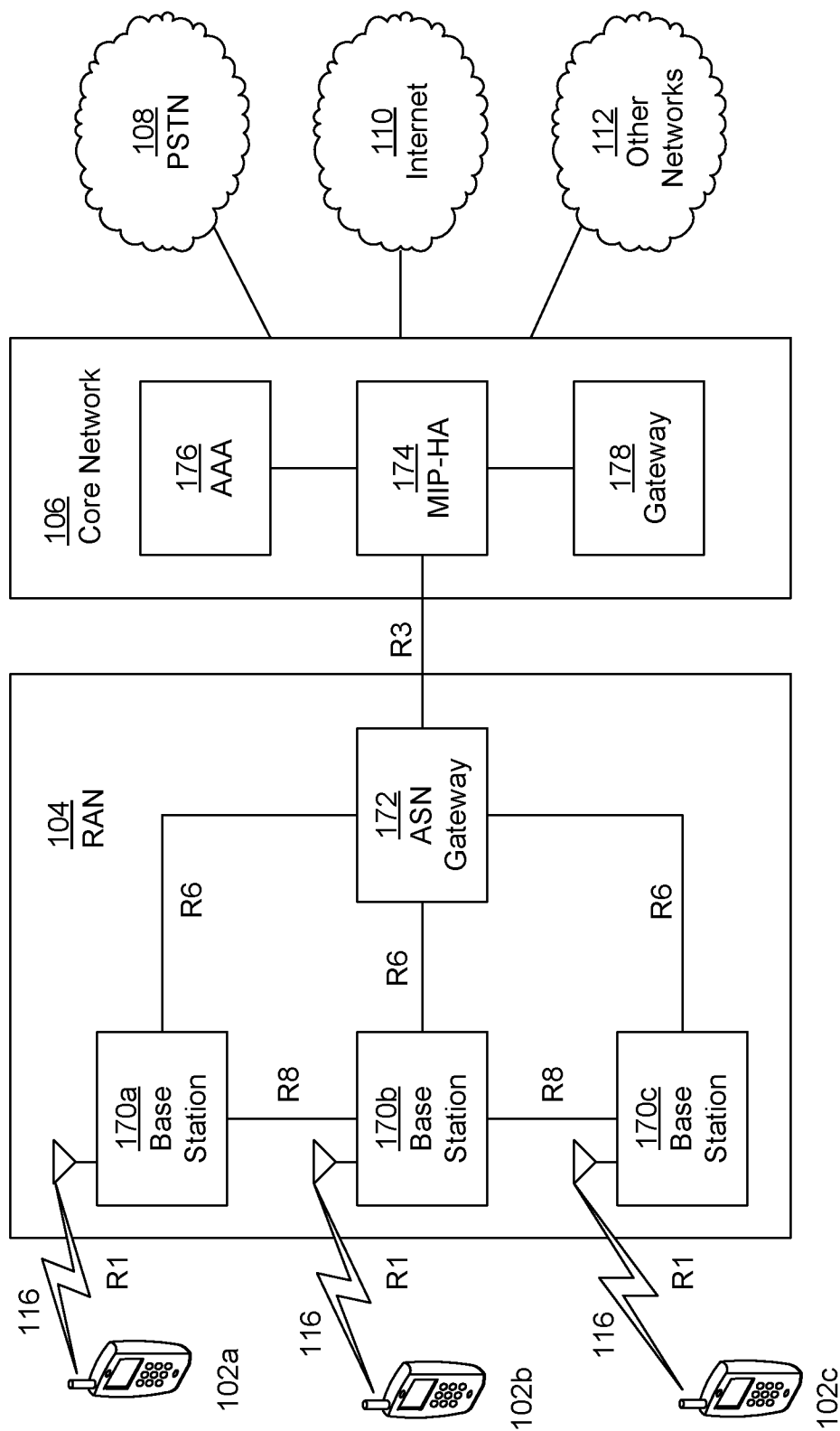


FIG. 1E

200

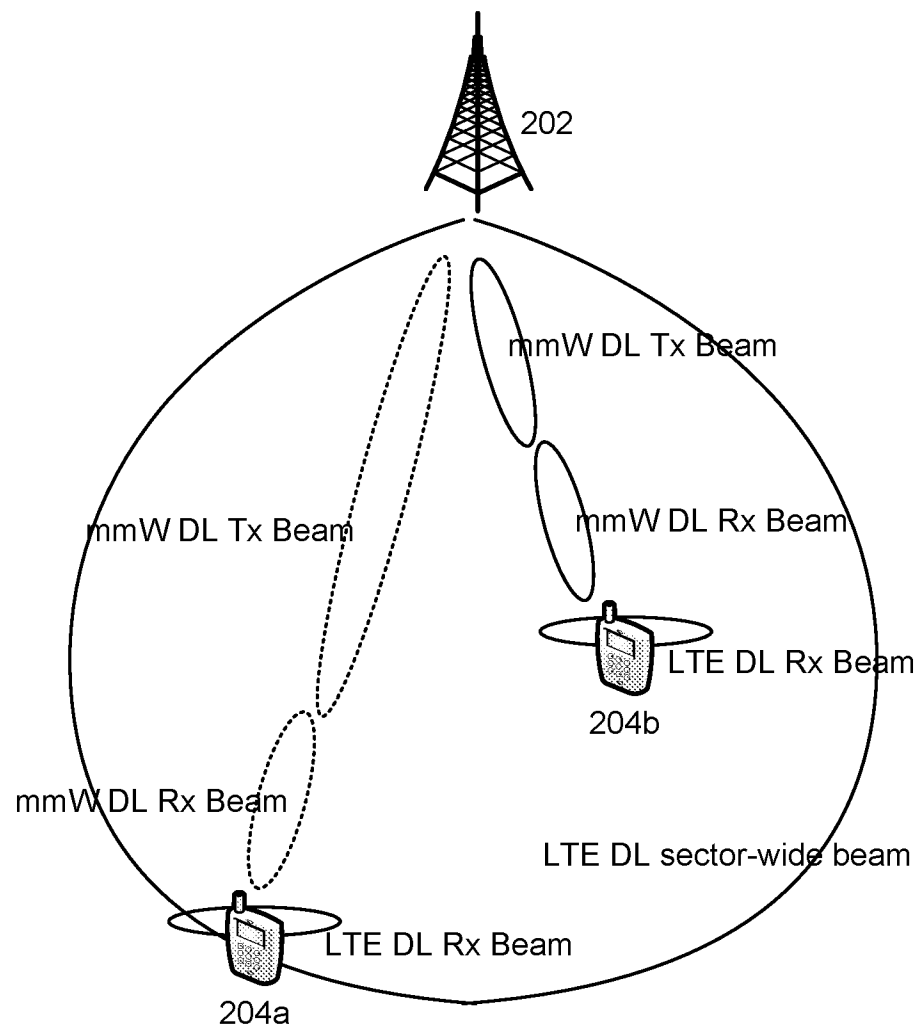


FIG. 2

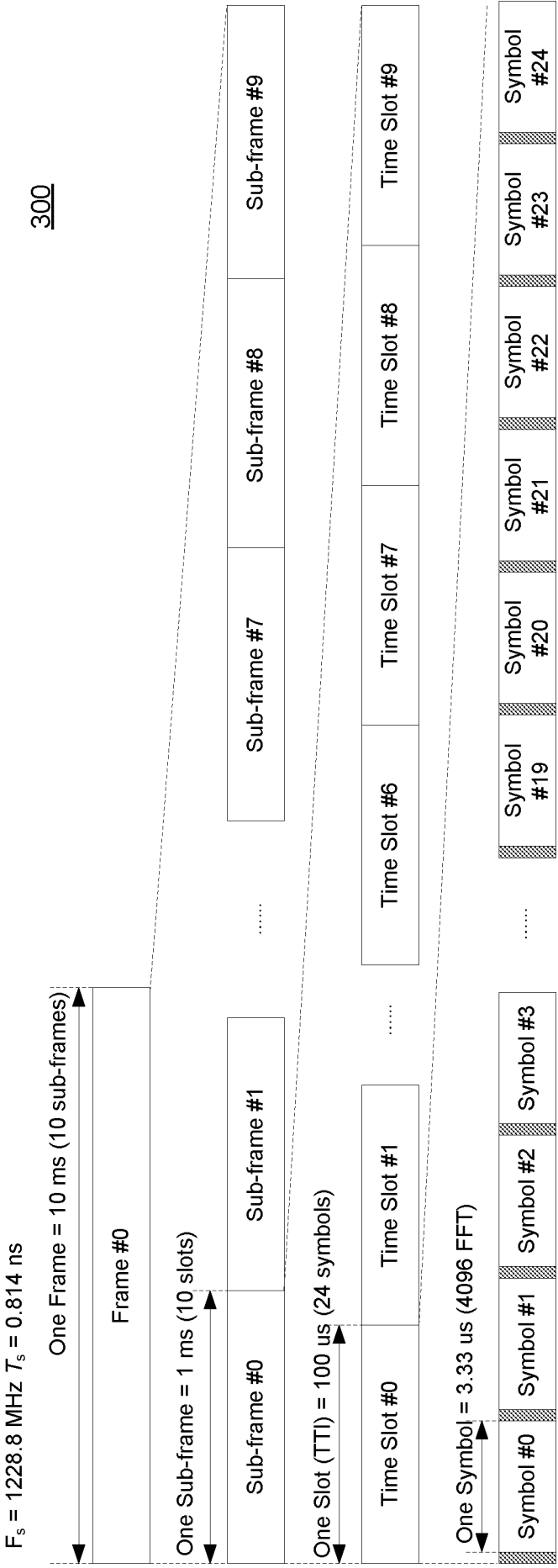


FIG. 3A

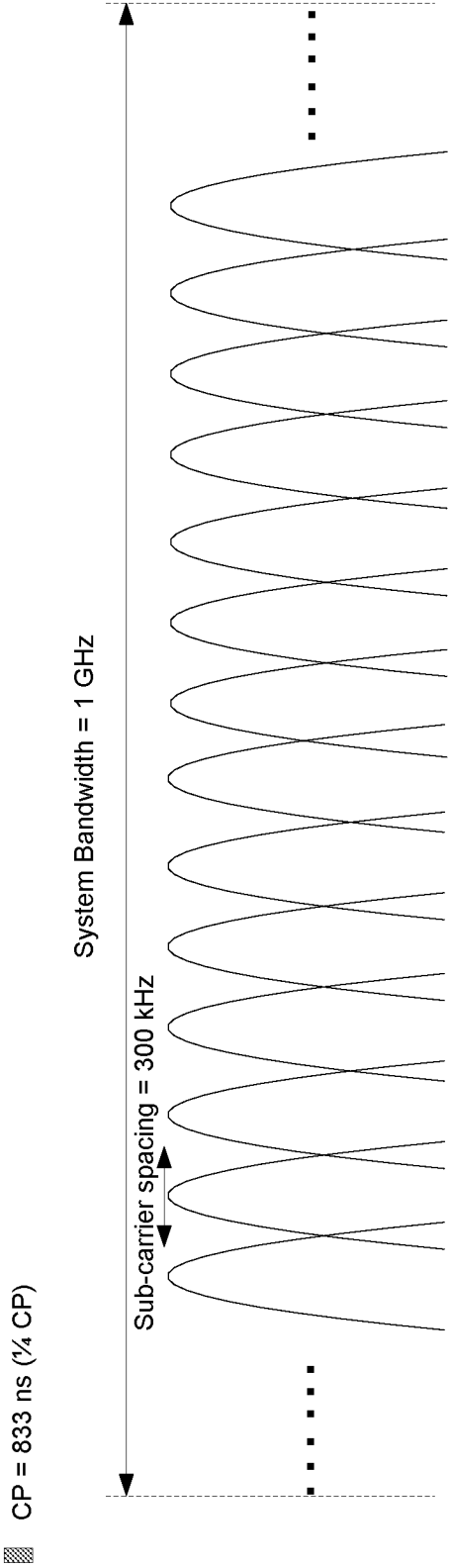


FIG. 3B

