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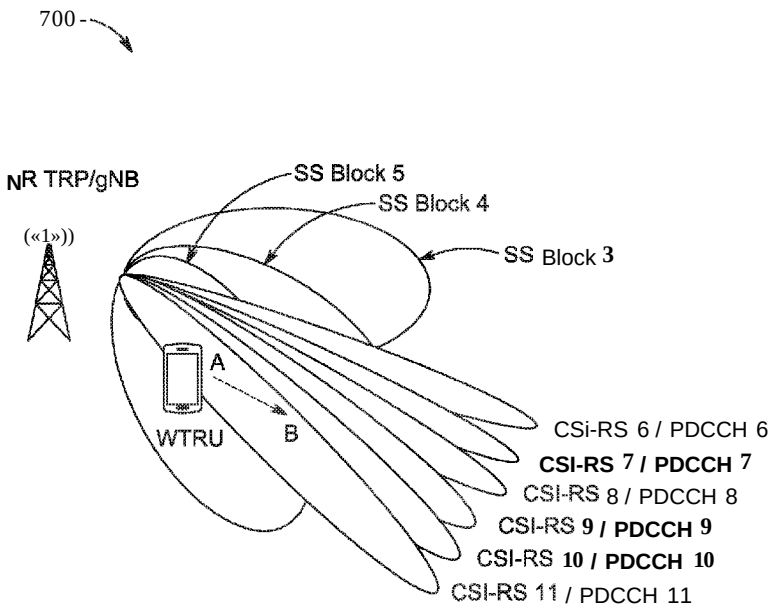


FIG. 7

(57) Abstract: A wireless/transmit receive unit (WTRU) may receive configuration information that includes a reporting setting for beam measurement of multiple reference signals (RSs) and a transmission power offset between RSs. The WTRU may send a unified beam report when measured Ll-RSRP of the RSs is above a threshold value and based on the transmission power offset.

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UNIFIED BEAM MANAGEMENT IN A WIRELESS NETWORK

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/615,725 filed January 10, 2018, U.S. Provisional Application Serial No. 62/586,596 filed November 15, 2017, U.S. Provisional Application Serial No. 62/565,341 filed September 29, 2017, U.S. Provisional Application Serial No. 62/555,755 filed September 8, 2017, U.S. Provisional Application Serial No. 62/543,136 filed August 9, 2017, and U.S. Provisional Application Serial No. 62/519,521 filed June 14, 2017, the contents of which are hereby incorporated by reference herein.

BACKGROUND

[0002] Next generation mobile communications include New Radio (NR), enhanced mobile broadband (eMBB), massive Machine Type Communications (mMTC), Ultra-Reliable Low Latency Communications (URLLC), or the like. Licensed and unlicensed spectrum bands are being considered for next generation mobile. NR communications may utilize channel state information-reference signal (CSI-RS) for beam management (BM). NR may also utilize other RSs such as a synchronization signal (SS) block (SSB or SS block), a demodulation RS (DMRS) associated with data and control channels, or the like for communication management and control.

[0003] A SS block and/or DMRS associated with data and control channels may be utilized for layer 1 (L1)/layer 2 (L2) BM since with periodic CSI-RS, a wireless transmit/receive unit (WTRU) may be unable to detect rapid or sudden beam changes due to WTRU motion, rotation, or the like. Configuring unified BM for beam discovery, beam tracking and refinement, beam recovery, or the like to utilize multiple RSs is desirable.

SUMMARY

[0004] A method and apparatus for performing unified beam management (BM) is provided. Unified BM may be performed using multiple reference signals (RSs). A unified BM framework may comprise a unified configuration, beam measurement, and reporting and beam indication. Unified BM for multiple transmission/reception points (TRPs), measurement and reporting, and beam reporting prioritizations may also be performed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings, wherein like reference numerals in the figures indicate like elements, and wherein:

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

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

[0008] FIG. 1C is a 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 according to an embodiment;

[0009] FIG. 1D is a system diagram illustrating a further example RAN and a further example CN that may be used within the communications system illustrated in FIG. 1A according to an embodiment;

[0010] FIG. 2 is an example of a transmission/reception point (TRP) and WTRU antenna model;

[001 1] FIG. 3 is an example of a synchronization signal (SS) burst and multiple SS blocks;

[001 2] FIG. 4 is an example of a measurement model for unified beam management (BM);

[001 3] FIG. 5 is an example of utilizing multiple reference signals (RSs) for unified BM;

[001 4] FIG. 6 is an example signal flow for unified BM;

[0015] FIG. 7 is an example of a WTRU that moves in an overlapped coverage of two narrow beams;

[001 6] FIG. 8 is an example of a beam level ping-pong effect for the signal flow;

[001 7] FIG. 9 is an example of RSs to reduce a beam level ping-pong effect;

[001 8] FIG. 10 is an example of TRP ping-pong effect due to use of multiple types of RSs for BM;

[001 9] FIG. 11 is an example of a configuration of a measurement and reporting setting for unified BM with joint and independent beam reporting of a channel state information-RS (CSI-RS) and a SS block;

[0020] FIG. 12 is an example of another configuration of a measurement and reporting setting for unified BM with joint and independent beam reporting of a CSI-RS and a SS block;

[0021] FIG. 13 is an example of a measurement model where layer 3 RS received power (L3-RSRP) beam filtering may be utilized for BM;

[0022] FIG. 14 is an example of a measurement model with layer 1 (L1) beam filtering;

[0023] FIG. 15 is an example with reported beams geographically close to and centered at a WTRU;

[0024] FIG. 16 is an example of unified beam measurement and reporting;

[0025] FIG. 17 is an example of beam measurement and reporting outside of an active bandwidth parts (BWP);

[0026] FIG. 18 is an example starting symbol index or symbol offset to schedule a new radio physical downlink shared channel (NR-PDSCH) utilizing downlink control information (DCI) decoding delays or beam switching time;

[0027] FIG. 19 is an example of a starting slot index or slot offset to schedule NR-PDSCH for different slot or cross-slot scheduling; and

[0028] FIG. 20 is an example of a timing delay when applying an updated spatial quasi-colocation (QCL) reference in a transmission configuration indicator (TCI) state.

DETAILED DESCRIPTION

[0029] 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 system 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 discrete Fourier transform spread orthogonal frequency division multiplexing (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0030] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104, a core network (CN) 106, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d, 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 Wi-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.

[0031] The communications system 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, 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 next generation node b (gNB), a new radio (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.

[0032] The base station 114a may be part of the RAN 104, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals 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 further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in one embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In 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.

[0033] 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).

[0034] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 116 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink (DL) Packet Access (HSDPA) and/or High-Speed Uplink (UL) Packet Access (HSUPA).

[0035] 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).

[0036] 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).

[0037] 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 communications sent to/from multiple types of base stations (e.g., an eNB and a gNB).

[0038] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as Institute of Electrical and Electronics Engineers (IEEE) 802.1 1 (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.

[0039] 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 802.1 1 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 orfemtocell. 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.

[0040] The RAN 104 may be in communication with the CN 106, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. 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 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104 and/or the CN 106 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104 or a different RAT. For example, in addition to being connected to the RAN 104, which may be utilizing a NR radio technology, the CN 106 may also be in communication with another RAN (not shown) employing a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or WiFi radio technology.

[0041] The CN 106 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 other networks 112 may include wired and/or wireless communication networks owned and/or operated by other service providers. For example, the other networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104 or a different RAT.

[0042] 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.

[0043] 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.

[0044] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Array (FPGA) 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.

[0045] 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.

[0046] 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.

[0047] 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 802.1 1, for example.

[0048] 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).

[0049] 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.

[0050] 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.

[0051] 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, a humidity sensor, or the like.

[0052] 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, simultaneous, or the like. The full duplex radio may include an interference management unit 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)).

[0053] 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.

[0054] 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.

[0055] 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.

[0056] 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.

[0057] 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.

[0058] 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.

[0059] 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.

[0060] 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.

[0061] 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.

[0062] In representative embodiments, the other network 112 may be a WLAN.

[0063] 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 also be referred to as an "ad-hoc" mode of communication.

[0064] 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 set 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.

[0065] 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.

[0066] Very High Throughput (VHT) STAs may support 20 MHz, 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, or 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).

[0067] Sub 1 gigahertz (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 802.11 η, and 802.1 1ac. 802. 11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV White Space (TVWS) spectrum, and 802.1 1ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.1 1ah may support Meter Type Control/Machine-Type Communication (MTC), 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).

[0068] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11 η, 802.1 1ac, 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 802.1 1ah, 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, due to a STA, such as a 1 MHz operating mode STA, transmitting to the AP, whole frequency bands may be considered busy even though a majority of frequency bands remain idle and may be available.

[0069] In the United States, the available frequency bands, which may be used by 802.1 1ah, 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 802.1 1ah is 6 MHz to 26 MHz depending on the country code.

[0070] FIG. 1D 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 NR 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.

[0071] The RAN 104 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 104 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. Also, in an example, gNBs 180a, 180b, 180c may utilize beamforming to transmit signals to and/or receive signals from the WTRUs 102a, 102b, 102c. 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 CCs (not shown) to the WTRU 102a. A subset of these CCs may be on unlicensed spectrum while the remaining CCs 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 communications from gNB 180a and gNB 180b (and/or gNB 180c).

[0072] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using communications associated with a scalable numerology. For example, the OFDM symbol spacing and/or OFDM subcarrier spacing (SCS) may vary for different communications, different cells, and/or different portions of the wireless communication 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).

[0073] 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.

[0074] 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.

[0075] The CN 106 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 106, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0076] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 104 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 protocol data unit (PDU) sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of non-access stratum (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 communication (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for MTC access, and/or the like. The AMF 182a, 182b may provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-third generation partnership project (3GPP) access technologies such as WiFi.

[0077] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 106 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 106 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 WTRU 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.

[0078] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 104 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 184, 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 DL packets, providing mobility anchoring, and the like.

[0079] The CN 106 may facilitate communications with other networks. 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. In one embodiment, the WTRUs 102a, 102b, 102c may be connected to a local 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.

[0080] In view of FIGs. 1A-1D, and the corresponding description of FIGs. 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-b, 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.

[0081] 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 perform testing using over-the-air wireless communications.

[0082] 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.

[0083] For sub-6 GHz transmission, multiple antenna configurations such as Multiple Input Multiple Output (MIMO), Single Input Multiple Output (SIMO), Multiple Input Single Output (MISO), or the like may increase wireless date rates. Different MIMO configurations may provide diversity gain, multiplexing gain, beamforming, array gain, or the like. When multiple WTRUs communicate to a single central node, MU-MIMO may increase system throughput by transmission of multiple data streams to different WTRUs at the same time and on the same or overlapping set of resources in time or frequency. In single user MIMO (SU-MIMO), the same central node may transmit multiple data streams to the same WTRU rather than multiple WTRUs as in multi-user MIMO (MU-MIMO). Multiple antenna transmission at millimeter wave frequencies may differ from sub-6 GHz multiple antenna configurations. This may be due to different propagation characteristics at millimeter wave frequencies, a BTS or WTRU having a different number of RF chains compared to antenna elements, or the like.

[0084] For multi-antenna, MIMO, or other configurations beam reporting, beam failure detection, or new candidate beam identification is desirable when multiple RSs are utilized for beam management (BM). While dynamic availability and unified usage of multiple RSs (RSs) for BM may provide flexibility and efficient use of resources, it is desirable to effectively discover and determine beam qualities from measurement results based on different RSs to avoid a beam-level ping-pong effect, a TRP or gNB level ping-pong effect, or the like is desirable.

[0085] Unified downlink (DL) BM may utilize different RS configurations for beam measurement and reporting. The beam measurement and reporting may be based on RSs, channel state information-RS (CSI-RS), a synchronization signal (SS) block, a demodulation RS (DMRS), or the like. In any of the examples given herein, a SS block may be sent together with a physical broadcast channel (PBCH) as a SS/PBCH block. In certain configurations, SSB, SS block, SS-block or SS/PBCH block may be used interchangeably. In the examples given herein, reporting may utilize joint beam reporting or independent beam reporting. In addition, a unified beam indication may include a mapping between actual transmission configuration indicator (TCI) states and an N-bit TCI state field. The unified beam indication may include a quasi-colocation (QCL) indication across multiple component carriers (CCs). The unified beam indication may also be used for optimization of using the TCI state, the update of spatial QCL reference in the TCI state, an uplink (UL) beam indication, or the like.

[0086] FIG. 2 is an example 200 of a transmission/reception point (TRP) and WTRU antenna model. A massive antenna model may be configured as Mg antenna panels per vertical

dimension and Ng antenna panels per horizontal dimension. Each antenna panel may be configured with N column and M row of antenna elements with or without polarization. Timing and phase may not be calibrated across panels. Multiple panels may be configured in the same eNB. A baseline massive antenna configuration may be different according to the operating frequency band as given in Table 1.

At 4 GHz	At 30 GHz	At 70 GHz
Dense Urban and Urban Macro: (M, N, P, Mg, Ng) = (8,8,2,1,1), (d_V, d_H) = (0.8, 0.5)λ	Dense Urban and Urban Macro: (M, N, P, Mg, Ng) = (4,8,2,2,2), (d_V, d_H) = (0.5, 0.5)λ, ($d_{g,V}$, $d_{g,H}$) = (2.0, 4.0)λ	Dense Urban: Baseline: (M, N, P, Mg, Ng) = (8,16,2,2,2), (d_V, d_H) = (0.5, 0.5)λ, ($d_{g,V}$, $d_{g,H}$) = (4.0, 8.0) λ
▪ 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

Table 1

[0087] Pre-coding at millimeter wave frequencies may be digital, analog, digital and analog, a hybrid of digital and analog, or the like. Digital pre-coding may be combined with equalization and utilized for SU, MU, and multi-cell pre-coding. Digital pre-coding may be similar to that used in sub 6 GHz, for example in IEEE 802.11η, 802.11x, 3GPP LTE, 4G, 5G, or the like. However, in millimeter wave frequencies, the presence of a limited number of RF chains compared with antenna elements and the sparse nature of the channel may require different digital beamforming configurations.

[0088] Analog beamforming may be configured with analog phase shifters on each antenna element due to the limited number of RF chains. Analog beamforming may be configured in IEEE 802.11ax, 802.11ad, or the like during a sector level sweep to identify the best sector, during beam refinement to refine the sector to an antenna beam, or during beam tracking to adjust the sub-beams over time to take into account any change in channel procedures. In hybrid beamforming, a pre-coder may be divided between analog and digital domains. Each domain may utilize pre-coding and combine matrices with different structural constraints such as a constant modulus constraint for combining matrices in the analog domain. Although limited by the number of RF chains, hybrid beamforming may achieve high digital pre-coding performance due to the sparse nature of channels, multi-user multiplexing, multi-stream multiplexing, or the like.

[0089] As frequencies increase, a channel may have higher path loss and more abrupt changes. In high frequency bands, a large-scale antenna array may be used for high beamforming gain to address high propagation loss. The use of directional beam based communication may need accurate beam pairing. A beam direction may be associated with a channel regarding angle of

arrival and angle of departure in both azimuth and elevation. A beam direction may be dynamically adjusted with channel change.

[0090] Beam management procedures may include, for example, DL and UL beam management procedures. Downlink beam management procedures may be referenced as P-1, P-2, P-3, etc. In certain configurations, P1 and P-1, P2 and P-2, and P3 and P-3 may be used interchangeably. Uplink beam management procedures may referenced as U-1, U-2, U-3, etc. A first downlink beam management procedure *{e.g.,* P-1) may be used for WTRU measurements on different TRP TX beams such as to support selection of TRP TX beam(s) or WTRU RX beam(s). P-1 may include intra or inter-TRP TX beam sweeping from a set of different beams such as for beamforming at a TRP. P-1 may also include a WTRU RX beam sweep operation from a set of different beams such as for beamforming at a WTRU. In certain configurations, a TRP TX beam and WTRU RX beam may be determined jointly or sequentially.

[0091] In an example, a second downlink beam management procedure *{e.g.,* P-2) may be used for WTRU measurement on different TRP TX beams. P-2 may be a case of P-1 to change inter or intra-TRP TX beam(s), such as from a smaller set of beams than P-1 for beam refinement. Moreover, a third downlink beam management procedure *{e.g.,* P-3) may be used for WTRU measurements on the same TRP TX beam to change a WTRU RX beam, for example, when a WTRU uses beamforming.

[0092] In examples given herein, a first uplink beam management procedure *{e.g.,* U-1) may be used to enable a TRP measurement on different WTRU TX beams such as to support selection of WTRU TX beam(s) or TRP RX beam(s). A second uplink beam management procedure *{e.g.,* U-2) may be used to enable a TRP measurement on different TRP RX beams such as to change or select inter or intra-TRP RX beam(s). A third uplink beam management procedure *{e.g.,* U-3) may be used to enable TRP measurement on the same TRP RX beam such as to change a WTRU TX beam.

[0093] In examples given herein, DL L1 or L2 BM procedures for selection of TRP TX or WTRU RX beams may be configured within one or multiple TRPs. Procedures P-1, P-2, or P-3 for beam selection, TX beam refinement, RX beam change, or TRP TX and WTRU RX beam sweep may be configured or utilized. A WTRU-triggered operation to recover from beam failure, beam group based reporting that is WTRU-specific, and a CSI-RS configuration for TX or RX beam sweeping for BM may also be utilized.

[0094] FIG. 3 is an example 300 of a SS burst and multiple SS blocks. An SS block may include primary synchronization signal (PSS), a secondary synchronization signal (SSS), and a

physical broadcast channel (PBCH). In 300, a SS burst may be configured for a x ms cycle and multiple SS blocks 1, 2, ... N in a SS burst.

