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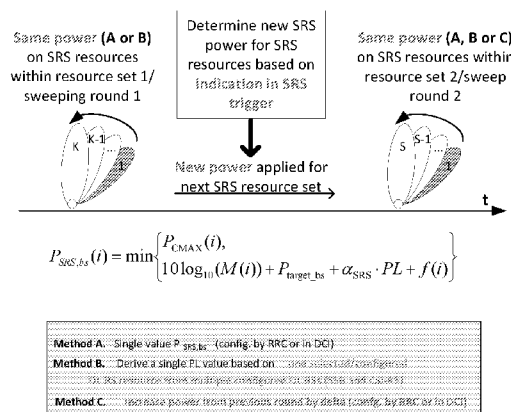
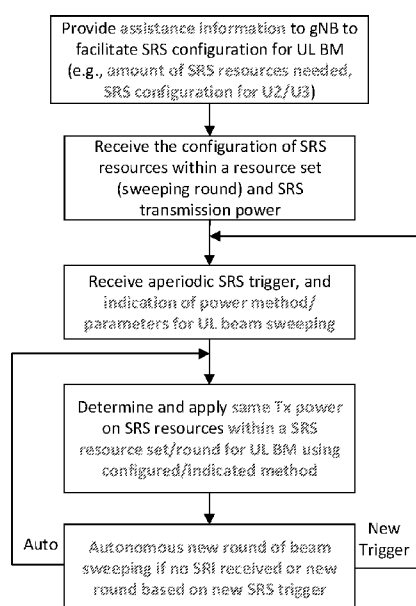


FIG. 15

(57) Abstract: Systems, methods and instrumentalities are disclosed for flexible SRS-based UL beam management. UL beam management may be assisted, for example, by DL beam management. In an example, a WTRU may determine a UL Tx beam based on a DL Rx beam for full beam correspondence (BC), a WTRU may engage in beam adjustment with data transmission for partial BC and a WTRU may, e.g., otherwise, transmit an SRS for UL beam sweeping. BC may be determined, for example, by a WTRU or a TRP. WTRU may provide the assist information to facilitate TRP SRS configuration. Flexible UL beam management may be provided, for example, by flexible SRS configuration of WTRUs depending on configured beam management procedures. Intra-symbol UL beam sweeping may be provided with frequency and time separations. SRS power setting may be provided for UL beam management.

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FLEXIBLE SRS-BASED UPLINK BEAM MANAGEMENT

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 62/500,762, filed May 3, 2017, U.S. Provisional Application No. 62/542,903, filed August 9, 2017, and U.S. Provisional Application No. 62/555,517, filed September 7, 2017, the contents of which are incorporated by reference herein their entireties.

BACKGROUND

[0002] Mobile communications continue to evolve. A fifth generation may be referred to as 5G. A previous (legacy) generation of mobile communication may be, for example, fourth generation (4G) long term evolution (LTE). Mobile wireless communications implement a variety of radio access technologies (RATs), such as New Radio (NR). Use cases for NR may include, for example, extreme Mobile Broadband (eMBB), Ultra High Reliability and Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC).

SUMMARY

[0003] Systems, methods and instrumentalities are disclosed for flexible SRS-based UL beam management. UL beam management may be assisted, for example, by DL beam management. In an example, a WTRU may determine a UL Tx beam based on a DL Rx beam for full beam correspondence (BC), a WTRU may engage in beam adjustment with data transmission for partial BC and a WTRU may, e.g., otherwise, transmit an SRS for UL beam sweeping. BC may be determined, for example, by a WTRU or a TRP. The WTRU may provide assist information, e.g., to facilitate TRP SRS configuration and/or UL beam management. Flexible UL beam management may be provided, for example, by flexible SRS configuration of WTRUs depending on configured beam management procedures. Intra-symbol UL beam sweeping may be provided with frequency and time separations. SRS power setting may be provided for

UL beam management. SRS power setting values may be determined and/or configured based on beam-specific control, power ramping for SRS transmission, and/or x-specific power control based SRS transmissions.

[0004] A wireless transmit/receive unit (WTRU) may include a processor configured to (i) send, from the WTRU, to a wireless communication system, a requested sounding reference signal (SRS) configuration for a WTRU transmitter beam; (ii) receive, at the WTRU from the wireless communication system, an SRS configuration that includes a first SRS resource set; (iii) receive, at the WTRU from the wireless communication system, a first SRS trigger comprising a WTRU transmitter power determination indication; (iv) determine, at the WTRU, an SRS transmission power from the WTRU transmitter power determination indication; (v) conduct a first beam sweep, at the WTRU, with the determined SRS transmission power for the first SRS resource set; (vi) determine whether the WTRU received, from the wireless communication system, a selected WTRU transmitter beam for uplink transmissions based on the first beam sweep; (vii) determine whether the WTRU received a second SRS trigger from the wireless communication system; (viii) conduct a second beam sweep, at the WTRU, with the determined SRS transmission power for a second SRS resource set if the WTRU determined that the WTRU did not receive the selected WTRU transmitter beam and the second SRS trigger, or conduct the second beam sweep for the second reference SRS resource set if the WTRU determined that the WTRU did receive the second SRS trigger; and (ix) receive, at the WTRU from the wireless communication system, the selected WTRU transmitter beam for uplink transmissions based on the second beam sweep.

[0005] The requested SRS configuration may include an indication that no SRS resources are requested or a number of SRS resources are requested. The requested number of SRS resources may indicate beam correspondence status and/or one of a full beam sweep and a partial beam sweep.

[0006] The SRS configuration may include one of an intra-slot frequency hopping pattern, an inter-slot frequency hopping pattern, or a combined intra-slot and inter-slot frequency hopping pattern.

[0007] An intra-slot frequency hopping pattern may include an SRS transmission pattern over a configurable number of adjacent symbols within a last fixed number of symbols in a time slot; and the SRS transmission pattern within a time slot may include a same number of resource blocks in a same or a different frequency range across the adjacent symbols.

[0008] A WTRU transmitter power determination indication may indicate to the WTRU to use one or more of a value configured in RRC or DCI, a power determined from at least one path loss value, and/or an increase in power from a previously used SRS transmission power for determining the SRS transmission power.

[0009] A WTRU processor may be configured to receive one or multiple configured DL reference signals, at the WTRU from the wireless communication system, determine a path loss power adjustment

based on one configurable DL reference signal from the received DL reference signals, and apply the path loss power adjustment in determining the SRS transmission power.

[0010] A WTRU processor may be configured to conduct a first and second beam sweep by conducting a partial beam sweep within an OFDM symbol with time and frequency separations.

[0011] The first and second triggers may be aperiodic triggers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1A is a system diagram illustrating an example communications system in which one or more disclosed embodiments may be implemented.

[0013] FIG. 1B is an example system diagram illustrating an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A.

[0014] FIG. 1C is an example system diagram illustrating an example radio access network (RAN) and an example core network (CN) that may be used within the communications system illustrated in FIG. 1A.

[0015] FIG. 1D is an example system diagram illustrating an example RAN and an example CN that may be used within the communications system illustrated in FIG. 1A.

[0016] FIG. 2 is an example of a Transmission/Reception Point (TRP) and Wireless Transmit/Receive Unit (WTRU) antenna model.

[0017] FIG. 3 is an example of DL beam management assisted UL beam management.

[0018] FIG. 4 is an example of beam adjustment with data transmission.

[0019] FIG. 5 is an example procedure for beam adjustment with data transmission.

[0020] FIG. 6 is an example of SRS transmissions multiplexed in time and frequency domains for UL beam management.

[0021] FIG. 7 is an example of large subcarrier spacing in NR networks with mixed numerologies to reduce beam sweeping overhead.

[0022] FIG. 8 is an example of symbol level frequency hopping of NR-SRS across multiple OFDM symbols.

[0023] FIG. 9 is an example of high density and low density SRS bandwidth.

[0024] FIG. 10 is an example of full sweeping and local (or partial) sweeping for a U3 procedure.

[0025] FIG. 11 is an example of intra-symbol UL beam sweeping with frequency and time separations.

[0026] FIG. 12 is an example (Example #1) for intra-symbol UL beam sweeping with frequency and time separations.

[0027] FIG. 13 is an example of a frequency and time representation of RS and corresponding UL Tx beams for Example #1.

[0028] FIG. 14 is an example (Example #2) for intra-symbol UL beam sweeping with frequency and time separations.

[0029] Figure 15 is an example of a WTRU SRS configuration and transmission power determination for UL beam management.

DETAILED DESCRIPTION

[0030] A detailed description of illustrative embodiments will now be described with reference to the various Figures. Although this description provides a detailed example of possible implementations, it should be noted that the details are intended to be exemplary and in no way limit the scope of the application.

[0031] FIG. 1A is a diagram illustrating an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), zero-tail unique-word DFT-Spread OFDM (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0032] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a RAN 104/113, a CN 106/115, 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, any of which may be referred to as a "station" and/or a "STA", may be configured to transmit and/or receive wireless signals and may include a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a subscription-based unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, a hotspot or Mi-Fi device, an Internet of Things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical

device and applications (e.g., remote surgery), an industrial device and applications (e.g., a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. Any of the WTRUs 102a, 102b, 102c and 102d may be interchangeably referred to as a UE.

[0033] The communications systems 100 may also include a base station 114a and/or 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 CN 106/115, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a gNB, a NR NodeB, 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.

[0034] The base station 114a may be part of the RAN 104/113, 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 on one or more carrier frequencies, which may be referred to as a cell (not shown). These frequencies may be in licensed spectrum, unlicensed spectrum, or a combination of licensed and unlicensed spectrum. A cell may provide coverage for a wireless service to a specific geographical area that may be relatively fixed or that may change over time. The cell may 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, e.g., one for each sector of the cell. In an embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and may utilize multiple transceivers for each sector of the cell. For example, beamforming may be used to transmit and/or receive signals in desired spatial directions.

[0035] 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, centimeter wave, micrometer wave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 116 may be established using any suitable radio access technology (RAT).

[0036] 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 104/113 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 115/116/117 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 (DL) Packet Access (HSDPA) and/or High-Speed UL Packet Access (HSUPA).

[0037] In an 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) and/or LTE-Advanced Pro (LTE-A Pro).

[0038] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as NR Radio Access, which may establish the air interface 116 using New Radio (NR).

[0039] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement multiple radio access technologies. For example, the base station 114a and the WTRUs 102a, 102b, 102c may implement LTE radio access and NR radio access together, for instance using dual connectivity (DC) principles. Thus, the air interface utilized by WTRUs 102a, 102b, 102c may be characterized by multiple types of radio access technologies and/or transmissions sent to/from multiple types of base stations (e.g., a eNB and a gNB).

[0040] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (WiFi)), 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.

[0041] 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, an industrial facility, an air corridor (e.g., for use by drones), a roadway, 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 an 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, LTE-A Pro, NR 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 CN 106/115.

[0042] The RAN 104/113 may be in communication with the CN 106/115, 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. The data may have varying quality of service (QoS) requirements, such as differing throughput requirements, latency requirements, error tolerance requirements, reliability requirements, data throughput requirements, mobility requirements, and the like. The CN 106/115 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 104/113 and/or the CN 106/115 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104/113 or a different RAT. For example, in addition to being connected to the RAN 104/113, which may be utilizing a NR radio technology, the CN 106/115 may also be in communication with another RAN (not shown) employing a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or WiFi radio technology.

[0043] The CN 106/115 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or the 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/or the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired and/or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104/113 or a different RAT.

[0044] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities (e.g., 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.

[0045] FIG. 1B is a system diagram illustrating an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130, removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and/or other peripherals 138, among others. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0046] 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 Arrays (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.

[0047] 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 an 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/or 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.

[0048] 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.

[0049] 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 NR and IEEE 802.11, for example.

[0050] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may

include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0051] 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.

[0052] 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.

[0053] 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 and/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, a Virtual Reality and/or Augmented Reality (VR/AR) device, an activity tracker, and the like. The peripherals 138 may include one or more sensors, the sensors may be one or more of a gyroscope, an accelerometer, a hall effect sensor, a magnetometer, an orientation sensor, a proximity sensor, a temperature sensor, a time sensor; a geolocation sensor; an altimeter, a light sensor, a touch sensor, a magnetometer, a barometer, a gesture sensor, a biometric sensor, and/or a humidity sensor.

[0054] The WTRU 102 may include a full duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for both the UL (e.g., for transmission) and downlink (e.g., for reception) may be concurrent and/or simultaneous. The full duplex radio may include an interference management unit 139 to reduce and or substantially eliminate self-interference via either hardware (e.g., a choke) or signal processing via a processor (e.g., a separate processor (not shown) or via processor 118). In an embodiment, the WTRU 102 may include a half-duplex radio for which transmission

and reception of some or all of the signals (e.g., associated with particular subframes for either the UL (e.g., for transmission) or the downlink (e.g., for reception)).

[0055] FIG. 1C is a system diagram illustrating the RAN 104 and the CN 106 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 104 may also be in communication with the CN 106.

[0056] 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/or receive wireless signals from, the WTRU 102a.

[0057] Each of the eNode-Bs 160a, 160b, 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 UL and/or DL, and the like. As shown in FIG. 1C, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0058] The CN 106 shown in FIG. 1C may include a mobility management entity (MME) 162, a serving gateway (SGW) 164, and a packet data network (PDN) gateway (or PGW) 166. While each of the foregoing elements are depicted as part of the CN 106, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0059] The MME 162 may be connected to each of the eNode-Bs 162a, 162b, 162c 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 provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM and/or WCDMA.

[0060] The SGW 164 may be connected to each of the eNode Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The SGW 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The SGW 164 may perform other functions, such as anchoring user planes during inter-eNode B handovers, triggering paging when DL data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0061] The SGW 164 may be connected to the PGW 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.

[0062] The CN 106 may facilitate communications with other networks. For example, the CN 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 CN 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 CN 106 and the PSTN 108. In addition, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers.

[0063] Although the WTRU is described in FIGS. 1A-1D as a wireless terminal, it is contemplated that in certain representative embodiments that such a terminal may use (e.g., temporarily or permanently) wired communication interfaces with the communication network.

[0064] In representative embodiments, the other network 112 may be a WLAN.

[0065] A WLAN in Infrastructure Basic Service Set (BSS) mode may have an Access Point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may have an access or an interface to a Distribution System (DS) or another type of wired/wireless network that carries traffic in to and/or out of the BSS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to respective destinations. Traffic between STAs within the BSS may be sent through the AP, for example, where the source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. The traffic between STAs within a BSS may be considered and/or referred to as peer-to-peer traffic. The peer-to-peer traffic may be sent between (e.g., directly between) the source and destination STAs with a direct link setup (DLS). In certain representative embodiments, the DLS may use an 802.11e DLS or an 802.11z tunneled DLS (TDLS). A WLAN using an Independent BSS (IBSS) mode may not have an AP, and the STAs (e.g., all of the STAs) within or using the IBSS may communicate directly with each other. The IBSS mode of communication may sometimes be referred to herein as an "ad-hoc" mode of communication.

[0066] When using the 802.11ac infrastructure mode of operation or a similar mode of operations, the AP may transmit a beacon on a fixed channel, such as a primary channel. The primary channel may be a fixed width (e.g., 20 MHz wide bandwidth) or a dynamically set width via signaling. The primary channel may be the operating channel of the BSS and may be used by the STAs to establish a connection with the AP. In certain representative embodiments, Carrier Sense Multiple Access with Collision Avoidance

(CSMA/CA) may be implemented, for example in 802.11 systems. For CSMA/CA, the STAs (e.g., every STA), including the AP, may sense the primary channel. If the primary channel is sensed/detected and/or determined to be busy by a particular STA, the particular STA may back off. One STA (e.g., only one station) may transmit at any given time in a given BSS.

[0067] High Throughput (HT) STAs may use a 40 MHz wide channel for communication, for example, via a combination of the primary 20 MHz channel with an adjacent or nonadjacent 20 MHz channel to form a 40 MHz wide channel.

[0068] Very High Throughput (VHT) STAs may support 20MHz, 40 MHz, 80 MHz, and/or 160 MHz wide channels. The 40 MHz, and/or 80 MHz, channels may be formed by combining contiguous 20 MHz channels. A 160 MHz channel may be formed by combining 8 contiguous 20 MHz channels, or by combining two non-contiguous 80 MHz channels, which may be referred to as an 80+80 configuration. For the 80+80 configuration, the data, after channel encoding, may be passed through a segment parser that may divide the data into two streams. Inverse Fast Fourier Transform (IFFT) processing, and time domain processing, may be done on each stream separately. The streams may be mapped on to the two 80 MHz channels, and the data may be transmitted by a transmitting STA. At the receiver of the receiving STA, the above described operation for the 80+80 configuration may be reversed, and the combined data may be sent to the Medium Access Control (MAC).

[0069] Sub 1 GHz modes of operation are supported by 802.11af and 802.11ah. The channel operating bandwidths, and carriers, are reduced in 802.11af and 802.11ah relative to those used in 802.11n, and 802.11ac. 802.11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV White Space (TVWS) spectrum, and 802.11ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.11ah may support Meter Type Control/Machine-Type Communications, such as MTC devices in a macro coverage area. MTC devices may have certain capabilities, for example, limited capabilities including support for (e.g., only support for) certain and/or limited bandwidths. The MTC devices may include a battery with a battery life above a threshold (e.g., to maintain a very long battery life).

[0070] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11n, 802.11ac, 802.11af, and 802.11ah, include a channel which may be designated as the primary channel. The primary channel may have a bandwidth equal to the largest common operating bandwidth supported by all STAs in the BSS. The bandwidth of the primary channel may be set and/or limited by a STA, from among all STAs in operating in a BSS, which supports the smallest bandwidth operating mode. In the example of 802.11ah, the primary channel may be 1 MHz wide for STAs (e.g., MTC type devices) that support (e.g., only support) a 1 MHz mode, even if the AP, and other STAs in the BSS support 2 MHz, 4 MHz, 8 MHz, 16 MHz, and/or other channel bandwidth operating modes. Carrier sensing and/or Network

Allocation Vector (NAV) settings may depend on the status of the primary channel. If the primary channel is busy, for example, due to a STA (which supports only a 1 MHz operating mode), transmitting to the AP, the entire available frequency bands may be considered busy even though a majority of the frequency bands remains idle and may be available.

[0071] In the United States, the available frequency bands, which may be used by 802.11ah, are from 902 MHz to 928 MHz. In Korea, the available frequency bands are from 917.5 MHz to 923.5 MHz. In Japan, the available frequency bands are from 916.5 MHz to 927.5 MHz. The total bandwidth available for 802.11ah is 6 MHz to 26 MHz depending on the country code.

[0072] FIG. 1D is a system diagram illustrating the RAN 113 and the CN 115 according to an embodiment. As noted above, the RAN 113 may employ an NR radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 113 may also be in communication with the CN 115.

[0073] The RAN 113 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 113 may include any number of gNBs while remaining consistent with an embodiment. The gNBs 180a, 180b, 180c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the gNBs 180a, 180b, 180c may implement MIMO technology. For example, gNBs 180a, 180b may utilize beamforming to transmit signals to and/or receive signals from the gNBs 180a, 180b, 180c. Thus, the gNB 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. In an embodiment, the gNBs 180a, 180b, 180c may implement carrier aggregation technology. For example, the gNB 180a may transmit multiple component carriers to the WTRU 102a (not shown). A subset of these component carriers may be on unlicensed spectrum while the remaining component carriers may be on licensed spectrum. In an embodiment, the gNBs 180a, 180b, 180c may implement Coordinated Multi-Point (CoMP) technology. For example, WTRU 102a may receive coordinated transmissions from gNB 180a and gNB 180b (and/or gNB 180c).

[0074] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using transmissions associated with a scalable numerology. For example, the OFDM symbol spacing and/or OFDM subcarrier spacing may vary for different transmissions, different cells, and/or different portions of the wireless transmission spectrum. The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using subframe or transmission time intervals (TTIs) of various or scalable lengths (e.g., containing varying number of OFDM symbols and/or lasting varying lengths of absolute time).

[0075] The gNBs 180a, 180b, 180c may be configured to communicate with the WTRUs 102a, 102b, 102c in a standalone configuration and/or a non-standalone configuration. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c without also accessing other

RANs (e.g., such as eNode-Bs 160a, 160b, 160c). In the standalone configuration, WTRUs 102a, 102b, 102c may utilize one or more of gNBs 180a, 180b, 180c as a mobility anchor point. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using signals in an unlicensed band. In a non-standalone configuration WTRUs 102a, 102b, 102c may communicate with/connect to gNBs 180a, 180b, 180c while also communicating with/connecting to another RAN such as eNode-Bs 160a, 160b, 160c. For example, WTRUs 102a, 102b, 102c may implement DC principles to communicate with one or more gNBs 180a, 180b, 180c and one or more eNode-Bs 160a, 160b, 160c substantially simultaneously. In the non-standalone configuration, eNode-Bs 160a, 160b, 160c may serve as a mobility anchor for WTRUs 102a, 102b, 102c and gNBs 180a, 180b, 180c may provide additional coverage and/or throughput for servicing WTRUs 102a, 102b, 102c.

[0076] Each of the gNBs 180a, 180b, 180c 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 UL and/or DL, support of network slicing, dual connectivity, interworking between NR and E-UTRA, routing of user plane data towards User Plane Function (UPF) 184a, 184b, routing of control plane information towards Access and Mobility Management Function (AMF) 182a, 182b and the like. As shown in FIG. 1D, the gNBs 180a, 180b, 180c may communicate with one another over an Xn interface.