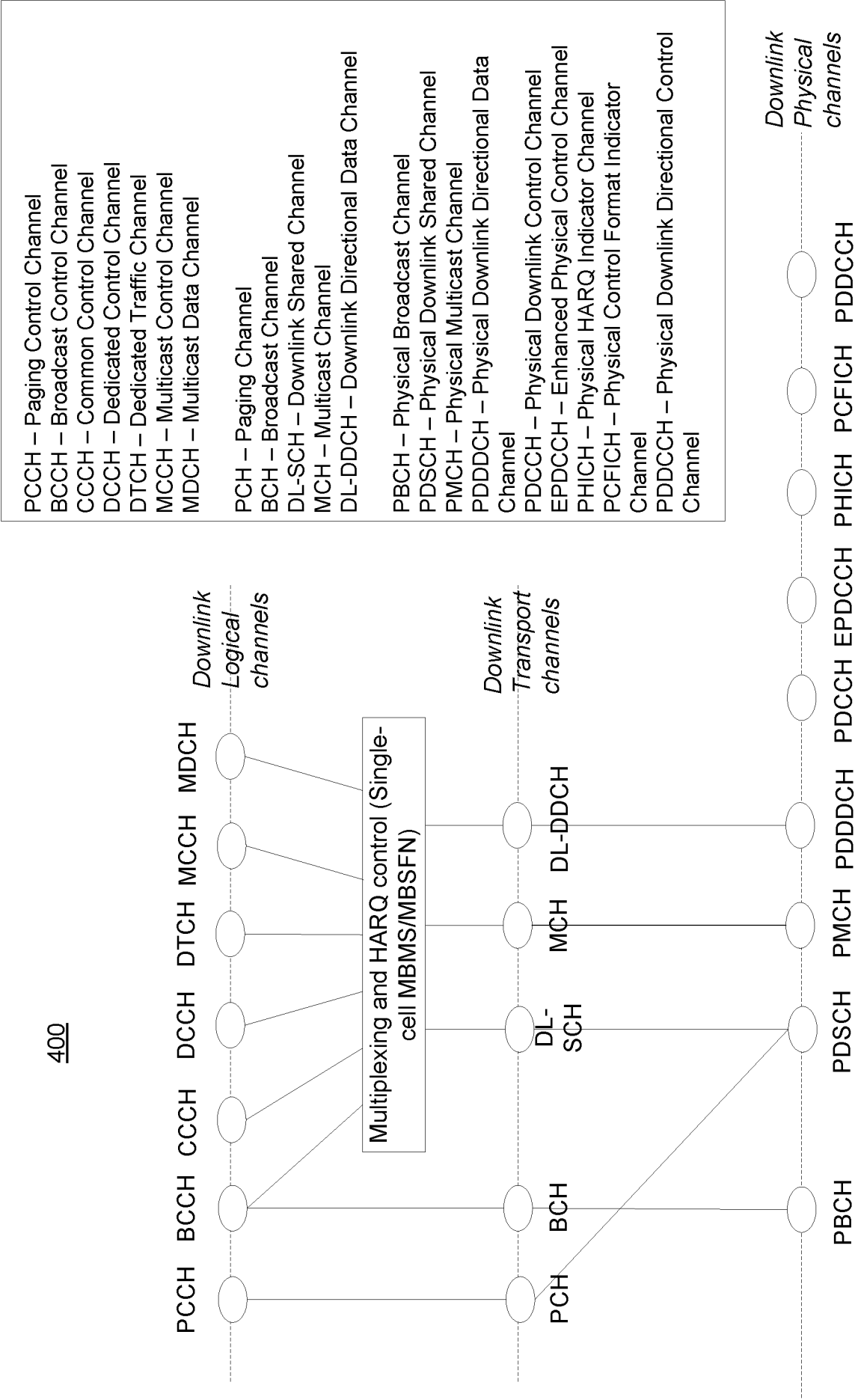


FIG. 4

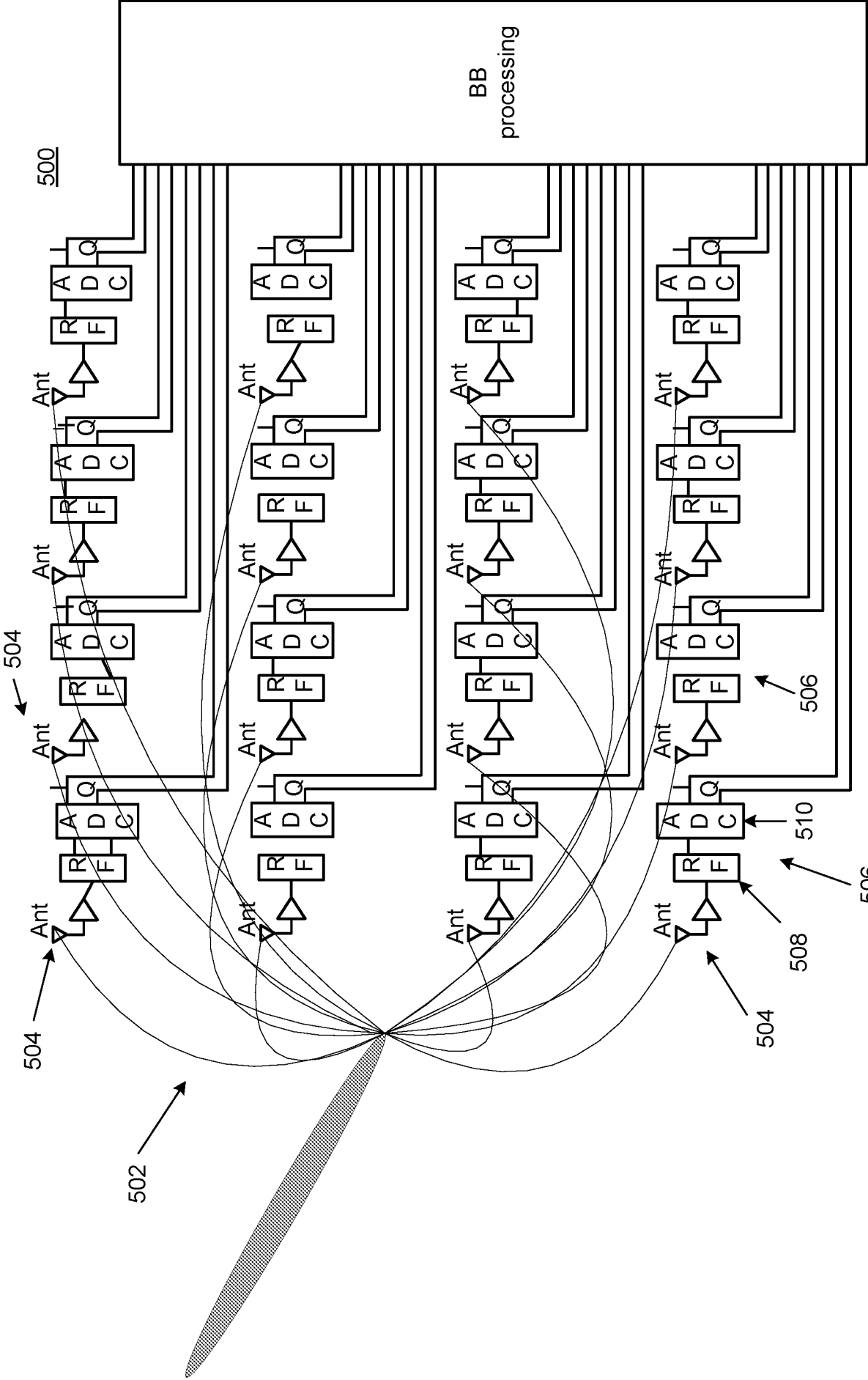


FIG. 5

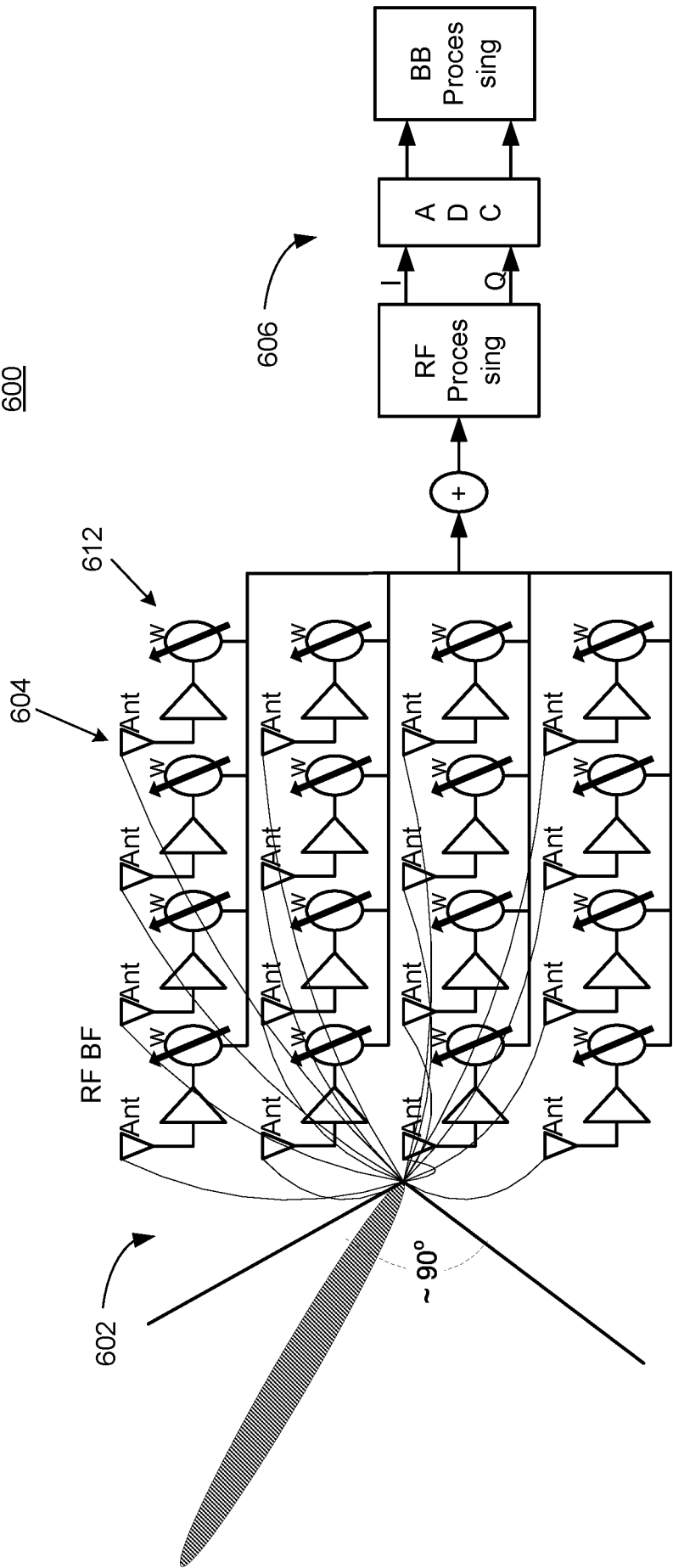


FIG. 6

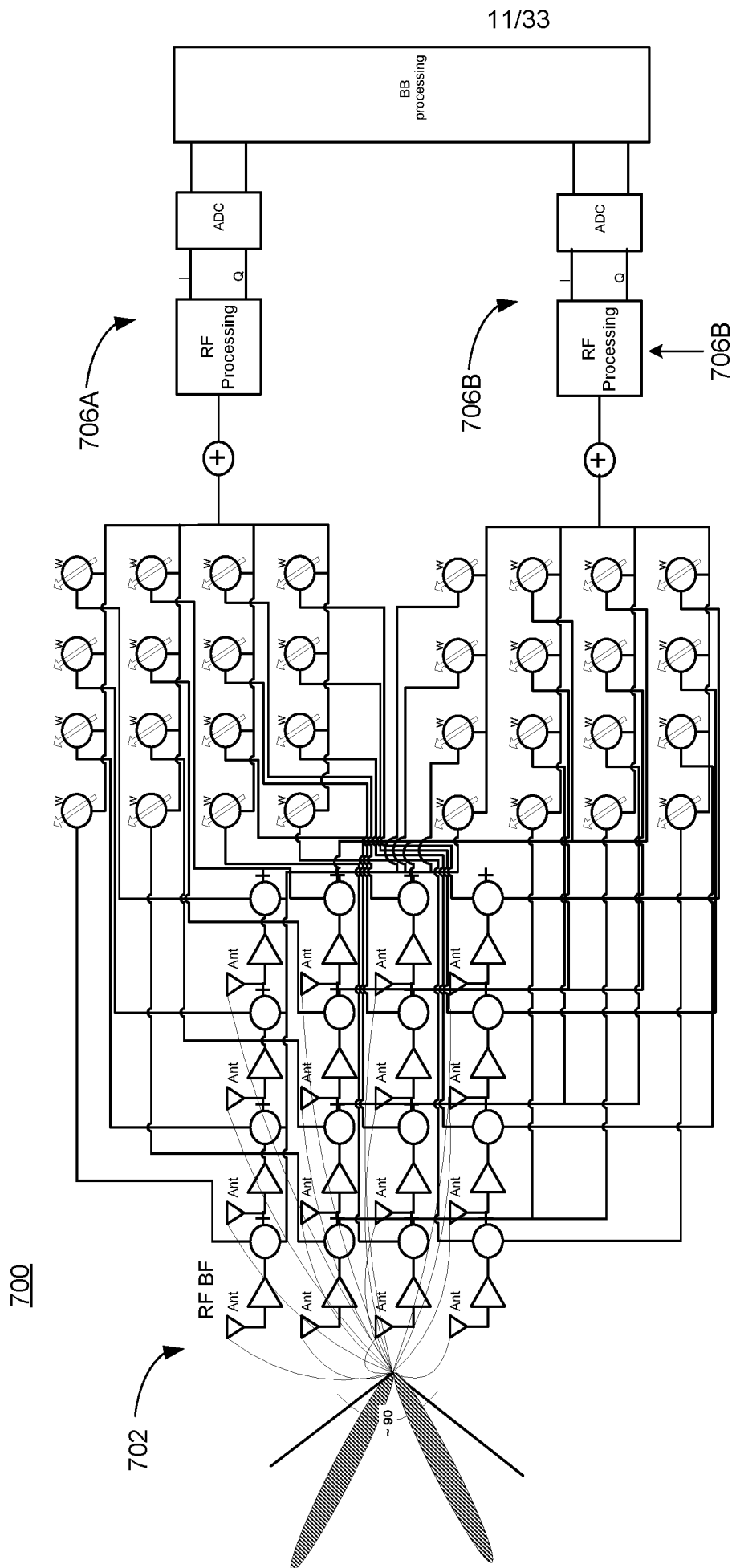


FIG. 7

800

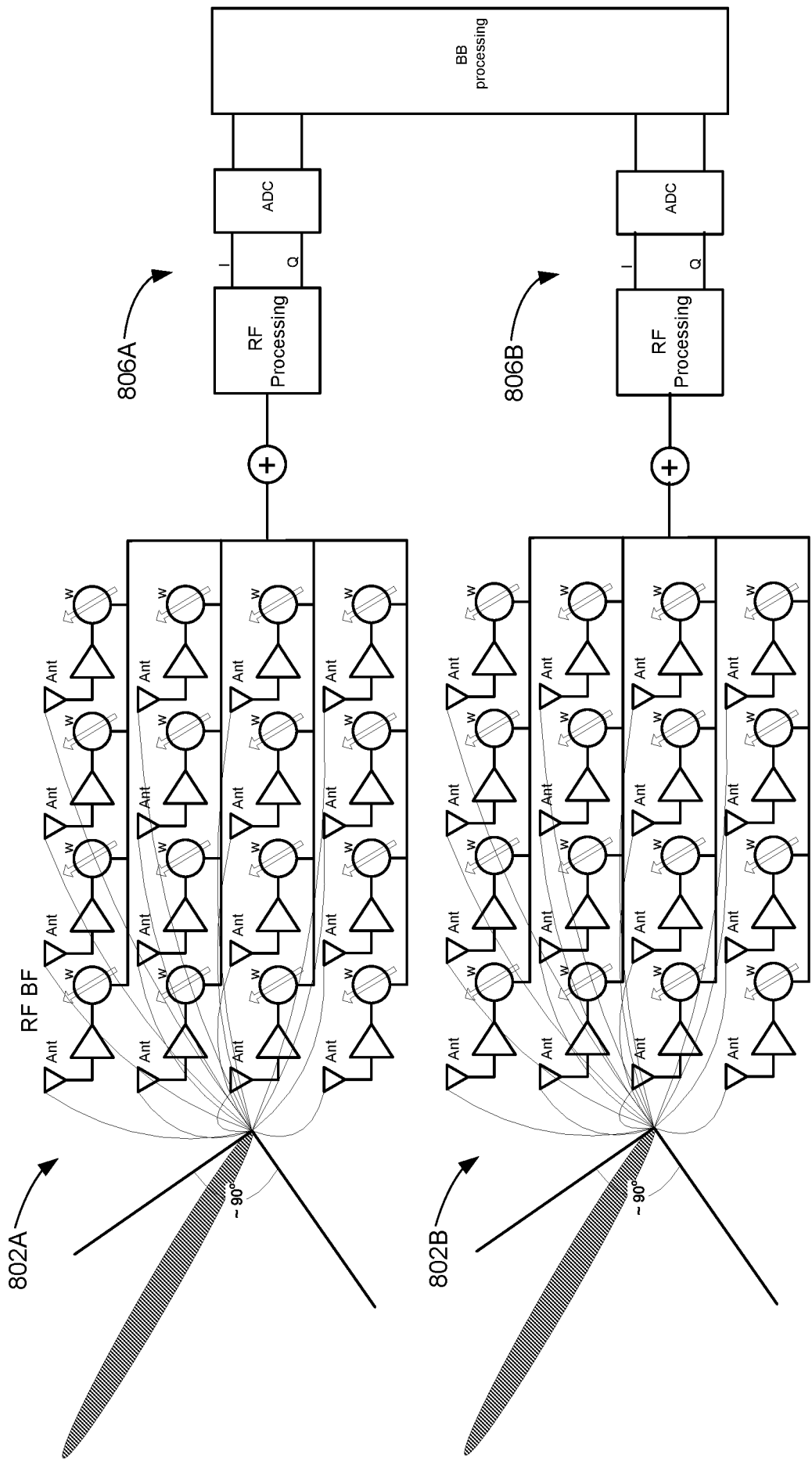