[0095] A network controlled mechanism for BM for UL transmissions may be configured. For example, in 300 a SS burst may be used when multiple beams are utilized for initial access. One or more SS blocks in a SS burst may be associated with one or more beams and the number of SS blocks in a SS burst may be determined by a gNB based on the number of transmit beams. In an example, if N beams are configured at a gNB, N SS blocks may be used or transmitted in a SS burst. A SS block may be configured with less resources than a WTRU-specific CSI-RS, utilize less signaling overhead, and have low interference. For OFDMA based networks, intra-cell WTRU communications may be orthogonal to each other and inter-cell interference, especially near cell boundaries, may be the primary interference source. In examples given herein, transmission power of CSI-RS or SS blocks may be changed or adapted for inter-cell interference coordination, interference mitigation, flexible cell coverage, or the like.

[0096] FIG. 4 is an example 400 of a measurement model for unified BM. DL unified BM may utilize multiple available RSs such as a WTRU-specific CSI-RS, a SS block, a DMRS when associated PDCCH or PDSCH with one RS or multiple RSs are configured, or the like. These references signals may be utilized for beam measurement and reporting by a WTRU. For a high frequency NR system configured with both SS block and DMRS beamformed transmission, references signals may be utilized to assist CSI-RS based BM procedures, such as P-1, P-2, P-3, for beam discovery, beam tracking, beam refinement, beam recovery, or the like. DMRS may provide early detection and accurate prediction of beam failure.

[0097] In 400, gNB beams 1 to K may be inputted as signals A into layer 1 filtering components 402 and outputted as signals A^1. RRC parameters and signals A^1 may be inputted to beam consolidation/selection component 404. K beams or signals A^1 and RRC parameters may also be inputted to L3 beam filtering components 406 and to outputted at signals E. Signals E may be inputted with RRC parameters to beam selection for reporting component 408 to produce output signals F of X beams. Output signal B and RRC parameters may be processed by layer 3 filtering for cell quality component 410 to produce signal C. Signal C and C^1 may be processed with RRC parameters at evaluation of reporting criteria component 412 to produce signal D.

[0098] FIG. 5 is an example 500 of utilizing multiple RSs for unified BM. During SS burst period 502 RSs SS blocks 1-3 and CSI-RS 1-4 may be transmitted by a TRP or gNB for reception by beams 506. WTRU-specific CSI-RS period (504) may be a period that CSI-RS 1-4 or a PDCCH may be transmitted by a TRP or gNB. RSs may include CSI-RS, SS block, or DMRS such that when transmitted along with PDCCH or PDSCH, they may be available in different time instances.

[0099] A WTRU may perform measurements on SS blocks for quick beam discovery and to establish a coarse beam pair link (BPL) for the BM procedure P-1. In addition, in configurations where a SS block may be configured to be transmitted with wider beams than a CSI-RS, covering a sweeping area with fewer beams than a CSI-RS may be achievable. This configuration may also reduce beam sweeping delays, overhead or resource usage of a CSI-RS, and reduce excessive inter-cell interference of WTRU specific CSI-RS since SS block may be an always-on signal without WTRU specific configurations.

[00100] Based on configured measured quantities, such as RS received power (RSRP), RS received quality (RSRQ), or the like, on different SS blocks, the WTRU may select N (N >= 1) preferred SS blocks based on certain pre-defined or configured rules. For instance, blocks with the best N RSRP to report to the TRP or gNB may be preferred.

[00101] A WTRU in RRC connected mode may communicate measurement results, such as layer 1-RSRP (L1-RSRP), beam resource indicators, CSI resource index (CRI), a synchronization signal block (SSB) index, or the like, aperiodically on the physical uplink shared channel (PUSCH) or short physical uplink control channel (PUCCH). In certain configurations, a CRI may be a CSI-RS resource indicator, CSI-RS resource index, CSI resource index, CSI identifier or indicator (ID), or the like. In certain configurations, a SSBRI may be a SSB resource indicator, SSB index, SS/PBCH resource indicator, SS/PBCH resource index, SS block identifier or indicator or index (ID), SSB ID, or the like. Measurement results may also be piggybacked on data, multiplexed with data, periodically feedback on the PUCCH with different formats, or the like. Different PUCCH formats may include regular format, extended format, long PUCCH, short PUCCH, or the like based on the size or amount of measurement results. The measurement results may be communicated in a semi-persistent report, during a certain time duration when the WTRU is moving quickly, an event triggered report, when at least one serving beam's quality drops below certain thresholds, when at least one measured beam's quality threshold value is higher than the at least one serving beam, or the like. In any of the examples given herein, event triggers may be based on a timer, a RS-specific timer, threshold values, or the like.

[001 02] A WTRU in RRC idle or inactive mode may communicate measurement results by a physical random access channel (PRACH) preamble, PRACH message 3, higher layer message, or the like. The WTRU may perform random access using the specific RACH resources, specific RACH preambles transmitted in specific subbands and symbols that may be associated with a selected SS block or blocks. TRP or gNB TX beams associated with SS blocks may be identified by the WTRU through a SS block time index. In addition, one or multiple SS blocks and a subset of RACH resources or subset of preamble indices may be sent to a WTRU in system information (SI) or be

known to the WTRU. One or multiple SS blocks and a subset of RACH resources or subset of preamble indices may also be sent to the WTRU by dedicated signals in a prior connected mode. Moreover, an idle or inactive WTRU may select a subset of RACH resources for a selected subset of RACH preambles in the step-1 of a RACH procedure. The TRP or gNB may implicitly derive selected beam IDs at the WTRU from the RACH resources or preambles and use it as a DL TX beam in the RACH procedure step-2.

[00103] Explicit BM and reporting may be configured for connected mode WTRUs. For connected mode WTRUs, the report feedback containing the beam quality information of selected SS blocks may directly be sent back to the TRP or gNB.

[00104] Once the TRP or gNB receives a RACH preamble from a WTRU in idle or inactive mode or a measurement report from a WTRU in connected mode, preferred SS block measurements may be known. The TRP or gNB may form M (M >=1) fine or narrow beam CSI-RSs such that the aggregated coverage of the M fine or narrow beams may match the SS block or blocks selected by the TRP or gNB from reported SS blocks. With feedback from a WTRU based on measured SS blocks, newly formed fine or narrow beams carrying CSI-RS may comprise a subset of possible DL beams of the TRP or gNB. This may result in reduced beam sweeping latency, overhead, power consumption, and interference by avoiding utilization of a large number of CSI-RS beams to cover a specific coverage area.

[00105] Based on measuring newly formed fine or narrow CSI-RS beams, a WTRU may further refine the serving BPL between a WTRU and a TRP or gNB for BM procedure P-2 or P-3. Beam refinement may be performed on aperiodic CSI-RS. Due to channel fluctuations or WTRU mobility, rotations, speed, or the like serving BPL between WTRU and gNB or TRP may be periodically monitored or reported in case a serving BPL quality degrades.

[00106] Serving BPL monitoring or tracking may utilize periodic or aperiodic RSs. For WTRU-specific periodic CSI-RS and SS blocks, if the periodicity is long, they may be unable to track or acquire frequent or abrupt channel variations. Examples are given herein for this scenario since a WTRU may be unable to detect or timely acquire beam quality information. Aperiodic signals, such as DMRS, may also be utilized for BM. Multi-beam transmission for control channel may improve reliability of control signals. DMRS resources transmitted with control channel or data channel may be utilized, based on the measurement of DMRSs associated with a multi-beam PDCCH or PDSCH, to measure and identify one or more new candidate beams for BM.

[001 07] To maintain performance of a serving BPL, a WTRU may maintain a candidate BPL list so that if a serving BPL quality degrades, the WTRU may quickly find another BPL. Updates of the candidate BPL list may utilize frequent measurements of RSs. As CSI-RS and SS blocks may

be unavailable, the DMRS associated with control channel or data control may be utilized. Utilizing DMRS to update a candidate BPL list may be desirable since the DMRS is transmitted on beams that may be used for subsequent data or control information, and the measurement results on the DMRS may represent accurate beam quality information.

[00108] FIG. 6 is an example 600 of a signal flow for unified BM. Sweep SS blocks 1-3 may be transmitted to a WTRU (602) by a TRP or gNB. Measurements may be performed by the WTRU on discovered SS blocks (604) and for connected mode a WTRU may report results on a PUCCH (606). For a WTRU in idle or inactive mode, a 4 step or 2 step RACH procedure may be performed, a RRC connection established, and a coarse BPL is established (608). A TRP or gNB may form M fine or narrow CSI-RS beams for a coverage area (610). Newly formed CSI-RS 1-4 beams may be transmitted (612) to a WTRU. A TRP or gNB and WTRU may perform beam refinement by beam management P-2 or P-3. The TRP or gNB may indicate to a WTRU DMRS port information of a control channel or a data channel on other candidate beams (616). The TRP or gNB may transmit a PDCCH or PDSCH on multiple beams (618). A WTRU may perform measurements on the DMRS with configured port information, acquire corresponding beam quality information, and update a candidate BPL list (620).

[00109] In 600, if blockage of a serving BPL is detected and cannot be recovered from a candidate BPL list (622), such as due to abrupt channel variations, a UE measurement may start on discovered SS blocks and signal flow to be repeated (624). Also, when a beam failure is detected, a SS block signal may be used to quickly find a coarse BPL. If beam reciprocity is applicable, a SS block may be used for beam discovery for UL BM.

[001 10] Dynamic availability or unified usage of multiple signals for BM may include configurations to discover or determine beam qualities from measurement results from different RSs. As an example, RSRP may be utilized as a measurement quantity for multiple RSs to perform BM. Beam measurements on different signals may have different characteristics. For example, if wide beams are utilized for transmission of SS blocks and narrow beams are utilized for transmission of CSI-RS, different values of beam RSRP, SS block RSRP, CSI-RS RSRP, or the like may result due to different beamforming gain. Moreover, a WTRU may utilize different spatial filtering when receiving different RSs such as a wide WTRU RX beam for SS block, narrow WTRU RX beam for CSI-RS, or the like.

[001 11] Frequent updates of the candidate BPLs may be configured in a list to keep the list current. Due to different frequencies of different signals, different periodicity and configuration of SS blocks and CSI-RS, random utilization of PDCCH and PDSCH, or the like, quality of the candidate BPLs may be averaged, updated with different number of samples and across similar or different

signals, or the like. This may be configured such that fluctuations of the quality ranking in the candidate BPL list may be avoided.

[001 12] FIG. 7 is an example 700 of a WTRU that moves in an overlapped coverage of two narrow beams. In 700, in a single NR TRP or NR gNB configuration, a WTRU may be under coverage of multiple beams, SS blocks 3-5, and CSI-RS 6-1 1/PDCCH 6-1 1. When the WTRU is in the location A, that may be near the middle of narrow beam 11, the serving beam quality, such as L1-RSRP above certain threshold, may be sufficient and the WTRU may be configured to skip measurement of neighbor beams 6-10.

[001 13] FIG. 8 is an example 800 of a beam level ping-pong effect. A WTRU may experience an undesirable beam level ping-pong effect due to the use of multiple types of RSs. In FIG. 7, this may occur when the WTRU bounces between narrow beam 10 and 11. When a DMRS is transmitted with a PDCCH or PDSCH, based on beam measurements at time tO, a WTRU's serving DL TX beam may be narrow beam 11 in FIG. 7. From time t1 to time t2, a WTRU may move into the overlapped coverage of narrow beams 10 and 11 from location A to B and the quality of serving beam 11 may drop below a certain threshold value. The WTRU may be triggered by an event, such as if serving beam quality < Th1, to start a candidate DL TX beam update procedure, and start measuring nearby RSs, such as SS blocks, to search for potential beams if the quality of the serving beam continues to degrade.

[001 14] After measurements based on SS blocks, a WTRU may send results to a NR TRP or gNb that may trigger and send aperiodic CSI-RS over several fine or narrow beams. For example, CSI-RSI may be transmitted on narrow beam 10 where the WTRU is under coverage without a transmission on beam 11 since the reported SS block based measurements did not trigger the CSI-RS transmission. Since the quality, for instance L1-RSRP, of the current serving beam 11 may be from previous DMRS signals without a current update, beam 10 may have a higher value of L1-RSRP measurement from the newly formed CSI-RS signals. Furthermore, a new BPL between WTRU and TRP may be established as beam 10 becomes the new DL TX serving beam. Beam switching from beam 11 to beam 10 may occur due to quality changes based on different RSs, DMRS, CSI-RS, or the like.

[001 15] If WTRU is outside the middle of beam 10 and the measured quality of beam 10 is insufficient or above a threshold value, the WTRU may discover or track neighbor beams by measuring SS blocks or the like. A TRP or gNB may configure a group of CSI-RS beams with beam 11 being included based on new or recent reported SS block measurements. WTRU may determine the measured L1-RSRP value of beam 11 has a higher value and switch back to using beam 11 as the new DL TX beam.

[001 16] Undesired switching between beam 10 and beam 11 may indicate beam level ping-pong switching. A beam level ping-pong switch may occur due to quality comparisons among different or the same beams based on measurements from different signals where the absolute quality value may be different if measured or determined by transmitting different RSs. Beam-level ping pong effect may be mitigated by pre-defining, specifying, or configuring a group of measurement settings. A measurement configuration setting may include at least one RS, one or more triggers or rules, such as L1-Unified or RS-RSRP below threshold, unification formulas, beam reporting format or the like, for measurement and reporting respectively. Related parameters, threshold values, offset values, or the like may also be configured. A maximum number of measurement settings by a cell may be dynamic or pre-configured. Measurement settings may be WTRU specific, WTRU-group based, cell-specific, or the like to reduce overhead or network signaling.

[001 17] A WTRU-group may be set-up or configured as multiple WTRUs with a similar property related to a beam-level ping-pong effect. For example, multiple WTRUs that have similar or different QoS requirements within a same cell may be formed as a group of WTRUs that may be used for a WTRU-group based configuration. For a group of WTRUs requiring higher energy efficiency, a measurement period may be relatively longer since beam quality surrounding the group of WTRUs may be stable. For a group of WTRUs with randomized or higher mobility/rotations, higher frequency or density of measurements may be configured for enhanced or fine beam tracking.

[001 18] A WTRU may be configured with one or multiple measurement configuration sets and each set may be triggered by pre-defined, specified, or configured measurement events. For example, a WTRU may have multiple applications running with diverse QoS requirements such as delay, throughput, reliability, or the like simultaneously. The WTRU may transition between different states such as an energy saving state, a high-performance state, a high speed state, or the like each with different QoS requirements. Then the WTRU may be configured with multiple configuration sets for different QoS requirements associated with different states.

[001 19] By configuring one or more specific measurement settings, a WTRU may perform beam measurements and reporting based on one type of RS or multiple RSs with comparable beam quality and flexible availability of different RSs. Measurement configuration may be achieved by higher layer signaling, RRC signaling, lower layer signaling, medium access control- control element (MAC-CE), DCI, orthe like.

[00120] Examples of beam measurement configurations that may reduce beam-level ping pong effects are given in Table 2 and Table 3. For example, when a serving beam's quality meets

certain conditions, intra-TRP or intra-gNB beam measurements may be skipped to save energy or avoid undesirable beam switching that may result in beam-level ping-pong effects. In addition, when more samples for a RS type is desirable, short-term channel fluctuations may result in variations on the measured quality of one or more beams and a GracePeriodForMeasurement may be utilized. A beam-level ping-pong effect may also be mitigated by setting a threshold such that the target beam or link's signal to noise ratio (SNR) or energy is X dB higher than the serving beam or link. The higher X may result in a lower ping pong effect with a cost of higher latency or delay of a beam switch.

Measurement set ID	Triggered Event and Associated Parameters	Measurement Set Body
1	WTRU speed is in the range of [V1, V2] and minimum throughput is in the range of [T1, T2]	• Signals to measure • Timing to perform intra-TRP or intra-gNB beam measurements • Filtering parameters and results consolidation mapping
2	WTRU battery level is in the range of [B1, B2], and target WTRU latency is in the range of [D1, D2]	• Signals to measure • Timing to perform intra-TRP or intra-gNB beam measurements • Filtering parameters and results consolidation mapping
…	…	…

Table 2

Signals to Measure	Bitmap that may include 1100, CSI-RS (on/off), SS block (on/off), DMRS-ctrl (on/off), or DMRS-data (on/off)
Measurement Quantity	Bitmap that may include 10, RSRP (on/off), or RSRQ (on/off)
L3 Beam Filtering Coefficient	Independent filtering for different signals: CSI-filter-Coefficient1-Intra-TRP-RSRP: Double value range (0.1, 1.5) … SS-Block-filter-Coefficient1-Intra-TRP-RSRP: Double value range (0.5, 2.0) …
NumOfBeamstoMeasure	CSI-filter-Coefficient1 -Intra-TRP: Integer range (1, 16) … SS-Block-filter-Coefficient1-Intra-TRP: Integer range (1, 8) … DMRS-ctrl-filter-Coefficientl -Intra-TRP: Integer range (1, 8)
NumOfBeamstoReport	CSI-filter-Coefficient1 -Intra-TRP: Integer range (1, 2) … SS-Block-filter-Coefficient1-Intra-TRP: Integer range (1, 3) …
Intra-TRP or Intra-gNB Beam Measurement	If CSI-RSRP of serving beam < Intra_Th1 … If DMRS-ctrl of serving beam < Intra_Th1 … then start intra-TRP or intra-gNB beam measurements.
Inter-TRP or Inter-gNB Beam Measurement	If CSI-RSRP of serving beam < Inter_Th1 … If SS-block-RSRP of serving beam < Inter_Th1 then start inter-TRP or inter-gNB beam measurements

GracePeriodForMeasurement	If number of samples is above X1, within time window W1, and the average value of CSI-RSRP is in the range of [V1, V2]; … If number of samples is above X2, within time window W2, and the average value of SS-block-RSRP is in the range of [V3, V4]; …. Update the candidate beam list with the measurement results.
Unified Format of Beam Report	Consolidate a beam's measurement result by different signals: Boolean value If true New RSRP of beam i = old RSRP of beam I * (1- β1)+ β1* (average of CSI_RS beam measurement within W 1 time window) OR old RSRP of beam I * (1- β2) + β2* (average of CSI_RS beam measurement within W 1 time window) OR old RSRP of beam I * (1- β3) + β3* (average of DMRS_ctrl beam measurement within W 1 time window) OR old RSRP of beam I * (1- β4) + β4* (average of DMRS_data beam measurement within W 1 time window) else New RSRP of beam I for CSI-RS = old RSRP of beam I for CSI-RS * (1 - μ1) + μ1* (* average of CSI_RS beam measurement within W 1 time window) New RSRP of beam I for SS block .... ….
Request for Beam Training	Serving beam or average of at least one serving beam's quality below certain thresholds value or, WTRU speed is above certain threshold value
Terminate Current Beam Training	WTRU battery is below certain threshold value, use wide beams or SS block transmitted beams from initial access

Table 3

[00121] As shown in Table 2, two measurement sets may be configured where each measurement set may comprise of a set ID (identifier or indicator), triggered events, a measurement set body, or the like. The measurement set body in Table 3 may specify how a configured WTRU performs beam measurements or may report measurement information. The types of signals a WTRU may measure may be indicated by a binary bit. For example, 1(or 0) may indicate ON or

used and 0 (or 1) may indicate OFF or unused. In Table 3, 1100 may indicate a RS, CSI-RS, or SS block is utilized which may be indicated by bit 1. At least one RS may be indicated with ON status to ensure that BM is properly performed. When one RS is enabled or indicated as having an ON, such as a SS block only or CSI-RS only, a WTRU may be configured to perform L1-RSRP beam measurement and reporting based on the one RS.