[0077] The CN 115 shown in FIG. 1D may include at least one AMF 182a, 182b, at least one UPF 184a, 184b, at least one Session Management Function (SMF) 183a, 183b, and possibly a Data Network (DN) 185a, 185b. While each of the foregoing elements are depicted as part of the CN 115, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0078] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N2 interface and may serve as a control node. For example, the AMF 182a, 182b may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, support for network slicing (e.g., handling of different PDU sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of NAS signaling, mobility management, and the like. Network slicing may be used by the AMF 182a, 182b in order to customize CN support for WTRUs 102a, 102b, 102c based on the types of services being utilized WTRUs 102a, 102b, 102c. For example, different network slices may be established for different use cases such as services relying on ultra-reliable low latency (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for machine type communication (MTC) access, and/or the like. The AMF 162 may provide a control plane function for switching between the RAN 113 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-3GPP access technologies such as WiFi.

[0079] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 115 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 115 via an N4 interface. The SMF 183a, 183b may select and control the UPF 184a, 184b and configure the routing of traffic through the UPF 184a, 184b. The SMF 183a, 183b may perform other functions, such as managing and allocating UE IP address, managing PDU sessions, controlling policy enforcement and QoS, providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0080] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, 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. The UPF 184a, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0081] The CN 115 may facilitate communications with other networks. For example, the CN 115 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 115 and the PSTN 108. In addition, the CN 115 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers. In one embodiment, the WTRUs 102a, 102b, 102c may be connected to a local Data Network (DN) 185a, 185b through the UPF 184a, 184b via the N3 interface to the UPF 184a, 184b and an N6 interface between the UPF 184a, 184b and the DN 185a, 185b.

[0082] In view of Figures 1A-1D, and the corresponding description of Figures 1A-1D, one or more, or all, of the functions described herein with regard to one or more of: WTRU 102a-d, Base Station 114a-b, eNode-B 160a-c, MME 162, SGW 164, PGW 166, gNB 180a-c, AMF 182a-ab, UPF 184a-b, SMF 183a-b, DN 185a-b, and/or any other device(s) described herein, may be performed by one or more emulation devices (not shown). The emulation devices may be one or more devices configured to emulate one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0083] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all, functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network.

The emulation device may be directly coupled to another device for purposes of testing and/or may performing testing using over-the-air wireless communications.

[0084] The one or more emulation devices may perform the one or more, including all, functions while not being implemented/deployed as part of a wired and/or wireless communication network. For example, the emulation devices may be utilized in a testing scenario in a testing laboratory and/or a non-deployed (e.g., testing) wired and/or wireless communication network in order to implement testing of one or more components. The one or more emulation devices may be test equipment. Direct RF coupling and/or wireless communications via RF circuitry (e.g., which may include one or more antennas) may be used by the emulation devices to transmit and/or receive data.

[0085] Next generation mobile communications may support applications such as enhanced mobile broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC) with a wide range of licensed and unlicensed spectrum bands (e.g., ranging from 700 MHz to 80 GHz) for a variety of deployment scenarios.

[0086] Multiple antenna transmission and beamforming may be provided. Multiple antenna techniques such as Multiple Input Multiple Output (MIMO) transmission and variations (e.g., Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO)) may be employed (e.g., for sub-6 GHz transmission). Different MIMO techniques may provide different benefits such as diversity gain, multiplexing gain, beamforming, array gain, etc. User Terminals (UTs) in cellular communication may communicate with a single central node. MU-MIMO may increase system throughput, for example, by facilitating the transmission of multiple data streams to different UTs at the same time on the same and/or overlapping set of resources in time and/or frequency. A central node implementing SU-MIMO may transmit multiple data streams to the same UT, for example, compared to multiple UTs for MU-MIMO.

[0087] Multiple antenna transmission at millimeter wave frequencies may differ from sub-6 GHz multiple antenna techniques. This may be due to different propagation characteristics at millimeter wave frequencies and the BTS/WTRU potentially having a limited number of RF chains compared to antenna elements.

[0088] FIG. 2 is an example of a Transmission/Reception Point (TRP) and a Wireless Transmit/Receive Unit (WTRU) antenna model. A massive antenna model may be configured as M_g antenna panels per vertical dimension and N_g antenna panels per horizontal dimension. An (e.g., each) antenna panel may be configured with N columns and M rows of antenna elements with or without polarization (e.g., as shown by an example in FIG. 2). Timing and phase may not be calibrated across panels although multiple panels may be equipped in the same eNB. A baseline massive antenna configuration may vary according to an operating frequency band, for example, as indicated in Table 1. Table 1 provides examples of baseline massive antenna configurations for dense urban and urban macro environments.

Table 1

At 4GHz	At 30GHz	At 70GHz
Dense urban and urban macro: $(M,N,P,Mg,Ng) = (8,8,2,1,1)$, $(dV,dH) = (0.8, 0.5)\lambda$	Dense urban and urban macro: $(M,N,P,Mg,Ng) = (4,8,2,2,2)$, $(dV,dH) = (0.5, 0.5)\lambda$, $(dg,V,dg,H) = (2.0, 4.0)\lambda$	Dense urban: Baseline: $(M,N,P,Mg,Ng) = (8,16,2,2,2)$, $(dV,dH) = (0.5, 0.5)\lambda$, $(dg,V,dg,H) = (4.0, 8.0)\lambda$
A single panel 64 elements per Pol. Total 128 elements	4 panels 32 elements per Pol. Total 256 elements	4 panels 128 elements per Pol. Total 1024 elements

[0089] Precoding at millimeter wave frequencies may be digital, analog or a hybrid of digital and analog. Digital precoding may be precise and may be combined with equalization. Digital precoding may enable single user (SU), multi-user (MU) and multi-cell precoding and may be similar to that used in sub 6 GHz (e.g., in IEEE 802.11n and beyond and in 3GPP LTE and beyond). The presence of a limited number of RF chains compared with antenna elements and the sparse nature of the channel may complicate the use of digital beamforming (e.g., in mmW frequencies). Analog beamforming may overcome the limited number of RF chains, for example, by using analog phase shifters on each antenna element. Analog beamforming may be used in IEEE 802.11ad during Sector Level Sweep (e.g., to identify the best sector), Beam Refinement (e.g., to refine the sector to an antenna beam) and beam tracking (e.g., to adjust sub-beams over time to account for a change in the channel) procedures. Hybrid beamforming may divide a precoder between analog and digital domains. Each domain may have precoding and combining matrices with different structural constraints (e.g., constant modulus constraint) for combining matrices in the analog domain. This may result in a compromise between hardware complexity and system performance. Hybrid beamforming may achieve digital precoding performance due to the sparse nature of channels and support for multi-user/multi-stream multiplexing. Hybrid beamforming may be limited by a number of RF chains, which may not be an issue where mmW channels are sparse in the angular domain.

[0090] A Sounding Reference Signal (SRS) may (e.g., in LTE) be a reference signal that may be transmitted by a WTRU in an uplink (UL) direction. An SRS may be used by an eNodeB, for example, to estimate an uplink channel quality over a wider bandwidth. An eNodeB may use this information, for example, for uplink frequency selective scheduling and uplink timing estimation. In an example, there may be multiple (e.g., three) types of SRS transmissions, e.g., Single SRS, Periodic SRS and Aperiodic SRS transmissions. Single SRS and Periodic SRS transmissions may be referred to as a "trigger type 0" SRS transmissions, which may be configured, for example, by RRC signaling. An Aperiodic SRS transmission

may be referred to as a “trigger type 1” SRS transmission, which may be configured, for example, by RRC and may be triggered, for example, by DCI. An eNodeB may configure a WTRU with a WTRU-specific SRS configuration. A WTRU specific SRS configuration may provide a WTRU with time domain (subframes) and frequency domain resources. A configuration may be, for example, wide band SRS (e.g., on an entire bandwidth of interest) or narrow band SRS (e.g., allowing a WTRU to frequency hop between transmissions). Different WTRUs may have different SRS bandwidths. In an example, an (e.g., each) SRS bandwidth may be a multiple of four RBs. Different WTRUs may have the same comb with different cyclic shift or phase rotations. SRS transmissions may be orthogonal to each other over the same frequency span. Different WTRUs may have different combs for frequency multiplexing with a same or different frequency span.

[0091] In an example, a power control of SRS may be given, for example, by Eq. 1:

$$P_{SRS} = \min\{P_{CMAX,C}, P_{0,PUSCH} + \alpha \cdot PL_{DL} + 10 \cdot \log_{10}(M_{SRS}) + \delta + P_{SRS}\}. \quad \text{Eq. 1}$$

[0092] where, for example, M_{SRS} may be a bandwidth of SRS transmissions, which may be expressed as number of RBs, and P_{SRS} may be a configurable offset.

[0093] In an example, an SRS transmit power may be regulated by a (e.g., an exact) bandwidth of an SRS transmission and with an additional power offset.

[0094] Beam management may be provided, e.g., for NR. Use of higher band frequencies may imply that their propagation characteristics may influence the system design. A channel may experience higher path losses and more abrupt changes as frequencies increase, e.g., due to the fact that transmission through most objects may be reduced, reflections may be amplified, blockage, WTRU rotation and movement may occur.

[0095] A large-scale antenna array may be used (e.g., in high frequency bands), for example, to achieve high beamforming gain, e.g., to compensate for high propagation loss. Resulting coupling loss may be kept at a high level, e.g., to support a desired data throughput or coverage. Use of a directional beam based communication may involve accurate beam pairing. A correct beam direction may be associated with a real channel, e.g., in terms of an angle of arrival and angle of departure in azimuth and elevation. A correct beam direction may be (e.g., dynamically) adjusted with a channel change.

[0096] Beam management procedures may include, for example, downlink (DL) and uplink (UL) beam management procedures. Downlink beam management procedures may have shorthand references such as P-1, P-2, P-3, etc. Uplink beam management procedures may have shorthand references such as U-1, U-2, U-3, etc.

[0097] In an example, a first downlink beam management procedure (e.g., P-1) may be used to enable WTRU measurements on different TRP Tx beams, e.g., to support selection of TRP Tx beams/WTRU Rx beam(s). P-1 may include an intra/inter-TRP Tx beam sweep from a set of different beams, e.g., for beamforming at a TRP. P-1 may include a WTRU Rx beam sweep from a set of different beams, e.g., for beamforming at a WTRU. A TRP Tx beam and WTRU Rx beam may be determined jointly or sequentially.

[0098] In an example, a second downlink beam management procedure (e.g., P-2) may be used to enable WTRU measurement on different TRP Tx beams, for example, to change inter/intra-TRP Tx beam(s) (e.g., from a smaller set of beams than P-1 for beam refinement). P-2 may be a special case of P-1.

[0099] In an example, a third downlink beam management procedure (e.g., P-3) may be used to enable WTRU measurements on the same TRP Tx beam to change a WTRU Rx beam, for example, when WTRU uses beamforming.

[0100] In an example, a first uplink beam management procedure (e.g., U-1) may be used to enable a TRP measurement on different WTRU Tx beams, e.g., to support selection of WTRU Tx beams/TRP Rx beam(s).

[0101] In an example, second uplink beam management procedure (e.g., U-2) may be used to enable a TRP measurement on different TRP Rx beams, e.g., to change/select inter/intra-TRP Rx beam(s).

[0102] In an example, a third uplink beam management procedure (e.g., U-3) may be used to enable TRP measurement on the same TRP Rx beam, for example, to change a WTRU Tx beam, e.g., when a WTRU uses beamforming.

[0103] NR may support, for example, one or more network (NW)-controlled mechanisms for beam management for UL transmission(s). A WTRU may provide information to a gNB, for example, to assist with UL beam management without WTRU beam correspondence. SRS resources may be used to train WTRU Tx beams, for example, based on DL beam management results. A WTRU may use a (e.g., the same) transmission power for SRS transmission (e.g., during a round of beam sweeping), which may be derived, for example, from beam-specific power control signaling and maximum transmit power.

[0104] DL Beam management may use, for example, procedures P-1, P-2 and P-3. Beam correspondence, which may be a WTRU capability, may be fulfilled at a TRP and/or a WTRU. DL beam management may be used to find suitable TRP TX/RX beams and/or WTRU TX/RX beams. A TRP RX beam and/or WTRU TX beam may not be determined based on DL beam management, for example, when beam correspondence may not be fulfilled at a TRP and/or a WTRU. UL beam management may be used, for example, when beam correspondence may not be fulfilled at a TRP and/or a WTRU.

[0105] WTRU beam correspondence capability or lack thereof may depend on, for example, a hardware limitation, Tx/Rx antenna configuration, and/or asymmetric interference between uplink and downlink. WTRU transmit and receive array patterns may be different, for example, due to beam control errors, which may lead to misalignment between Tx and Rx beam directions and performance degradation and incomplete or imperfect WTRU beam correspondence. A Tx beam that may be determined by a WTRU based on full or perfect beam correspondence may not (e.g., always) be the best Tx beam from a gNB perspective. An efficient UL beam management procedure and/or mechanism may override UL Tx beam determination by a WTRU, for example, based on full beam correspondence, e.g., to handle system performance degradation.

[0106] An efficient UL beam management procedure and/or mechanism may operate without full beam correspondence. Information that may be provided by a WTRU may be based on DL beam management results (e.g., when available). System overhead and latency may be reduced while maintaining system performance.

[0107] A TRP and/or gNB may flexibly configure SRS resources for UL beam management. A WTRU may generate and transmit flexible SRS for UL beam management.

[0108] A WTRU may use the same or different transmission power for SRS transmission during a (e.g., one) round of beam sweeping. SRS transmission power may be determined, for example, during a (e.g., one) round of beam sweeping for UL beam management.

[0109] Efficient uplink (UL) beam management procedures and/or mechanisms may include SRS configuration, beam sweeping and SRS transmission power setting for UL beam management.

[0110] FIG. 3 is an example of DL beam management assisted UL beam management. One or more of the following may apply.

[0111] In an example, a WTRU may (e.g., first) determine a UL Tx beam, e.g., based on a DL Rx beam from DL beam management such as P1 or P3.

[0112] WTRU beam correspondence (BC) may be determined, for example, by a TRP and/or a WTRU.

[0113] In an example, a WTRU may (e.g., when there may be full beam correspondence) continue determining a UL Tx beam based on a DL Rx beam from DL beam management such as P1 or P3.

[0114] Partial beam correspondence may be determined and declared, for example, when a difference between UL Tx and Rx beam directions may not be significant. In an example, Mechanism 1 (e.g., as discussed below) with local beam sweeping or Mechanism 2 (e.g., as discussed below) may be used for beam adjustment for UL transmission.

[0115] Beam correspondence may not be determined and declared, for example, when a difference between UL Tx and Rx beam direction may be sufficiently large. In an example, Mechanism 1 may be used for beam adjustment for UL transmission.

[0116] A WTRU may (e.g., to facilitate a TRP to initiate, request, trigger and/or configure UL BM) signal an imperfect BC (e.g., no BC or partial BC). Information may be provided to assist a TRP. In examples, a WTRU may indicate a WTRU BC capability or BC status (e.g., full BC, no BC, or partial BC) to a TRP, e.g., via PUCCH or PUSCH. In examples, a WTRU may implicitly indicate WTRU BC capability or BC status (e.g., full BC, no BC or partial BC) to TRP. It may do so by requesting different amount of SRS resources for UL beam management or beam sweeping (e.g., Fig. 15). For example, in a case of full BC, then no SRS resource may be requested; in a case of partial BC, then a certain amount of SRS resources may be requested which may request local sweeping; in a case of no BC, then a large amount of SRS resources may be requested, which may request full (or global) beam sweeping (e.g., Fig. 15). A WTRU may signal its beamforming capability, such as a number of Tx beams, for example, a max number of SRS resource sets and a max number of SRS resource per set, to help a gNB or TRP determine SRS resources that may be configured for a (e.g., each) WTRU. A WTRU may request and/or recommend local or full beam sweeping to a TRP. A WTRU may request SRS resources for UL beam management or beam sweeping. A WTRU may signal a timing of scheduled SRS transmissions.

[0117] A WTRU may use assist information for UL Beam management.

[0118] A TRP may configure SRS resources for UL beam management, for example, to do local (or partial) beam sweeping or full beam sweeping (e.g., as shown by example in FIG. 10).

[0119] A WTRU may (e.g., based on SRS configuration) execute local beam sweeping, e.g., by transmitting a group of SRS around a preferred UL Tx beam that may be selected based on DL beam management, or execute full beam sweeping, e.g., by transmitting SRS over all or most WTRU Tx beams. The WTRU may identify the best UL Tx beam within the best subset of beams by local beam sweeping or among all or most WTRU Tx beams by full beam sweeping. A WTRU may generate and transmit SRS for intra-symbol UL beam sweeping with frequency and time separation.

[0120] A TRP may measure a received SRS and may determine the best Tx beam(s) for a next UL transmission.

[0121] A TRP may send determined (e.g., best) Tx beam(s) to a WTRU, e.g., by SRS resource indicator (SRI).

[0122] A WTRU may (e.g., upon receiving SRI) adjust to a (e.g., the best) Tx beam for a next UL transmission.

[0123] SRS power setting for UL beam management may use one or more (e.g., any combination of) procedures. A beam-specific power control may be used for UL transmission, for example, when UL beam sweeping may be finished.

[0124] Mechanism 2 may be used for beam adjustment with data transmission. One or more of the following may apply.

[0125] WTRU beam correspondence (e.g., for UL beam management) may be determined, for example, based on one or more procedures.

[0126] In a (e.g., first) example procedure, WTRU Beam correspondence (e.g., for UL beam management) may be determined by the WTRU.

[0127] A WTRU may perform Tx beam sweeping.

[0128] A TRP may select (e.g., determine) a WTRU Tx beam or beams, for example, based on a beam reference signal (BRS) measurement.

[0129] A TRP may indicate selected WTRU Tx beam information, e.g., based on the determined beam or beams. A selected beam index or beam indices may be signaled to a WTRU, for example, via a downlink control channel, CSI-RS resource, RACH Msg2 or Msg4, NR-PDCCH/NR-ePDCCH, NR-PDSCH, or the like.

[0130] A WTRU may perform WTRU Rx beam sweeping.

[0131] A WTRU may determine a WTRU Rx beam or beams, e.g., based on a DL beam management CSI-RS or SS-block measurement.

[0132] A WTRU may select (e.g., derive) a WTRU Tx beam or beams, for example, using a determined WTRU Rx beam or beams, e.g., assuming beam correspondence at the WTRU.

[0133] A WTRU may compare selected (e.g., determined or derived) beams. A WTRU may determine a final beam correspondence at the WTRU, e.g., based on one or more (e.g., asset of) rules.

[0134] Beam correspondence or full beam correspondence at a WTRU may be determined and declared, for example, when compared selected beams may be the same.

[0135] Beam correspondence at a WTRU may not be declared and determined, for example, when compared selected beams may be different.

[0136] Partial beam correspondence at a WTRU may be declared and determined, for example, when a difference between compared selected beams may be within a pre-defined or pre-configured threshold. In an example, a WTRU's Tx beams may be a certain beam offset (e.g., two beams away) from a WTRU's Rx beams.

[0137] Measurement or metrics that may be used to determine beams or beam correspondence may be based on, for example, SNR, signal strength, power, beam-quality, RSRP, CSI, SS-block-RSRP, or the like.

[0138] In a (e.g., second) example procedure, WTRU Beam correspondence (e.g., for UL beam management) may be determined by a TRP, a gNB, or a network. One or more of the following may apply.

[0139] A WTRU may perform Tx beam sweeping.

[0140] A TRP may select (e.g., determine) WTRU Tx beam or beams, for example, based on a beam reference signal (BRS) measurement.

[0141] A WTRU may perform WTRU Rx beam sweeping.

[0142] A WTRU may select (e.g., determine) WTRU Rx beam or beams, for example, based on a DL beam management CSI-RS or SS-block measurement.

[0143] A WTRU may report a DL Rx beam to a TRP.

[0144] A TRP may select (e.g., derive) a WTRU Tx beam or beams, for example, using the selected (e.g., determined) WTRU Rx beam or beams, e.g., assuming beam correspondence at the WTRU.

[0145] A TRP may compare selected beams. A TRP may determine a final beam correspondence at a WTRU, for example, based on one or more (e.g., a set of) rules.

[0146] Beam correspondence or full beam correspondence at a WTRU may be determined and declared, for example, when compared selected beams may be the same.

[0147] Beam correspondence at a WTRU may not be declared and determined, for example, when compared selected beams may be different.

[0148] Partial beam correspondence at a WTRU may be declared and determined, for example, when a difference between compared selected beams may be within a pre-defined or pre-configured threshold. In an example, a WTRU's Tx beams may be a certain beam offset (e.g., two beams away) from a WTRU's Rx beams.

[0149] Measurement or metrics that may be used to determine beams or beam correspondence may be based on, for example, SNR, signal strength, power, beam-quality, RSRP, CSI, SS-block-RSRP, or the like.

[0150] A TRP may send a beam adjustment request to a WTRU, for example, when a TRP may determine that there may be no correspondence or partial correspondence. A WTRU may, for example, adjust its UL Tx beam, e.g., using mechanism 2. A TRP may (e.g., alternatively) trigger or initiate UL beam sweeping for UL beam adjustment and transmission.