FIG. 8

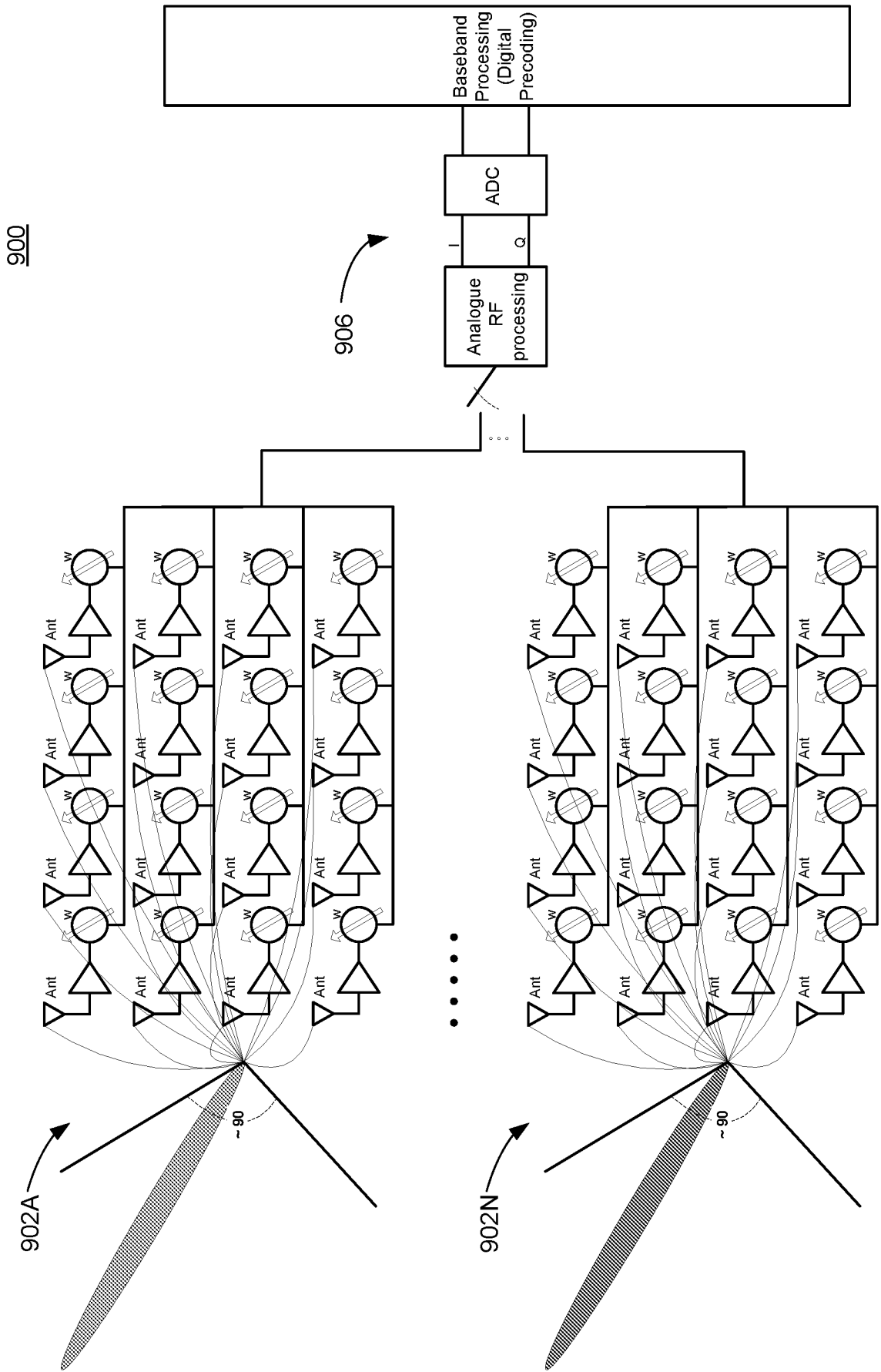


FIG. 9

1000

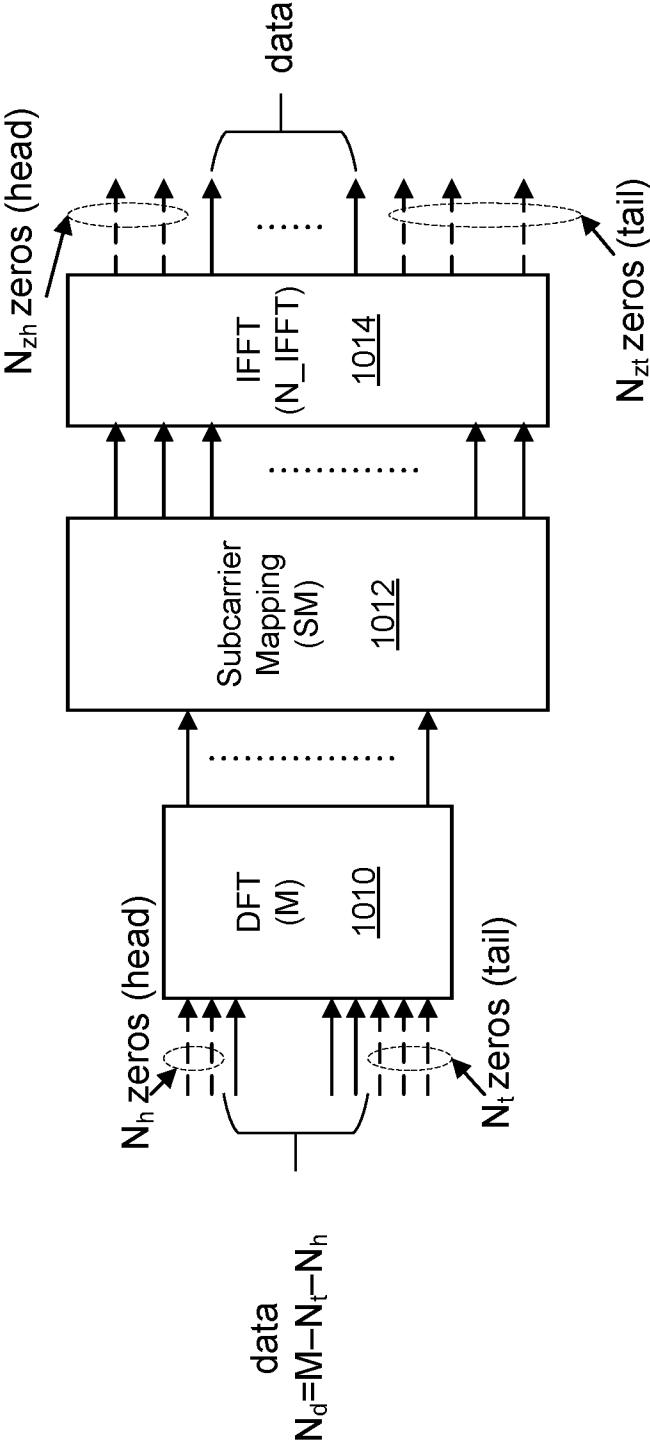


FIG. 10

1100

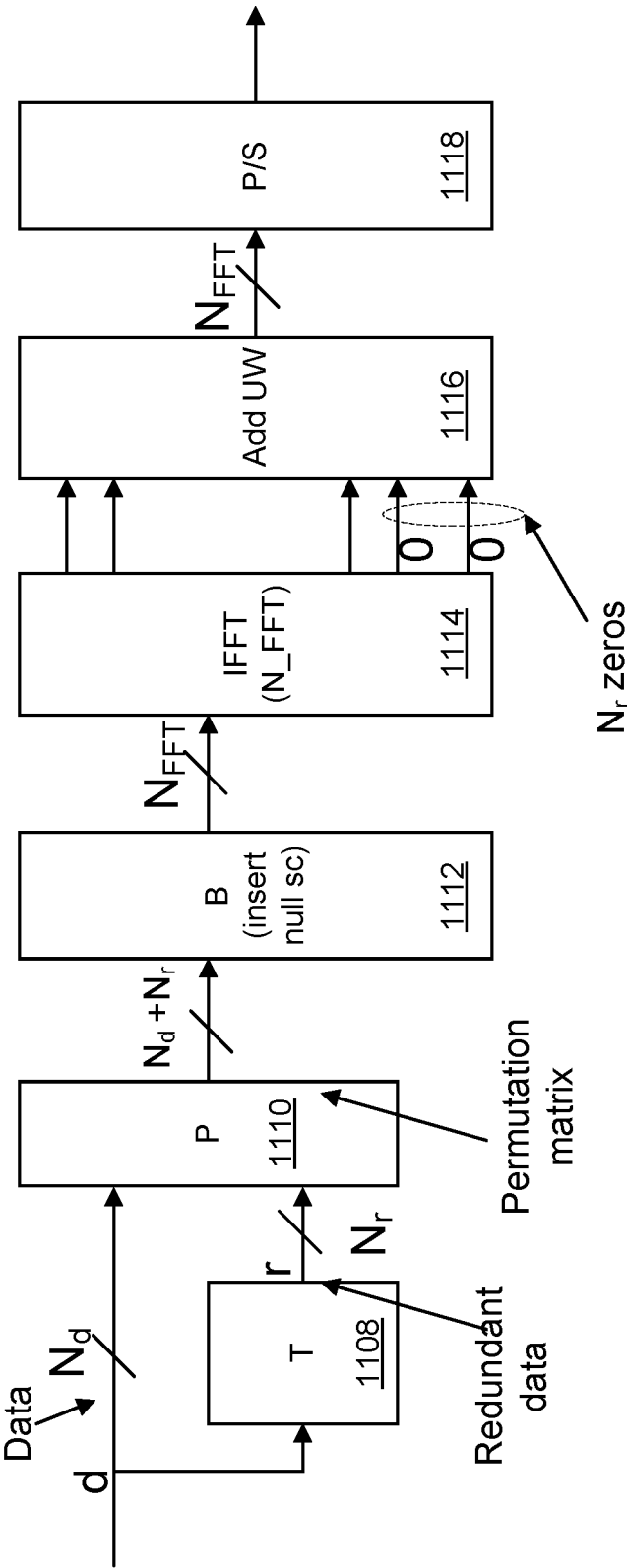


FIG. 11

1200

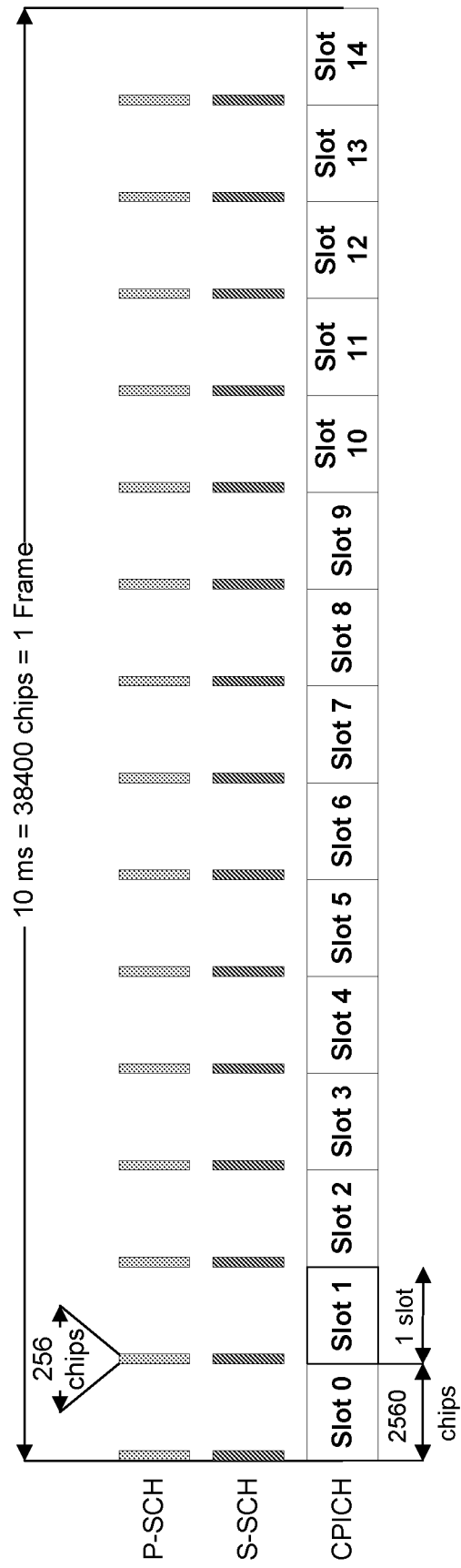


FIG. 12