[00122] A binary bit may be used to indicate a measurement quantity measured by a WTRU. For example, 1(or 0) may indicate ON or used and 0 (or 1) may indicate OFF or unused. In Table 3 bitmap 10 may indicate that a RSRP value is utilized that may be indicated by bit 1.

[00123] Layer 1 filtering may be configured to utilize measurement averaging. The averaging operation may be WTRU specific and based on performance requirements such as energy or delay for different cases such as intra-TRP, inter-TRP, intra-frequency, or the like. Time domain averaging may be utilized to reduce large fluctuations among different measurement samples, and some configurable coefficients may be sample frequency, such as one sample every 1 ms, number of samples before averaging, or the like.

[00124] Due to delay and energy consumption, a WTRU may be configured to measure a limited number of beams, for different cases such as intra-TRP, inter-TRP, intra-frequency, or the like, and report measurement results on a limited number of beams. For instance, beams with top N quality may be reported to minimize signaling overhead. A time duration may be configured for measurement results to be valid, used, expired, or the like. Higher time duration may be more stable or reliable but may not capture fast channel or beam quality variations.

[00125] When multiple types of RSs are configured, the same beam may have different representative values due to different beam characteristics from different RSs. For example, time resources, frequency resources, number of used symbols, different subbands, or the like may be utilized differently for a RS. With different characteristics, if a single value of a beam's quality is needed before reporting, a combination of beam quality information across different measured RSs may be configured.

[001 26] Referring again to Table 3, a Unified Format of Beam Report may utilize a weighted moving averaging operation as a unification formula and configure weight coefficients for different RSs. Parameters $\beta 1$, $\beta 2$, $\beta 3$ and $\beta 4$ may be different configurable weight coefficients for different RSs when unification reporting is configured. Parameter $\mu 1$ may be a configurable weight coefficient for different RSs when independent reporting is configured. If a beam's measurement results from different RSs are available, and a unified value is to be generated, a configurable unification formula may be used to consolidate multiple measurement results into a single value. If a unified value is not

to be generated, independent reports or measurement results from different RSs of the beam's quality may be generated and reported when associated reporting triggers are satisfied.

[001 27] A unification formula may be adjusted and configured to a WTRU for different beam measurement reporting. Referring to the unification formula in Unified Format of Beam Report in Table 3, when one RS is configured to a WTRU for beam measurement reporting such as SS block only or CSI-RS only, and the Boolean value is true, one weight coefficient $\beta 1$ may be configured as positive and non-zero while the other weight coefficients $\beta 2$, $\beta 3$, $\beta 4$, or the like may be configured as zero. If the Boolean value is false, a similar procedure may be performed.

[00128] When multiple RSs are configured to a WTRU for beam measurement and reporting, both joint beam measurement reporting and independent beam measurement reporting may be utilized. For joint beam measurement reporting, a unified value from beam measurements of different RSs such as a SS block or a CSI-RS may be generated with a false Boolean value and different weight coefficients $\beta 1$, $\beta 2$, $\beta 3$, or the like, with non-zero values. For independent beam measurement reporting, the Boolean value in the example may be configured as false, so that measurement results from different RSs are reported independently instead of jointly.

[001 29] A TRP or gNB may be configured such that RSs transmitted on potential beams are measured at least once in a configurable time window, such as SS burst period 802 having SS burst set 804. Referring again to FIG. 8, at time t4 the current serving DL TX beam of the WTRU may change from beam 11 to 10 without a measurement opportunity of beam 11, even though the quality of beam 11 and beam 10 may be comparable. This switch may occur when the WTRU is in the middle of the overlapped coverage of beams 10 and 11.

[00130] FIG. 9 is an example 900 of RSs to reduce a beam level ping-pong effect. In example 900, if supplementary transmissions of CSI-RSs on beam 11 to 14 (902) are available to measure, a WTRU may determine that the quality of beam 11 and beam 10 are comparable such that undesired beam switching from beam 11 to beam 10 may be avoided. Supplementary transmissions of CSI-RSs may be network, TRP, or gNB initiated. Supplementary transmissions may also be initiated or requested by the WTRU either explicitly or implicitly.

[00131] A TRP or gNB may add a current serving DL TX beam of the WTRU into newly formed CSI-RS beams for the WTRU to perform new measurements on both serving beams or neighbor beams. The TRP or gNB may also account for other beams spatially co-located with the serving beam such as supplementary transmissions on beams 11 to 14 in the FIG. 9.

[00132] In an implicit initiation or request, in the last reported SS block based measurement results, a WTRU may include the last measurement of the serving beam. In an explicit initiation or request, a WTRU may send a transmission request of RSs on specific beams, serving beams, QCL

beams, or the like. This request may be a stand-alone message, a PUCCH message, a MAC-CE message, or several bits of information piggybacked on other messages. For instance, a field following a SS block based measurement report may be utilized. An explicit initiation or request may be sent out immediately within a measurement report, following measurement reports, or delayed until the RS on expected beams do not arrive.

[00133] Different RSs may have different characteristics such as beam width, periodicity, number of available measurement samples, or a particular measurement duration for a full beam sweep. Due to different beamforming gain, various measurement quantity or quality parameters may be utilized to characterize a beam. When a single value, such as L1-RSRP, is configured to represent a beam's quality, the single value of SS-block based measurements may be lower than a single value of CSI-RS based measurements if more measurement samples come from CSI-RSs than SS blocks.

[001 34] The measurement quantity or quality of two or more signals may vary over time due to changes in the wireless channel or from measuring at different time instances. In a configuration, individual filtering or consolidation, such as averaging over time, may be performed such that measured beam quality information from different RSs are consolidated and merged before the WTRU reports or feedbacks to the TRP or gNB. A pre-configured mapping table, such as Table 4, may be utilized for individual filtering or consolidation.

Beam ID	RS type indicator (2 bits)	Measurement Quantity Type Indicator (1 bit)
1	CSI-RS (00)	RSRP (0)
2	SS-block (01)	RSRQ (1)
3	DMRS of PDCCH (10)	RSRP (0)
…		

Table 4

[00135] Measured beam quality information from different RSs may be directly reported back to the TRP or gNB to consolidate or merge the measurement results. Based on the consolidation or merging, a DL TX beam may be generated or adapted by the TRP or gNB. Table 5 is an example of consolidation or a merging operation by a TRP or gNB.

	SS block	CSI-RS	DMRS with PDCCH	DMRS with PDSCH
RSRP	Measured value	Measured value - relevant offset value V1	Measured value - relevant offset value V2	Measured value - relevant offset value V3
RSRQ	Calculated value * 1.0	Calculated value * α1	Calculated value * α2	Calculated value * α3
…				

Table 5

[00136] The power offset in Table 5 may be applied to beam failure detection or beam measurement and reporting. Values V1, V2, V3, a1, a2 and a3 may be WTRU specific or configurable. For example, for beam failure detection, a power offset may be the transmission power offset between DL RSs, a CSI-RS, a SS block, or the like and DMRS of PDCCH.

[00137] In examples given herein, L1-RSRP or signal to noise to interference ratio (SINR) may be utilized for beam failure detection. Such detection may be based on hypothetical control channel performance, hypothetical PDCCH block error rate (BLER), or the like. If beam failure determination is based on the measurement of DL RSs, CSI-RSs, SS blocks, or the like, to convert the DL RS based measurement to hypothetical control channel performance, a transmission power offset between the used DL RSs and DMRS of PDCCH may be computed by a WTRU. The transmission power offset may be utilized when either quality measurement metric L1-RSRP or hypothetical PDCCH BLER is used.

[001 38] Beam failure may be determined when all or part of one or more serving beams fail. If a quality measure metric for beam failure detection such as L1-RSRP, hypothetical PDCCH BLER, or the like is beyond a pre-specified or configured threshold by higher layer signaling, it may be counted as one beam failure instance. If the number of consecutive detected beam failure instances exceeds a configured maximum number, a beam recovery request may be transmitted.

[00139] When a beam failure is detected, one or more candidate beams may be identified and reported along with a beam failure recovery request transmission. To identify a higher quality candidate beam, one or more candidate beams may be identified based on the quality measurement metric of a candidate beam that is higher than a threshold. The quality measurement metric of a candidate beam may be L1-RSRP, SINR, hypothetical PDCCH BLER, or the like.

[00140] Similar or different thresholds may be introduced for a SS block, SSB, and CSI-RS while taking into account the similar or different transmission power offset between DL RSs, CSI-RS, SS block, DMRS of PDCCH, or the like. For example, the network may configure the similar or different threshold for candidate beam identification corresponding to a CSI-RS or SS block. The network may configure the quality measure metric of a selected candidate beam to be above a beam failure threshold by a configurable offset and/or better than one or more serving beams by a configurable offset. In the examples given herein, for a candidate beam identification and triggering beam failure recovery request, a WTRU may need to know the transmission power offset between the used DL RSs, such as CSI-RSs, or SS block and DMRS of a PDCCH that are pre-specified to a fixed value configured by higher layer signaling, a RRC message, a MAC-CE, or the like. For example, with a configured transmission power offset, from the threshold of one DL RS (SS block),

the threshold of another DL RS (CSI-RS) may be derived. This may be performed by scaling operation or similar methods.

[00141] Unified BM for multiple TRPs may be configured to avoid TRP or gNB ping-pong effects. In multiple TRP configurations, a beam level ping-pong effect may become a TRP level or cell level ping-pong effect. TRP level or cell level beam switching may result in more overhead, delay, energy consumption, data interruption time, or the like. This may be due to data forwarding, path switching, WTRU context retrieving, or the like during cell switching.

[00142] FIG. 10 is an example 1000 of a TRP ping-pong effect due to use of multiple types of RSs for BM. In 1000, beam 11 and beam 10 in FIG. 7 may be transmitted from different TRPs 1-2 or gNBs 1-2 as different (1002) or similar (1004) types of beams. To avoid TRP or gNB level ping-pong issues from multiple TRPs deployments, a serving gNB may configure the WTRU with a group of parameters or threshold values to utilize differential beam measurement configurations. A differential measurement configuration may show partiality for the serving TRP or gNB due to the high cost of beam switching. For example, to report beam quality information for beams from neighboring TRPs or gNBs, in a configuration the value of a beam's measurement quantity may have to be above another higher threshold than the beam from the serving TRP during an extended time period.

[00143] Each SS block may have configurable features such as transmitted in a specific time, frequency, subbands, symbols, or the like. Each SS block may also have configurable features such as periodicity, a beam sweeping pattern, full sweeping or partial sweeping within each SS block burst set, beam sweeping order, association with RACH resources, association with specific physical random access channel (PRACH) preambles. A CSI-RS may have configurable features such as periodicity, explicit or implicit triggering signals, a CSI-RS resource configuration, a CSI-RS resource element (RE) pattern, a number of CSI-RS antenna ports, a composition of CSI-RS resource sets, a number of CSI-RS resources, a number of time-domain repetitions associated with each CSI-RS resource, or the like.

[00144] A SS block or CSI-RS may become dynamically available such that at a specific time instance when the WTRU performs beam measurement, a CSI-RS or a SS block may unavailable at the same time. In addition, a CSI-RS or a SS block may be used and configured for unified beam measurement, unified beam reporting (UBR), beam failure detection, new candidate beam identification, or the like by a TRP or gNB. The type of periodic NR-PUCCH feedback, time or frequency resources for aperiodic report, or the like may also be configured by a TRP or gNB.

[00145] A dedicated PRACH resource may be configured to either an SS block or a CSI-RS resource. When multiple SS blocks are configured, one or more SS blocks may be associated with

the same uplink resource, PRACH resource, or the like. For example, a dedicated PRACH resource(s) may be reserved and configured for a WTRU. Multiple SS blocks may be associated with the same or different uplink resource such as PRACH resource. For robust transmission, a control channel may be transmitted with multiple beams when a beam is unusable due to blockage, WTRU rotation, or the like. If a network, gNB, TRP, or the like receives an uplink transmission from a WTRU over an uplink resource which is associated with multiple SS blocks, the network may respond by transmitting over all the associated SS blocks simultaneously or TX beam sweeping, depending on WTRU capability or network capability. A network may request further beam measurement and reporting on a SS block from the WTRU, so that the network can select a subset or all of the associated SS blocks for the next or subsequent transmissions.

[00146] A CSI-RS and a SS block may be complementary for BM as a SS block may be periodically available and may be used to reduce the overhead of configuring a WTRU specific CSI-RS. A WTRU may be configured with all of the SS block resources or beams or a subset of the SS block resource or beams depending on if a beam measurement on a subset of SS blocks is sufficient for the WTRU to perform beam discovery, refinement, tracking, or the like.

[00147] A SS block and a CSI-RS may be transmitted through the same TX beam. In a case when a SS block and a CSI-RS are transmitted through different TX beams, each signal may be utilized as the baseline RS for each beam. When one RS, SS block, CSI-RS, or the like is configured to a WTRU for beam measurement and reporting, the configured RS may become the baseline reference by default. When multiple RSs are configured to a WTRU but independent beam measurement reporting is configured by the network, each RS may become the baseline signal separately, and the WTRU may perform beam measurement and reporting on each configured RS independently.

[00148] CSI-RS may be utilized as a baseline RS for unified BM since CSI-RS is WTRU specific and may be flexibly configured for each WTRU according to the channel and mobility conditions, bandwidth, or the like. In examples given herein, a CSI resource may be transmitted on multiple CSI-RS ports. The CSI-RS may be transmitted as periodic, aperiodic, or semi-persistent with flexible triggers.

[00149] When both SS blocks and CSI-RS are used for BM, a WTRU may be configured to compare a measurement quantity between a CSI-RS and SS block resource for corresponding beams. With different characteristics of a CSI-RS and SS block, a measured RSRP may be different even for the same beam measured at the same time instance. In response, a WTRU may utilize a SS block RSRP adjusted to the baseline RS RSRP or CSI-RS with a certain offset value when the WTRU compares, selects, or reports the RSRP to a TRP or gNB for BM.

[00150] If the transmission power of downlink RSs is fixed, the relative transmission power offset between CSI-RS and SS block may be configured to a WTRU through dedicated signaling, such as SI transmission or RRC reconfiguration, by a TRP or gNB. This may be performed upon the WTRU entering connected mode or during handover from another cell or TRP that configured the WTRU differently. If the transmission power of downlink RSs is changed for inter-cell interference coordination or flexible cell coverage, a WTRU may need the power value of different SS blocks or a power offset between different SS blocks and different CSI-RS beams. A WTRU may also need the power value of different SS blocks or power offset between different SS block sets if transmission power of all SS block beams within the same SS block set is the same and different CSI-RS beams. In a configuration, a TRP or gNB may not transmit different CSI-RS ports within a CSI-RS resource with different transmission power and instead may transmit different CSI-RS resources with different transmission power.

[00151] In certain configurations, SS blocks may be cell specific. When transmission power of SS blocks are changed, the power value or reference power value plus power offset of each individual SS block, if transmission power of each SS block beam is different, may be configured. If power information comprises a small payload, or transmission power is the same within a single SS burst set, the power value may be delivered in a SI so that all WTRUs in a cell receive the information. If the power information comprises a large payload, the power values and offsets may be configured through dedicated SI or common search space PDCCH for a group of WTRUs. For example, the power information may be embedded in a common PDCCH transmitted in a same time slot as the SS blocks. A CSI-RS may also be WTRU specific and power information may be sent to a WTRU when configuring CSI-RS resources in higher layer signaling, layer 3 signaling, a RRC configuration message, or the like.

[00152] A SS block may be configured as a baseline RS for unified BM. This configuration may reduce configuration overhead, scheduling CSI-RS resources, interference coordination, or the like for idle and connected mode WTRUs. Using a SS block as a baseline RS may also reduce interference from CSI-RS transmissions and latency from scheduling WTRU-specific CSI-RS.