[0151] Mechanism 1 may comprise, for example, beam adjustment with flexible UL beam management. Mechanism 1 may be implemented, for example, using one or more (e.g., any combination of) procedures discussed with respect to flexible UL beam management and SRS power setting for UL beam management.

[0152] Mechanism 2 may comprise, for example, beam adjustment with data transmission. Mechanism 2 may be used, for example, for partial beam correspondence.

[0153] FIG. 4 is an example of beam adjustment with data transmission.

[0154] WTRU transmit and receive array patterns may be subject to beam control errors, in which case beam correspondence may not hold. A difference between the two directions (e.g., UL and DL) may not be significant.

[0155] Using an UL Tx beam corresponding to the best DL Rx beam (e.g., obtained during DL beam management or DL beam sweeping) for UL transmission may be sufficient for one or more data modulation and coding schemes (MCSs), but may be an insufficient beam for higher MCSs, e.g., due to imperfect beam correspondence.

[0156] A WTRU may (e.g., in this scenario) adjust its beam directions during data transmission, for example, based on feedback that may be associated with a link quality of an effective channel, which may include a beam pattern impact. Feedback may be, for example, a channel quality indicator (CQI), SINR of a channel estimation, CSI, RI, L1-RSRP, and/or data detection results, such as ACK/NACK, BLER, or BER, etc. A WTRU may (e.g., based on a change in link quality of an effective channel) change its beam direction, for example, with a certain step size, b . A change in beam direction may be performed iteratively, which may lead to the best Tx beam (e.g., as shown by example in FIG. 4). A step size b may be set with different values (e.g., over time), for example, for fast and/or accurate beam direction adjustments.

[0157] FIG. 5 is an example for beam adjustment with data transmission. One or more of the following may apply.

[0158] A WTRU may start transmitting a packet per transmission interval (e.g., a slot, a mini-slot, a subframe, a TTI, or a radio frame) using the best receive beam, $B(0)$, which may be obtained during DL beam management or a DL beam training process. A WTRU may receive feedback from a gNB, denoted as $F(0)$, for an effective channel that may be associated with $B(0)$.

[0159] A WTRU may (e.g., when transmitting a next packet $P(1)$) use a new beam that may be in the neighborhood (e.g., in terms of beam angle) of the previous beam, $B(1) = B(0) + b$, where b may be a predefined, configured, or signaled small angle, which may be indicated as a beam offset (e.g., in terms of the number of beams). A WTRU may receive a new feedback, $F(1)$, from a gNB for an effective channel that may be associated with the new beam.

[0160] A WTRU may compare current feedback $F(1)$ and previous feedback $F(0)$. A WTRU may increase its beam direction for a next transmission (e.g. $B(2) = B(1) + b$), for example, when feedback may indicate a current effective channel condition using $B(1)$ may be better than a previous one using $B(0)$, e.g., denoted as $F(1) > F(0)$ in FIG. 5. A WTRU may decrease its beam direction for a next transmission (e.g. $B(2) = B(1) - b$), for example, when feedback may indicate a current effective channel condition using $B(1)$ may be worse than a previous one using $B(0)$, e.g., denoted as $F(1) < F(0)$ in FIG. 5. A WTRU may keep a beam direction the same as a previous one for a next transmission, (e.g., $B(2) = B(1)$), for example, when feedback may indicate a current effective channel condition using $B(1)$ may be the same as a previous one using $B(0)$, e.g., $F(1) = F(0)$.

[0161] A beam adjustment procedure (e.g., as shown by example in FIG. 5) may be repeated, for example, until a whole packet may be transmitted, or beam failure may be declared. A beam adjustment procedure may be performed as a process by process basis, for example, when HARQ may be implemented.

[0162] A flexible UL beam management implementation may be provided. A UL beam management procedure may identify and track proper TRP Rx beam(s) and/or WTRU Tx beam(s) for UL transmission, for example, by UL beam sweeping or beam training. A suitable reference signal, e.g., for network (e.g., TRP or gNB) controlled UL beam management, may be a sounding reference signal (SRS). In an example (e.g., using SRS for UL beam management), channel state information (CSI) may be obtained (e.g., simultaneously) with suitable TRP RX and/or WTRU TX beams, which may reduce a delay between UL beam management and UL data transmission. Flexible SRS configurations may be provided.

[0163] A flexible SRS configuration may be provided for UL beam management (e.g., Fig. 15). A network (e.g., gNB or TRP) may configure an NR-SRS for a WTRU for UL beam management, for example, to identify and track a WTRU TX beam and a TRP RX beam for UL transmission. Different NR-SRS resource settings may be pre-defined or specified and configured for different UL beam management procedures such as U1/U2/U3, for example, by an RRC signaling message (e.g., RRC configuration and/or RRC reconfiguration messages) (e.g., Fig. 15). An NR-SRS resource setting may be configured to include multiple NR-SRS resource sets (e.g., for a UL beam management procedure). An (e.g., each) NR-SRS resource set may have one or more resources, e.g., to support beam sweeping.

[0164] In an example, a WTRU may be configured with $M \geq 1$ NR-SRS resources. Transmission of M NR-SRS resources may be used for WTRU Tx beam sweeping for U1 or U3. In an (e.g., another) example, a WTRU may be configured with a (e.g., one) NR-SRS resource that may be transmitted over multiple symbols, slots, mini-slots, or sub-frames for TRP Rx beam sweeping for U2. A beam sweeping pattern across $M \geq 1$ NR-SRS resources in one or more NR-SRS transmissions may be configurable, for example,

for different UL beam management procedures. For example, for U2, a WTRU may be configured to apply the same Tx beam across the SRS resources in a SRS resource set.

[0165] Configuration of SRS resources may (e.g., also) include mapping to REs (e.g., bandwidth such as sub-band, resource blocks, subcarriers, frequency hopping, symbols, comb), time domain behavior (e.g., period, aperiodic), SRS ports, sequence configuration (e.g., Zadoff Chu sequence, root, cyclic shift, or new NR-SRS sequence, NR-SRS index, or new NR-SRS sequence groups, NR-SRS sequence group index). An SRS configuration may have a SRS resource setting that may, for example, consist of N ($N \geq 1$) SRS resource sets, where each NR-SRS resource set may include M ($M \geq 1$) SRS resources. A (e.g., one) resource set with M SRS resources may be configured, for example, to support beam sweeping over multiple symbols/slots in a time domain and resource blocks in a frequency domain. A (e.g., each) SRS resource may be predefined, for example, to indicate an index of a specific beam.

[0166] A cell-specific NR-SRS may be configured, for example, in minimum SI. A WTRU-specific SRS may be configured, for example, in other SI. In an (e.g., alternative) example, a WTRU-specific NR-SRS may be configured, for example, by RRC signaling. Aperiodic SRS may be configured with multiple sets of SRS parameters, for example, via MAC CE signaling, which may (e.g., in part) be (e.g., further) activated/triggered by DCI on NR-PDCCH and/or NR-ePDCCH. SRS parameters may (e.g., alternatively) be selected and triggered via DCI on NR-PDCCH and/or NR-ePDCCH. A timing offset between triggering and SRS transmission may (e.g., also) be configurable, for example, to support flexible UL beam training.

[0167] FIG. 6 is an example of SRS transmissions multiplexed in time and frequency domains for UL beam management. FIG. 6 shows how NR-SRS resources may be flexibly configured for UL beam management for different WTRUs. Multiplexing NR-SRS transmissions from multiple (e.g., five) different WTRUs (e.g., as shown by example in FIG. 6) may be used, for example, to facilitate flexible UL beam management using one or more (e.g., any combination of) procedures. One or more of the following may apply. FIG. 6 shows an example with 5 UEs or WTRUs. UE1's time and frequency resource blocks are shown as 501. UE2's time and frequency resource blocks are shown as 502 or from an arrow from UE2. UE3's time and frequency resource blocks are shown as 503. UE4's time and frequency resource blocks are shown as 504. UE5's time and frequency resource blocks are shown as 505. UE3 and UE4 are shown to have partially overlapping time and frequency resource blocks are labeled in FIG. 6. Each of UE1-UE5's Tx beams are shown directly above or below their respective resource blocks by the oval above or below the respective resource blocks, except that UE3 and UE4's shared Tx beams are labeled as 534.

[0168] A (e.g., each) rectangular box in FIG. 6 may represent a minimum number of resource blocks (RBs). WTRU 1 may, for example, occupy two boxes (e.g., 501 on the bottom left set of blocks in FIG. 6) within one interval X while WTRU 2 may occupy 4 boxes (e.g., the top row of blocks labeled 502 in the bottom left set of blocks in FIG. 6). A minimum number of RB may be four (e.g., in LTE) for SRS

bandwidth. NR may allow a larger minimum number of RBs (e.g., eight) or a smaller minimum number of RBs (e.g., 2 or 1) for better flexibility to accommodate diverse uses cases. In an example, a larger minimum number of RBs may be configured for a high frequency band. A reference-signal sequence (e.g., for NR-SRS) may, for example, be mapped every N ($N \geq 1$) subcarrier, which may create a "comb"-like spectrum. In an example (e.g., LTE), N may be 2 or 4. N may be another value larger than 2, for example, to adapt to a larger frequency spectrum supported in NR. Lengths of reference-signal sequences of NR-SRS may (e.g., always) be multiples of $X \cdot (12/Y)$, for example, when a bandwidth of an NR-SRS transmission may (e.g., always) be a multiple of X resource blocks and the number of different combs may be Y . In an example, NR-SRS signals may be multiples of 24 bits, for example, when X may be 8 and Y may be 4.

[0169] In an example, WTRU 1 and WTRU 2 may perform U3 procedures (e.g., WTRUs refine UL TX beams). WTRU 2 may, for example, perform full UL TX beam sweeping (e.g., repeating among all TX beams such as 1 to 8) across multiple symbols. WTRU 1 may perform local or directional UL TX beam sweeping, for example, where WTRU 1 may keep the same two TX beams (beam 3 and beam 7), e.g., to reduce associated delay/overhead compared to full sweeping. A reduced U3 procedure (e.g., local beam sweeping) may be feasible, for example, when a network may be in control of UL beam management. A WTRU may receive SRI(s) and/or beam indications from a network that may indicate which UL TX beam may (e.g., should) be used during transmissions (e.g., offloading traffic to release a congestion status of some beams) (e.g., Fig. 15). A reduced U3 procedure may (e.g., alternatively) be feasible, for example, due to assistance information from DL beam management procedures.

[0170] In an example, WTRU 3 may perform a U2 procedure and may keep the same TX beam 4 during SRS transmissions (e.g., Fig. 15). WTRU 3 may, for example, utilize frequency hopping to cover a relatively larger bandwidth, e.g., due to a transmit power limitation. A frequency hopping pattern may be configured by a network (e.g., gNB or TRP), for example, depending on how a WTRU location, channel condition, and latency requirement.

[0171] In an example, WTRU 4, may have a partially overlapped bandwidth with WTRU 3. SRS transmissions from WTRU 3 and WTRU 4 may be frequency multiplexed, e.g., by assigning them to different frequency shifts or "combs," for example, since each SRS from WTRU 3 or WTRU 4 may (e.g., only) occupy every second (fourth or larger configurable number of) subcarrier. A number of combs (e.g., in NR) may be higher than four (e.g., in LTE) and may be configurable for different cells.

[0172] A WTRU may prefer non-consecutive symbols, for example, instead of occupying consecutive symbols for SRS transmissions (e.g., WTRU 1 and WTRU 2). WTRU 4 and WTRU 5 may perform beam switching with non-negligible delay, for example, given a one symbol interval between beam 4 and 5 of WTRU 4 and a one symbol interval between beam 1 and beam 2 of WTRU 5.

[0173] In an example, a (e.g., each) NR-SRS resource may span an (e.g., exactly one) OFDM symbol (e.g., as shown by example in FIG. 6). Multiple NR-SRS resources may reside in a (e.g., single) OFDM symbol, for example, when a sub-time unit may be smaller than a symbol size of current numerology.

[0174] In an example, beam sweeping types or UL BM procedure (e.g., U2, U3) among all assigned SRS resources may be (e.g., explicitly) indicated for a (e.g., each) SRS resource set (e.g., group of SRS resources), for example, for high flexibility of SRS configurations. In an (e.g., another) example, beam sweeping types may (e.g., also) be (e.g., implicitly) indicated by an SRS resource set index. For example, a specified field (e.g., an SRS request field) in an AP SRS triggering DCI may activate a SRS resource set within which each SRS resource may be configured with the same beam (e.g., implicitly indicates U2) or a different beam (e.g., implicitly indicates U3). SRS resources used by WTRU 1 may, for example, be grouped into a (e.g., single) SRS resource set and a whole resource set may be reserved/indicated as being (e.g., only) for a U3 procedure.

[0175] Signaling overhead may (e.g., for a WTRU specific NR-SRS configuration) become significant, for example, when a number of WTRUs may be high, such as WTRUs equipped with multiple beams. NR-SRS overhead reduction schemes may be implemented. In an example, multiple repetitions may be created within an (e.g., one) OFDM symbol, for example, using IFDMA, DFT-based Sub-Unit Time methods, or the like. A TRP may sweep UL Rx beams across repetitions to perform U2 procedures, for example, when a WTRU fixes a (e.g., one) UL TX beam. In an (e.g., alternative) example, a sub-band with large subcarrier spacing may result in short OFDM symbols, for example, for mixed numerologies in NR systems, which may permit a WTRU to sweep UL TX beams across multiple short OFDM symbols.

[0176] FIG. 7 is an example of large subcarrier spacing in NR networks with mixed numerologies to reduce beam sweeping overhead. As shown by example in FIG. 7, WTRU2 or UE2 may (e.g., in the same time duration), for example, transmit NR-SRS on more beams than WTRU1 or UE1 (e.g., two beams for WTRU 2 and one beam for WTRU 1 over one OFDM symbol). UE1's two Tx beams are shown below UE1's resource blocks, and UE2's four Tx beams are shown above each of UE2's resource blocks.

[0177] In an (e.g., another) example that may reduce overhead, intra-symbol UL beam sweeping with frequency and time separation may be implemented.

[0178] Wideband beam measurement may be implemented, for example, to obtain relatively more accurate beam quality evaluation. A WTRU may be limited to transmit NR-SRS in a narrow sub-band, for example, due to interference avoidance, WTRU transmit power limitation, etc. A WTRU may perform NR-SRS frequency hopping across multiple symbols (e.g., instead of across multiple slots) with the same TX beam, for example, to cover a large bandwidth. A network (e.g., TRP or gNB) may combine measurement results on those symbols, for example, to obtain wideband measurement for a (e.g., one) WTRU TX beam.

AWTRU may (e.g., using symbol level frequency hopping) sounding an entire frequency range of interest within a single time interval, which may (e.g., significantly) reduce latency.

[0179] FIG. 8 is an example of symbol level frequency hopping of NR-SRS across multiple OFDM symbols. NR-SRS and PUSCH may exist in a (e.g., the same) symbol, for example, to increase resource utilization efficiency and flexibility. In an (e.g., another) example, combined slot-level (e.g., inter-slot) and symbol-level (e.g., intra-slot) frequency hopping may be configured, for example, to facilitate different UL beam management procedures across multiple WTRUs.

[0180] A configurable and efficient design of NR-SRS transmissions may be generalized, for example, based on different comb levels and mixed numerologies. Different use cases may be created for UL beamforming based SRS transmissions.

[0181] FIG. 9 is an example of high density and low density SRS bandwidth. UE1 is shown with respect to frequency-time Option 1, and UE2 is shown with respect to frequency-time Option 2.

[0182] In an example, a WTRU may not transmit an SRS sequence in a large bandwidth with high density, for example, due to a transmit power limit. There may be multiple (e.g., two) options for a beamformed WTRU to cover an entire frequency range of interest.

[0183] In an example of a first option (e.g., Option 1 in Figure 9), a WTRU may (e.g. with frequency hopping) cover a large bandwidth in a (e.g., single) time slot and transmit high/medium density SRS sequences on different beams with different time slots. A WTRU may (e.g., alternatively) transmit on different beams in a (e.g., single) time slot, applying frequency hopping on different time slots.

[0184] In an example of a second option (e.g., Option 2 in Figure 9), a WTRU may (e.g., without frequency hopping) transmit low density SRS sequences on a large bandwidth.

[0185] In an example (e.g., as shown in FIG. 9), WTRU 2 may transmit low density SRS sequences, for example, to cover a large bandwidth within a single SRS transmission and may sweep three beams within a single interval X. In comparison, in the Figure 9 example, WTRU 1 may use three intervals to sweep three beams. WTRU 1 may (e.g., in each interval) fix one beam to do frequency hopping to cover a large bandwidth.

[0186] An SRS transmission in option 2 may have lower density, which may provide lower accuracy for beam measurement results, while also reducing overhead and latency, e.g., in terms of an aggregate number of time intervals.

[0187] In an example (e.g. for high speed WTRUs), option 2 may be better for a radio environment that may change fast, where fast beam measurements may be critical. Option 2 may be better for URLLC use case WTRUs, where low latency requirements may demand fast beam sweeping measurements.

[0188] FIG. 10 is an example of full sweeping and an example of local sweeping for a U3 procedure. In an example, a WTRU may perform full sweeping of a U3 procedure or local sweeping of a U3 procedure, e.g., to find a most suitable UL TX beam. Option 2 may be applied to full beam sweeping, for example, to permit a WTRU to quickly cover an entire frequency range of interest from all available TX beams. Option 1 may be applied to local beam sweeping. An SRS transmission on a subset of full sweeping beams may incur tolerable overhead. High density SRS bandwidth may lead to more accurate beam measurement results.

[0189] An exemplary WTRU frequency hopping procedure is shown in FIGS. 6-8.

[0190] Within one interval X (e.g., a time slot), a WTRU (e.g., UE) may be configured to transmit one or multiple SRS resource(s) on multiple adjacent or non-adjacent X symbols within the last N symbols. The value of N may be fixed/pre-defined (e.g., as 4, 5, or 6). For example, in FIG. 6 N is equal 4. In FIG. 6, UE 3 transmits an SRS resource on 1 symbol, while UE 1 and UE 2 transmit an SRS resource on 2 and 4 adjacent symbols respectively over the last N (e.g., N = 4 in this example) symbols. This means that a UE may transmit SRS resource(s) on 1, 2, or 4 adjacent symbols over the last N symbols. In another embodiment, a UE may transmit SRS resource(s) on non-adjacent symbols, such as UE 4 and UE 5, as shown in FIG. 6.

[0191] Within one interval X (e.g., a time slot), a UE may be or may be not configured with frequency hopping (intra-slot and/or symbol-level frequency hopping). As illustrated in FIG. 6, UE 2 transmits SRS resource(s) on 4 adjacent symbols but with no frequency hopping. As illustrated in FIG. 8, a UE transmits SRS resource(s) on 3 adjacent symbols with frequency hopping. For intra-slot or symbol-level frequency hopping on a UE, two variables may be defined. One variable may be N_s , which may be used to specify how many symbols within one interval X (e.g., a time slot) a UE may use to transmit SRS resource(s). Another variable may be N_r , which may be used to specify whether a subset of symbols from the N_s symbols are repeated or not. For UE 2 in FIG. 6, N_s is 4, and N_r is 4, which means SRS transmissions on all 4 (N_r) symbols from the 4 (N_s) symbols are repeated on the same range of subcarriers. For the UE in 8, N_s is 3, and N_r is 1, which means SRS transmission on each 1 (N_r) symbol is not repeated for the 3 (N_s) symbols. Note that the N_r symbols which have repeated SRS transmissions may be grouped together (e.g., a group/pair of N_r adjacent OFDM symbols). Note that within one group/pair of N_r symbols, (e.g., all) antenna ports of the SRS resource (s) which are transmitted/repeated on the N_r symbols may be mapped to the same set of subcarriers. Note that for the SRS resources transmitted on the symbols from different group/pairs, the antenna ports of a SRS resource may be mapped to a different set of subcarriers. The different set of subcarriers may be non-overlapping or partially over-lapping on the frequency domain.

[0192] The UEs shown in FIG. 6 may transmit different types of SRS resources. For example, UE 2 and UE 1 may transmit aperiodic SRS resources over 4 and 2 symbols respectively. Since aperiodic SRS

resources are triggered to be transmitted only once, a UE which is triggered to transmit aperiodic SRS resources may perform (e.g., only) intra-slot frequency hopping. In another embodiment, a UE which is configured with periodic or semi-periodic SRS resource(s) may perform inter-slot frequency hopping only or combined intra-slot and inter-slot frequency hopping.

[0193] A UE may support a higher granularity of frequency hopping in the time domain (e.g., to reduce the delay of frequency hopping covering a specific BWP or sub-band). An example is shown in FIG. 7, where different UEs may perform frequency hopping on OFDM symbols with a different symbol length if a NR system supports mixed numerologies (e.g., sub-band with large subcarrier spacing results in short OFDM symbols). Different granularity of frequency hopping may provide lower delay and/or higher flexibility (e.g., because more UEs may be configured to do SRS transmissions within the same time duration).

[0194] Note that a sub-band (e.g., as shown in FIGS. 6-8) may represent a specific BWP on a specific composite carrier or a partial band of a specific BWP. An SRS transmission may support different usages (e.g., beamManagement, codebook, nonCodebook, and/or antennaSwitching). The described beam management examples may be applied to other usage scenarios or any combination of the applicable usages. For example, UE frequency hopping may be used for either or both UL channel quality estimation for PUSCH and beam management (e.g., if a network wants to estimate both the quality of beams and quality of the UL channel on a specific BWP or sub-band).