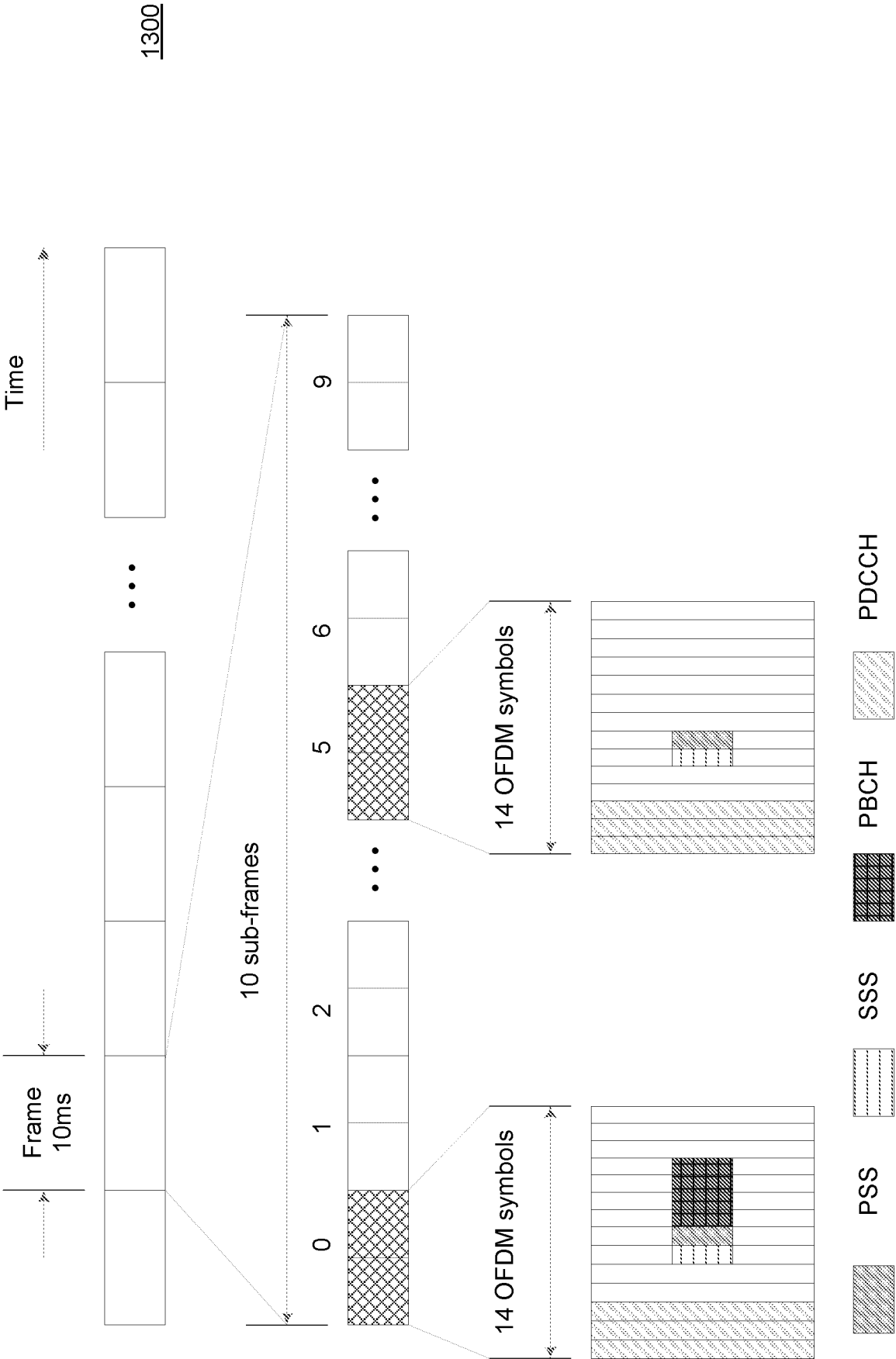


FIG. 13

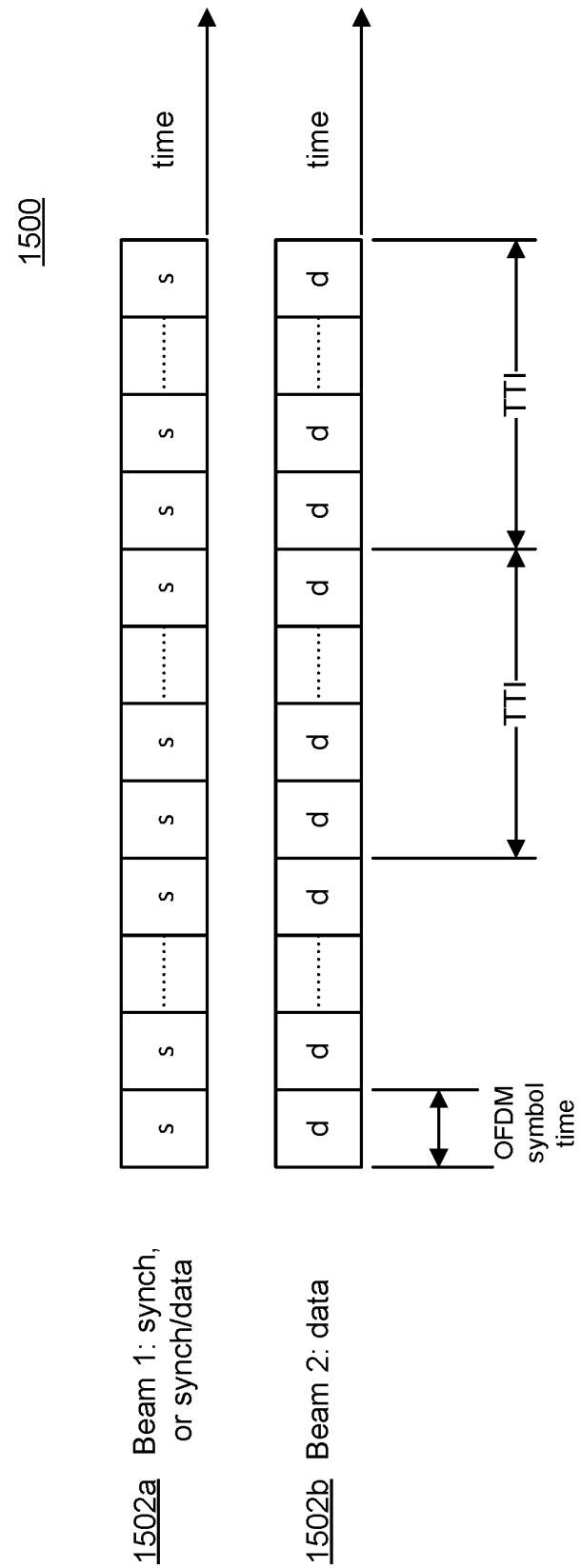
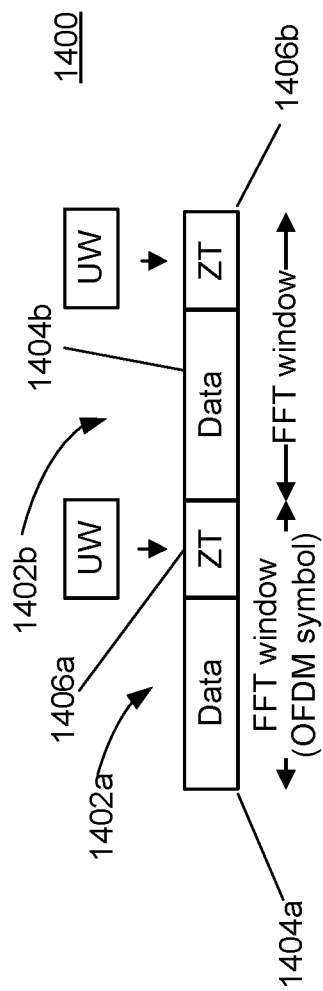


FIG. 16

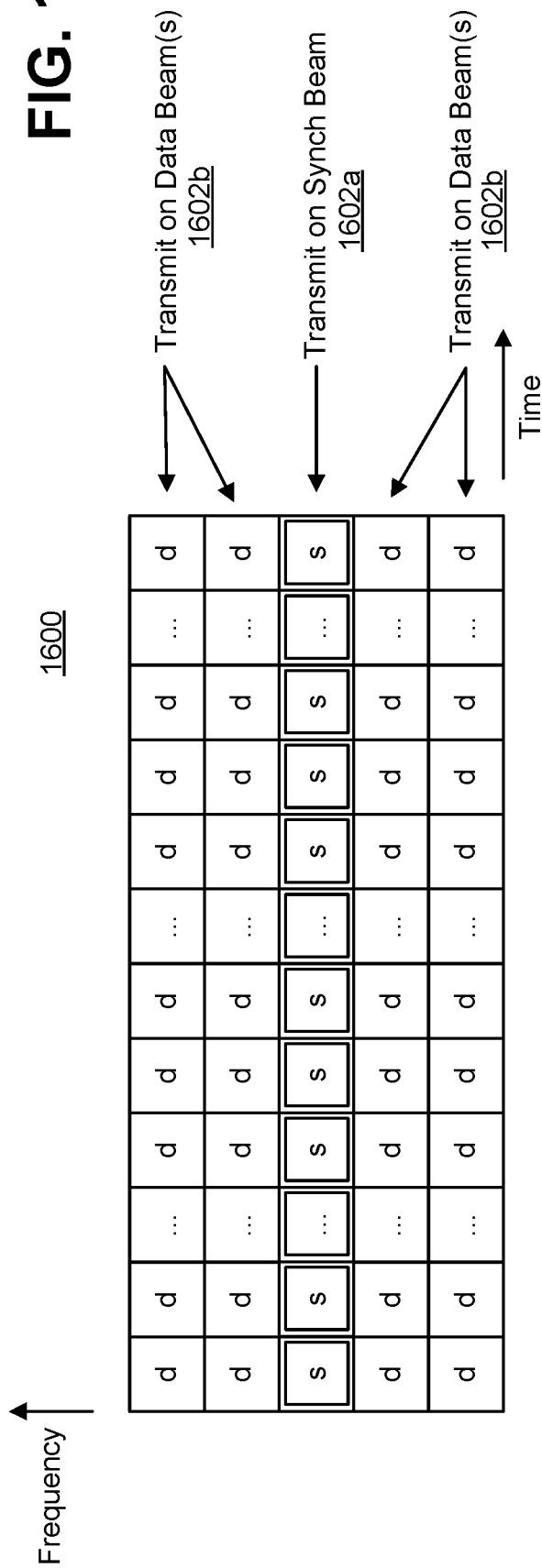
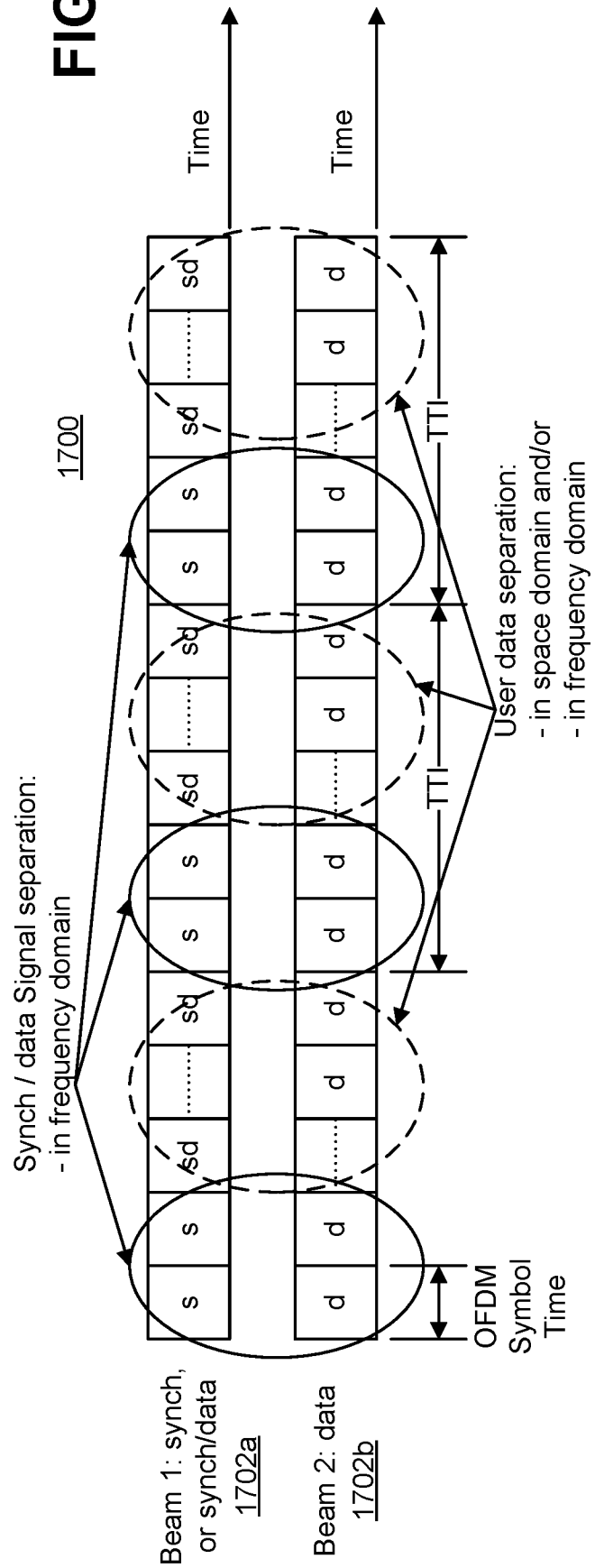