[00153] In the examples given herein, when a SS block is configured as a baseline RS, measurement quantities of other RSs may be converted to equivalent values for comparing beam qualities. For example, if the transmission power of different CSI-RS resources is fixed, the power information may be configured for the WTRU at the time when the CSI-RS resource is configured. If the transmission power of different CSI-RS resources is dynamically changed, the information may be configured for a WTRU similar to when CSI-RS is selected as a baseline RS by a dedicated MAC-CE, higher layer signaling, RRC signaling, or the like. Power information format may be

flexible and if the power information or payload does not comprise large overhead for a WTRU, the absolute value of transmission power may be transmitted. In other configurations, the offset value of transmission power or even differential value of transmission power with different levels of resolution may be transmitted.

[00154] In examples given herein, a UBR may be periodic, semi-persistent or aperiodic. UBR for beam measurement information (BMI) or beam related information (BRI) may include a reference signal received power (RSRP), a reference signal received quality (RSRQ), a channel state information (CSI), a beam index, a beam group index, a channel quality indicator (CQI), a rank indicator (RI), a CSI resource indicator (CRI), an SS block resource indicator associated with beam information, or the like. One or more BRI for reporting by the WTRU may be pre-specified or configured by a RRC message or dynamically signaled by L1 signaling, L2 signaling, a MAC-CE, NR-(e)PDCCH/NR-DCI, or the like. Beam measurement information or beam related information may be periodic or aperiodic as configured by a TRP or gNB.

[00155] Unified BM measurement and reporting configuration may utilize a mapping table including a RS type, periodicity, beam width, on-demand or active configurations, or the like. As given herein, unified BM measurement and reporting may be periodic, aperiodic, semi-persistent, or based on an event trigger. An event trigger may be based on a RS-specific timer or threshold values.

[00156] FIG. 11 is an example 1100 of a configuration of a measurement and reporting setting for unified BM with joint and independent beam reporting of a CSI-RS and a SS block. BM may comprise reference resource configuration, measurement configuration, reporting configuration, or the like and utilize a similar format of resource settings and reporting settings for CSI-RS and SS block resources. When a WTRU is configured for unified BM with $N \geq 1$ reporting settings and $M \geq 1$ resource settings, a measurement setting (1102) may link the N reporting settings with the M RS settings, or the like. Configuration parameters N, M, and L may be indicated or signaled either implicitly or explicitly in higher layer signaling, layer 3 signaling, RRC signaling, or the like. Configuration parameters that may be signaled in each reporting setting may include reported RS ID, SS block ID, CRI, reported BRI, measurement qualities, L1-RSRP on SS block, CSI-RS, reporting type, a joint reporting parameter, an independent reporting parameter, time-domain behavior, aperiodic settings, periodic settings, semi-persistent settings, or the like.

[00157] In 1100, Report Setting 1 may be periodic and report the best 3 L1-RSRP values while Report Setting 2 may be aperiodic and report all measured L1-RSRP. Resource Setting 1 (periodic) may comprise Joint CSI-RS and SS Resource Sets with Set 1 having four CSI-RS and four SS block Resources with repetition set to OFF. Resource Setting 2 (aperiodic) may comprise

CSI-RS resource sets with Set 1 having eight resources with repetition set to on. In addition, Set 2 may have four resources with repetition set to OFF. Resource Setting 3 (periodic) may comprise independent CSI-RS and SS block Resource Sets with Set 1 having twelve CSI-RS resources with repetition set to OFF. In another configuration, Set 1 may have twenty four SS block resources with repetition set to OFF.

[00158] In certain configurations, $S \geq 1$ CSI-RS or one or more SS block resource sets may be signaled. A resource set may correspond to different selections from a pool of all configured CSI-RS or SS block resources. When $K_S \geq 1$ and CSI-RS or SS block resources correspond to each set, mapping to REs, the number of ports, time-domain behavior, aperiodic reporting, periodic reporting, semi-persistent reporting, RS frequency span, RS power, RS power offset, mapping to an OFDM symbol in a configured time period/slot, or the like may be configured.

[00159] In certain configurations, each of the L links in a CSI or SS block beam measurement setting may include a joint or independent reporting setting indication on a SS block or CSI-RS, a resource setting indication, a quantity to be measured, L1-RSRP measurements, L1-RSRP measurements on SS block, L1-RSRP measurements on CSI-RS, or the like. A joint or independent reporting setting may be linked with one or multiple resource settings or the same resource setting.

[00160] In example 1100, one periodic reporting setting may be linked to two resource settings containing joint and independent CSI-RS and SS block resource sets, respectively. Resource sets may be configured with a repetition information element (IE) set to OFF for performing TRP or gNB TX beam sweeping. A similar configuration may be utilized for WTRU RX beam sweeping with the repetition set to ON. In addition, an aperiodic reporting setting may be linked to Resource Setting 3, where the two sets with repetition set to ON and OFF respectively. In example 1100, the WTRU may be configured to perform Reporting Setting 1 with Resource Setting 1 or Resource Setting 3, so that joint L1-RSRP reporting using a QCL based SS block and CSI-RS or independent L1-RSRP reporting using SS block and CSI-RS is utilized.

[00161] FIG. 12 is an example 1200 of another configuration of a measurement and reporting setting for unified BM with joint and independent beam reporting of a CSI-RS and a SS block. In example 1200, both Reporting Setting 1 and Reporting Setting 2 may be linked to the same periodic Resource Setting 1. Resource Setting 1 may comprise resource set 1 having four CSI-RS resources and resource set 2 having eight SS block resources. Any one set or both sets may be selected by DCI, MAC-CE, or the like and configured by higher layer signaling, RRC signaling, or the like. In example 1200, since Resource Setting 1 contains periodic RSs, either aperiodic reporting or periodic reporting may be utilized.

[00162] Since independent reporting, such as independent L1-RSRP reporting using a QCL based SS block and CSI-RS, may have large overhead, aperiodic reporting may be utilized. Periodic joint reporting, such as joint L1-RSRP reporting using QCL based SS block and CSI-RS, may be configured due to low overhead to consolidated L1-RSRP measurements from QCL based SS block and CSI-RS compared to independent reporting. A TRP or gNB may command WTRUs within the same cell to perform a similar type of reporting, such as independent L1-RSRP reporting for periodic reporting. A WTRU may also operate independent L1-RSRP reporting for periodic reporting.

[00163] Referring again to FIG. 4, unified BM L3 beam filtering may be utilized or configured for L3-RSRP or L3-RSRP for a SS block for WTRU L3 mobility. L3 filtering may be more flexible than L1 filtering due to RRC configuring or re-configuring. In a configuration with a battery-constrained WTRU with a static position, L3 filtering may be performed at a long time scale for stable and long term beam quality. In another configuration, mobility events may be more frequent and accurate measurements of beam quality highly desirable for battery moderately constrained or non-constrained WTRUs. To capture short-term beam quality fluctuation from blockage, L3 filtering may be RRC configured to perform measurement averaging at a shorter time scale. This configuration may allow the network and WTRU to switch beams quickly if the serving beam experiences a beam blockage. L3-filtering may also be utilized with a different configuration from L3-RSRP to address short-term beam quality fluctuations. However, a larger UL resource overhead may result since a L3-RSRP report may be carried on the PUCCH, PUSCH, MAC-CE, or the like.

[00164] FIG. 13 is an example 1300 of a measurement model where layer 3 RS received power (L3-RSRP) beam filtering may be used for BM. In 1300, the L3-RSRP beam filtering shown in example 400 may be used for BM by configuring L3 filtering parameters such that both L3-RSRP (1302) or L1-RSRP (1304) are reported.

[00165] FIG. 14 is an example 1400 of a measurement model with layer 1 (L1) beam filtering. L1-filtering for calculating L1-RSRP may utilize averaging or weighted moving averaging of existing or available L1 beam measurements. For different RSs, L1-filtering may be pre-defined, configured similar to L3-filtering, configured differently than L3-filtering, or the like. L1-filtering may be flexible or adaptive and indicated by L1 or L2 control such as DCI signaling, MAC messaging, or the like. In 1400, gNB beams 1 to K may be inputted as signals A into layer 1 filtering components 1402 and outputted as signals A^1. RRC parameters and signals A^1 may be inputted to beam consolidation/selection component 1404. K beams or signals A^1 and RRC parameters may also be inputted to L3 beam filtering components 1406 and outputted as signals E. Signals E may be inputted with RRC parameters to beam selection for reporting component 1410 to produce output F of X beams. Output B and RRC parameters may be processed by layer 3 filtering for cell quality

component 1414 to produce signal C. Signal C and C^1 may be processed with RRC parameters at evaluation of reporting criteria component 1416 to produce signal D.

[00166] In example 1400, signals A^1 and DCI parameters may also be inputted to L1 beam filtering components 1408 and outputted as signals G. Signals G may be inputted with DCI parameters to beam selection for reporting component 1412 to produce outputs H of Y beams. When multiple RSs are configured or available to a WTRU, beam measurement reporting may be performed jointly or independently. When independent beam measurement reporting is configured, beam reporting information may comprise measurement results from only one RS and reported directly since measurement results are comparable with each other when based on the same RS. With joint beam measurement reporting, such as joint L1-RSRP using a QCL based SS block and CSI-RS, beam reporting information may comprise measurement results from multiple RSs. In this configuration, to generate a single representative value for each beam, since measurement results are not comparable when measuring different RSs, UBR may be utilized to combine measurement results of a beam and reduce overhead.

[00167] UBR 1 may utilize a unified value where measurement results from measuring different RSs of a specific beam are merged into a unified value based on a configured unification formula. Table 3 shows an exemplary body of a measurement configuration set and Table 6 shows an example of unified values. A WTRU may be configured to measure a group of beams, such as beams 0 - 10. Measurement results from different RSs may be merged or combined into a single representative or unified value for each beam. In UBR 1, RS information may be unavailable or RS type information may not be included in the report by UBR 1.

Beam ID	Measurement quantity
2	Unified Value1
5	Unified Value2

Table 6

[00168] In UBR 2, RS reporting may be utilized and a WTRU may be configured to select a certain RS as a baseline RS. If a different RS other than the configured baseline RS is measured, the measurement result may be converted into an equivalent value based on the baseline RS and configured or measured offset value. Table 7 shows an example of converted values.

Beam ID	Measurement quantity
2	Converted Value1
5	Converted Value2

Table 7

[00169] In UBR 3, a 1 bit RS type indicator may be utilized for two RSs, such as CSI-RS and SS block, as shown in Table 8. The 1 bit RS type indicator may be communicated by a WTRU in a bit-map on the PUCCH, PUSCH, or any other uplink channel. Similarly, a UBR format may comprise a 2 bit RS type indicator for more than two RSs. Table 9 shows an example of four RSs including CSI-RS, SS block, PDCCH-DMRS, and PDSCH-DMRS represented by a 2 bit RS type indicator that may be communicated by a WTRU in a bit-map on the PUCCH, PUSCH, or any other uplink channel.

RS type	RS type indicator (1 bit)	RS-RSRP
CSI-RS	0	CSI-RS-RSRP
SS	1	SS-RS-RSRP

Table 8

RS type	RS type indicator (2 bit)	RS-RSRP
CSI-RS	00	CSI-RS-RSRP
SS	01	SS-RS-RSRP
PDCCH DMRS	10	PDCCH-DMRS-RSRP
PDSCH DMRS	11	PDSCH-DMRS-RSRP

Table 9

[00170] In UBR 3, a full expression of a measurement result may comprise fields for RS type, such as 1 or 2 bits, and variable length of measurement quantities for different RSs and associated values. The length of measurement quantities for different RSs may be similar or different depending on reporting overhead, accuracy, L1-RSRP resolution, L1-RSRP step size, a maximal L1-RSRP range, or the like. An example of beam reporting is shown in Table 10. For example, when the measurement quantity is 001 101, the first two bits of 00 may indicate the SS block beam and four bits 1101 may be utilized for a range of SS block L1-RSRP values. In another example, when the measurement quantity is 011000101, the first two bits of 01 may indicate a CSI-RS beam and 7 bits 1000101 may be utilized for a large range of CSI-RS L1-RSRP values.

Beam ID	Measurement quantity
2	001101
5	011000101

Table 10

[00171] In the examples given herein, UBR 1 or UBR 2 may be configured for joint beam reporting. For example, UBR 1 may perform joint reporting without RS information while UBR 2 performs joint reporting with the baseline RS information, such as when measurements from multiple RSs are converted into a baseline RS based measurement. UBR 3 may be used for

independent beam reporting where measurements from different RSs may be calculated separately and reported independently.

[00172] In UBR 4, a hybrid UBR format may be utilized to indicate information such as beam ID, RS type, SS block usage, CSI-RS usage, measurement quantities, L1-RSRP, L1-RSRQ, reporting types, independent L1-RSRP reporting, joint L1-RSRP reporting, or the like. In UBR 4, a reporting type field may be utilized such that both joint and independent reporting is utilized by the hybrid UBR format. An example of beam reporting by using UBR 4 is shown in Table 11. Beam 2 and beam 3 may use independent beam reporting with one bit to indicate the RS measured for the independent beam reporting. A first bit of measurement quantity may indicate RS type, such as 1 and 0 may indicate CSI-RS and SS block for beam 2 and beam 3, respectively. The remaining 5 bits of measurement quantity 01101 may be used for a measurement quantity, such as L1-RSRP value of a CSI-RS and SS block, respectively. Beam 5 may use joint beam reporting with all 6 bits of measurement quantity 101 101 utilized to represent a L1-RSRP value for UBR 1 or UBR 2.

Beam ID	Reporting Type	Measurement Quantity
2	0 (independent reporting)	1,01101
3	0 (independent reporting)	0,01101
5	1 (joint reporting)	1,01101

Table 11

[00173] Moreover, beam 2 and beam 5 may be configured with the same measurement quantity value, such as 101 101, with different reporting types such as independent beam reporting or joint beam reporting. A measurement quantity with the same value 101 101 for beam 2 and beam 5 may represent a different measurement quantity, such as L1-RSRP value, due to different reporting type. For beam 2, as independent reporting is used, the first 1 bit may be used to indicate which RS, such as CSI-RS, is utilized and the remaining 5 bits 01101 may represent a L1-RSRP value. Beam 5 may use joint beam reporting, where all 6 bits of measurement quantity 101 101 may be utilized to represent a L1-RSRP value.

[00174] Periodic beam measurement may be configured with a normal trigger to maintain the quality status of a group of beams. The overhead for periodic measurement may be reduced or optimized by limiting measurement and reporting of beams around a serving beam(s) or BPL(s). Limiting or restricting measurement may capture short-term fluctuations due to WTRU rotation and beam blockages while managing overhead. The group of beams in each periodic measurement and report may be adjusted by the WTRU although it is initiated (e.g. configured or signaled) or controlled (e.g. configured or signaled) by the WTRU or the network. For example, based on a periodic measurement at a particular moment, the WTRU independently or the network may

determine the next time to measure the beams around the best beams reported without measurement of surrounding serving beam(s).

[00175] For aperiodic beam measurement, a WTRU or network may configure a trigger for a one-time beam measurement for suddenly degraded SNR in a decoded control transmission, a decoded data transmission, detected beam failures, or the like. A large report may be configured for aperiodic since it is a single time.

[00176] Differential beam reporting that is flexible may be utilized for the beam measurements given herein. As tolerance of different levels of measurement complexity and overhead may be different, RSRP resolution and RSRP reference may also be configured differently. In addition, for different RSs, transmission power, frequency selective fading, or the dynamic range of a measurement quantity may be different due to different beam forming gain. Differential beam reporting for unified BM may utilize one format to represent differential beam reporting with differential reference RSRPs or resolutions for different RSs.

[00177] Differential RSRP for per-beam basis reporting or non-grouping based multi-beam reporting may be configured. Table 12 shows multi-offset and multi-resolution RSRP used for different beams. All reported beams may be based on a similar reference RSRP and any beams with measured RSRP below this reference may not be reported since the reference RSRP may be the largest RSRP in a multi-beam configuration.

[00178] For beams measured on different RSs, a different offset value may be utilized. In Table 12, beam 1 may be an SS block with offset value 0 dBm and beam 5 a CSI-RS beam with offset value 30 dBm. A WTRU may adjust the RSRP of multiple RS resources, a SS block, a CSI-RS, or the like based on the power offset of a respective RS. In addition, beams close to and including a serving beam(s), may be reported with higher resolution, such as 1 for beam 3. For beams measured on different RSs, different resolutions may be utilized. For example, for frequencies above 6 GHz, CSI-RS beams and PDSCH beams may have a number of beams larger than 64. In this configuration, SS block beams may have wider beam widths and relatively coarser RSRP values and may be reported with a lower RSRP resolution.

Beam ID	Reference RSRP (dBm)	Offset RSRP (dBm)	Resolution (dB)	Reported RSRP	RSRP bits	Note (assuming maximum RSRP is -44 dBm)
1	-140	0	2	*	6	SS block beam
2	-140	0	4	*	5	SS block beam
3	-140	35	1	*	6	DMRS of the serving PDSCH beam
4	-140	35	2	*	5	Other PDSCH beam
5	-140	30	2	*	6	CSI-RS beam
6	-140	30	4	*	5	CSI-RS beam

Table 12

[00179] Table 13 includes multiple differential RSRP reporting rules each with different measurement reporting features that may be mapped to a specific BM RS. In a configuration, to determine an absolute RSRP value of a beam using Table 12 and Table 13, an offset type and relative RSRP value may be utilized. A reference RSRP value may be similar for a group of beams. An offset type may indicate a RS based on the measured beam.