[0195] A WTRU may request SRS resources for UL beam management and/or beam sweeping. One or more SRS resources may be used and each SRS resource may be associated with a beam. For example, if a WTRU has a capability of N_b Tx beams, the WTRU may use, determine, and/or indicate N_b SRS resources for beam sweeping. Each SRS resource may include one or more SRS ports, wherein the SRS ports (e.g., all the SRS ports) in a same SRS resource may be quasi-collocated or assumed to use a same beam. In examples, one or more SRS ports in an SRS resource may be used and each SRS port may be associated with a beam. A WTRU may use, determine, or indicate N_b antenna ports, e.g., if the WTRU has N_b Tx beams as a capability. Hereafter, SRS resource may be similarly used with SRS port.

[0196] A WTRU may request or indicate a required or a preferred number of SRS resources (or SRS ports) which may be used for at least one of beam pairing, beam sweeping, or beam selection (e.g., Fig. 15). One or more of following may apply.

[0197] The indication of a required or a preferred number of SRS resources (or SRS ports) may include '0' which may imply that no SRS resource for beam pairing, beam selection, or beam sweeping is needed. For example, if the required number of SRS resource (or SRS ports) is '0,' a network may assume that a WTRU may have a beam correspondence capability (e.g., Fig. 15). A WTRU may send or indicate the

required number of SRS resource (or SRS ports) as '0' if the WTRU has a beam correspondence capability.

[0198] One or more candidate number of SRS resources may be predefined, predetermined, or configured via higher layer signaling (e.g., minimum SI, other SI, or a WTRU-specific RRC). A WTRU may determine or indicate one of the candidate numbers (e.g., based on one or more signaling messages (e.g., capability signaling, msg1, and/or msg3) and/or dynamic signaling (e.g., L1 UCI)).

[0199] A WTRU may indicate a required number of SRS resources based on at least one of following (e.g., Fig. 15).

[0200] A set of PRACH resources (or PUCCH resources) may be preconfigured, predetermined, or configured to indicate a required number of SRS resources. For example, if a WTRU needs no SRS resource since the WTRU has full beam correspondence capability, the WTRU may select or determine a first PRACH resource (or a first PUCCH resource); if a WTRU needs a full beam sweeping (or global beam sweeping) since the WTRU may have no beam correspondence capability, the WTRU may select or determine a second PRACH resource (or a second PUCCH resource); if a WTRU needs a partial beam sweeping (or local beam sweeping), the WTRU may select or determine a third PRACH resource (or a third PUCCH resource).

[0201] A WTRU may indicate a required number of SRS resources as a WTRU capability. For example, a WTRU may indicate its beam correspondence capability and a required number of SRS resources if the WTRU does not have a beam correspondence capability.

[0202] A WTRU that needs a partial beam sweeping may indicate a required number of SRS resources and an associated Tx beam index from a TRP (e.g., Fig. 15). A WTRU that needs a full beam sweeping may indicate a required number of SRS resources without an associated Tx beam index. The associated Tx beam may be derived based on DL Rx beam from DL beam management results (e.g., P1 or P3) or DL data reception results with different DL Rx beams assuming WTRU beam correspondence hold. In examples, the associated Tx beam may be selected from the beam(s) by the previous UL beam management results (e.g., U1 or U3) or the beam(s) used by the previous UL transmission.

[0203] A WTRU may indicate a corresponding Rx beam at a TRP for SRS resource transmission. For example, a WTRU may indicate a preferred Tx beam index from a TRP and request SRS resources associated with the preferred Tx beam index. A WTRU may indicate a set of corresponding Rx beams at a TRP, and the WTRU may request SRS resources for each corresponding Rx beam at a TRP, wherein a WTRU may be indicated to transmit one or more SRS resources associated with a Rx beam at a TRP.

[0204] One or more SRS resources may be used for beam sweeping if a WTRU has no beam correspondence capability and one or more SRS ports in an SRS resource may be used for beam

sweeping if a WTRU has a partial beam correspondence capability. The partial beam correspondence capability may be a case that a WTRU has no beam correspondence but may still be able to report a preferred TRP Tx beam index. A preferred TRP Tx beam index may be selected or determined during a downlink beam management procedure (e.g., P-1), wherein the preferred TRP Tx beam index may be selected based on the reference signal quality measurement of downlink reference signals (e.g., CSI-RS or SS blocks). In examples, the partial beam correspondence capability may be a case that a WTRU indicated beam correspondence capability but request SRS resources for beam pairing. Note that SS block resource, SSB resource, SSB/PBCH resource or SS/PBCH block index may be interchangeably used in this application.

[0205] A WTRU may request a number of SRS resources for beam sweeping, beam pairing, or beam selection and if the WTRU is configured with a number of SRS resources that is larger than the requested number of SRS resources, the WTRU may perform at least one of following. The WTRU may perform full beam sweeping using the configured SRS resources although the WTRU has partial beam correspondence capability. The WTRU may use a subset of configured SRS resources. The WTRU may repeat beams cyclically.

[0206] A WTRU may provide (e.g., to assist UL beam management) one or more of the following multi-panel related information to gNB: (i) type of antenna structure (e.g., omni-directional antenna panel or directional antenna panel); and/or (ii) number of panels and the related UL QCL information. Multi-panels at a WTRU may not be QCL'ed because the panel orientations may be different (e.g., two panels are facing the other side). UL QCL information may be reported by the WTRU, e.g., via WTRU capability signaling, or msg3, or dynamic signaling over PUCCH or PUSCH.

[0207] For example, a WTRU may report antenna port grouping information to the gNB. Antenna ports may be partitioned into N_g groups (where $N \geq N_g$) (e.g., where N UL antenna ports are supported by the WTRU). Antenna ports in a group may be QCL'ed but antenna ports in different groups may not be QCL'ed. UL BM may be per port group (e.g., because the BPLs can be maintained per port group rather than per port). The TRP may allocate one set of SRS resources for each of the multiple parallel groups. In case of U3, the TRP may feedback one SRI for each of the multiple parallel groups. UL QCL information may be reported per antenna port.

[0208] Intra-symbol UL beam sweeping with frequency and time separations of reference signals (RS) may provide efficient UL beam management. This scheme may be applied to one or more (e.g., any combination of) UL RS, such as SRS, PRACH preamble, UL DMRS, or PRACH preamble-like, etc.

[0209] FIG. 11 is an example of intra-symbol UL beam sweeping with frequency and time separations. In an example, multiple beamforming vectors may be applied to OFDM symbols. An OFDM symbol may achieve (e.g., simultaneously within a symbol), for example: (i) Frequency Domain Multiplexed Reference

Signals (FDM'd RSs); (ii) Time Domain Multiplexed Reference Signals (TDM'd RSs); (iii) frequency diversity; and/or (iv) low PAPR

[0210] An (e.g., a special) OFDM, where RSs may be simultaneously FDM'd and TDM'd, may be implemented. Such an OFDM signal may be generated, for example, by using a set of special sequences that may be based on or may employ DFT-spread, upsampling, and/or repetition operations.

[0211] A WTRU transmitter may (e.g., to satisfy conditions i, ii, iii and iv) adopt a framework shown by example in FIG. 11.

[0212] FIG. 12 is an example (example #1) for intra-symbol UL beam sweeping with frequency and time separations. FIG. 12 is an example implementation of FIG. 11 for specified parameters. In an (e.g., this) example, a (e.g., one) beam direction may associate with a (e.g., only one) RS (e.g., SRS).

[0213] FIG. 13 is an example of a frequency and time representation of RS and corresponding UL Tx beams for Example #1. FIG. 13 shows an example of how RSs (e.g., SRSs) may be distributed in time and frequencies. RSs (SRSs) may not be overlapped and orthogonal in both the frequency domain and the time domain.

[0214] FIGS. 12 and 13 illustrate an example of intra-symbol UL beam sweeping with frequency and time separations RS (e.g., SRS) that may be generated by and transmitted from a WTRU, for example, using an example procedure shown in FIG. 11. The example shows there may be two DFT branches, e.g., $K = 2$. The example may (e.g., further) be based on the following: (i) $R_{i|i \in \{1,2\}} = 2$; (ii) $\uparrow_{i|i \in \{1,2\}} = 4$; (iii) $C_{d_{t1}} = 0$, $C_{r_{t1}} = 1$, $C_{d_{t2}} = 2$, $C_{r_{t2}} = 3$; (iv) $C_{d_{f1}} = 0$, $C_{r_{f1}} = 1$, $C_{d_{f2}} = 0$, $C_{r_{f2}} = 1$; and (v) beamforming may change every three other sample blocks related to one of the RS sequences (e.g., each beam direction may associate samples for at least one RS sequence).

[0215] In an example (e.g., as shown in FIGS. 11-13), frequency domain response RS sequences on a k th branch may be generated (e.g., in the example framework), for example, as follows:

[0216] A base sequence c_{ka} (or a base sequence c_{kb}) may be repeated by a factor of R_k . In an example with a base sequence $[1, 2]$ and $R_k = 2$, a repeated sequence may be $[1, 2, 1, 2]$.

[0217] Upsampling by a factor $\uparrow_k$ may be used. In an example with an input sequence $[1, 2, 1, 2]$ and $\uparrow_k = 2$, an upsampled sequence may be $[1, 0, 2, 0, 1, 0, 2, 0]$.

[0218] Circularly shifted by a factor $C_{d_{tk}}$. In an example with an input sequence $[1, 0, 2, 0, 1, 0, 2, 0]$ and $C_{d_{tk}} = 1$, an upsampled sequence may be $[0, 1, 0, 2, 0, 1, 0, 2]$.

[0219] DFT of the sequence may be calculated. In an example with an input sequence $[0, 1, 0, 2, 0, 1, 0, 2]$, a DFT of this sequence may be $[2.1213, 0, 0.7071i, 0, -2.1213, 0, -0.7071i, 0]$, where the DFT size may be 8 and it may be normalized.

[0220] Circular shifting by a factor $C_{d_{fk}}$ may be used. In an example the circular shift of an input sequence $[2.1213 \ 0 \ 0.7071i \ 0 \ -2.1213 \ 0 \ -0.7071i \ 0]$ with factor $C_{d_{fk}} = 1$ is $[0 \ 2.1213 \ 0 \ 0.7071i \ 0 \ -2.1213 \ 0 \ -0.7071i]$.

[0221] FDM'd and TDM'd RS and frequency diversity may be achieved, for example, when one or more of (e.g., all) the following conditions hold: (i) $R_{i|i \in \{1,2,\dots,K\}} = a \geq 2$ (e.g., to generate interleaved sequences in frequency for FDM'd RSs); (ii) $\uparrow_{i|i \in \{1,2,\dots,K\}} = b \geq 2K$ (e.g., to generate interleaved sequences in time for low TDM'd RSs); (iii) $C_{d_{tk}} \neq C_{d_{ti}} \neq C_{r_{tk}} \neq C_{t_{ti}}$ and $i, k \in \{1,2, \dots, K\}$ (e.g., to avoid overlap in time for TDM'd RSs); or (iv) $C_{d_{fk}} \neq C_{r_{tk}}$ and $k \in \{1,2, \dots, K\}$ (e.g., to avoid overlap in frequency for FDM'd RSs).

[0222] A receiver side may have multiple receive examples. Three examples are provided.

[0223] In an (e.g., a first) example, a receiver may detect energy in the time domain and may determine a position of a sequence, e.g., to identify good beams (e.g., time domain energy detection).

[0224] In an (e.g., a second) example, a receiver may calculate a DFT of a receiver signal and calculate an energy of a received signal on subcarriers where RSs may fall, for example, to identify good beams (e.g., frequency domain energy detection).

[0225] In an (e.g., a third) example, a receiver may correlate a received signal at an output of IDFT with RSs (e.g., a time domain symbol), for example, to identify good beams. This option may (e.g., also) allow an RS to carry certain WTRU or beam specific information (e.g., identification), *via* blind detection.

[0226] An example procedure depicted in FIGS. 11 and 12 may be used for simultaneous data transmission and beam sweeping or beam searching. In an example (e.g., as shown in FIG. 12), RS1 at an input of a DFT block of a first branch may be replaced with data, which may be transmitted, for example, using a beam direction that may be (e.g., currently) good enough to keep the link. Reference signals transmitted over other branches may be used for beam sweeping or beam searching, e.g., for querying a better beam. This process may be performed, for example, every few symbols (e.g., every slot, mini-slot, subframe, or radio frame). This process may be used, for example, for beam adjustment with local beam sweeping and/or beam adjustment with data transmission (e.g., as previously discussed).

[0227] An example procedure described in FIG. 11 may transmit a reference signal orthogonally in both time and frequency domain. The procedure may be extended for multi user transmissions. In an example, WTRU 1 may use branch 1 and 2 to transmit two reference signals in two different beam directions. WTRU 2 may use branch 3 and 4 to transmit two reference signals in two different beam directions. A gNB may identify the best beam for WTRU 1 and/or WTRU 2, for example, *via* a resource granting procedure (e.g., reference signal resource that may be a function of an index of a WTRU-specific sub-band, resource blocks, subcarriers, comb index, etc.) or *via* a reference signal ID identification procedure (e.g. the same

Zadoff Chu base sequence with different cyclic shifts configured to different WTRUs, or different orthogonal sequences), e.g., assuming grant free transmission may be possible.

[0228] FIG. 14 is an example (Example #2) for intra-symbol UL beam sweeping with frequency and time separations. In an example, two DFT-spread operations may be considered. The first M symbols may be mapped to the first M inputs of a first DFT-spread and remaining $L - M$ symbols may be mapped to the last $L - M$ inputs of a second DFT-spread. Frequency diversity may be achieved, for example, as a result of using two DFT-spread operations. A main lobe of a pulse shape associated with the symbols may be located at different time instants (e.g., TDM'd sequences), for example, because a symbol order at an input of DFT-spread and an order of the pulse shape in time may be identical. A transmitter may use different beams for the first N_1 samples and the rest of the N_2 samples, where $N_1 + N_2 = N$, and where N may be the IDFT size. A two DFT-spread operation is one of many possible examples. The concept may be generalized to K different DFT-spread operations mapped to different subcarriers where sequences mapped to different DFT-spread may use disjoint indices of DFT-spread operations. In an example, f indices $\mathcal{L} = \{1, 2, \dots, L\}$, and $\mathcal{L}_k$, for $k = 1, \dots, K$, may be subsets of $\mathcal{L}$ (e.g. $\mathcal{L}_k \subset \mathcal{L}$) such that they do not intersect each other (e.g. $\mathcal{L}_k \cap \mathcal{L}_j = \phi$ (empty), for $1 \leq k, j \leq L$). This may assume that there may be (e.g., are) K size- L DFT spreading blocks before an IDFT operation. Beamforming in time may follow the position of the sequences in the time domain.

[0229] SRS power setting may be provided for UL beam management (e.g., Fig. 15). Beam-specific power control may be provided for UL transmission (e.g. in NR), which may be applied to SRS transmission. Power control for UL transmission may adjust WTRU transmit power, for example, to counter path loss and channel fades, e.g., to maintain a desired target performance at a gNB or a TRP and to minimize an interference level (e.g., Fig. 15).

[0230] SRS transmission for UL beam management may have a different objective compared to regular power control. Multiple SRS transmissions may be required to measure one or more WTRU Tx beams and/or TRP Rx beams in a (e.g., one) round of beam sweeping. A transmit power for SRS transmission during one round of beam sweeping may be kept the same, for example, to have a fair comparison between candidate beams (e.g., Fig. 15). An example of SRS power setting for UL beam management is provided below.

[0231] In an example, an SRS power setting for one round of beam sweep in UL beam management may be kept the same as a minimum value of a maximum transmit power that a WTRU may afford and the value $P_{SRS_{bs}}$ (bs denotes beam sweep) (e.g., Fig. 15). The value $P_{SRS_{bs}}$ may be determined, for example, by one or more of the following procedures. Configured SRS power setting may be used (e.g., Fig. 15).

[0232] In an (e.g., a first) example, $P_{SRS_{bs}}$ may be configured by gNB or TRP (e.g., by RRC signaling), or may be signaled by DCI (e.g., Fig. 15). Method A in FIG. 15 may be illustrated as an example. $P_{SRS_{bs}}$ may, for example, be provided with a trigger or request to perform aperiodic SRS transmissions for beam sweeping in a DCI (e.g., Fig. 15). The number of SRS transmissions for one round of beam sweeping may (e.g., also) be provided in a trigger or SRS transmission request (e.g., Fig. 15). An indication to use a maximum power for SRS transmissions for one round of beam sweeping may (e.g., alternatively) be included in a trigger or SRS transmission request.

[0233] SRS power setting determined based on beam-specific control may be used. In an (e.g., a second) example, $P_{SRS_{bs}}$ may be derived from beam-specific power control signaling (e.g., RRC signaling) (e.g., Fig. 15). $P_{SRS_{bs}}$ may be derived, for example, from parameters configured for UL power control (e.g., for a beam pair link that is to be measured) (e.g., Fig. 15). In an (e.g., another) example, $P_{SRS_{bs}}$ may be derived from a beam-specific power control signal for other channels, such as PUCCH, PUSCH or PRACH (e.g., Fig. 15).

[0234] $P_{SRS_{bs}}$ may be used for connected mode WTRU. $P_{SRS_{bs}}$ power control may be a combination (e.g., due to the active RRC connection) of an open-loop mechanism, (which may imply that the transmission power depends on estimates of the downlink path loss) and other predefined or earlier configured parameters (e.g., configurable offset value), and a closed-loop mechanism, (which may imply that the network can (e.g., directly) adjust the transmission power (e.g., by means of explicitly power-control commands transmitted in the downlink)). WTRU uplink power control may use the general formula below to decide transmission power:

$$P(i) = \min \left\{ P_{\text{CMAX}}(i), \left[10 \log_{10}(M(i)) + P_o(j) + \alpha(j) \cdot PL + \Delta_{\text{TF}}(i) + f(i) \right] \right\}$$

[0235] There are several flexible components: nominal power $P_o(j)$, factor $\alpha(j)$, path-loss PL, transmit format factor $\Delta_{\text{TF}}(i)$, dynamic TPC command $f(i)$. To determine an appropriate value for $P_{SRS_{bs}}$ for beam management purpose, the above general formula may be reused with additional design for the components by considering beam management or beam sweeping purpose.

[0236] $P_o(j)$ may be a cell-specific parameter that is broadcast as part of the cell system information (e.g., SIB2 in LTE) or configured by higher layer (e.g., RRC connection setup, RRC connection reconfigure). The design of $P_o(j)$ (e.g., for beam management purpose) may take the average and relatively static interference level and noise level into account, and the value of $P_o(j)$ may be configured or broadcast to a WTRU. A WTRU may not read system information continuously and the estimated uplink

path loss may not be fully accurate (e.g., mismatch between path-loss for DL and UL). The value of $P_o(j)$ may be set as an average desired or target received power $P_{\text{target_bs}}$, for all SRS transmissions within a round of beam sweeping at the serving gNB/TRP. The SRS resources transmitted within one round of beam sweeping may be from the same SRS resource set. The value of $P_o(j)$ may be a higher layer configured cell level parameter and may take each beam sweeping (e.g., the SRS resource set transmitted within one round of beam sweeping) into account. The final value of $P_o(j)$ may have two parts, where one part takes cell level average power into account and the other part takes each beam sweeping (e.g., the SRS resource set transmitted within one round of beam sweeping) into account. The final value of $P_o(j)$ may have one part, which may merge the target power values based on cell level consideration and SRS resource set consideration into a single value.

[0237] A WTRU may be configured with one or multiple $P_{\text{target_bs}}$ values. Within each round of beam sweeping, SRS transmissions may use the same $P_{\text{target_bs}}$ value. Between different rounds of beam sweeping, different $P_{\text{target_bs}}$ values may be used for one or any combination of the reasons, such as WTRU mobility speed change (e.g., high speed to low speed), WTRU location change (e.g., from cell center to cell edge), WTRU service type change (e.g., performance requirements such as SINR may be different for eMBB and URLLC due to different mechanisms such as scheduling time unit length and numerology), WTRU remaining battery percentage (e.g., WTRU enters different power saving mode), etc.

[0238] Factor $\alpha(j)$ may take a value smaller than or equal to 1 (e.g., FIG. 15). When $\alpha(j)$ is equal to 1, $\alpha(j)$ may allow a (e.g., full) path-loss compensation, while when $\alpha(j)$ is smaller than 1, $\alpha(j)$ may allow a partial path-loss compensation. When the above general formula is applied to PUSCH (e.g., if the received power at the network (gNB/TRP) is too low), the corresponding WTRU may either increase the transmit power or reduce the MCS data rate by use of link adaptation (rate control). The benefit of partial path-loss compensation is relatively lower transmit power for devices closer to the cell boarder, implying less interference to other cells. There may be no availability for MCS data rate control (e.g., for SRS transmissions for beam management). $\alpha(j)$ may be set to 1, which means full path-loss compensation may be used for $P_{\text{SRS_bs}}$.