FIG. 17



1800

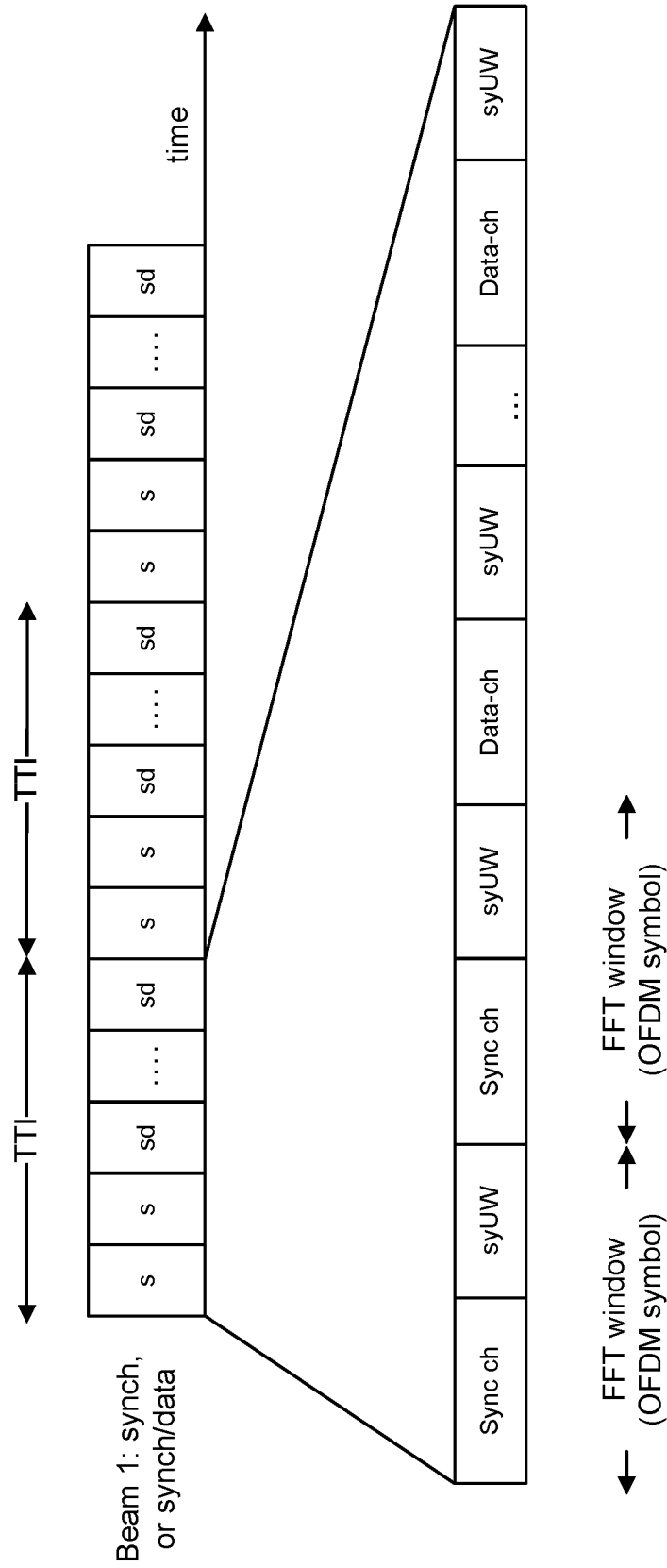
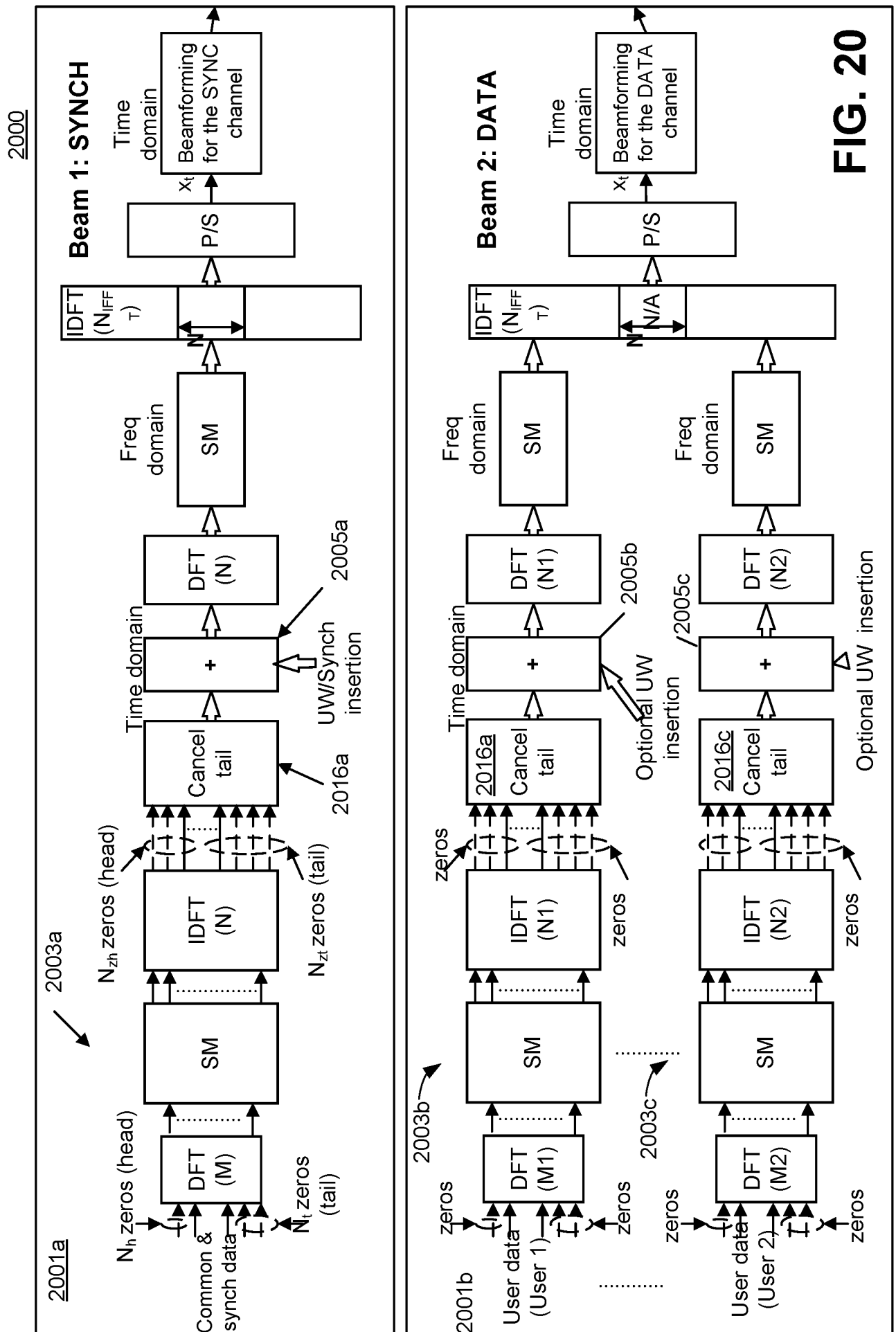