[001 80] For non-group based differential beam reporting for multiple beams, bit-width for the reference RSRP and the differential RSRP may be pre-specified or configured as similar or different values. For example, a reference L1-RSRP may be reported with a first bit-width, such as X 1 bits = 7 bits, and the differential L1-RSRP may be reported with a second bit-width, such as X2 bits = 4 bits. For differential L1-RSRP on different RSs, the same set of bit-width for the reference L1-RSRP and differential L1-RSRP may be utilized. Alternatively, the different set of bit-width for the reference L1-RSRP and differential L1-RSRP may be used for differential L1-RSRP on different RSs.

Rule Index	Reference RSRP (dBm)	Offset to Reference RSRP(dBm)	Baseline Resolution	Min RSRP	Max RSRP	Min Reporting Period	Max Reporting Period	…
1	RS-specific Reference RSRP	0	2	-140	-44	2 ms	10 ms	…
2	common reference RSRP	20	1	-130	-35	1 ms	3 ms	…
3	common reference RSRP	10	2	-125	-30	1 ms	4 ms	…

Table 13

[00181] Differential RSRP for group-based beam reporting may also be utilized where different groups are configured for different rules. In this configuration, beams reported by measuring the same RS may be designated to the same group, RS-specific beam group, or the like. Beams from the same TRP, gNB, or same panels may be designated to the same group, RS-

specific beam group, or the like. Beams reported with same level of resolution RSRP or received/measured simultaneously may be designated to the same group, RS-specific beam group, or the like.

[00182] For L1-RSRP reporting for group-based beam reporting, bit-width for a reference RSRP or differential RSRP may be pre-specified or configured as similar or different values. For example, a reference L1-RSRP may be reported with similar bit-width for different RS-specific beam groups, such as SS block based beam group and CSI-RS based beam group, while a differential L1-RSRP may be reported with similar or different bit-width for different beam groups. A bit-width may depend on the number of beams for different beam groups if different stepping sizes of differential quantization are used for different beam groups. For example, a similar bit-width, such as 7 bits, may be utilized for reference L1-RSRP for both SS block and CSI-RS, while smaller bits may be used for the differential L1-RSRP on a SS block. In addition, different bit-widths, such as 7 bits or 5 bits, may be utilized for a reference L1-RSRP for SS block and CSI-RS based beam groups while similar or different bit-widths may be used for SS block and CSI-RS based beam groups.

[00183] When a beam group is constructed by a RS or the group is not constructed by a single type RS and independent beam reporting is configured, the following reporting format may be configured:

Base reference RSRP

Rule R1 for RS1, number of reported beams n1.

Pair 1: (Beam G1_1, relative RSRP value 1)

…

Pair n: (Beam G1_n, relative RSRP value n1)

Notes: Beams with RSRP value below Min RSRP may not be reported; Beams with RSRP value above Max RSRP is adjusted to be the Max RSRP; the pairs are reported in order; the number of reported beams is given at the beginning.

Rule R2 for RS2, number of reported beams n2.

Pair 1: (Beam G2_1, relative RSRP value 1)

…

Pair n: (Beam G2_n, relative RSRP value n2)

Rule R3 for RS3, number of reported beams n3.

Pair 1: (Beam G3_1, relative RSRP value 1)

…

Pair n: (Beam G3_n, relative RSRP value n2)

[00184] When a beam group is not constructed by the RS being used and joint beam reporting is configured, a reporting format using two-level group reporting structure may be configured:

Base reference RSRP

Group 1

Rule R1 for RS1, number of reported beams n1.

Pair 1: (Beam 1, relative RSRP value 1)

…

Rule R2 for RS2, number of reported beams n2.

…

Group 2

Rule R1 for RS1, number of reported beams n1.

Pair 1: (Beam 1, relative RSRP value 1)

…

Rule R2 for RS2, number of reported beams n2.

…

Group 3

Rule R1 for RS1, number of reported beams n1.

Pair 1: (Beam 1, relative RSRP value 1)

…

Rule R2 for RS2, number of reported beams n2.

…

In the second level, beams are sorted within each given group based on the RS.

[00185] A differential beam ID on per-beam basis reporting may also be configured. In addition to beam quality information such as RSRP, a beam ID may result in signaling overhead. To identify a beam, such as a CSI-RS or SS block from an unknown TRP or gNB, a large number of bits may be needed. In a configuration with 64 SS blocks in a SS burst set, an additional 6 bits may be needed to identify an SS block time index. For CSI-RS based beams at higher frequencies than 6 GHz, more than 6 bits may be needed resulting in more than 16 bits of overhead. To reduce signaling overhead for a beam ID, when a WTRU is configured with a number of SS block and CSI-RS resources for beam measurements and reporting, a mapping table may comprise a list of

shortened beam IDs. Compared to a full beam ID, a shortened ID may identify a subset of available SS blocks and CSI-RS beams.

[00186] FIG. 15 is an example 1500 with reported beams geographically close to and centered at a WTRU between cell 1 and cell 2. When a WTRU is triggered to perform beam measurements and reporting, since final reported beams may be geographically close to and centered at the WTRU, other beams further away from the WTRU with low RSRP may go unreported. In 1500, cell 1 may comprise beams (m-2, m-1, m, m+1) and cell 2 may comprise beams (n-2, n-1, n, n+1). Using the beam ID of one selected beam, such as the beam with lowest value of index, as the reference value, differential beam IDs other beams may be utilized for beam reporting. Table 14 provides examples of differential beam ID based reporting. With differential ID, a shortened beam ID may comprise 2 bits for each reported beam ID.

Original Beam ID	Reference Beam ID	Differential Beam ID	Beam ID bits
15	15	00	2
16	15	01	2
17	15	10	2
18	15	11	2

Table 14

[00187] For efficiency, a WTRU may be configured to measure and report a subset of all available CSI-RS or SS block resources or beams. The WTRU may report all or a subset of measurement results. For example, when a WTRU is configured to measured M beams it may report N beams, where N <= M.

[001 88] A network configured mapping Table 15 at the WTRU may comprise multiple full-to-shorted ID mappings to represent IDs, such as a combination of cell ID, beam ID, or beam type, of CSI-RS or SS block resources/beams for measurement. A network may configure WTRU-specific mapping tables where the mapping table is also known by the network. For a WTRU reporting measurement results, shorted IDs such as a combination of shorted cell ID, shorted beam ID, or beam type may be utilized to indicate beam identities with the network determining full IDs by utilizing a locally stored WTRU-specific mapping table. As shown in Table 15, the length of a full beam ID may be 17 bits with a 10 bit cell ID, a 1 bit beam type, and a 6 bit beam ID. The length of a short beam ID may be 4 bits with a 1-bit cell ID, a 1-bit beam type, and a 2 bit beam ID.

Cell ID		Beam ID		
Original Cell ID (10 bits)	Short Cell ID (1 bits)	Original Beam ID (6 bits)	Beam Type (CSI-RS 0, SSB 1)	Shortened beam ID (2 bits)
X	0	30	0	00
X	0	20	1	01
Y	1	40	0	00
Y	1	45	0	01

Table 15

[001 89] If a CSI-RS, SS block beam, or resource ID are jointly indexed such that there is no overlap, a joint encoding of cell ID, beam type, beam ID, or the like may be configured for a WTRU mapping table by the network. As shown in Table 16, jointly indexing a CSI-RS or SS block beam/resource ID may reduce bits needed for a short beam ID. Since the CSI-RS and SS block beam/resource ID are jointly indexed, beam type in the Table 16 may be unnecessary, leading to a further reduced number of bits (3 bits) for a short beam ID. In Table 15 and Table 16, a TRP or gNB may have a local copy of a WTRU-specific mapping table. To reduce overhead, all or a subset of WTRUs within a cell may not have a mapping table at the network. A mapping table may utilize a reference ID for a short cell ID or beam ID as shown in Table 17.

Cell ID		Beam ID	
Original Cell ID (10 bits)	Short Cell ID (1 bits)	Original Beam ID (6 bits)	Shortened Beam ID (2 bits)
X	0	30	00
X	0	20	01
Y	1	40	00
Y	1	45	01

Table 16

Cell ID			Beam ID		
Original Cell ID (10 bits)	Reference Cell ID (10 bits)	Short Cell ID (1 bits)	Original Beam ID (6 bits)	Reference Beam ID (6 bits)	Shortened Beam ID (2 bits)
X	X	0	30	20	10
X	X	0	20	20	00
Y	X	1	40	40	00
Y	X	1	45	40	01

Table 17

[00190] When a mapping table configured at a WTRU is not stored at the network, overhead may also be reduced by a WTRU update of the mapping table and reporting a subset of the beam measurement results according to a prior beam reporting configuration. For example, a

WTRU may report the beams which have a L1-RSRP above a certain threshold. As shown in Table 18 for this configuration, 1 bit may be needed for a shorted beam ID.

Cell ID			Beam ID		
Original Cell ID (10 bits)	Reference Cell ID (10 bits)	Short Cell ID (1 bits)	Original Beam ID (6 bits)	Reference Beam ID (6 bits)	Shortened Beam ID (1 bit)
X	X	0	30	20	- (this beam is not reported)
X	X	0	20	20	0
Y	X	1	40	40	0
Y	X	1	45	40	- (this beam is not reported)

Table 18

[001 91] Signaling overhead between the network and a WTRU may also be reduced when a mapping table update is skipped by a network even when a beam reporting setting at the WTRU is changed. When both SS block and CSI-RS are configured for beam reporting of measurements, a WTRU may perform beam reporting independently on a per-beam basis or on a per-group basis. Differential beam reporting for unified BM may also be used for independent beam reporting when both SS block and CSI-RS are configured for beam measurement and reporting.

[001 92] Independent beam reporting for SS block or CSI-RS may be configured or specified with different parameters. For L1-RSRP reporting of measurements of a SS block, the maximal TX beam numbers to measure for a given reporting instance may be band-dependent and indicated as K_{SSB}. For example, $K_{SSB} = 4$ for < 3 GHz, $K_{SSB} = 8$ for < 6 GHz, $K_{SSB} = 64$ for > 6 GHz and < 52.6 GHz. The maximal TX beam numbers reported by a WTRU per reporting instance may be band-dependent and also configured by a TRP or gNB with N_{SSB}. In a configuration, $N_{SSB} = 1$ for < 3 GHz, $N_{SSB} = [1, 2]$ for <6 GHz, $N_{SSB} = [1, 2, 4, 8]$ for > 6 GHz and < 52.6 GHz.

[001 93] Values may be different for PUCCH and PUSCH based reporting. For example, a larger value may be configured for PUSCH based reporting and smaller value may be configured for PUCCH based reporting by a TRP or gNB. Referring again to FIG. 4, values may be different for P-1, P-2, and P-3 procedures. For example, a larger value may be configured for a P-2 procedure and a smaller value may be configured for a P-1 procedure. Reporting values may also be different for aperiodic reporting, semi-persistent reporting, periodic reporting, or the like. For example, a larger value may be configured for aperiodic reporting and smaller value may be configured for semi-persistent or periodic reporting.

[001 94] Reporting values may be different for associated reporting contents. For example, a large value may be configured for less measurement quantities to be reported, such as with

differential L1-RSRP reporting, while small value may be configured for more measurement quantities to be reported, such as with absolute or regular L1-RSRP reporting. In examples given herein, a subset of N (<= NSSB) beams may be selected by a TRP or gNB and indicated to the WTRU by higher layer signaling, RRC signaling, MAC-CE, L1 signaling, a DCI, or the like.

[001 95] Maximal TX beam numbers for a WTRU to measure for a given reporting instance may be band-dependent and indicated as KcsiRs for L1-RSRP reporting of measurements of a CSI-RS. For example, KCSIRS =8 for < 6 GHz, KCSIRS =64 or KCSIRS = 128 for > 6 GHz. In another example, a single maximal TX beam number for a WTRU to measure for a given reporting instance may be band-independent, such as KCSIRS = 128.

[001 96] Maximal TX beam numbers reported by a WTRU per reporting instance may be band-dependent and configured by a TRP or gNB for L1-RSRP reporting of measurements of a CSI-RS. The indication for this configuration may be NCSIRS, such as NCSIRS = [1, 2] for < 6 GHz, NCSIRS = [1, 2, 4, 8] for >6 GHz. In another example, single maximal TX beam numbers reported by a WTRU per reporting instance may be band-independent such as e.g. KCSIRS = [1, 2, 4, 8].

[001 97] Different configurations may be utilized for NCSIRS where a larger value of NCSIRS may be configured by a TRP or gNB for PUSCH based reporting and a smaller value may be configured for PUCCH reporting. A larger value may be configured for a P-2 procedure and a smaller value may be configured for a P-1 procedure. A larger value may be configured for aperiodic reporting and a smaller value may be configured for semi-persistent or periodic reporting. Moreover, NCSIRS may be different for associated reporting contents. For example, a large value may be configured for less measurement quantities to be reported, such as with differential L1-RSRP reporting, while a small value may be configured for more measurement quantities to be reported, such as with absolute or regular L1-RSRP reporting. Similar to other example given herein, a subset of N (<= NCsiRs) beams may be selected by the TRP or gNB and indicated to the WTRU by higher layer signaling, RRC signaling, MAC-CE, L1 signaling, a DCI, or the like for reporting.

[001 98] For L1-RSRP levels, maximal L1-RSRP range and step-size of a L1-RSRP on a SS block and CSI-RS may be similar or different and may depend on the number of beam to be measured and reported on SS block and CSI-RS, desired signaling overhead, or the like. For example, with larger beam-widths on a SS block a L1-RSRP level may be less or equal to L1-RSRP on CSI-RS. In addition, the step-size of L1-RSRP on CSI-RS may be larger than the step-size of L1-RSRP on a SS block to reduce overhead when the number of beams measured on a CSI-RS is more than on SS block.

[001 99] Maximal TX beam numbers reported by a WTRU per reporting instance on a SS block or CSI-RS may be similar or different depending on PUCCH based reporting, PUSCH based

reporting, a P-1 procedure, P-2 procedure, P-3 procedure, periodic reporting, or the like. For maximal TX beam reporting or any other parameters given herein, WTRU-specific configuration may be indicated in a WTRU-capability information element.

[00200] For beam resource indicators, CRI reporting, SS block index reporting, L1-RSRP reporting, periodic reporting, aperiodic reporting, or the like for BM, a WTRU may use different UL channels, a short PUCCH, a short PUSCH, a long PUCCH, a long PUSCH, or the like. For example, for periodic beam reporting, a WTRU may be configured for long PUCCH and short PUCCH reporting. For semi-persistent beam reporting, a WTRU may be configured for short PUCCH, long PUCCH, and PUSCH. For aperiodic beam reporting, a WTRU may be configured for a short PUCCH and PUSCH.

[00201] A beam reporting prioritization map shown in Table 19 may be configured to optimize the beam reporting for low overhead or energy consumption. Based on the beam reporting prioritization map, a WTRU may be configured for multi-level beam reporting for different WTRU conditions such as a configured UL channel, WTRU speed, WTRU service type, or the like.

Beam Reporting Content	Priority Value (lower value means higher priority)	Priority Rule
The best X1 beams with L1-RSRP value above Y1 dB	2	X and Y are configurable depending on the capacity of used UL channel, WTRU remaining battery, WTRU moving speed, WTRU service type, and the like
The best X2 new beams (the new beams are the beams that have not being part of previously reported beams.)	3	Same as above, plus that this priority value is only applied for aperiodic beam reporting
The best X3 beams with threshold L1-RSRP value higher than the serving beam (s)	1	Same as above
…	…	…

Table 19

[00202] When both beam reporting and CSI-reporting are transmitted on a short PUCCH, due to the capacity limit of one short PUCCH, the WTRU may be configured to report just the beam reporting content with a higher priority than a pre-determined or configured value. By signaling a low priority value for the same L1 signaling triggering aperiodic beam measurement reporting, a large size of beam reporting may be configured. This configuration may apply for aperiodic beam reporting if the aperiodic beam report is transmitted on PUSCH since it is a single event and the PUSCH has a larger payload capacity than a short PUCCH. In certain configurations, for aperiodic

reporting with low delay, a WTRU may report content with high priorities on a short PUCCH with low payload capacity. For UL transmissions, a WTRU may be configured for SRS transmissions with beam reporting and CSI reporting.

[00203] Optimization rules may be configured to reduce transmission overhead and possible conflicts. For instance, when the total payload size of CSI reporting and beam reporting is above the capacity of a short PUCCH, a conflict may exist when the available number of OFDM symbols within a slot is insufficient to transmit both SRS and PUCCH. Scalable multi-level beam reporting may be utilized by a WTRU to avoid these and other conflicts.

[00204] Aperiodic transmissions, beam reporting, CSI-reporting, SRS, or the like may be configured for higher transmission priorities than periodic transmissions. A PUCCH, short PUCCH, or long may have higher transmission priorities than PUSCH and SRS transmissions. At the time of a collision, a channel may be partially dropped in the time domain. For example, SRS transmissions may be partly overlapped with a PUCCH, short PUCCH, or long PUCCH and only SRS symbols overlapped with PUCCH, short PUCCH, or long PUCCH are not transmitted. When aperiodic transmissions are delivered, the next scheduled periodic or semi-persistent transmission may be skipped. In certain configurations, aperiodic beam reporting may be triggered per urgent request and periodic reporting may be utilized during periods of slow channel variation.

[00205] FIG. 16 is an example 1600 of unified beam measurement and reporting. In 1600, unified beam measurement and reporting on multiple reference signals, such as joint or independent L1-RSRP reporting on CSI-RS and SSB, based on a power offset indication is shown. In 1600, a WTRU may receive a unified beam configuration for beam measurement and reporting on a SS block and CSI-RS (1602). Beam measurements may be performed based on the configured RSs (1604). If a trigger is met for beam reporting (1606), a determination may be made based on whether a single RS is configured or not (1612). Otherwise, a determination may be made to send a request to a TRP or gNB for measurement assistance (1608) and a request for measurement assistance info is received (1610) to perform additional measurements. If a request for measurement assistance info is not sent, additional measurements may be performed. The WTRU may request the TRP or gNB for measurement assistance for supplementary RS transmissions in time division multiplexing (TDM) or frequency division multiplexing (FDM).