[0239] Path-loss may be denoted as PL. Uplink path-loss may be obtained by using the estimated path-loss from downlink path. If beam correspondence does not hold between NW (gNB/TRP) and WTRU, there may be a mismatch between downlink and uplink path-loss. Uplink path-loss from uplink reference signal (e.g., SRS) transmissions may be (e.g., directly) estimated. This estimation may be done at the

network side. The transmission power (or even per-port power) of the used uplink reference signal (e.g., SRS) may be informed to the network (e.g., L1/L2 signaling) (e.g., Fig. 15). For uplink beam management, one single BPL specific path-loss may not represent all BPLs' path-loss value. The values of estimated uplink path-loss from multiple BPLs may be combined. Multiple BPLs can be all the BPLs of one round of beam sweeping or a subset of BPLs. The combination could be different (e.g., averaging within one-time instance, moving averaging by considering historical values, or weighed moving averaging). Exemplary combinations can be expressed as:

$$PL_{uplink}(i) = \sum_k^N w_k \cdot PL_k \quad \text{or} \quad PL_{uplink}(i) = \alpha \cdot \sum_k^N w_k \cdot PL_k + (1 - \alpha) \cdot PL_{uplink}(i - 1)$$

[0240] K is the BPL index. N may be the number of BPLs that are used to transmit SRS within one round of beam sweeping or the configured or specified number of BPLs that are used to calculate the uplink PL denoted as PL_{uplink}. w_k is the weight factor for each individual BPL when calculating the combined path-loss. $PL_{uplink}(i - 1)$ is the previous or historical value in the last round of beam sweeping. α is the weighed moving averaging filter factor between [0,1]. When $\alpha = 1$, the uplink PL may be estimated based on a current round of beam sweeping. When $\alpha = 0$, the uplink PL may be kept as the same value as the initial uplink PL, which may be configured or obtained from DL PL estimation (e.g., the last value of DL PL).

[0241] Path-loss differences between different carrier frequencies may become significant due to some factors such as penetration loss, shadow fading, TX/RX antenna configuration, etc. When an UL carrier is in one frequency range and a DL NR carrier is in a different frequency range (e.g., for a WTRU in NR networks), and a WTRU uses DL path-loss as the estimation of the UL path-loss, the mismatch between downlink and uplink path-loss may be serious. A group of path-loss offset/adjustment values may be configured to the WTRU (e.g., to compensate for the mismatch between downlink and uplink path-loss). A WTRU may use a specific path-loss offset/adjustment value from the group according to some predefined rules, e.g., threshold values may be related to WTRU speed, differential value, or absolute value of WTRU UL carrier frequency and DL carrier frequency. Whether a path-loss offset/adjustment value is used or not may depend on evaluations of predefined rules (e.g., as described herein for the threshold value on carrier frequency difference between UL and DL). The configuration of path-loss offset/adjustment values may be common to all WTRUs within a specific TRP or gNB. The configuration of path-loss offset/adjustment values may be WTRU specific. The configured path-loss offset/adjustment values may depend on the carrier frequency difference between DL and UL. The larger the difference is, the higher value of path-loss offset/adjustment may be configured to the WTRU. The configuration may be broadcasted to a WTRU over minimum system information, dedicated to the WTRU over other system information, or signaled to the WTRU via MAC-CE or RRC messages.

[0242] An (e.g., each) UL carrier available for UE SRS transmissions for beam sweeping may have its own power control configurations (e.g., Fig. 15). Carrier frequency related path-loss offset/adjustment value may be included in $P_{\text{target_bs}}$ (e.g., instead of applying offset/adjustment on path-loss estimation).

[0243] One DL reference signal for UL PL estimation may be used. Which DL reference signal is used by the WTRU for UL path loss estimation for SRS beam sweeping should be configurable (e.g., regarding the DL based UL path-loss estimation, when multiple DL reference signals are configured to WTRU beam management). A WTRU may be configured to use the available periodic CSI-RS for path loss calculation for SRS beam sweeping, by determining P_{Luplink} with the replacement of UL PL by DL PL (e.g., if the WTRU is already configured with periodic CSI-RS for beam management). Aperiodic and/or semi static CSI-RS may be configured for path loss calculation for SRS beam sweeping. CSI-RS signals are not always-on. A network may make sure the signals are available when path loss calculation/estimation is used. The aperiodic and/or semi static CSI-RS may be triggered by a WTRU (e.g., WTRU includes a CSI-RS transmission trigger request carried in last UL transmissions such as UCI, SRS, etc.). An SS block may be an always-on signal used for L3 and/or L1 RSRP reporting and may be configured to support the spatial QCL assumption with CSI-RS to support UL PL estimation or UL PL estimation enhancement. For example, path loss may be enhanced by combining path loss estimation from L1-RSRP and L3-RSRP on an SS block, from L1-RSRP on CSI-RS and L1-RSRP on SS block, and/or from L1-RSRP on CSI-RS and/or SS block and L3-RSRP on SS block. One example is shown in Method B in FIG. 15 where one DL configured reference signal (RS) resource may be selected from multiple configured DL reference signals such as CSI-RS and SSB for UL PL estimation.

[0244] Transmit format factor may be denoted as $\Delta_{\text{TF}}(i)$. This parameter may add (e.g., for PUCCH) a format-dependent power offset to the transmit power (e.g., since different PUCCH formats may have different SINR requirements). The transmit form factor may add (e.g., for PUSCH) a MCS-dependent power offset (e.g., to reflect that a different SINR may be required for different MCS rates used for PUSCH transmissions). SRS transmissions (e.g., all SRS transmissions) within one round of beam sweeping (e.g., for uplink beam management) may use the same transmission power (e.g., to ensure fair energy comparison of different BPLs). Transmit form factor may not be used when the same transmission power is used for SRS transmissions in one round of beam sweeping.

[0245] Dynamic TPC command may be denoted as $f(i)$. A WTRU specific power control command may be used to carry the network newly calculated compensation for uplink path-loss estimation and send it to the corresponding WTRU (e.g., if uplink reference signal based path-loss estimation is used) compares the different BPLs within one round of beam sweeping,

[0246] All the received BPLs (e.g., for network efficiency in comparing the different BPLs with one round of beam sweeping) may not have high or low measurement quantities (e.g., RSRP). If the SRS transmissions received by the network have some BPLs measured to have relatively higher RSRP and some BPLs measured to have relatively lower RSRP, the network may select the best beam(s) by setting a suitable threshold value and the BPLs above the threshold value are compared and selected to be indicated at the subsequent beam indication step. The network may (e.g., directly) adjust the WTRU transmission power on the SRS transmissions (e.g., by using a dynamic TPC command transmitted on the downlink). The TPC command may be determined at the network (e.g., based on prior network measurements of the received SRS transmissions in the last round of beam sweeping).

[0247] L1/L2 control signaling may have higher priority in terms of power assignments. If PUCCH is multiplexed on the same component carriers with SRS for beam management purpose, the power is (e.g., first) assigned to PUCCH (e.g., before any power is assigned to any PUSCH or uplink beam management SRS).

[0248] An exemplary formula for SRS transmissions for uplink beam management may be defined. If the WTRU transmits PUCCH simultaneous with uplink beam management reference signal SRS for the serving cell C, then the WTRU transmit the same power $P_{SRSbs}(i)$ for the beam management SRS transmissions within one round of beam sweeping in subframe i for the serving cell C as:

$$P_{SRSbs}(i) = \min \left\{ 10 \log_{10}(P_{CMAX}(i) - P_{PUCCH}(i)), 10 \log_{10}(M(i)) + P_{target_bs} + PL_{uplink} + f(i) \right\} \text{ [dBm]}$$

[0249] If the WTRU is not transmitting PUCCH simultaneous with SRS, then the $P_{SRSbs}(i)$ may be given by (e.g., Fig. 15):

$$P_{SRSbs}(i) = \min \left\{ P_{CMAX}(i), 10 \log_{10}(M(i)) + P_{target_bs} + PL_{uplink} + f(i) \right\} \text{ [dBm]}$$

PL_{uplink} may be determined by a network based on previous uplink reference signal measurements (e.g., SRS). This formula may be illustrated in FIG. 15 with the Factor $\alpha(j)$ equal to 1, which may indicate full path loss compensation assumed described in [0229] as an example. SRS based UL beam management may be performed per BWP based (already explained as part of the flexible SRS configuration above), so that the final value of $P_{SRSbs}(i)$ may be calculated per BWP of a specific carrier for a specific serving cell for a UE.

[0250] P_{SRSbs} may be transmitted from an inactive mode WTRU (e.g., beam management may be needed for the inactive mode WTRU when the WTRU performs a CN tracking area update or a RAN-based

notification area update), where no active RRC connection exists. $P_{SRS_{bs}}$ power control may be based on an open-loop mechanism. An exemplary formula for SRS transmissions may be given by

$$P_{SRS_{bs}}(i) = \min \left\{ P_{\text{CMAX}}(i), 10 \log_{10}(M(i)) + P_{\text{target_bs}} + PL \right\} \text{ [dBm]}$$

[0251] In this example, there may not be a close-loop part (e.g., the explicit TPC command $f(i)$). The value of $P_{\text{target_bs}}$ may also be provided over system information. Path-loss may be based on downlink estimation or direct uplink estimation. The value of PL may be obtained from historical value (e.g., when a WTRU was in connected mode if a WTRU is relatively static), downlink measurements and estimation (e.g., SS-block based), or uplink measurements and estimation (e.g., network measures previous SRS transmissions and informs the estimated uplink path-loss to the UE over RAN notifications).

[0252] SRS transmissions and other reference signals may be used. For example, where a PRACH preamble may be used for a beam management purpose and transmitted in multiple beams (e.g., beam sweeping), the PRACH preamble power setting may be determined by the as described herein based on the PRACH power control.

[0253] Power ramping for SRS transmission for uplink beam management or beam sweeping may be used (e.g., Fig. 15). A WTRU may use power ramping together with the open-loop mechanism for SRS transmission. For example, TRP/gNB may broadcast the initial transmission power configurations and power ramp steps to a WTRU (e.g., system information) and/or power ramp steps may be dynamically configured to a WTRU over higher layer signaling such as MAC-CE or RRC signals. The power ramping related parameters may be configured to a WTRU or obtained from previous active connections (e.g., for inactive mode WTRUs) (e.g., Fig. 15).

[0254] For SRS transmissions for beam sweeping, power ramping may be used (e.g., for the same beam SRS transmission across different round of beam sweeping) (e.g., Fig. 15). Two counters may be used (e.g., for beam sweeping and power ramping respectively). The first counter may be named as a beam sweeping counter which may be increased in terms of WTRU Tx beams to be swept within a round. A round of beam sweeping may be defined and/or configured as either local (or partial) beam sweeping or full beam sweeping (e.g., Fig. 15). Full and local (or partial) beam sweeping may be configured and/or indicated in one or any combination of an RRC message, MAC-CE, and L1 control signaling such as DCI field. The number of SRS resources used for full and local (or partial) beam sweeping may be configured and/or indicated in one or any combination of an RRC message, MAC-CE and L1 control signaling such as DCI field, or autonomously known to the WTRU based on its capability (e.g., Fig. 15). For example, if the value of the beam sweeping counter is larger than the total number of transmitted SRS resources for a current round of beam sweeping, which may be configured as full or local sweeping, a new round of beam

sweeping may be identified or determined. Higher power may be ramped for the new round of beam sweeping. For example, the second counter may be introduced as the power ramping counter, which may be increased, when a new round of beam sweeping is identified and higher SRS transmission power may be used for the new round of beam sweeping. If the same SRS resource transmission is configured for new round, this may indicate the same beam should be swept at the WTRU, power ramping counter may be also increased so that WTRU may find a suitable transmission power to assist TRP/gNB side beam measurement. One example of using power ramping is illustrated as Method C in FIG. 15.

[0255] For SRS transmissions for beam sweeping, power ramping may be proposed for the same beam SRS transmissions (e.g., same transmissions) within one round of beam sweeping. For example, within a (e.g., each) round of beam sweeping, if (e.g., all) swept beams are different (e.g., no beam has SRS resource being transmitted more than once), power ramping counter may not change, which means swept beams using the same transmission power and a fair comparison of beam quality at the TRP/gNB side can be maintained (e.g., Fig. 15). Within a round of beam sweeping, if a beam or multiple beams have SRS resources being transmitted more than once (e.g., TRP/gNB may schedule same SRS resource transmission for a repeated beam sweeping on a specific beam or a specific group of beams), power ramping counter may be increased (e.g., L1-RSRP of all measured beams are lower than a threshold, which means TRP/gNB cannot find a best UE TX beam). Within one round of beam sweeping, a beam sweeping counter may be used by the WTRU to determine whether repeated beam sweeping happens or not within a (e.g., same) round of beam sweeping. For example, the initial value of the beam sweeping counter may be set to any arbitrary value not equal to any possible beam index value (e.g., -1). If the next swept beam has an index value (e.g., may started from 0 or 1) higher than the value of the current beam sweeping counter, the value of the current beam sweeping counter may be updated as the index value of the next swept beam; otherwise, if the next swept beam has an index value which is already swept within this round of beam sweeping (e.g., lower than or equal to the value of the current beam sweeping counter), the value of the current beam sweeping counter may be updated as the index value of the next swept beam, and the power ramping counter may be increased so that higher transmission power may be used for future SRS resource transmissions.

[0256] X-specific power control based SRS transmission may be used. Compared with LTE, NR may be more complicated, (e.g., multi-numerology (e.g., different sub-carrier spacing), multi-beam (multi-panel), two waveforms (e.g., different sets of maximum power reduction (MPR) values may be specified for CP-OFDM and DTF-S-OFDM based transmissions), multi-service/traffic (e.g., eMBB, URLLC), multi-access schemes (e.g., OFDM, NOMA), all of which may affect the UL power control design and may be named as x-specific power control). A network may configure one or multiple open-loop power control parameter

set(s) for a WTRU. Independent value(s), (e.g., for $P_{\text{target_bs}}$, path-loss offset/adjustment values, reference

signal(s) used for path-loss estimation/calculation), can be configured in each set (e.g., if multiple sets are configured). A (e.g., each) set may be associated with one or any combination of properties such as traffic service type (traffic specific power control), beam (multi-beam/BPL specific power control), waveform (waveforms specific power control), energy efficiency, etc. Multiple sets may be common to all or a group of WTRUs within a specific TRP/gNB or independently configured (WTRU specific). For WTRU SRS transmissions for UL beam sweeping, multiple open-loop power control parameter set(s) may be also configured to the WTRU. The possible property combinations in each set may be tuned according to the actual requirements for SRS beam sweeping purpose. For example, the beam-specific consideration may not be used (all beams within one round of beam sweeping use the same power), but service type consideration may be still be used (e.g., based on performance requirements such as SINR and decoding reliability).

[0257] In an (e.g., a third) example, $P_{SRS_{bs}}$ may be predefined, for example, based on a WTRU category or WTRU capability.

[0258] In an example (e.g., the first, second or third examples), the same power setting may be kept for (e.g., all) SRS transmissions for a (e.g., each) round of beam sweeping (e.g., Fig. 15). The same SRS power setting may be used for (e.g., all) beam sweeping (e.g., for full beam sweeping). In an example of local sweeping, the same SRS power setting may be used for all beam sweeping within a local beam sweeping group. Beam-specific power control for UL SRS transmission may be used, for example, when SRS transmissions for beam sweeping may be finished.

[0259] Systems, methods and instrumentalities have been disclosed for efficient UL beam management. UL beam management may be assisted, for example, by DL beam management. In an example, a WTRU may determine a UL Tx beam based on a DL Rx beam for full beam correspondence (BC), a WTRU may engage in beam adjustment with data transmission for partial BC and a WTRU may, e.g., otherwise, transmit an SRS for UL beam sweeping. BC may be determined, for example, by a WTRU or a TRP. Flexible UL beam management may be provided, for example, by flexible SRS configuration of WTRUs depending on configured beam management procedures. Intra-symbol UL beam sweeping may be provided with frequency and time separations. SRS power setting may be provided for UL beam management.

[0260] Features, elements and actions (e.g., processes and instrumentalities) are described by way of non-limiting examples. While examples may be directed to LTE, LTE-A, New Radio (NR) or 5G protocols, subject matter herein is applicable to other wireless communications, systems, services and protocols. Each feature, element, action or other aspect of the described subject matter, whether presented in figures or description, may be implemented alone or in any combination, including with other subject matter, whether known or unknown, in any order, regardless of examples presented herein.

[0261] A WTRU may refer to an identity of the physical device, or to the user's identity such as subscription related identities, e.g., MSISDN, SIP URI, etc. WTRU may refer to application-based identities, e.g., user names that may be used per application.

[0262] Figure 15 shows an example of a WTRU SRS configuration and transmission power determination for UL beam management. The same SRS transmission power may be applied on SRS resources within a SRS resource set for UL BM. SRS transmission power may be determined by using one or more of Methods A, B, and C as described for example in paragraphs [0223], [0234] and [0245] in Figure 15. As shown in Fig. 15, a wireless transmit/receive unit (WTRU) can include a processor configured to send, from the WTRU, to a wireless communication system, a requested sounding reference signal (SRS) configuration for a WTRU transmitter beam; receive, at the WTRU from the wireless communication system, an SRS configuration comprising a first SRS resource set; receive, at the WTRU from the wireless communication system, a first SRS trigger comprising a WTRU transmitter power determination indication; determine, at the WTRU, an SRS transmission power from the WTRU transmitter power determination indication; conduct a first beam sweep, at the WTRU, with the determined SRS transmission power for the first SRS resource set; determine whether the WTRU received, from the wireless communication system, a selected WTRU transmitter beam (e.g., SRS resource indicator or SRI) for uplink transmissions based on the first beam sweep; and determine whether the WTRU received a second SRS trigger from the wireless communication system. The WTRU processor may further conduct a second beam sweep, at the WTRU, with the determined SRS transmission power for a second SRS resource set (e.g. the same SRS resource set used for the first beam sweep) if the WTRU determined that the WTRU did not receive the selected WTRU transmitter beam and the second SRS trigger, or conduct the second beam sweep for the second reference SRS resource set (e.g., the same or different SRS resource set from the first beam sweep based on the received second SRS trigger) if the WTRU determined that the WTRU did receive the second SRS trigger. The WTRU may determine to select a received WTRU transmitter beam for uplink communications if the WTRU does not receive a second SRS trigger but receives a selected WTRU transmitter beam. The WTRU processor may be configured to receive, at the WTRU from the wireless communication system, the selected WTRU transmitter beam for uplink transmissions based on the second beam sweep.

[0263] Each of the computing systems described herein may have one or more computer processors having memory that are configured with executable instructions or hardware for accomplishing the functions described herein including determining the parameters described herein and sending and receiving messages between entities (e.g., WTRU and network) to accomplish the described functions. The processes described above may be implemented in a computer program, software, and/or firmware incorporated in a computer-readable medium for execution by a computer and/or processor.

[0264] The processes described above may be implemented in a computer program, software, and/or firmware incorporated in a computer-readable medium for execution by a computer and/or processor. Examples of computer-readable media include, but are not limited to, electronic signals (transmitted over wired and/or wireless connections) and/or 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, but not limited to, internal hard disks and removable disks, magneto-optical media, and/or optical media such as CD-ROM disks, and/or digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, terminal, base station, RNC, and/or any host computer.

CLAIMS

What is Claimed:

1. A method of uplink (UL) beam management for a wireless transmit/receive unit (WTRU), comprising:
 - sending, from the WTRU, to a wireless communication system, a requested sounding reference signal (SRS) configuration for a WTRU transmitter beam;
 - receiving, at the WTRU from the wireless communication system, an SRS configuration comprising a first SRS resource set;
 - receiving, at the WTRU from the wireless communication system, a first SRS trigger comprising a WTRU transmitter power determination indication;
 - determining, at the WTRU, an SRS transmission power from the WTRU transmitter power determination indication;
 - conducting a first beam sweep, at the WTRU, with the determined SRS transmission power for the first SRS resource set;
 - determining whether the WTRU received, from the wireless communication system, a selected WTRU transmitter beam for uplink transmissions based on the first beam sweep;
 - determining whether the WTRU received a second SRS trigger from the wireless communication system;
 - conducting a second beam sweep, at the WTRU, with the determined SRS transmission power for a second SRS resource set if the WTRU determined that the WTRU did not receive the selected WTRU transmitter beam and the second SRS trigger, or conducting the second beam sweep for the second reference SRS resource set if the WTRU determined that the WTRU did receive the second SRS trigger;
 - and
 - receiving, at the WTRU from the wireless communication system, the selected WTRU transmitter beam for uplink transmissions based on the second beam sweep.
2. The method of claim 1, wherein the requested SRS configuration comprises an indication that no SRS resources are requested or a number of SRS resources are requested.
3. The method of claim 2, wherein the requested number of SRS resources indicates beam correspondence status and/or one of a full beam sweep and a partial beam sweep.
4. The method of claim 1, wherein the SRS configuration comprises one of an intra-slot frequency hopping pattern, an inter-slot frequency hopping pattern, or a combined intra-slot and inter-slot frequency hopping pattern.