FIG. 18



2100

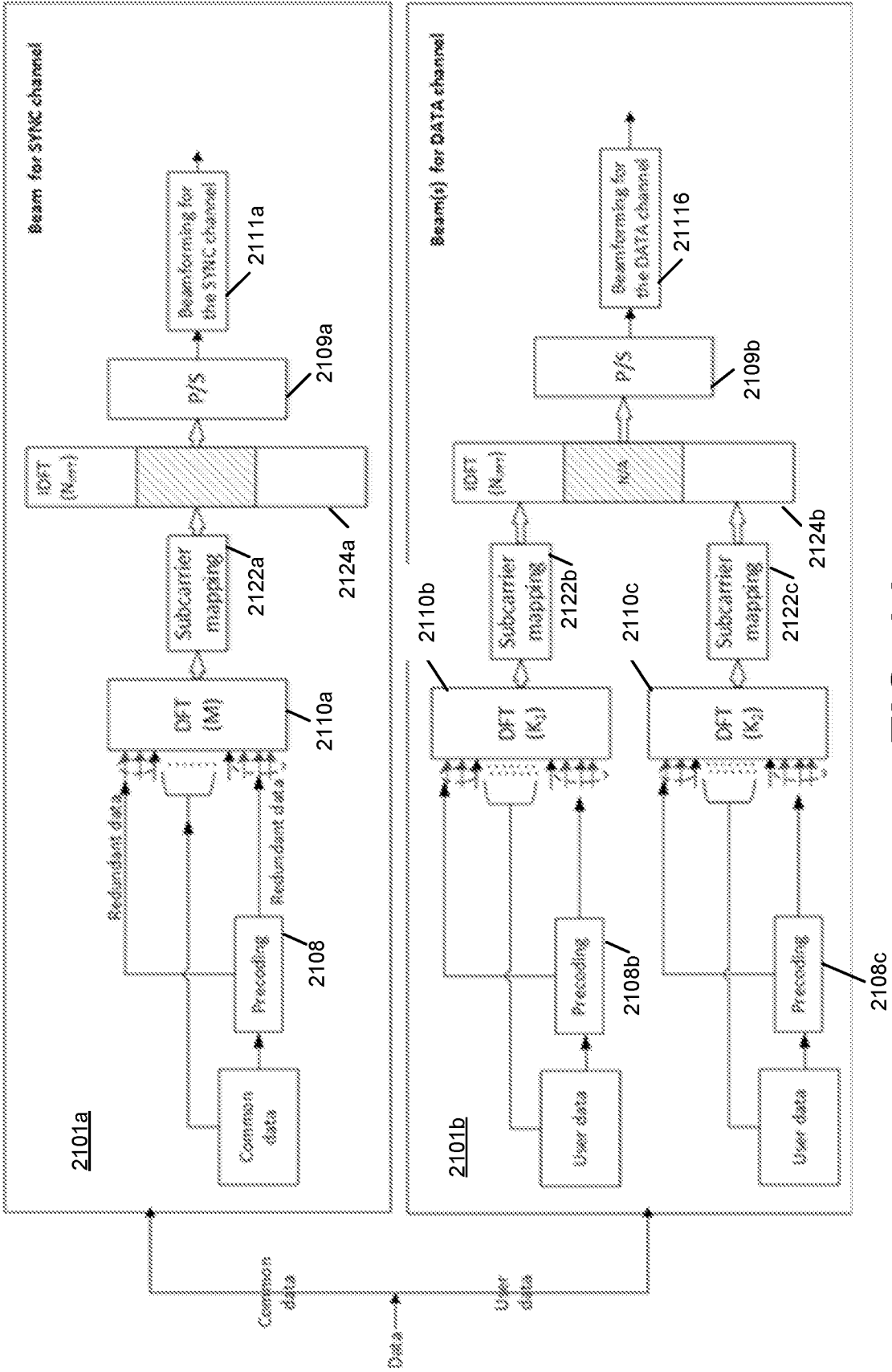


FIG. 21

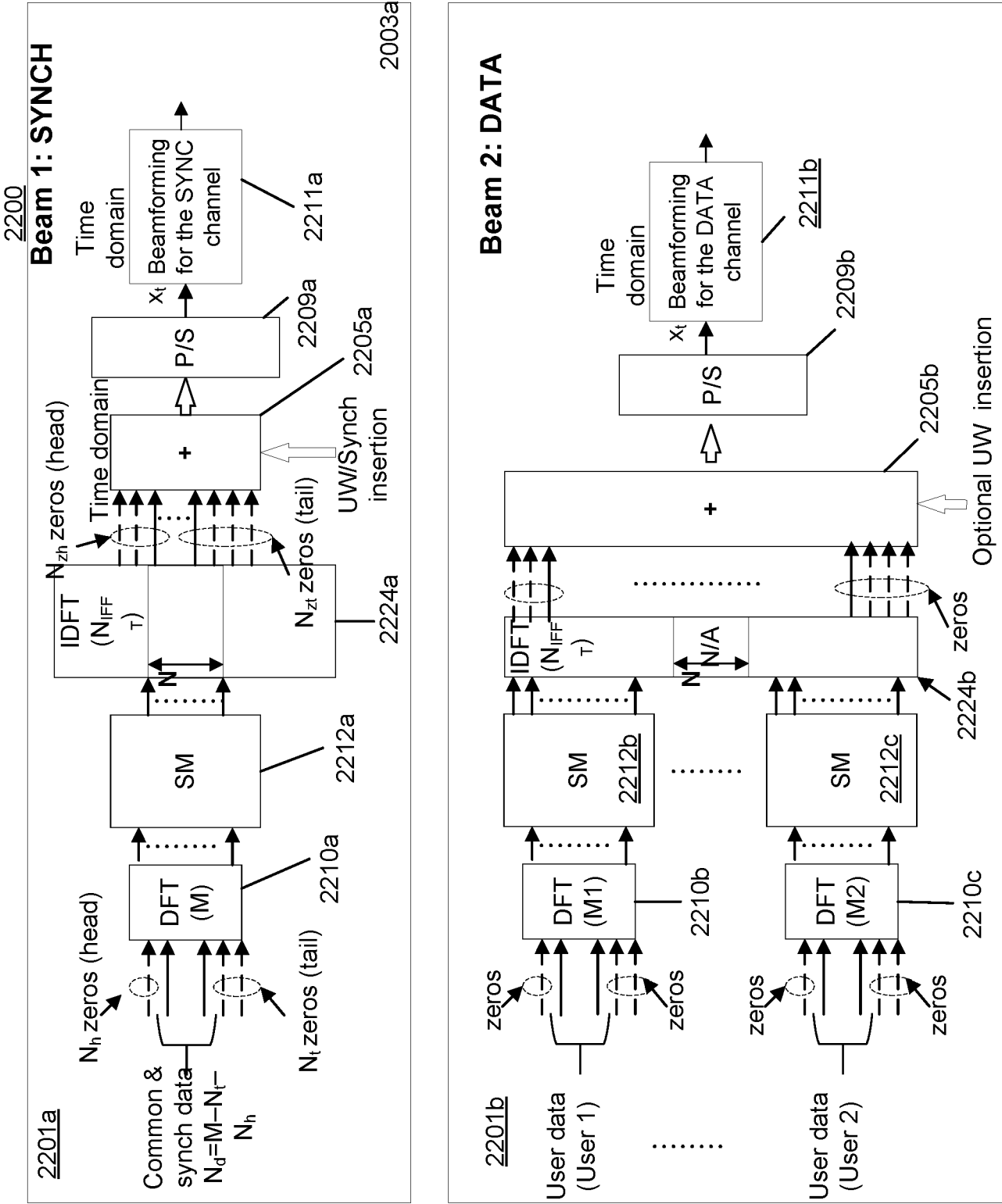
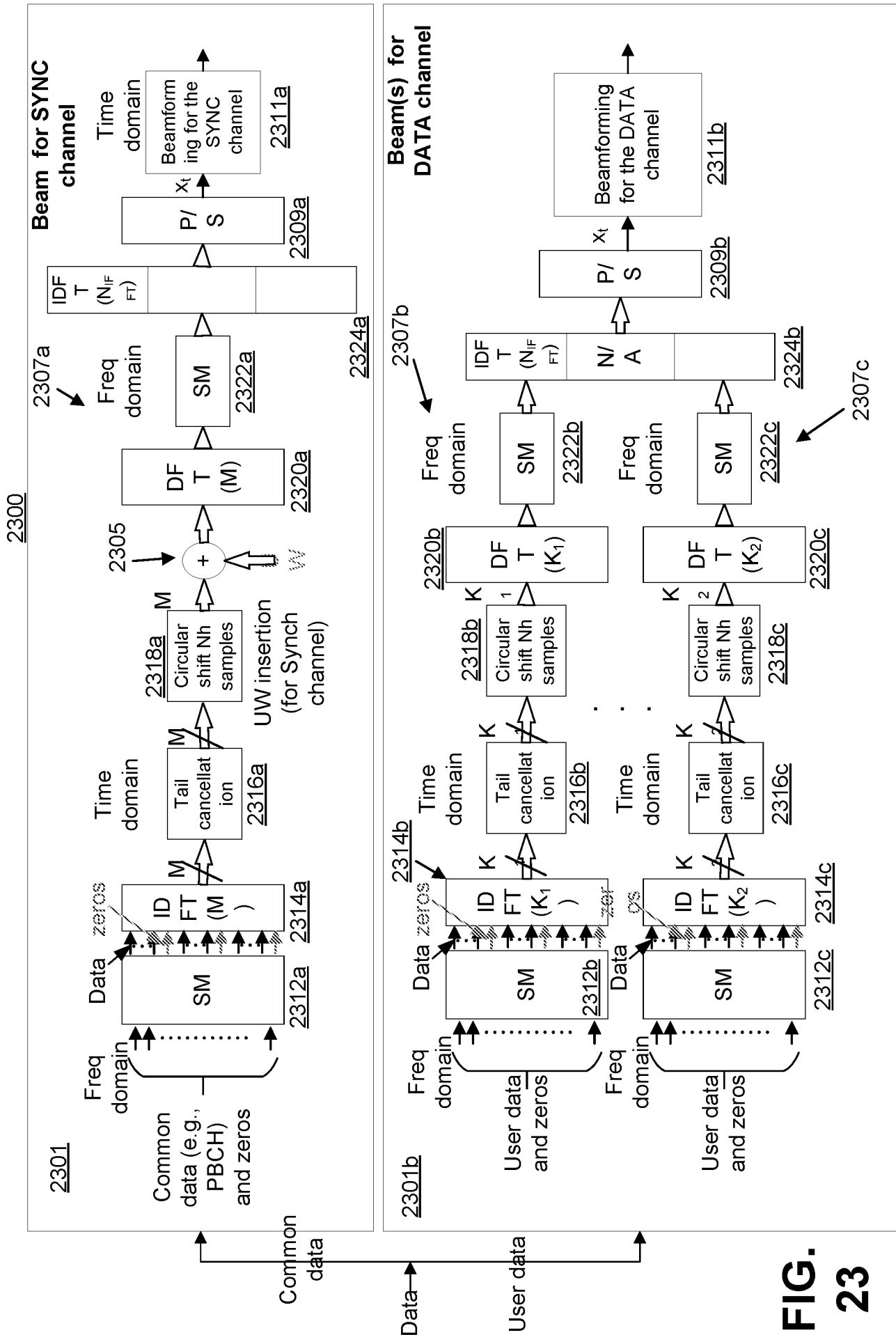