[00206] If a single RS is configured, a beam measurement and report of a single RS may be performed (1614). If more than a single RSs or multiple RSs are configured, a power offset, such as by the network, may be configured/indicated and joint or independent measurement and reporting (1618) may be performed based on the indicated power offset. Otherwise, join or independent measurement and reporting (1624) may be performed without an indicated power offset.

[00207] For joint measurement and reporting with a power offset, joint measurement and reporting may be performed using a unified baseline RS reporting (UBRR) (1620). UBRR may be performed for accurate measurement and reporting by a WTRU with joint L1-RSRP on a SS block and CSI-RS based on a baseline RS and an indicated power offset with respect to the baseline RS. In UBRR, measured L1-RSRP values by a WTRU may be converted to a value range of a configured baseline RS.

[00208] For independent measurement and reporting with a power offset, flexible independent beam reporting (FIBR) (1622) may also be performed. In FIBR, a WTRU may perform separate measurement on a SS block or CSI-RS, but report measurement results from one RS, SS block, or CSI-RS or two reference signals based on the indicated power offset.

[00209] For joint measurement and reporting without a power offset, joint reporting unified measurement reporting (UMR) (1626) may be utilized. A WTRU may perform coarse measurement such as with a simple average on multiple RSs, and report joint L1-RSRP on multiple RSs with UMR. For UMR, a WTRU may perform separate measurements on a SS block or CSI-RS, but report joint or consolidated results. An example of a consolidated result may be a linear average of L1-RSRP values from a SS block or CSI-RS for the same beam.

[00210] For independent measurement and reporting, without a power offset, independent beam reporting (IBR) (1628) may also be utilized. In IBR, a WTRU may perform separate measurements on a different RSs, SSBs, CSI-RSs, or the like. For this configuration two measurement results on SSB or CSI-RS may be reported separately or independently.

[00211] After the beam measurement and reporting procedure is performed and determined, the WTRU may report joint or independent L1-RSRP reporting on a SS block and/or CSI-RS via the unified beam reporting format. A unified beam report format may include a beam ID (e.g., differential or absolute beam ID), RS type (e.g, SSB or CSI-RS), measurement quantities (e.g., L1-RSRP value or differential L1-RSRP value), reporting type (e.g, joint or independent L1-RSRP reporting), or the like.

[00212] In the examples given herein, a WTRU may receive unified BM configurations for beam measurement and reporting from the network. Configurations may include minimum SI from broadcast, RRC configurations and the like. The configuration may include at least a RS, triggers for beam reporting, L1-RSRP thresholds, a reporting setting, a power offset, a reporting type, or the like. Configurations may be based on a mapping table that maps RS type, periodicity, beam width, on-demand reporting, active reporting, periodical reporting, aperiodic reporting, semi-persistent reporting, event triggers, or the like. Examples of configurations are given in Table 3 and report settings and possible measurement resources/report setting given in FIG. 11 and FIG. 12.

[00213] In the examples given herein, a WTRU may be configured by a network for periodic beam measurement and reporting. A WTRU may also be requested by a network to perform aperiodic or semi-persistent beam measurement and reporting. In a WTRU triggered case, a WTRU may utilize actively triggered beam measurement and reporting. For example, the WTRU may utilize a signal request for beam training, measurement, or beam reporting. The WTRU may also be configured to terminate current beam training procedures. Event triggers may be configured and defined by utilizing a RS-specific timer and threshold values. Measurement configuration settings, such as in table 2 and table 3, given herein may be utilized. For certain configurations, if the trigger is not satisfied (e.g., L1-RSRP not above a threshold), the WTRU may request explicitly or implicitly to the network TRP or gNB for measurement assistance for supplementary RS transmissions using TDM or FDM. FIG. 9 shows an example 900 of supplementary RS transmissions.

[00214] During beam measurement, overall bandwidth of the measured RS may be considered and a minimum measurement bandwidth may be configured. For example, measurement results may reflect accurate beam quality information when the measured reference resources occupy minimum bandwidth. Due to a minimum bandwidth, one or more of the combination of measurement RS resources, QCL different RS resources, or the like may be utilized. In an example, WTRU-specific configured CSI-RS resources may go beyond a minimum bandwidth. To meet the minimum bandwidth with FDM, both SS block resources and CSI-RS resources may be transmitted over the same symbols. To meet the minimum bandwidth with TDM, S block resources and CSI-RS resources may be transmitted over the different symbols. A minimum bandwidth for BM and CSI acquisition may be different or similar. When CSI-RS or SS block resources meet a minimum bandwidth requirement, measurement on a single RS may trigger beam measurement reporting.

[00215] In examples given herein, for BM and CSI acquisition, different or similar CSI-RS configurations may be used. If CSI-RS configurations are used for BM, additional configurations may or may not be needed to differentiate whether beam measurement or CSI acquisition is performed or possible time instances.

[00216] If either CSI-RS or SSB resources meet a minimum bandwidth requirement, measurement on single RS may be sufficient to trigger beam measurement reporting. In certain configurations, a WTRU may send a request of measurement assistance related to a minimum bandwidth and amount of CSI-RS resources or sets. This may be performed during P-1 and P-3 procedures due to RX beam sweeping. For a different number of swept WTRU RX beams, the number of CSI-RS resources within a CSI-RS resource set may be different during a P-3 procedure. For instance, one CSI-RS resource may be transmitted over one beam. The number of CSI-RS

resource sets may also be different during a P-1 procedure. For instance, a WTRU may use the same RX beam within a network TX beam sweeping period but use a different RX beam when network switches to the next TX beam sweeping period.

[00217] As given in examples herein, if a trigger is satisfied after measurements of a single RS, SS block, or CSI-RS, the WTRU may perform beam measurement reporting of L1-RSRP of the single RS. If a trigger is satisfied after measurements on multiple RSs, SS blocks, CSI-RSs, or the like, the WTRU may perform joint or independent L1-RSRP reporting on the CSI-RS and SS block based on a power offset indication from a network, TRP, gNB, or the like.

[00218] Referring again to FIG. 16, once a reporting procedure is determined, the WTRU may report joint or independent L1-RSRP of a SS block and/or CSI-RS via the unified beam reporting format. As one example, a unified beam report format may include one or any combination of a beam ID with differential value or absolute value (i.e., differential beam ID or absolute beam ID/regular beam ID/beam ID), RS type of SSB type or CSI-RS type, measurement quantities of L1-RSRP value, differential L1-RSRP value, RSRP values, or RSRQ values, reporting type of join or independent L1-RSRP reporting, or the like.

[00219] In a configuration, a unified beam indication for beam measurement, beam-based transmission, or beam switching may be explicitly signaled to a WTRU via a RRC message, a MAC-CE or NR-(e)PDCCH, NR-DCI, DCI fields, random access response (RAR) grant, or the like. A unified beam indication from a TRP or gNB may include a beam to utilize for WTRU data reception, a unified beam measurement for beam tracking, transmission, or switching, a number of beams and associated RS to be measured and reported by a WTRU, a type of beam measurement quantity for WTRU reporting, or the like. A unified beam indication may also be a bit-map with one or more fields to indicate a RS type indicator, the number of beams and associated beam measurement quantities, RSRP, CSI, or the like.

[00220] In some configurations, a unified beam indication may be implicitly signaled since a TRP or gNB may be unaware of WTRU's measurement capability. For example, instead of explicitly signaling the number of beams or beam groups to be measured and reported by a WTRU, different thresholds for the associated beam measurement quantities such as SS-RSRP, CSI-RSRP, DMRS-RSRP, or the like may be also signaled to the WTRU for reporting to a TRP or gNB.

[00221] An N-bit indicator field in a DCI may be used for a spatial QCL reference to a DL RS, CSI-RS SS block, or the like for demodulation of a downlink channel, PDCCH, PDSCH, or the like. An indicator may be an indicator state associated with an index of the DL RS, CRI, SS block, or the like. For CSI-RS, the resource may be periodic, semi-persistent, aperiodic, or the like. The DL RS index may be associated with the indicator state through explicit signaling or implicitly during a

WTRU measurement. As an example of implicit signaling, a network may configure a subset of DL RSs for measurement for a WTRU, and the WTRU may establish an association between a DL RS index and an indicator state based measurement results. The N-bit indicator may be a function of a TCI and communicated in a DCI field size. The field size for the TCI may be pre-specified as a fixed value or configured by higher layer signaling, RRC signaling, MAC-CE, or the like.

[00222] A WTRU may be RRC configured with a list of up to M TCI states for QCL indication. In certain configurations, M may be equal to or larger than 2^N, where N is the size of the N-bit TCI state field in DCI. Since the total number of DL RSs index, CRI, SS block index, or the like may be above 2^N, the value of M may be larger than 2^N and the mapping between actual TCI states to the states described by N-bit DCI field may utilize a hierarchical group-based or three-stage mapping.

[00223] In a hierarchical group-based mapping, a full set of DL RS indexes may be divided into several groups according to pre-defined or configured rules. Rules may include a spatial QCL reference or RS type such as SS block, periodic CSI-RS, aperiodic CSI-RS, semi-persistent CSI-RS, or the like. A WTRU may be configured to measure and report a subset of groups of DL RS indexes. In this configuration, the total number of the configured DL RS index may be a one-to-one mapping to the number of states indexed by N-bit TCI field. For example, a WTRU may be configured to measure 7 DL RSs to be indexed by a 3-bit ($23 = 8 > 7$) indicator field in DCI. If a full set of DL RS indexes is 10, it may be divided into two groups based on RS type where a first group may include 4 DL RS indexes for SS block and a second group may include 6 DL RS indexes for CSI-RS.

[00224] Moreover, a WTRU may be configured to measure the first group of 4 DL RS that may be indicated by 2 bits for 4 DL RS indexes in 3-bit TCI field. The remaining 1 bit may be reserved to indicate the group or grouping rule. The second group of 6 DL RS indexes may be indicated by 3-bit TCI field. Another grouping rule may be a QCL DL RS, such as 7 DL spatially QCL RSs, is grouped together and indexed by a 3-bit ($2^3 = 8 > 7$) indicator field in DCI. If TCI states, where each state may be associated with a DL RS set, have associated QCL configurations, they may be mapped to the same N-bit TCI state field in DCI. Associated QCL configurations may be DL RS(s) carried in the RS set of one TCI state includes a QCL with DL RS(s) carried in the RS set of another TCI state.

[00225] A three-stage mapping may comprise a RRC configuration in a first stage, MAC-CE activation or deactivation in a second stage, and DCI field indication in a third stage. In addition, a WTRU may be RRC configured with a DL RS pool. The network may use a MAC-CE to dynamically

activate or deactivate a subset of DL RSs within the DL RS pool. The size of the dynamically activated DL RSs may be indexed by an N-bit TCI field in a DCI.

[00226] TCI states may be used as QCL references for the reception and demodulation of PDSCH. For a PDSCH, the QCL reference may be dynamically indicated by a TCI field carried in DCI. A TCI field may be present when a TCI state is configured. For example, a WTRU may contain one fixed RX beam or omni-beam without DL RX beam sweeping. TCI states may also be QCL references for monitoring or reception of a PDCCH.

[00227] A WTRU may be configured with multiple resource control resource sets (CORESETs), and if a subset or all of the configured CORESETs are linked with a TCI state or multiple TCI states, the QCL references indicated by the one or more TCI states may be also used for a PDCCH. Unlike a TCI state used for a PDSCH that may be indicated by a L1 DCI, for a PDCCH the TCI state that is used for a CORESET may be configured or signaled by a reference carried in higher layer signaling, RRC signaling, a MAC-CE, RRC signaling and a MAC-CE, or the like. A PDCCH CORESET configuration may also be semi-statically configured.

[00228] In NR configurations, QCL setups may apply across carriers and bandwidth parts (BWPs) for the DL. For high frequency (HF) carrier aggregation, if two transceivers are co-located and two frequencies are close in value, the two HF carriers may have a similar power distribution in the spatial domain. In this configuration, BM information in a first HF CC may be, at least partly, utilized in the second HF CC reducing overhead for the second CC.

[00229] When NR is configured for wider bandwidth for higher capacity, the network, TRP, or gNB may configure the active bandwidth dynamically from one BWP to another BWP with or without overlap. During dynamic bandwidth adjustment, SS block resources and CSI-RS resources may or may not be present. When both SS block and CSI-RS resources are available within a new BWP, the WTRU may need the indication of the spatial QCL parameter across BWPs. If a spatial QCL configuration is applicable between the SS block and CSI-RS resources, the QCL SS block and CSI-RS resources may be transmitted over the same beam indicating that both joint and independent L1-RSRP reporting using a QCL SS block and CSI-RS are being utilized by the WTRU. Examples of joint L1-RSRP reporting are described above. If the spatial QCL configuration is not applicable between the SS block and CSI-RS resources, a WTRU may utilize independent L1-RSRP reporting.

[00230] FIG. 17 is an example 1700 of beam measurement and reporting outside of active BWPs. In 1700, configured BWPs 1-3 may be configured for robust transmissions in case some BWPs are fully used, blocked, reserved, or the like. In certain configurations, configured BWP 2 may be active. BWPs 1-3 may also allow flexible capacity requirements when a WTRU requests different

capacities for different applications or service types. The WTRU may switch one or more active BWPs dynamically for robustness, capacity, or the like by DCI-based or timer-based switching. Before switching, the WTRU may determine QoS for different candidate BWPs for appropriate selection. The WTRU may be configured or indicated by higher layer signaling, RRC signaling, a MAC-CE, a DCI, or the like to explicitly or implicitly measure BWPs outside active BWPs.

[00231] A bandwidth resource of CSI-RS may be smaller than a BWP and a BWP may or may not contain a SS block. A size of a BWP may range from the SS block bandwidth to the maximal bandwidth capability utilized by a WTRU for a CC. As such, a WTRU may perform beam measurement and reporting over multiple BWPs, including both active BWP(s) and non-active BWPs, by considering one type of RS or multiple types of RSs. These RSs may include a periodic CSI-RS, aperiodic CSI-RS, a semi-persistent CSI-RS, a SS block, or the like.

[00232] In Table 20, a WTRU may be configured with a spatial QCL relationship among different CCs, such as CC1 and CC2, and indicate that TCI state 0 is maintained for CC1 to be utilized for another QCL CC2. A gNB may signal in DCI that for TCI state 0 a WTRU is to use CRI #0 in CC1. This configuration may be utilized by the WTRU for subsequent BM and data and control transmission in CC2. In the RS set associated with TCI state 0, two DL RSs in CRI #0 and SSB #1 may be in the same QCL. These two indexes may point to the same beam and BM based on TCI state 0 that may indicate that the WTRU is to utilize joint L1-RSRP reporting using QCLed SS block and CSI-RS.

TCI State	RS Set(s)	Used for PDCCH	Used for PDSCH	Associated Component Carriers (CCs)
0	Set 0: CRI #0, SSB #1 (QCL)	Y	Y	CC1, CC2
1	Set 1: CRI #2, SSB #3 (not QCL)	Y	Y	CC1
…				

Table 20

[00233] Spatial QCL relationships among different CCs may be obtained by a WTRU from SI in initial access. A QCL relationship may be related to WTRU capability, CCs related to a WTRU, or the like. QCL information may be obtained after a WTRU capability report is received from the network. A WTRU in RRC connected mode may be configured to measure and report on multiple CCs. Due to the dynamically changed propagation environment observed by a WTRU, including mobility, blockage, multi-path, reflection, or the like, a gNB may utilize WTRU feedback to dynamically update or indicate the spatial QCL information among different CCs. Updating may be performed by a higher layer signal, RRC signaling, a RRC message, a MAC-CE, a DCI, or the like.

A measurement report or spatial QCL information may be signaled on a higher layer signal, RRC signaling, a RRC message, a MAC-CE, a UCI, or the like from the WTRU to the gNB. Similarly, a WTRU may be RRC configured with the spatial QCL parameter across multiple BWPs so that the WTRU may perform joint or independent L1-RSRP reporting using a QCL SS block and CSI-RS.

[00234] QCL relationship among different CCs may also be signaled to a WTRU when a new CC is activated. For example, the QCL configuration across carriers for DL may be signalled by the primary CC or the primary serving cell. Similarly, the QCL configuration or relationship among BWPs may be also signaled when a BWP is activated. For example, the QCL configuration across multiple BWPs may be signalled over the middle BWP located at the carrier frequency. The signaling may be higher layer signaling, RRC signaling, a MAC-CE, or RRC signaling and a MAC-CE for high reliability. The signaling may also utilize lower layer signaling, such as DCI, for low overhead with less reliability.

[00235] As shown in Table 20, a TCI state may include one or multiple DL RS indexes and utilize single-beam or multi-beam transmission configurations. For example, TCI state 0 may refer to one DL RS index, where CRI #0 and SSB #1 may be the same beam, and TCI state 1 may refer to two DL RS indexes CRI #2 and SSB #3. When one DL RS ID is included within a RS set referred by a TCI state, single-beam transmission, single TRP, single panel, or the like may be utilized. When multiple DL RS IDs, such as two DL RS IDs, are included within a RS set, simultaneous multi-beam transmission, multi-TRP, multi-panel, or the like may be utilized. More than one RS set per TCI state may be also configured to utilize more than one DMRS port group for a PDSCH.

[00236] A multi-beam indication may also be configured as a multi-bitmap in a DCI or MAC-CE. For example, the length of a multi-bitmap may indicate the number of multiple beams and each bit may indicate one beam or one DL RS ID. A multi-dimension multi-bitmap for multi-TRP or multi-panel deployments may also be configured with each dimension utilized for one TRP, one gNB, one panel, one group of beams, or the like.