5. The method of claim 4, wherein the intra-slot frequency hopping pattern comprises a SRS transmission pattern over a configurable number of adjacent symbols within a last fixed number of symbols in a time slot; and the SRS transmission pattern within a time slot comprises a same number of resource blocks in a same or a different frequency range across the adjacent symbols.
6. The method of claim 1, wherein the WTRU transmitter power determination indication indicates to the WTRU to use one or more of a value configured in RRC or DCI, a power determined from at least one path loss value, and/or an increase in power from a previously used SRS transmission power for determining the SRS transmission power.
7. The method of claim 6, further comprising receiving one or multiple configured DL reference signals, at the WTRU from the wireless communication system, determining a path loss power adjustment based on one configurable DL reference signal from the received DL reference signals, and applying the path loss power adjustment in determining the SRS transmission power.
8. A wireless transmit/receive unit (WTRU), comprising:
- a processor configured to:
 - send, from the WTRU, to a wireless communication system, a requested sounding reference signal (SRS) configuration for a WTRU transmitter beam;
 - receive, at the WTRU from the wireless communication system, an SRS configuration comprising a first SRS resource set;
 - receive, at the WTRU from the wireless communication system, a first SRS trigger comprising a WTRU transmitter power determination indication;
 - determine, at the WTRU, an SRS transmission power from the WTRU transmitter power determination indication;
 - conduct a first beam sweep, at the WTRU, with the determined SRS transmission power for the first SRS resource set;
 - determine whether the WTRU received, from the wireless communication system, a selected WTRU transmitter beam for uplink transmissions based on the first beam sweep;
 - determine whether the WTRU received a second SRS trigger from the wireless communication system;
 - conduct a second beam sweep, at the WTRU, with the determined SRS transmission power for a second SRS resource set if the WTRU determined that the WTRU did not receive the selected WTRU transmitter beam and the second SRS trigger, or conduct the second beam sweep for the second reference SRS resource set if the WTRU determined that the WTRU did receive the second SRS trigger; and
 - receive, at the WTRU from the wireless communication system, the selected WTRU transmitter beam for uplink transmissions based on the second beam sweep.

9. The WTRU of claim 8, wherein the requested SRS configuration comprises an indication that no SRS resources are requested or a number of SRS resources are requested.
10. The WTRU of claim 9, wherein the requested number of SRS resources indicates beam correspondence status and/or one of a full beam sweep and a partial beam sweep.
11. The WTRU of claim 8, wherein the SRS configuration comprises one of an intra-slot frequency hopping pattern, an inter-slot frequency hopping pattern, or a combined intra-slot and inter-slot frequency hopping pattern.
12. The WTRU of claim 11, wherein the intra-slot frequency hopping pattern comprises a SRS transmission pattern over a configurable number of adjacent symbols within a last fixed number of symbols in a time slot; and the SRS transmission pattern within a time slot comprises a same number of resource blocks in a same or a different frequency range across the adjacent symbols.
13. The WTRU of claim 11, wherein the WTRU transmitter power determination indication indicates to the WTRU to use one or more of a value configured in RRC or DCI, a power determined from at least one path loss value, and/or an increase in power from a previously used SRS transmission power for determining the SRS transmission power.
14. The WTRU of claim 13, wherein the processor is further configured to receive one or multiple configured DL reference signals, at the WTRU from the wireless communication system, determine a path loss power adjustment based on one configurable DL reference signal from the received DL reference signals, and apply the path loss power adjustment in determining the SRS transmission power.
15. The WTRU of claim 8, wherein the processor configured to conduct the first and second beam sweep further comprises the processor configured to conduct a partial beam sweep within an OFDM symbol with time and frequency separations.

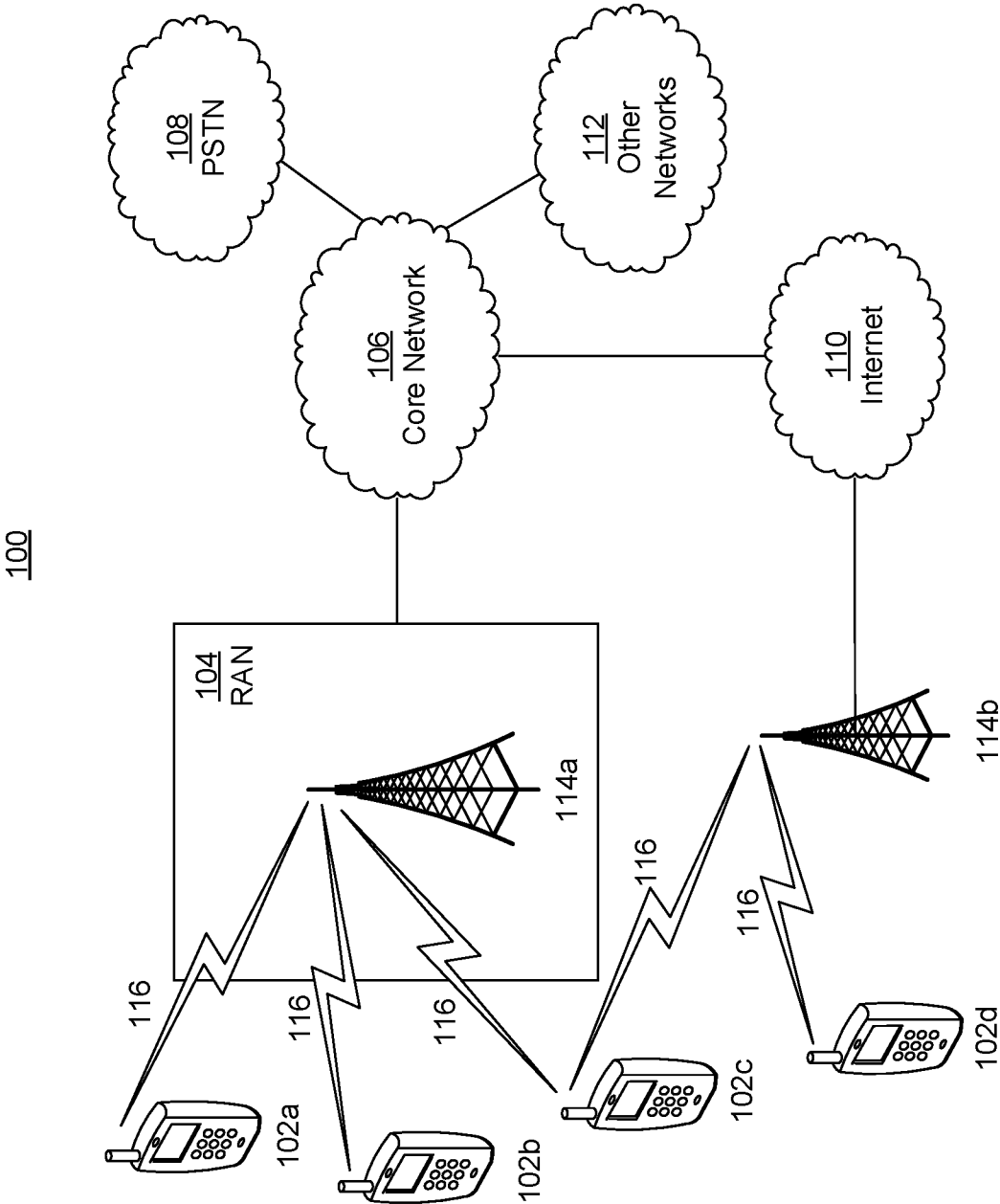
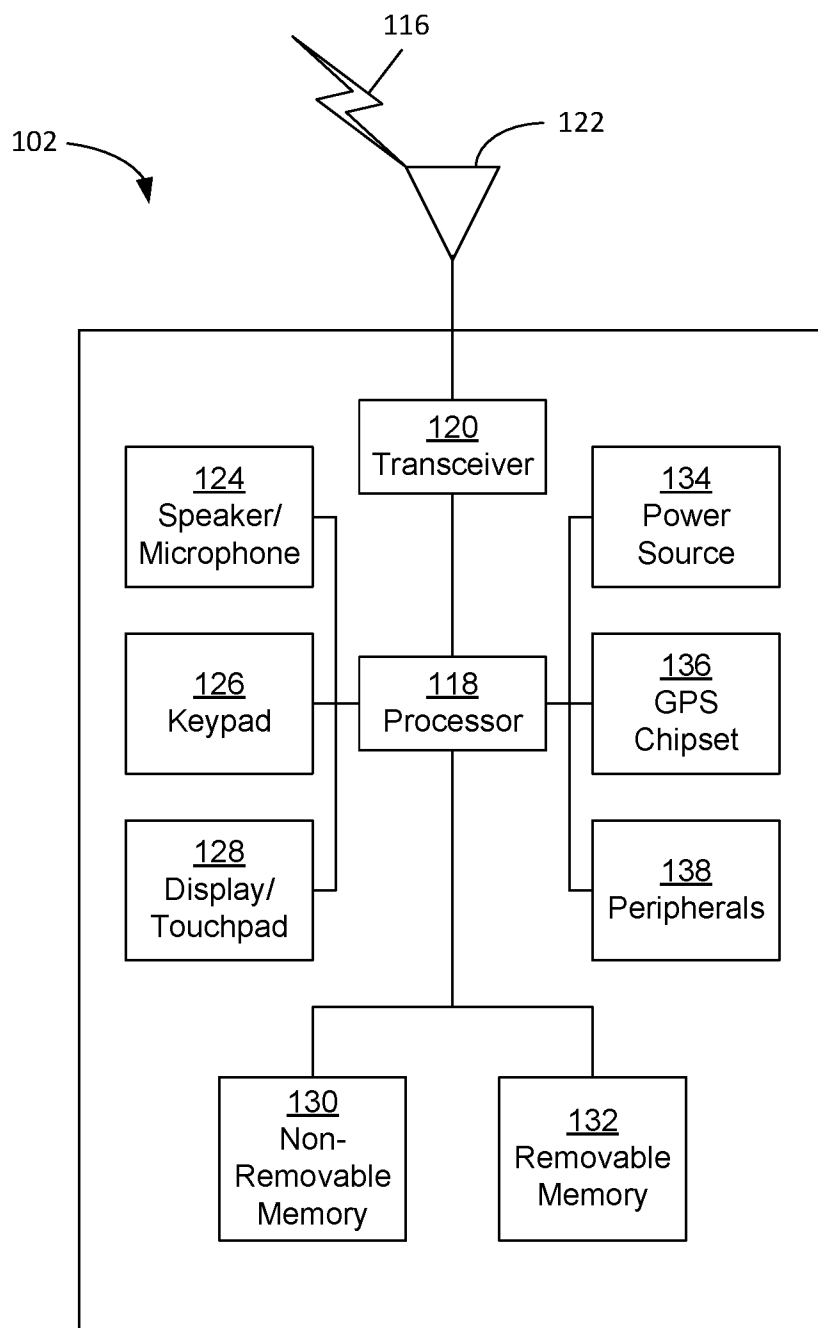


FIG. 1A

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**FIG. 1B**

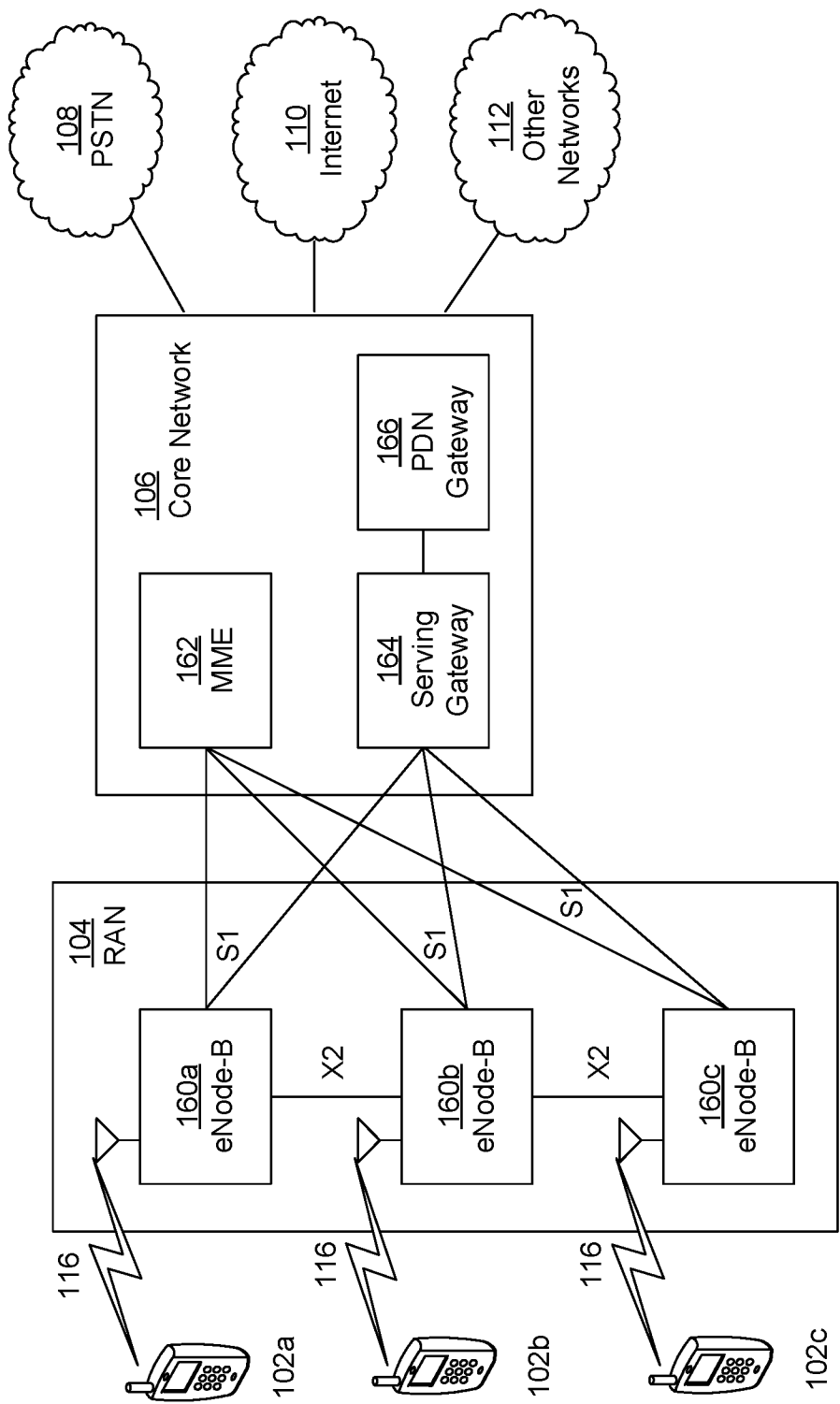


FIG. 1C

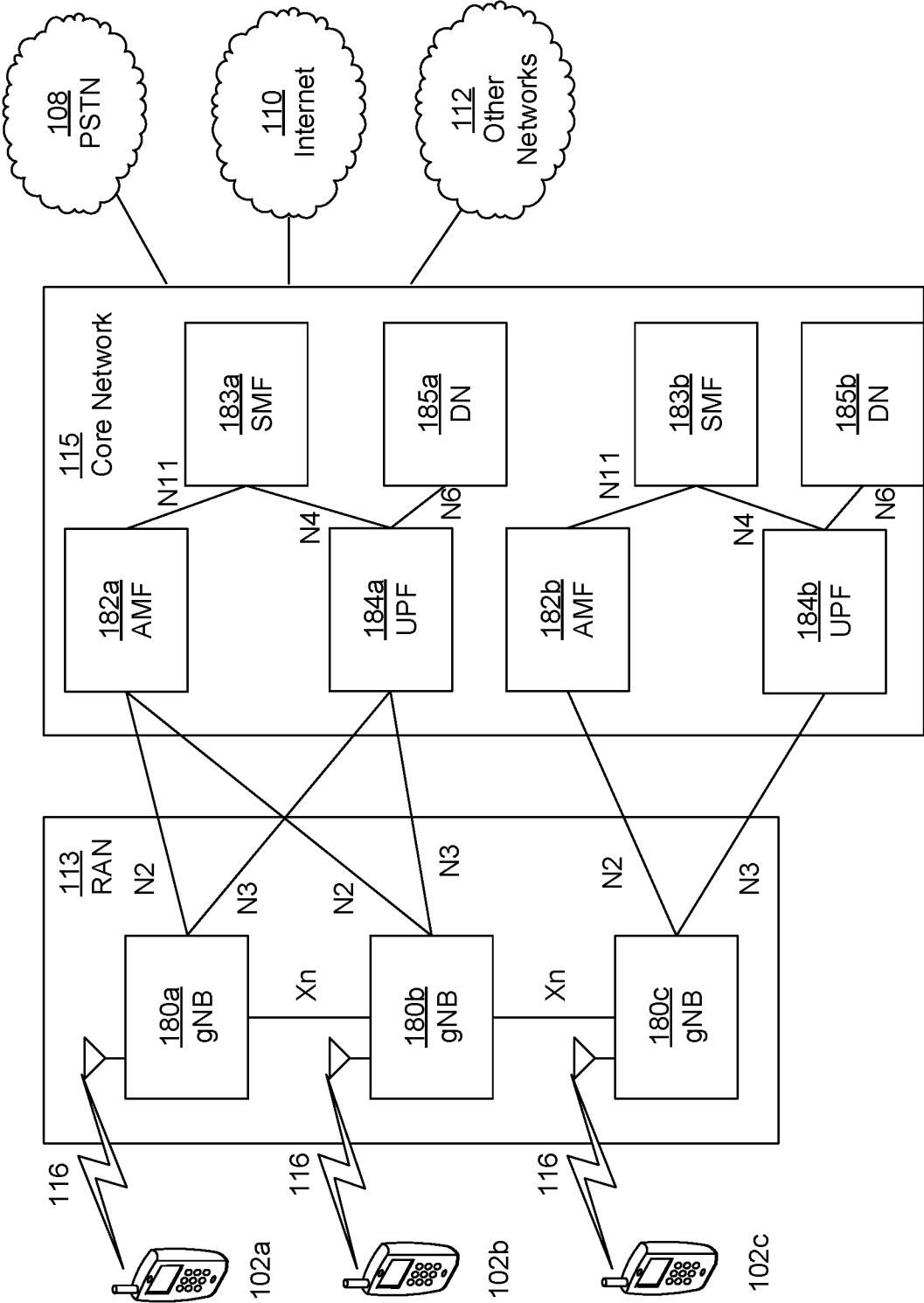


FIG. 1D

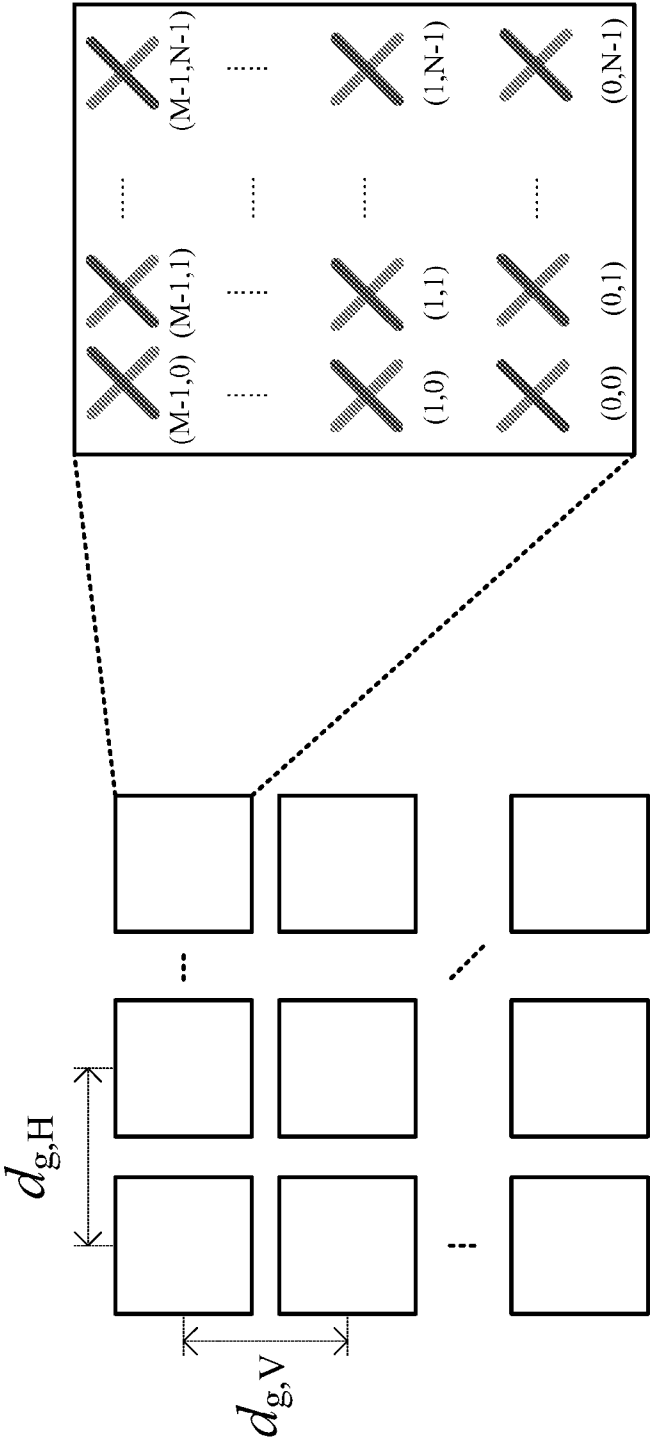
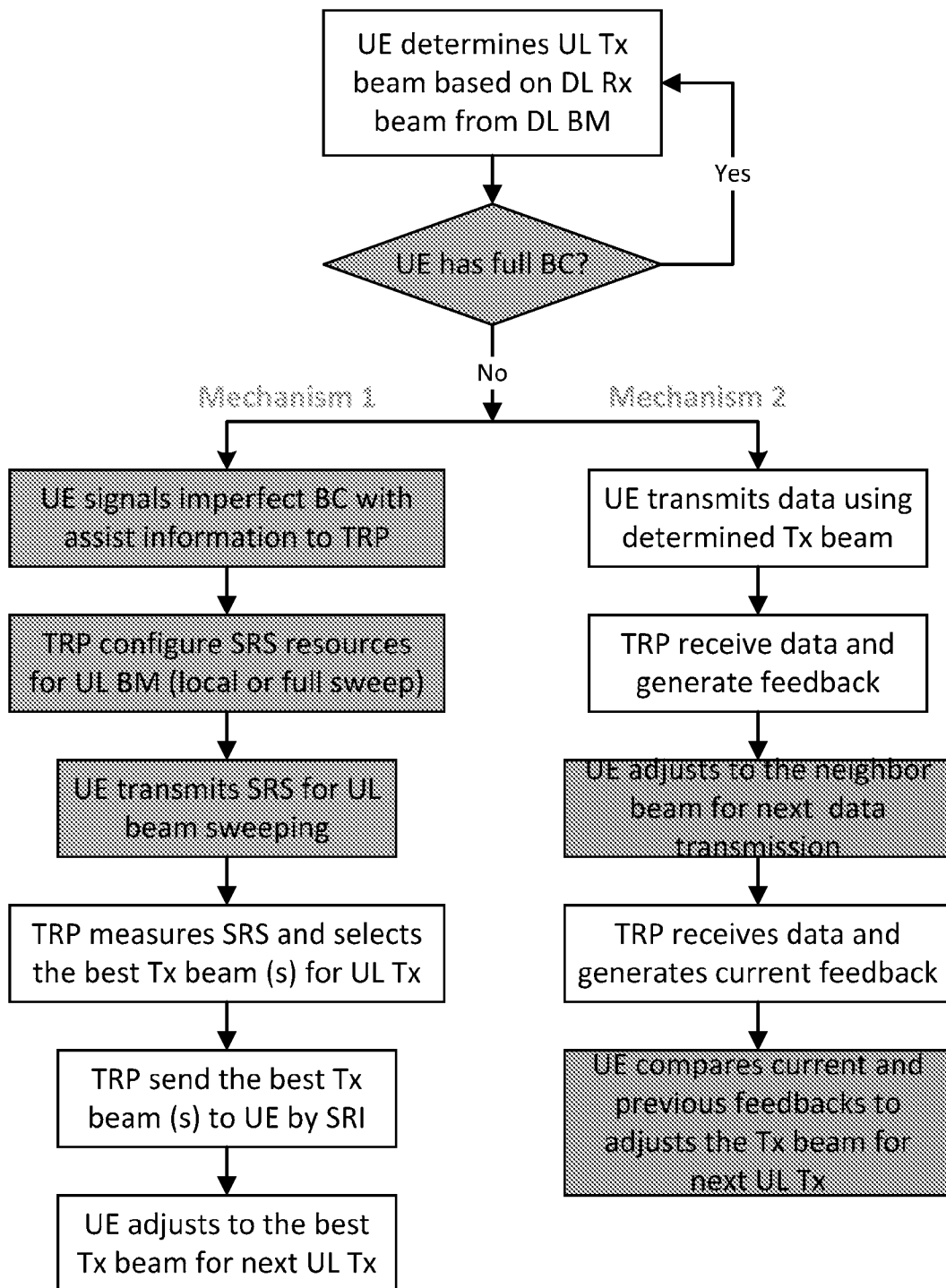