FIG. 22



2400

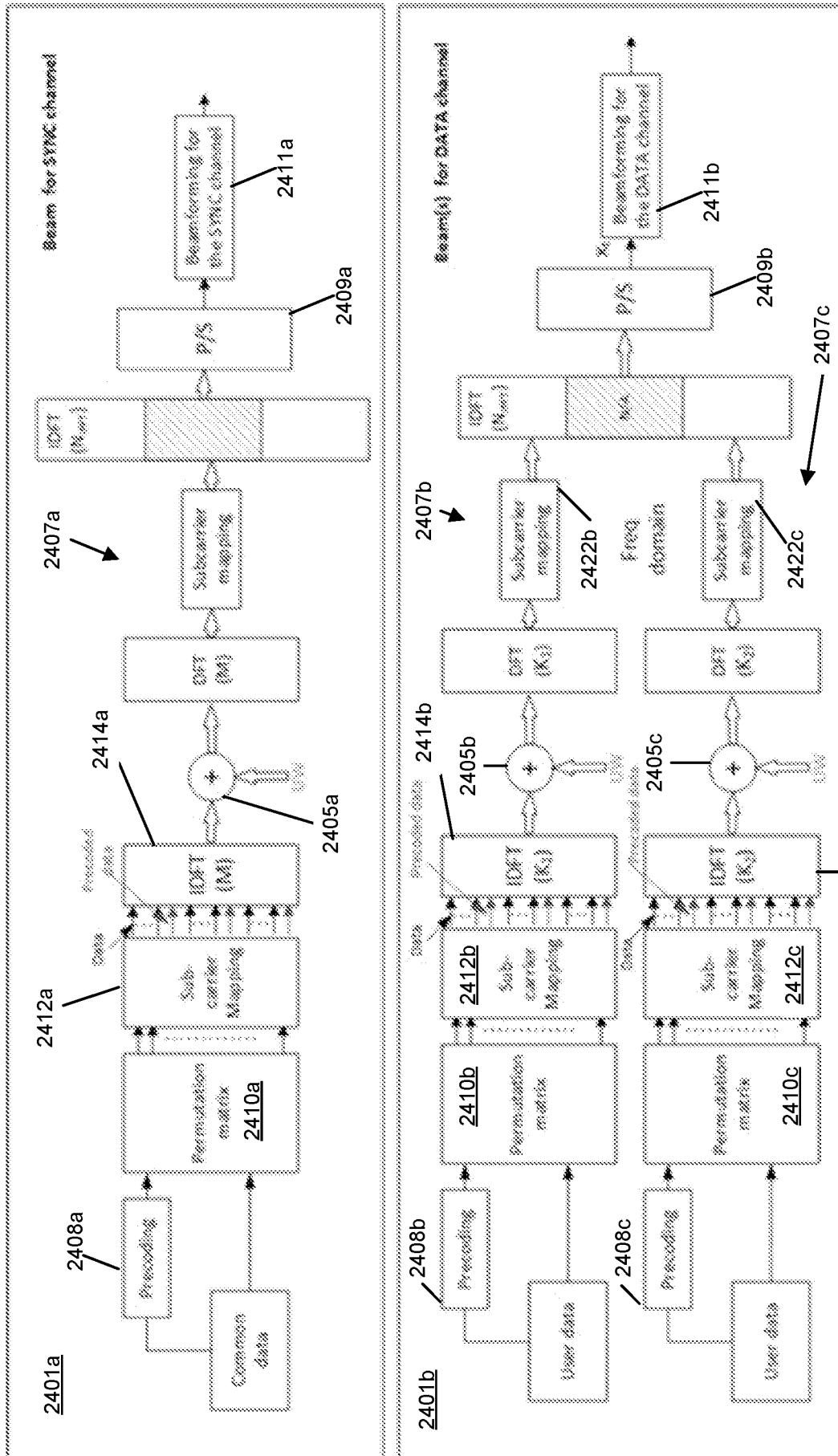


FIG. 24

2500

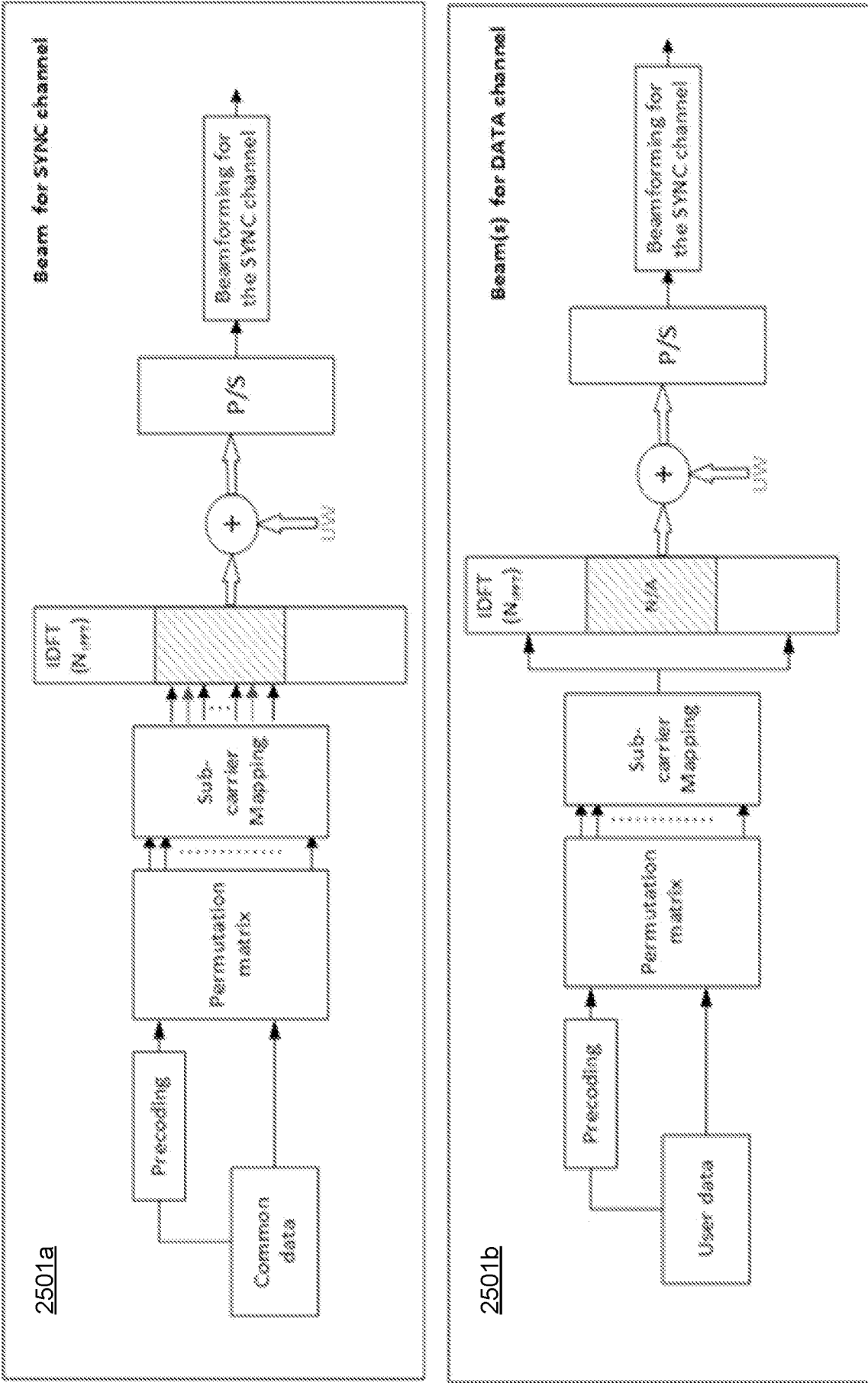
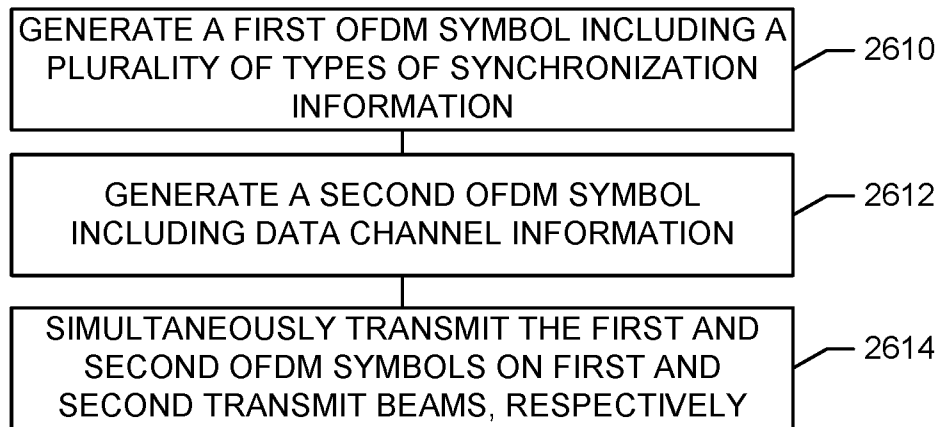
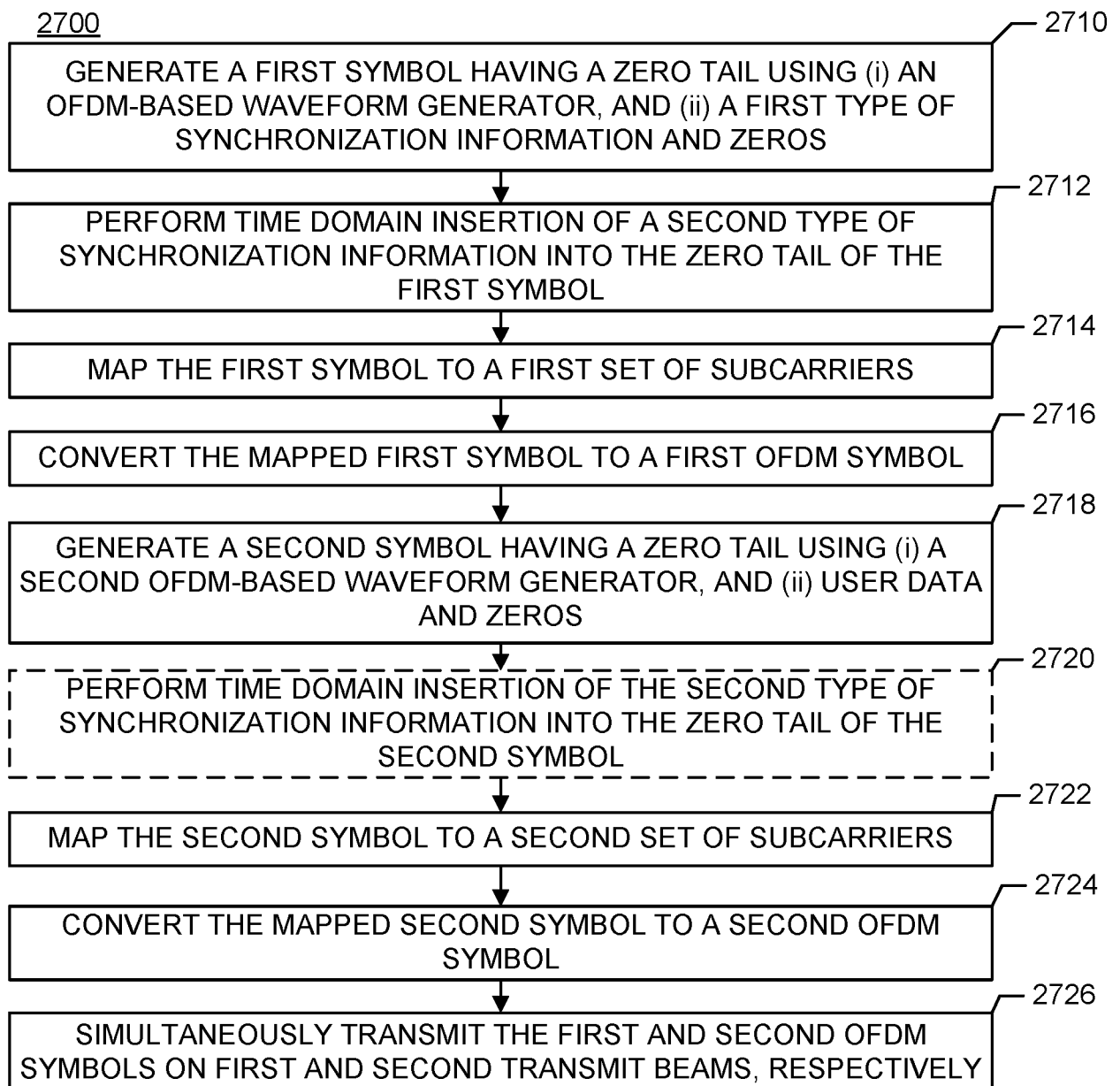


FIG. 25

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2600**FIG. 26**2700**FIG. 27**