[00237] Moreover, a TCI state may be represented in an N-bit field carried in DCI for PDSCH or PDCCH beam indications. A TCI state or the N-bit indicator field may include additional parameters depending on capacity or overhead. A TCI may include the PDSCH or PUSCH rate matching parameters. In addition, in NR a PDSCH or PUSCH RE mapping may be RRC configured with a large set of potential RE mapping parameters. A MAC-CE signaling may be utilized to reduce or activate a subset of the RRC configured RE mapping parameters. Lastly, PDSCH RE Mapping and Quasi-co-location Indication (PQI) bits carried in a DCI may be utilized to dynamically indicate an actual RE mapping set for a scheduled PDSCH or PUSCH. RE mapping parameters may include

a PDSCH starting symbol, a PUSCH starting symbol, a PDSCH ending symbol, a PUSCH ending symbol, a number of PDSCH symbols, a number of PUSCH symbols, or the like.

[00238] Parameters may be directly related to QCL indication of a TCI state. The timing regarding when the QCL is applied relative to the time of the QCL indication may vary. For instance, a value of time delay, a number of slots, a number of symbols, or the like may be configured for the timing gap to correctly decode the PDCCH and change or apply the PDSCH beam according to the PDCCH indication. A PDSCH starting symbol may provide a DCI decoding time and beam switching time gap for applying or changing a PDSCH beam. For example, if the value of PDSCH starting symbol is K, K symbols of time may be available for determining the beam for corresponding PDSCH reception.

[00239] FIG. 18 is an example 1800 showing the relationship between starting symbol index or symbol offset to schedule a new radio physical downlink shared channel (NR-PDSCH) and DCI decoding delays or potential beam switching time. The value of K may indicate the starting symbol index or symbol offset (1802) between the DCI and the starting symbol of the corresponding NR-PDSCH allocation. Based on K, a DCI decoding time or beam switching time (1804) may be configured. A value of K may be pre-specified, configured, or indicated by higher layer signaling, RRC signaling, a MAC-CE, or the like and be based WTRU hardware capability, DCI decoding delay, RF tuning delay, beam switching time, or the like. The value of K may implicitly represent a threshold value for a time delay accounting for TCI decoding time, decoding time for a DCI having a TCI, RF tuning time, beam switching time, or the like. For example, a WTRU may apply different RX beams for DCI reception and PDSCH reception and may need time to obtain and apply an appropriate RX beam to receive the corresponding PDSCH indicated by the DCI.

[00240] A threshold value may vary depending on WTRU hardware capabilities, a DCI decoding delay, a beam switching delay, carrier frequencies, WTRU specific configurations, a WTRU CORESET, a WTRU search space, WTRU operating numerologies, a symbol length, WTRU service types, URLLC operation, or the like. The value of K may be bigger or smaller than a threshold value. When the value of K is bigger than the threshold value, a WTRU may have appropriate time to obtain and apply the indicated beam of a DCI. When the value of K is smaller than the threshold value, with limited time a WTRU may rely on one or more pre-configured beams or utilize pre-defined configurations or rules to determine an appropriate RX beam for reception of corresponding a PDSCH. The pre-configured beam or beams and pre-defined rules may be explicitly configured to a WTRU using higher layer signaling, RRC signaling, broadcasted SI, unicast SI, or the like. In certain configurations, the value of K may represent the scheduling offset of the PDSCH allocation and be included in the same scheduling assignment DCI which carries the TCI

state. In this configuration the value of K is carried inside of the TCI state field or outside of the TCI state field in a DCI.

[00241] FIG. 19 is an example 1900 of a starting slot index or slot offset to schedule NR-PDSCH for different slot or cross-slot scheduling. In 1900, the value of K may indicate starting slot index or slot offset (1902) if cross-slot scheduling of a DCI and corresponding NR-PDSCH allocation are configured. Based on K, a DCI decoding time or beam switching time (1904) may be available.

[00242] Once there are TCI states configured to a WTRU, the spatial QCL reference or pre-configuration in a TCI state or multiple TCI states may be updated based on WTRU movement, WTRU rotations, WTRU switching of active BWP, WTRU switching of active CC, or the like by explicit or implicit signaling. In certain configurations, a QCL relationship or spatial QCL reference may reflect the beam or spatial RX parameter to be used for beam management or control or data reception.

[00243] Explicit updates may be based on beam measurement reporting from a WTRU, and the network, TRP, or gNB may determine if an explicit update is needed. Updates may be based on a subset or all RS indexes in measurement reporting that are associated with different TCI state(s).). If an explicit update is needed, the network may signal the one or more TCIs and the associated DL RS index or indexes to the WTRU for QCL reference updates in the one or more TCI states.

[00244] A WTRU-initiated spatial QCL reference or configuration update in a TCI state may also be configured. A WTRU may initiate an update instead of a network initiated update. For example, when a WTRU determines degradation of serving beam quality, such as a low L1-RSRP or low SNR, the WTRU may send a specific update request to the network or directly send updated results of beam measurement reporting. Upon receiving the request or updated measurement reporting, the network may be triggered to decide and update the QCL reference or configuration in the one or more TCI states at the WTRU.

[00245] A timing delay when the WTRU is able to apply the updated spatial QCL reference or configuration in a TCI state may be utilized by certain configurations. Once the QCL update is performed at a WTRU, the network may indicate the starting time that the WTRU may apply the updated QCL reference or configuration for demodulation of a channel, PDCCH, PDSCH, or the like. If the QCL update is performed by explicit signaling, a WTRU may take time to process signaling content and update TCI states, and perform beam switching as needed. If the QCL update is performed by implicit signaling, a WTRU may inform the network that the update is successfully finished and provide update details. Update details may include the updated spatial QCL references or configuration. A network may need to coordinate scheduling of a PDCCH or PDSCH with a WTRU based on the explicit or implicit signaling.

[00246] If the scheduling offset of a PDCCH or PDSCH is larger than the time delay needed by a WTRU to complete updating of a QCL reference or configuration and beam switching, a WTRU may obtain and apply one or more appropriate RX beams. If the scheduling offset is smaller than the time delay, a WTRU may switch to an appropriate RX beam according to pre-configurations, a pre-defined ruled, or the like before applying the updated QCL reference or configuration. A time delay may be similar or different for a PDSCH and PDCCH when related TCI states are updated. When both PDCCH and PDSCH share the same TCI state, similar time delays may be used for both channels.

[00247] A time delay when the WTRU is able to apply the updated spatial QCL reference or configuration in a TCI state, may be included in the same signaling used to update the spatial QCL reference or pre-configuration of the TCI state. A time delay may be pre-specified, configured or indicated by higher layer signaling, RRC signaling, a MAC-CE, or the like based on a WTRU hardware capability to process the signaling content, resources for updating TCI states and subsequent beam switching, or the like. If a WTRU receives PDCCH or PDSCH based on the updated TCI state after the time delay, the WTRU may apply the new spatial QCL reference or pre-configuration. However, if the WTRU receives PDCCH or PDSCH based on the updated TCI state before the time delay, pre-configurations, pre-specified rules, or the like may be utilized.

[00248] FIG. 20 is an example 2000 of a timing delay when applying an updated spatial QCL reference in a TCI state. In 2000, TCI 001 for a NR-PDSCH (2002) may be received by WTRU RX beam 3. After update of a QCL reference of TCI 001 (2004), a time delay may exist for the WTRU to apply the updated QCL reference in the TCI state 001 (2010). During the delay, a WTRU may be configured to continue applying the old QCL reference or apply a pre-configured QCL reference for PDCCH, PDSCH, or NR-PDSCH (2006) reception. For example, a pre-configuration for a WTRU may utilize a specific pre-configured beam to receive a PDCCH or PDSCH if the updated QCL reference or pre-configuration is not applied. In another example, the pre-configuration may utilize a beam obtained from idle mode, an omni-beam as fall back mode, a primary serving beam, an anchor beam, or the like. If a time delay is sufficient, a WTRU may utilize the updated QCL reference for RX beam 5 to receive a NR-PDSCH (2008).

[00249] The QCL indication may be utilized to indicate spatial QCL relation between different DL RSs. A SS block may be spatially QCL with one or more ports within another a CSI-RS resource for periodic, aperiodic, semi-persistent, or the like reporting. A spatial QCL may be utilized for BM P-1 procedure with CSI-RS resources configured to be spatially QCL with a SS block since P-1 may be utilized to provide coarse beam related information. In another embodiment, a CSI-RS resource may be spatially QCL with another CSI-RS resource for P-2 and P-3 procedures. In this

configuration, beam refinement may be performed and QCL relation may be used to refer to a previously transmitted CSI-RS resources or beams.

[00250] The spatial QCL relation may be configured using higher layer signaling, RRC signaling, or RRC signaling and a MAC-CE. A spatial QCL relation may also be indicated by DCI such as for aperiodic CSI-RS reporting. Since the purposes of QCL indication for PDCCH or PDSCH reception and DL RSs may be different, the DCI field or format may also be different. PDCCH or PDSCH reception and DL RSs may also be jointly indicated and the DCI field or format may be jointly encoded.

[00251] DL beam indication configuration given herein may be applied to UL beam indication. A separate TCI table containing multiple TCI states for UL beam indication may be configured and maintained. Higher layer or RRC signaling may initially configure the QCL association between a TCI state and RS set for the UL. Each TCI state may be a candidate of reference RS which is spatially QCL with a targeted RS, a DM-RS of a PUCCH, a DM-RS of a PUSCH, or the like for UL transmission. Dynamic signaling, higher layer signaling, RRC signaling, a MAC-CE, a DCI, or the like may be used to update relationships between a TCI state, a RS ID, a SRI, a CRI, a SS block index, or the like for dynamic beam indication for UL transmission.

[00252] When beam correspondence between UL and DL is applicable, a RS set may contain just a DL RS ID for efficiency or contain both SRS ID and DL RS ID. Without beam correspondence, the RS set may contain a PRACH preamble, SRS ID, or the like. In another embodiment, a joint TCI table may be configured for both DL beam indication and UL beam indication. In this case, if a RS set referred by a TCI state just contains DL RS IDs, it may indicate that beam correspondence between UL and DL is applicable and the same DL ID may be utilized for both DL and UL QCL reference. Therefore, the WTRU may use the SRS beam with the same direction of the DL RX beam which is paired with the indicated DL RS ID as the UL TX beam.

[00253] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks

(DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

* * *

CLAIMS

What is claimed is:

1. A wireless/transmit receive unit (WTRU) comprising:

a transceiver configured to receive, from a transmission reception point (TRP), configuration information that includes a reporting setting for beam measurement of multiple reference signals (RSs) and a transmission power offset between RSs;

a transceiver configured to measure layer 1 reference signal received powers (L1-RSRPs) of a first references signal (RS) and a second RS of a beam; and

a processor configured to send a joint report or an independent report, wherein the joint report or the independent report is generated on a condition that the measured L1-RSRP of the first RS or the second RS is above a threshold value and based on the transmission power offset.

2. The WTRU of claim 1, wherein the WTRU requests the TRP for measurement assistance for supplementary RS transmissions in time division multiplexing (TDM) or frequency division multiplexing (FDM).

3. The WTRU of claim 1, further comprising the WTRU performs measurement for a joint report of the first RS and the second RS based on a baseline RS and the power offset of the baseline RS.

4. The WTRU of claim 1, wherein the first RS is a synchronization signal (SS)/physical broadcast channel (SS/PBCH) block and the second RS is a channel state information reference signal (CSI-RS) that are on quasi-colocated (QCL) resources within a bandwidth part (BWP).

5. The WTRU of claim 1, wherein the WTRU sends a unified report of the first RS and the second RS and the unified report includes one or more of a beam identification (beam-ID), a reporting type, a RS type, or a L1-RSRP value.

6. The WTRU of claim 5, wherein the reporting type indicates joint reporting or independent reporting.

7. The WTRU of claim 1, wherein an updated transmission configuration indicator (TCI) table is received based on the joint report or the independent report that includes an updated quasi-colocated (QCL) reference for a plurality of component carriers or a plurality of bandwidth parts (BWPs).

8. The WTRU of claim 1, wherein the transmission power offset is between a synchronization signal (SS)/physical broadcast channel (SS/PBCH) block and a channel state information reference signal (CSI-RS) utilized for assistance for beam measurement reporting or beam failure recovery.

9. The WTRU of claim 8, wherein the transmission power offset between the SS/PBCH block and the CSI-RS is used to derive a unified L1-RSRP value on a quasi-colocated (QCL) SSB and CSI-RS for the beam measurement reporting.

10. The WTRU of claim 8, wherein the transmission power offset between the SS/PBCH block and the CSI-RS is used to derive different L1-RSRP thresholds candidate beam selection for the beam failure recovery.

11. A method performed by a wireless/transmit receive unit (WTRU), the method comprising:

receiving, by the WTRU from a transmission reception point (TRP), configuration information that includes a reporting setting for beam measurement of multiple reference signals (RSs) and a transmission power offset between RSs;

measuring, by the WTRU, layer 1 reference signal received powers (L1-RSRPs) of a first references signal (RS) and a second RS of a beam; and

sending, by the WTRU, a joint report or an independent report, wherein the joint report or the independent report is generated on a condition that the measured L1-RSRP of the first RS or the second RS is above a threshold value and based on the transmission power offset.

12. The method of claim 11, wherein the WTRU requests the TRP for measurement assistance for supplementary RS transmissions in time division multiplexing (TDM) or frequency division multiplexing (FDM).

13. The method of claim 11, further comprising performing, by the WTRU, measurement for a joint report of the first RS and the second RS based on a baseline RS and the power offset of the baseline RS.

14. The method of claim 11, wherein the first RS is a synchronization signal (SS)/physical broadcast channel (SS/PBCH) block and the second RS is a channel state information reference signal (CSI-RS) that are on quasi-colocated (QCL) resources within a bandwidth part (BWP).

15. The method of claim 11, further comprising the WTRU sending a unified report of the first RS and the second RS and the unified report includes one or more of a beam identification (beam-ID), a reporting type, a RS type, or a L1-RSRP value.

16. The method of claim 15, wherein the reporting type indicates joint reporting or independent reporting.

17. The method of claim 11, wherein an updated transmission configuration indicator (TCI) table is received based on the joint report or the independent report that includes an updated

quasi-colocated (QCL) reference for a plurality of component carriers or a plurality of bandwidth parts (BWPs).

18. The method of claim 11, wherein the transmission power offset is between a synchronization signal (SS)/physical broadcast channel (SS/PBCH) block and a channel state information reference signal (CSI-RS) utilized for assistance for beam measurement reporting or beam failure recovery.

19. The method of claim 18, wherein the transmission power offset between the SS/PBCH block and the CSI-RS is used to derive a unified L1-RSRP value on a quasi-colocated (QCL) SSB and CSI-RS for the beam measurement reporting.

20. The method of claim 18, wherein the transmission power offset between the SS/PBCH block and the CSI-RS is used to derive different L1-RSRP thresholds for candidate beam selection for the beam failure recovery.

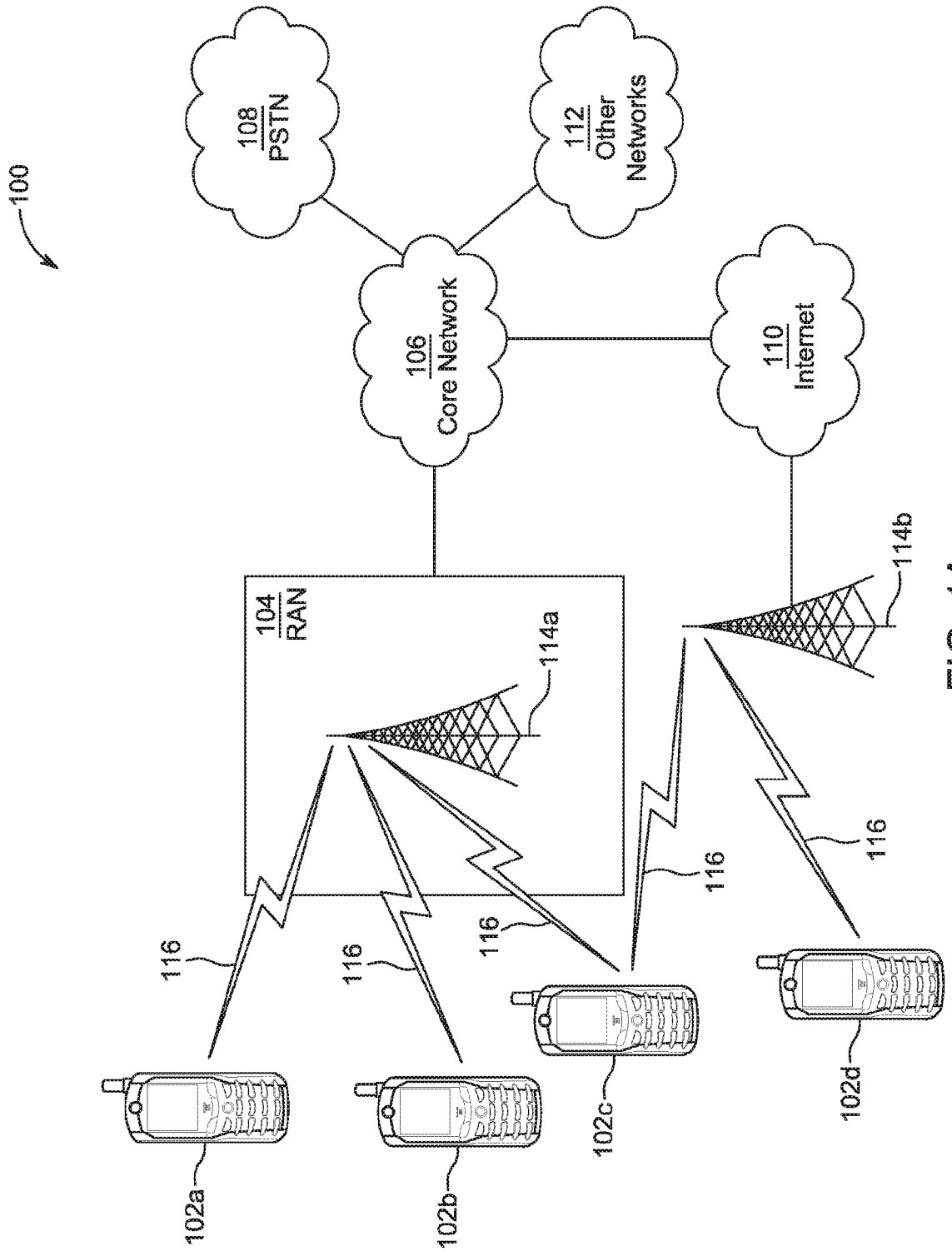

100
108 PSTN
112 Other Networks
106 Core Network
110 Internet
104 RAN
114a
114b
116
116
116
116
116
102a
102b
102c
102d