FIG. 2

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**FIG. 3**

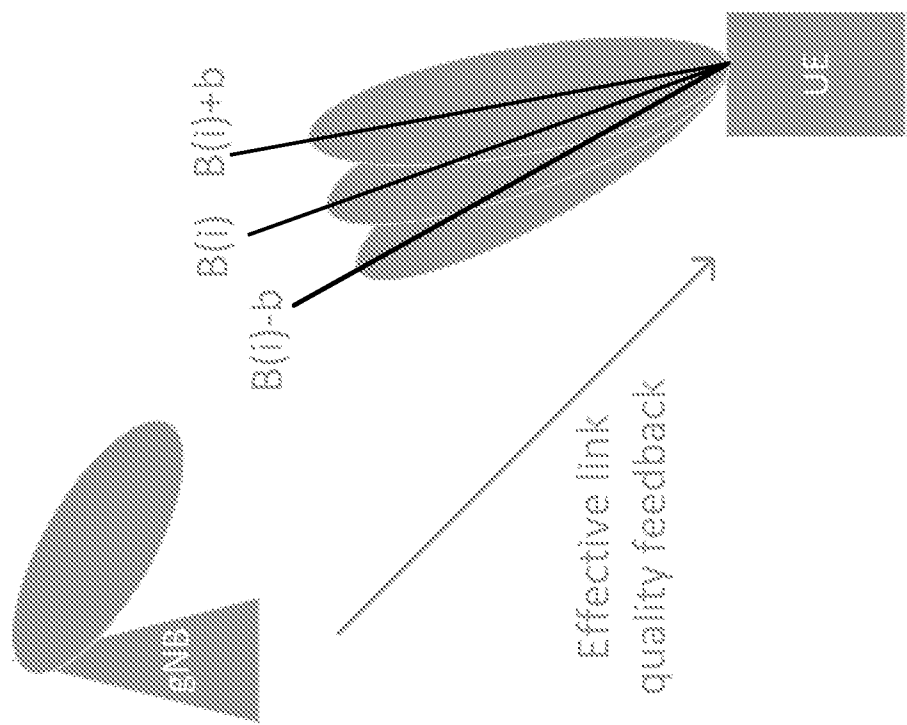


FIG. 4

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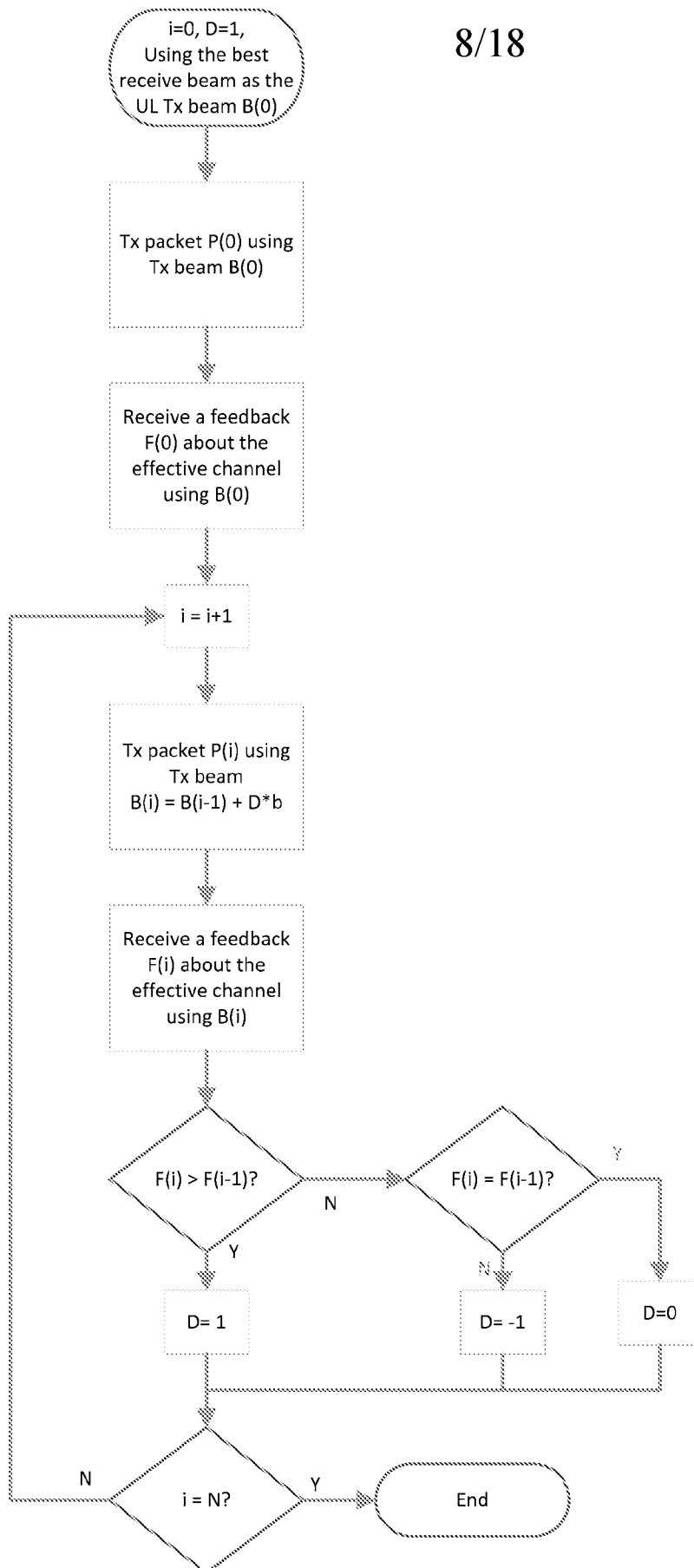