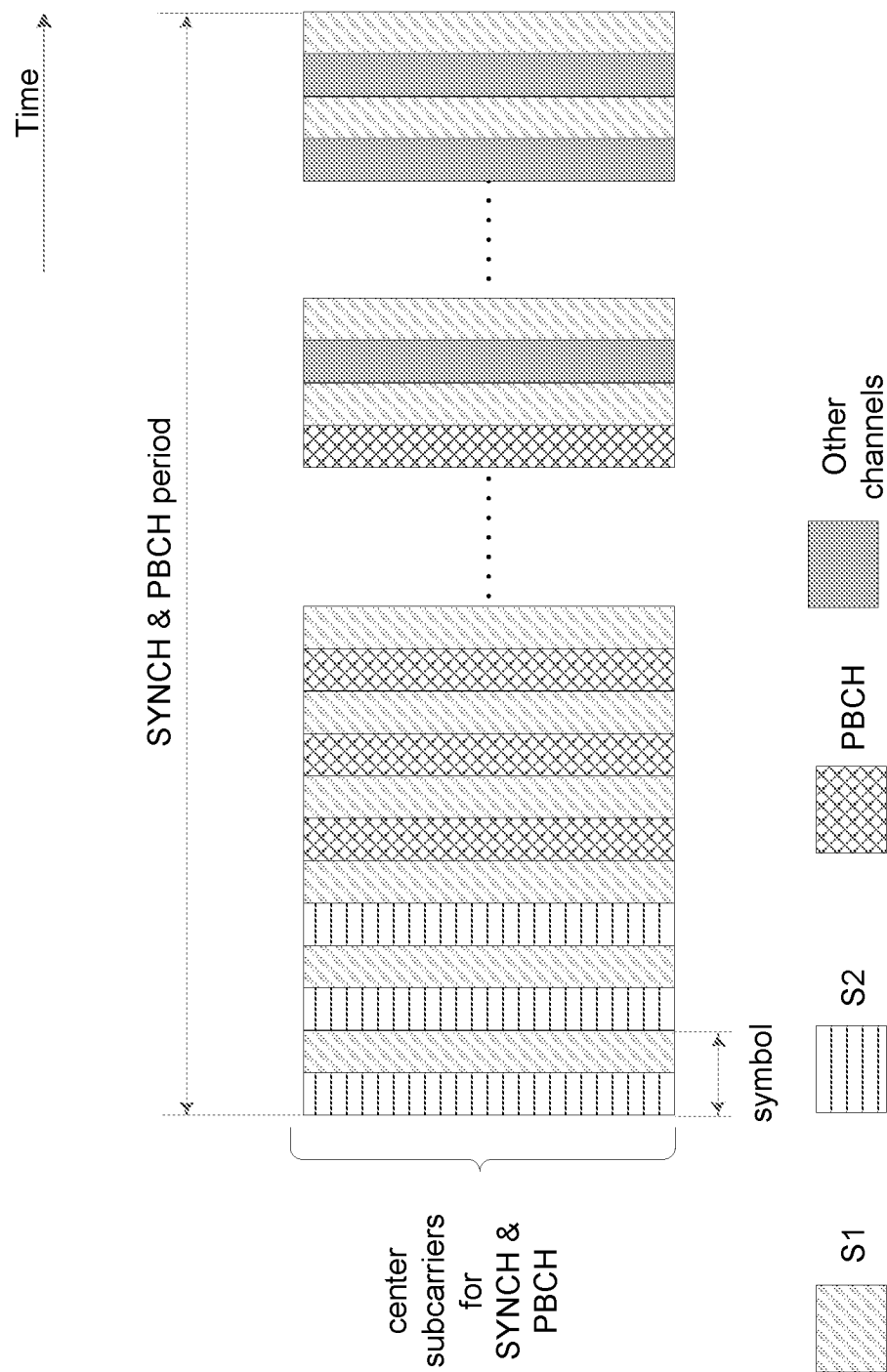


FIG. 28

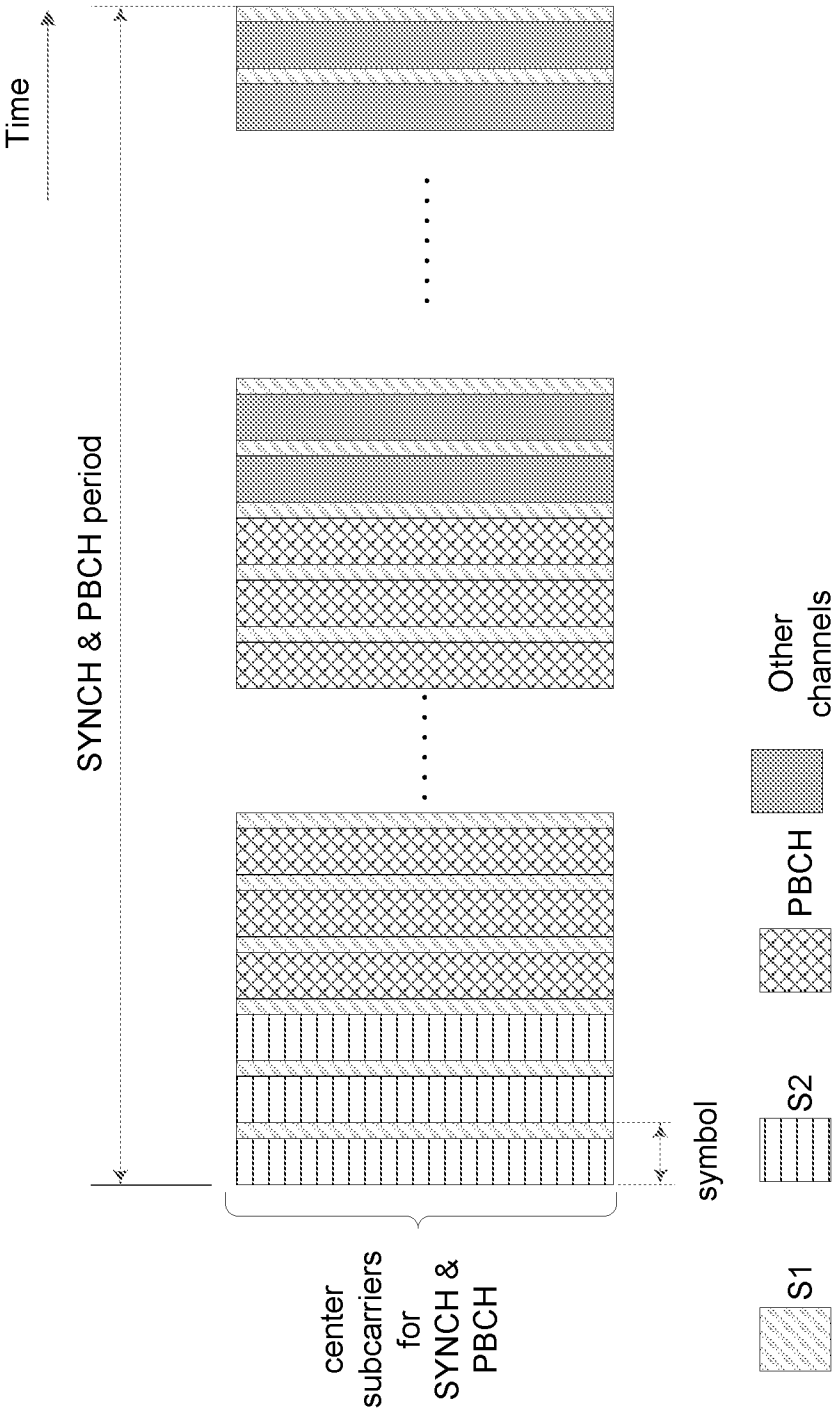


FIG. 29

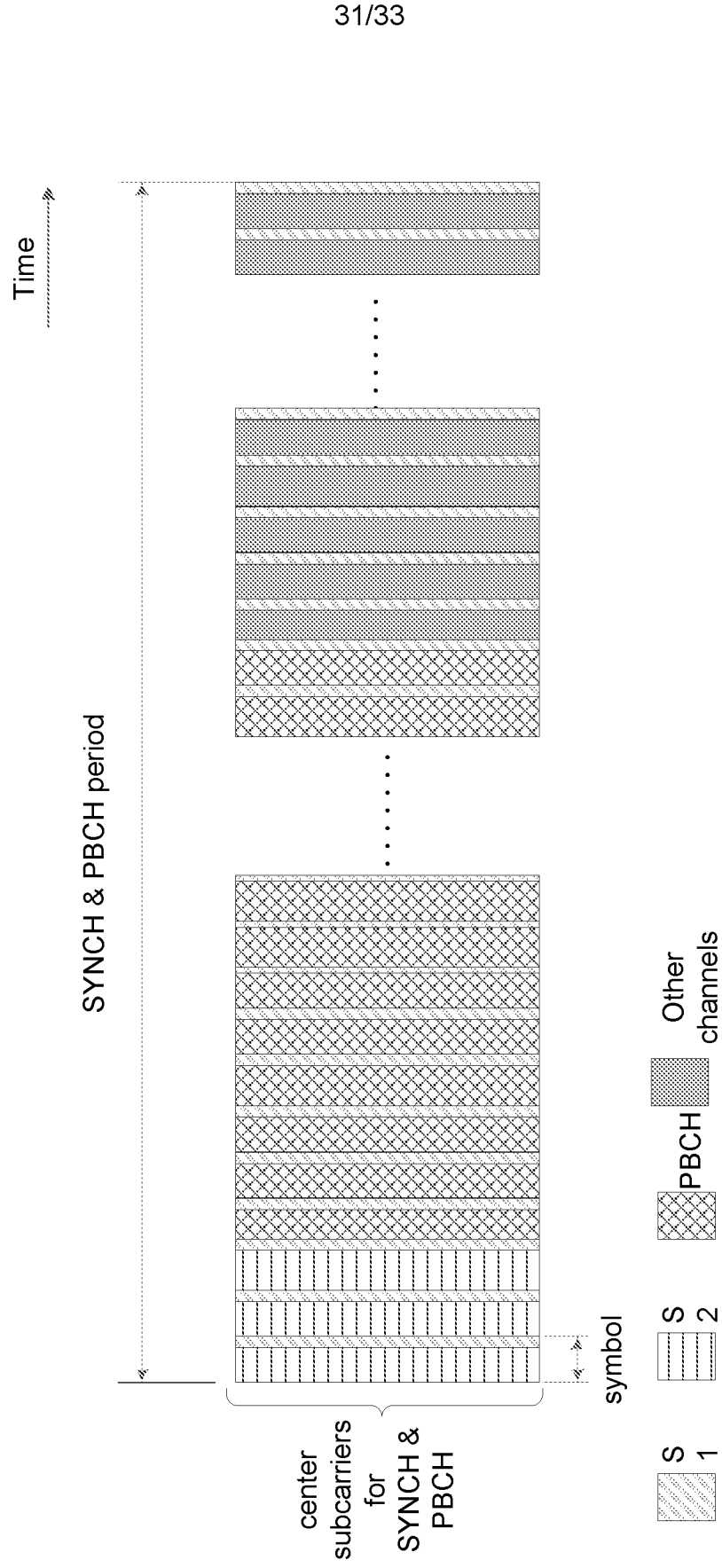


FIG. 30

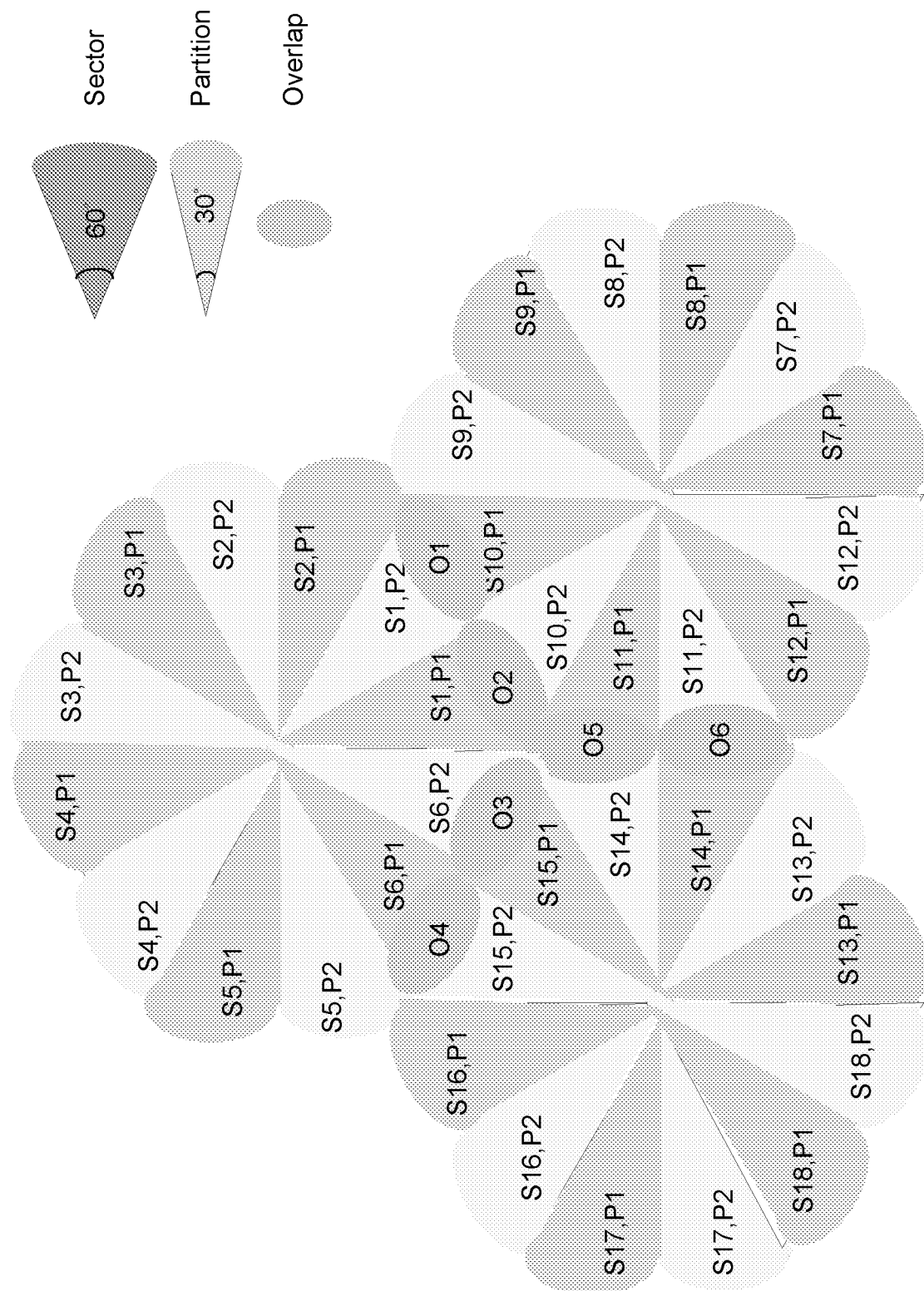
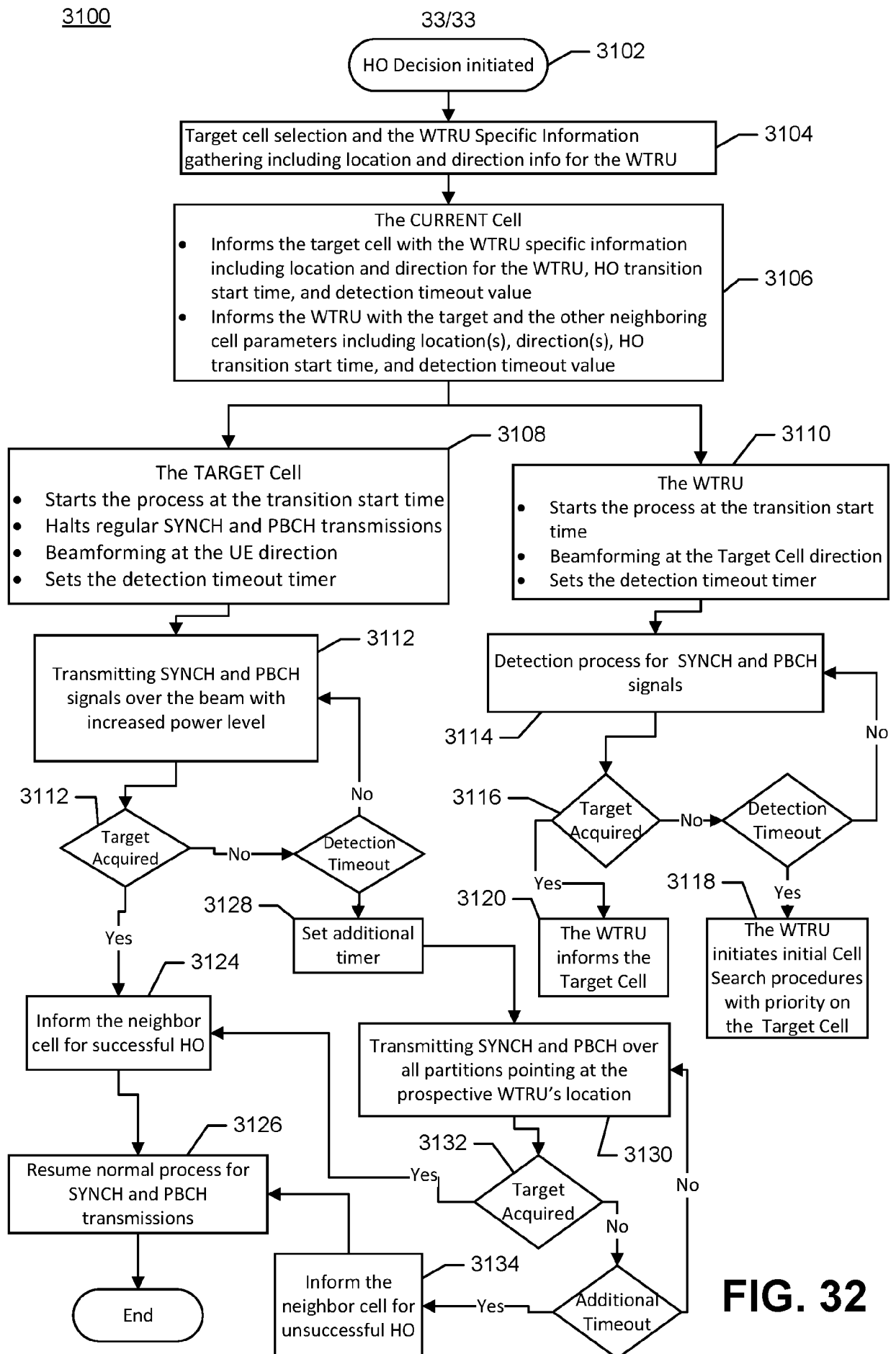


FIG. 31



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/064551

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/26 H04B7/06
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L H04B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/109153 A1 (INTERDIGITAL PATENT HOLDINGS [US]) 23 July 2015 (2015-07-23)	1-5,14,15,17
Y	paragraph [0125] - paragraph [0128] paragraph [0189] - paragraph [0191]	6-13,16,18-28
Y	"Air Interface for Fixed Broadband Wireless Access Systems Part A: Systems between 2 and 11 GHz ; 80216ab-01_01", IEEE DRAFT; 80216AB-01_01, IEEE-SA, PISCATAWAY, NJ USA, vol. 802.16, 3 July 2001 (2001-07-03), pages 1-212, XP017620931, [retrieved on 2001-07-03] page 70 - page 73; figures 47,48 Section 8.3.10.4	6-13,16,18-28

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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INTERNATIONAL SEARCH REPORT

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