FIG. 5

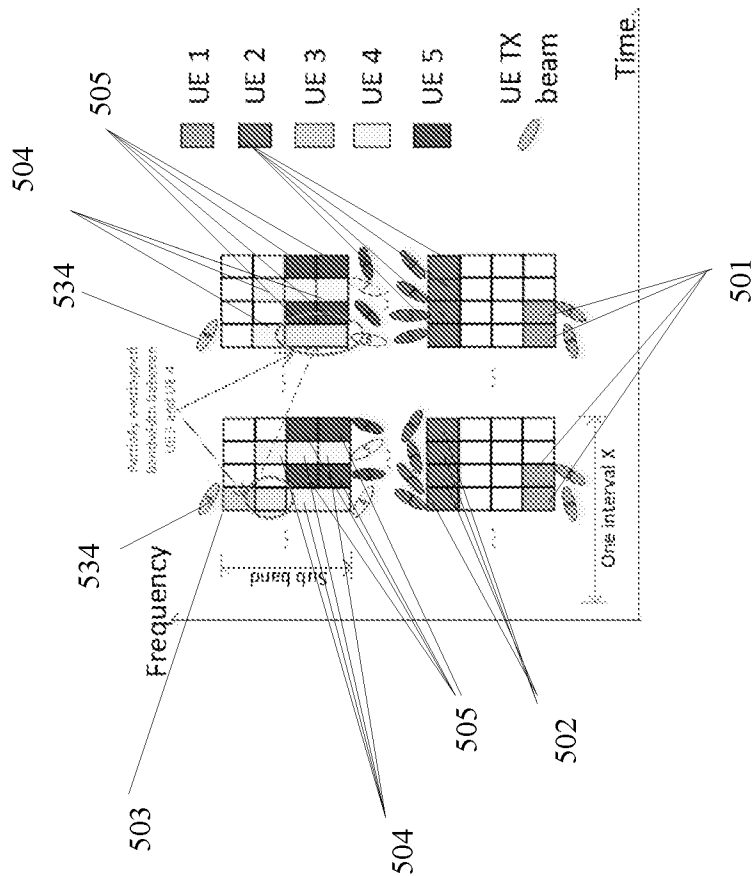


FIG. 6

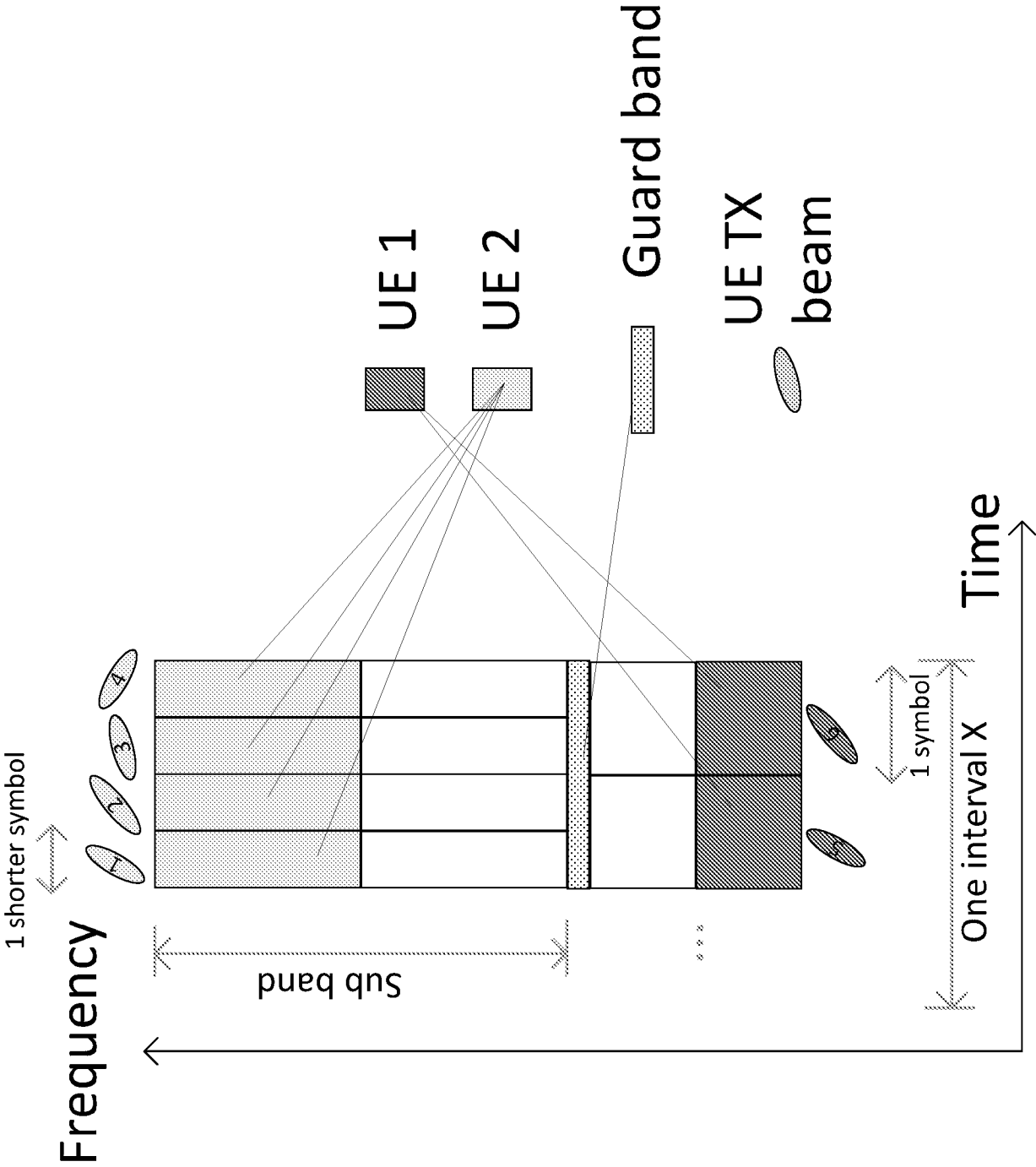


FIG. 7

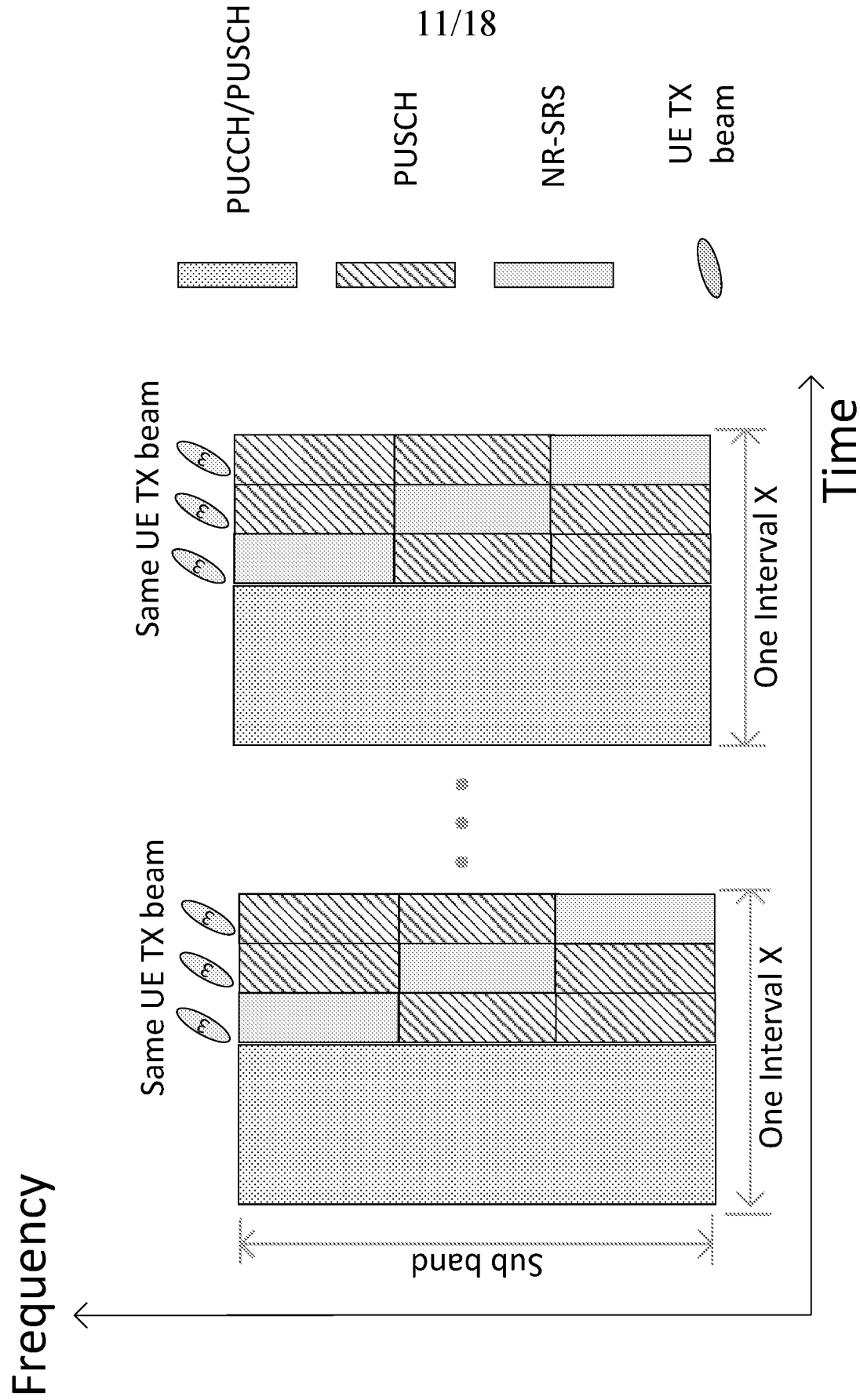


FIG. 8

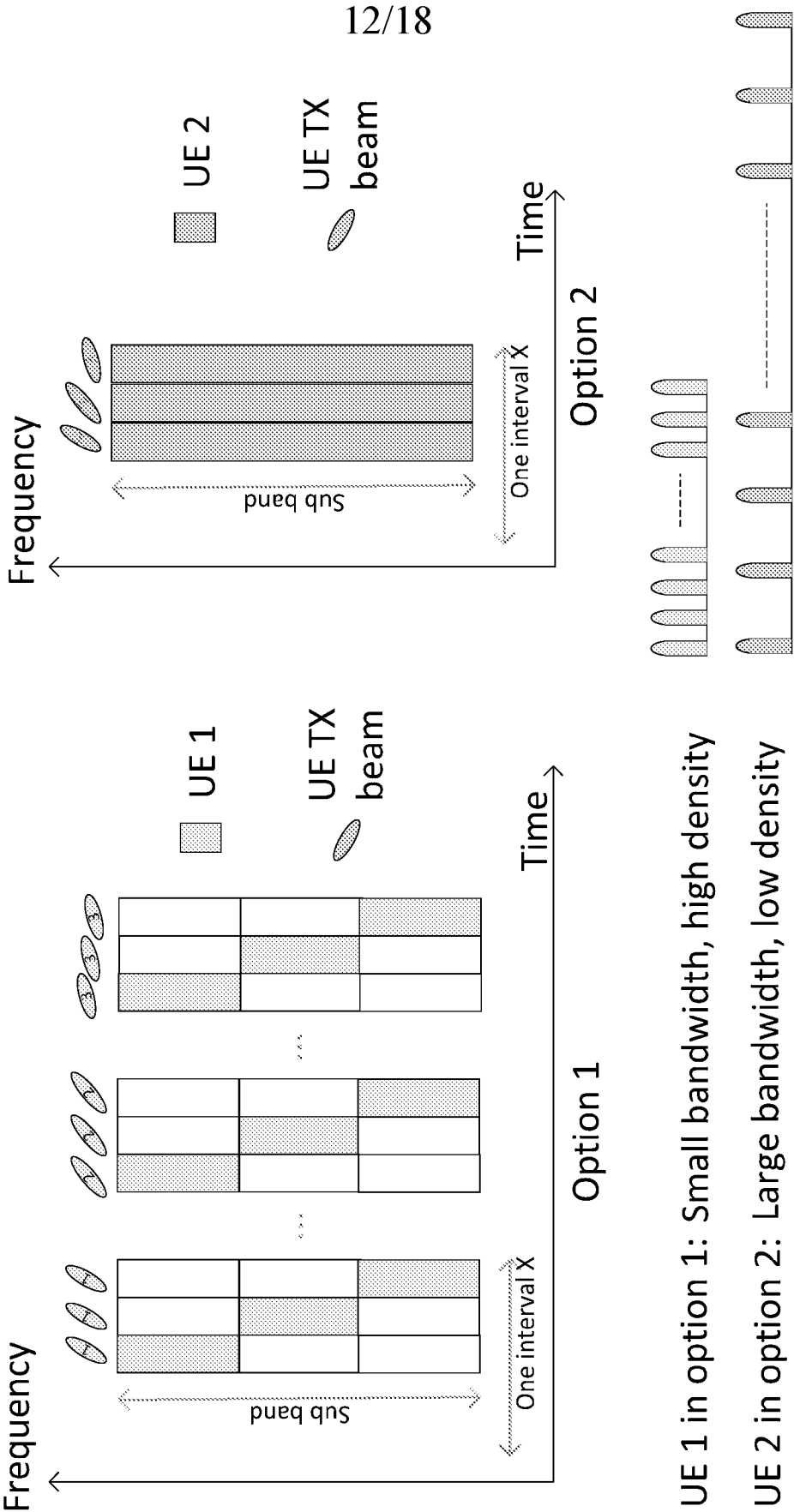


FIG. 9

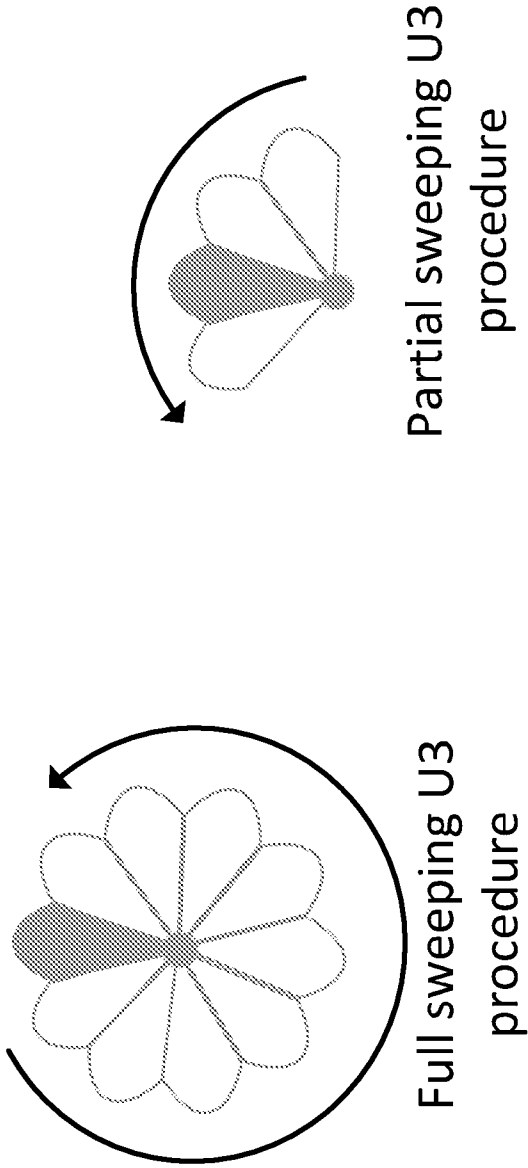


FIG. 10

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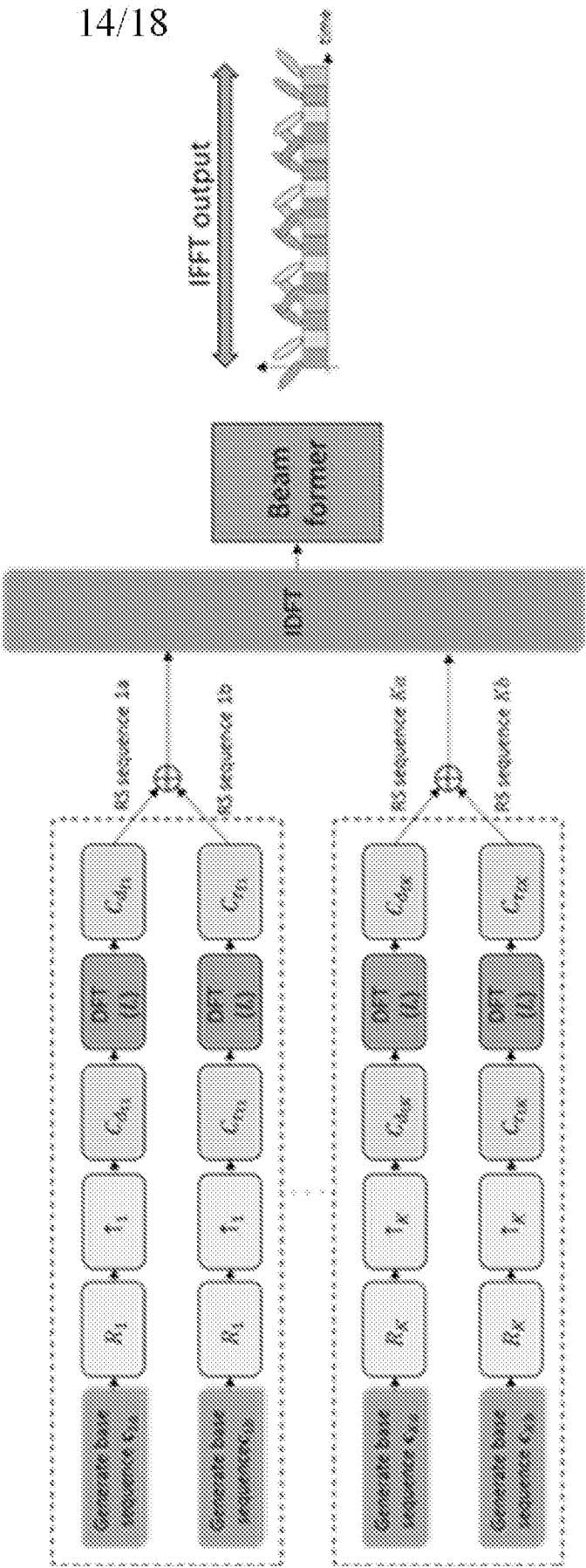


FIG. 11

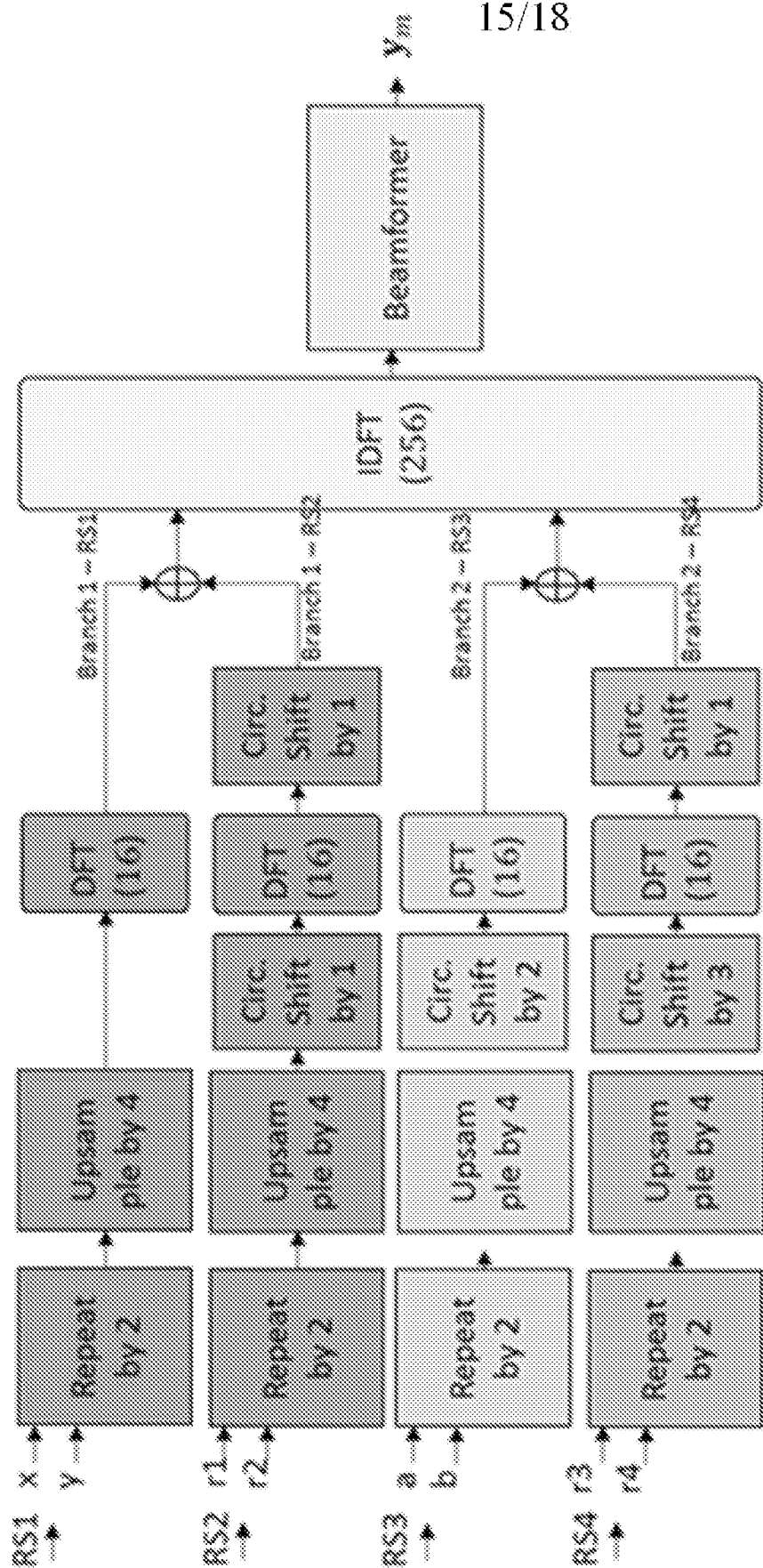


FIG. 12

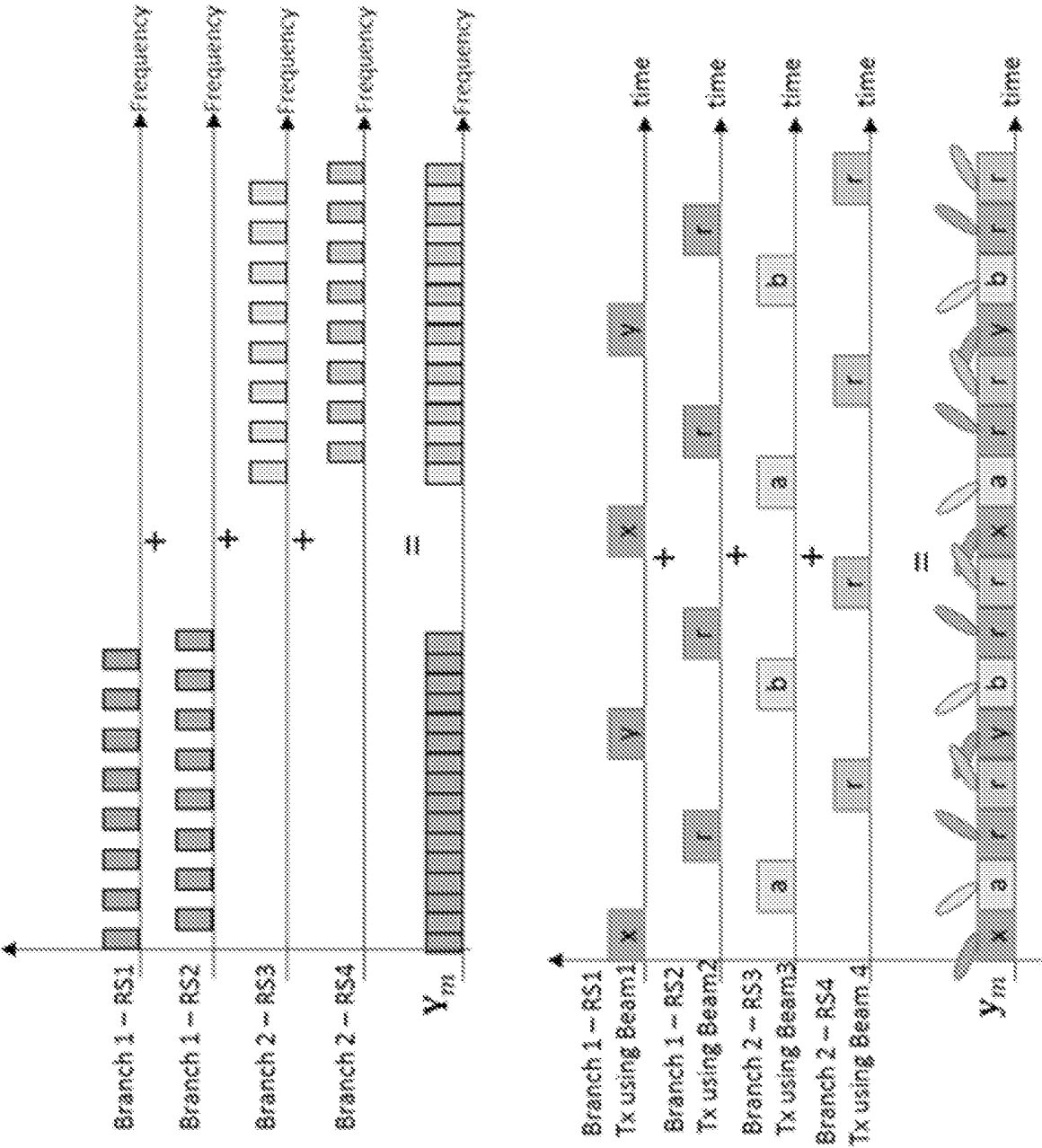


FIG. 13

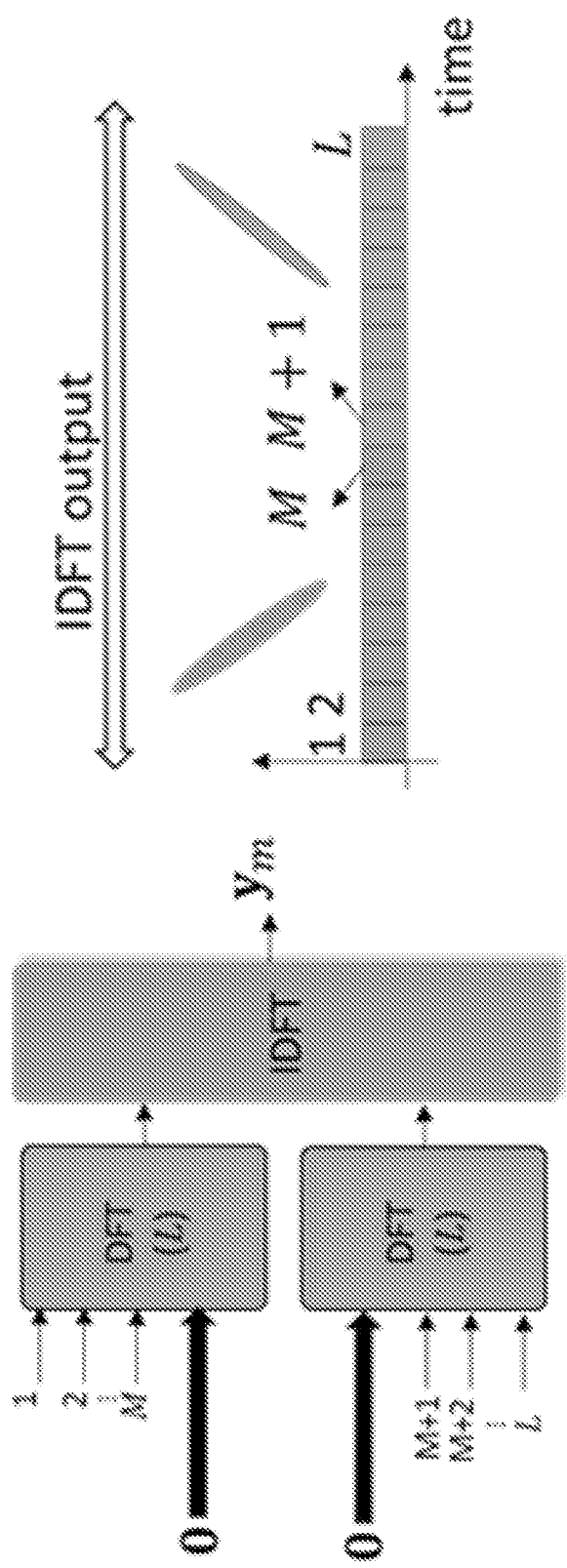


FIG. 14

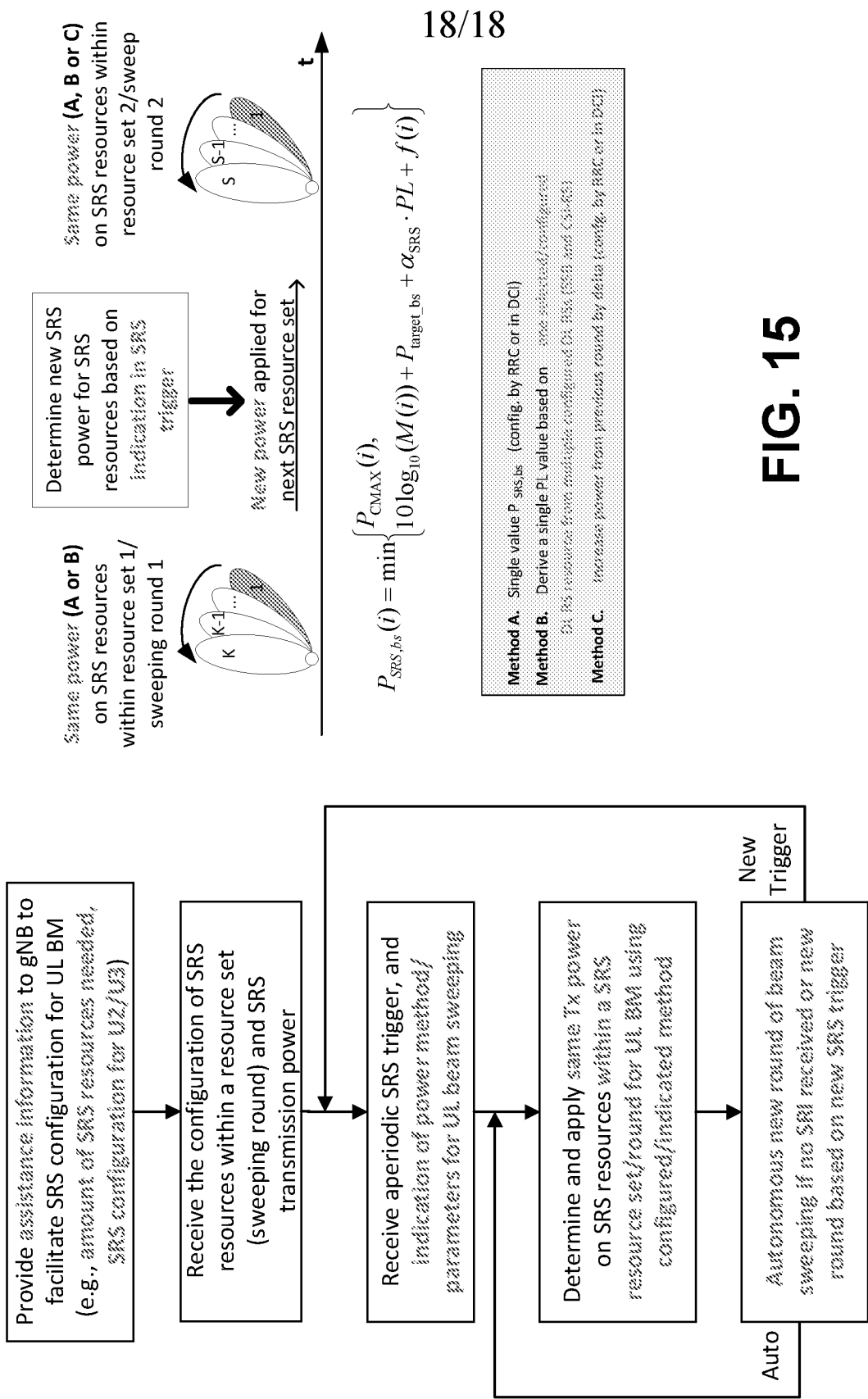


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/030414

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06 H04W52/14 H04W72/04
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)
H04B H04W

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.
Y	SAMSUNG: "Discussion on UL beam management", 3GPP DRAFT; R1-1705341, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Spokane, USA; 20170403 - 20170407 2 April 2017 (2017-04-02), XP051243471, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2017-04-02] Title, Section 2.2, Section 3 ----- -/--	1-15

☒ 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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

11 July 2018

Date of mailing of the international search report

18/07/2018

Name and mailing address of the ISA/

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Authorized officer

Franz, Stefan

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/030414

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/092699 A1 (CHEN WANSHI [US] ET AL) 2 April 2015 (2015-04-02) paragraphs [0053], [0059], [0061]; claim 9	1-15
A	----- ZTE ET AL: "UL beam management", 3GPP DRAFT; R1-1704399 UL BEAM MANAGEMENT FOR NR MIMO, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Spokane, USA; 20170403 - 20170407 2 April 2017 (2017-04-02), XP051242547, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_ SYNC/RAN1/Docs/ [retrieved on 2017-04-02] Section 2.2 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/030414

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015092699 A1	02-04-2015	BR 112016007325 A2	01-08-2017
		CN 105637945 A	01-06-2016
		EP 3053388 A1	10-08-2016
		JP 6139027 B2	31-05-2017
		JP 2016536847 A	24-11-2016
		KR 20160067905 A	14-06-2016
		KR 20170094465 A	17-08-2017
		US 2015092699 A1	02-04-2015
		WO 2015051015 A1	09-04-2015