FIG. 1A

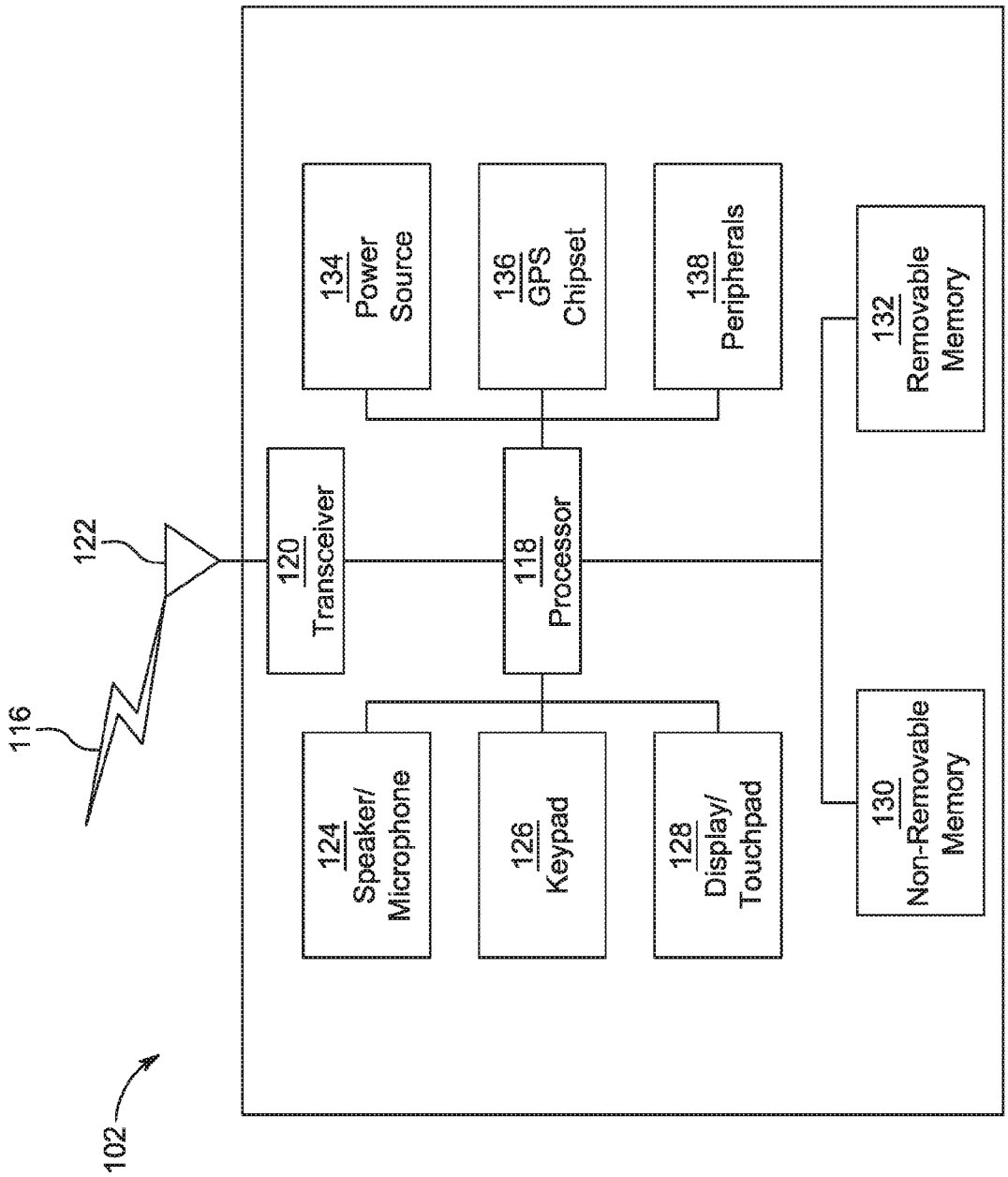

102
116
122
120 Transceiver
118 Processor
134 Power Source
136 GPS Chipset
138 Peripherals
132 Removable Memory
130 Non-Removable Memory
124 Speaker/ Microphone
126 Keypad
128 Display/ Touchpad

FIG. 1B

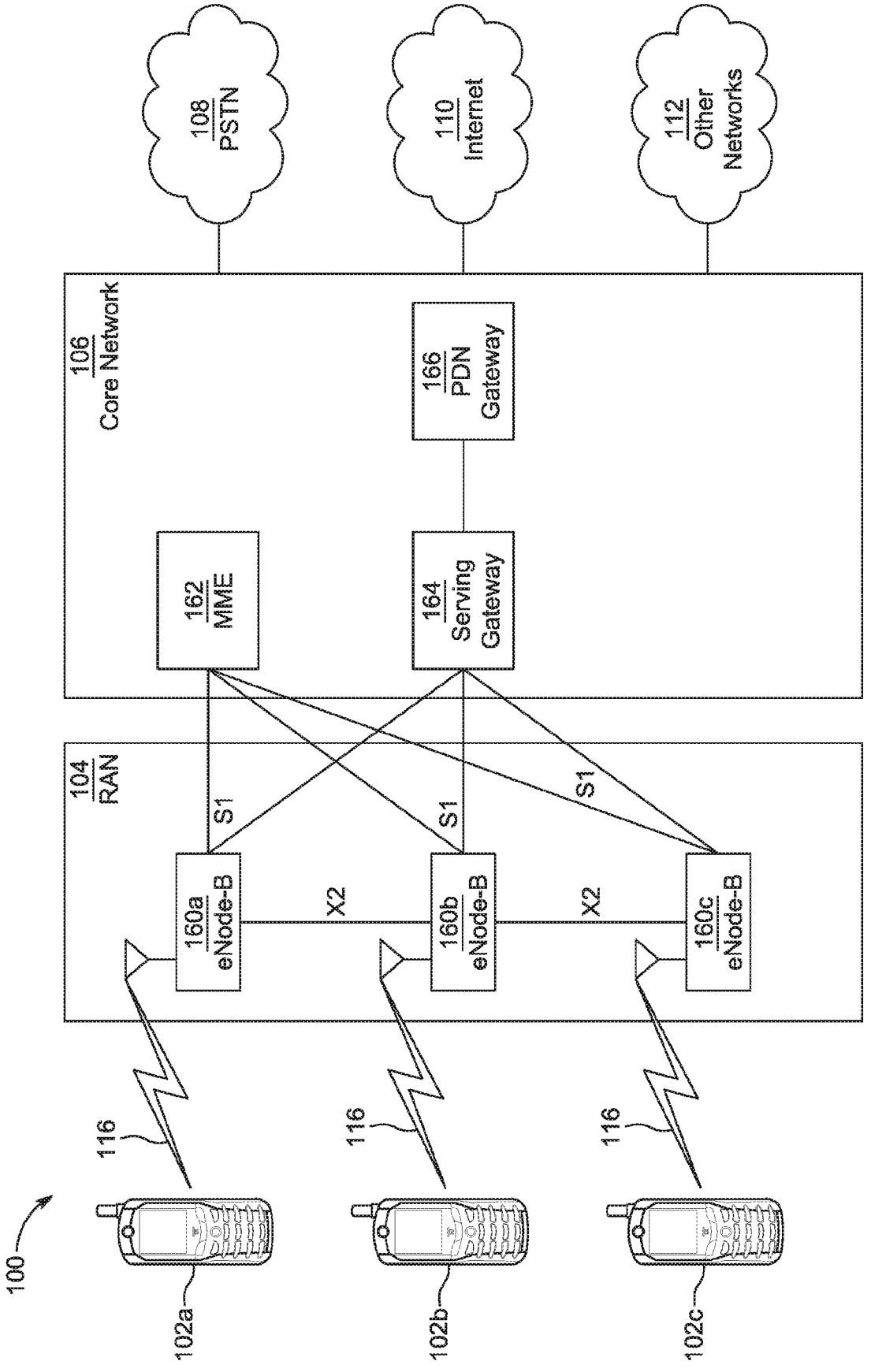

100
102a
102b
102c
116
116
116
104
RAN
106
Core Network
160a
eNode-B
160b
eNode-B
160c
eNode-B
X2
X2
S1
S1
S1
162
MME
164
Serving
Gateway
166
PDN
Gateway
108
PSTN
110
Internet
112
Other
Networks

FIG. 1C

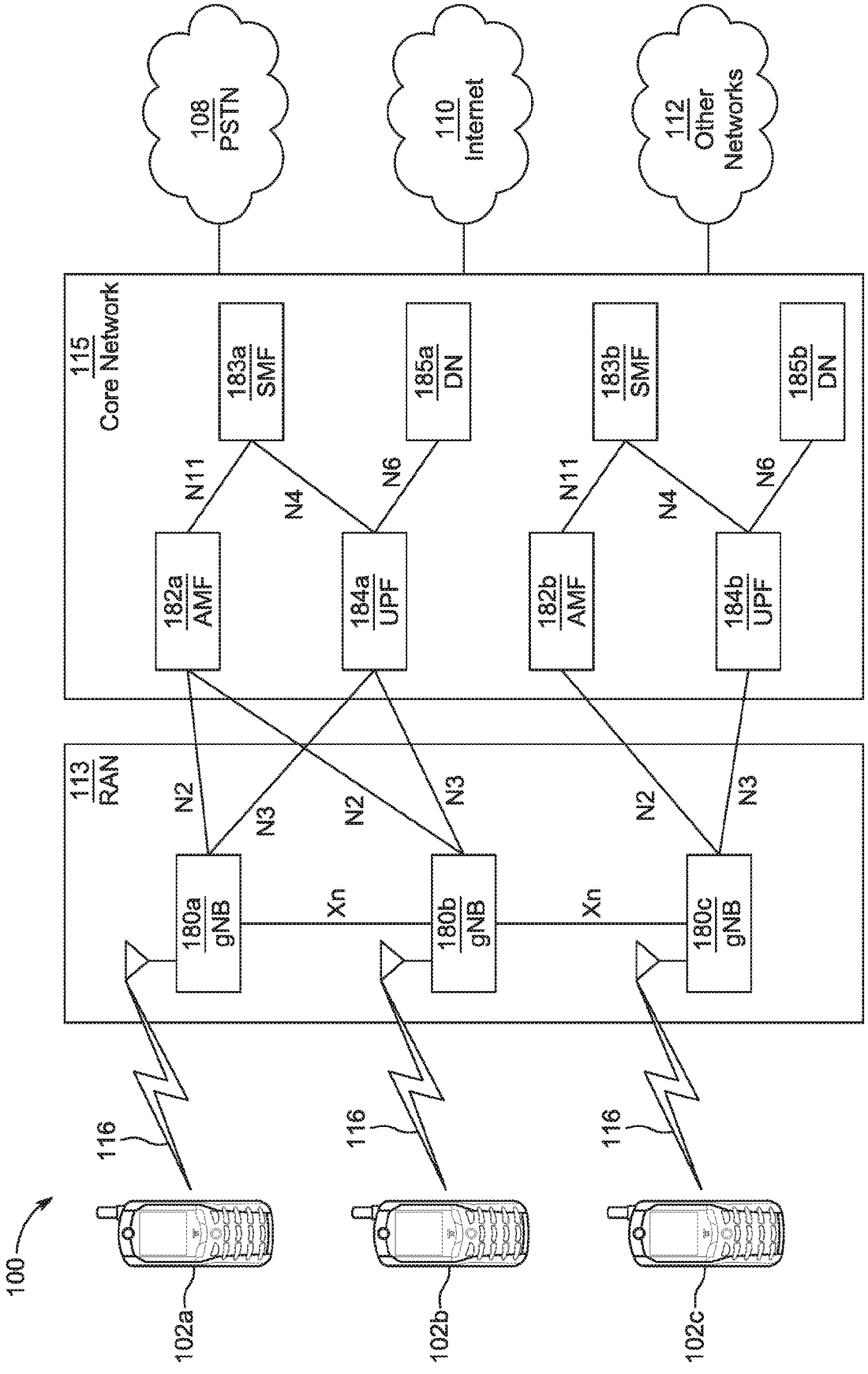

100
102a
102b
102c
116
116
116
113
RAN
115
Core Network
108
PSTN
110
Internet
112
Other
Networks
180a
gNB
180b
gNB
180c
gNB
Xn
Xn
182a
AMF
182b
AMF
184a
UPF
184b
UPF
183a
SMF
183b
SMF
185a
DN
185b
DN
N2
N3
N2
N3
N2
N3
N11
N4
N6
N11
N4
N6

FIG. 1D

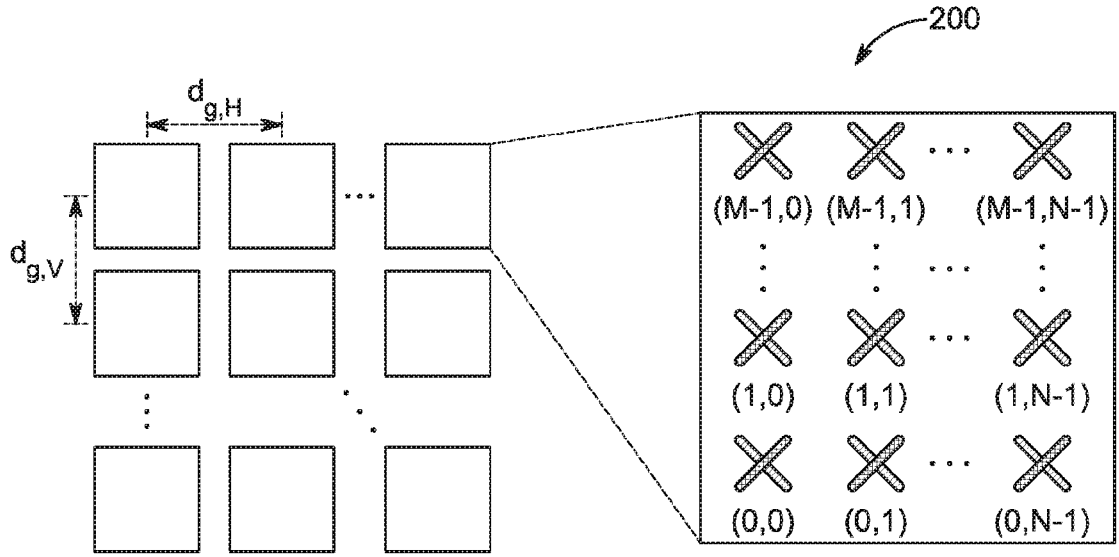

200
$d_{g,H}$
$d_{g,V}$
(M-1,0)
(M-1,1)
(M-1,N-1)
(1,0)
(1,1)
(1,N-1)
(0,0)
(0,1)
(0,N-1)

FIG. 2

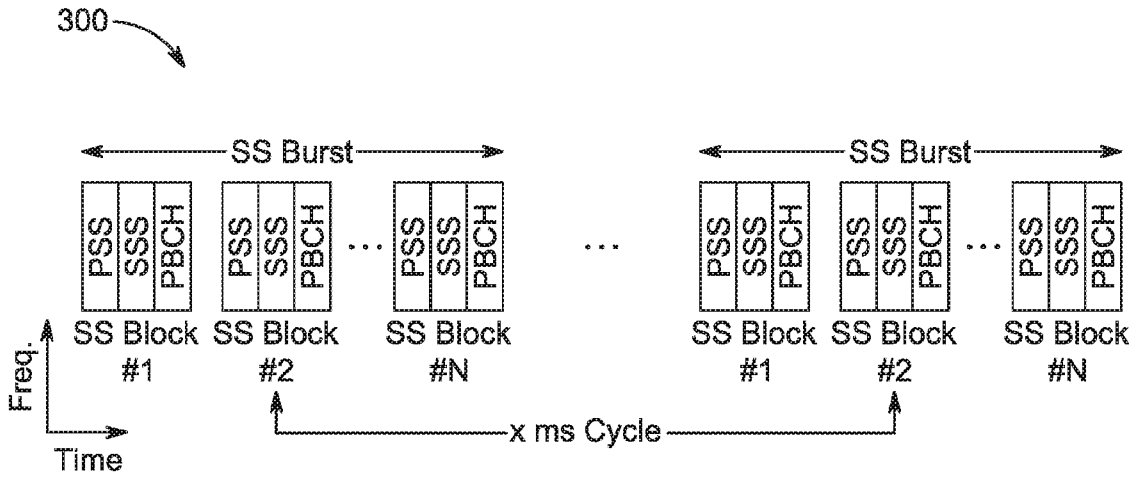

300
SS Burst
SS Burst
PSS
SSS
PBCH
SS Block #1
SS Block #2
SS Block #N
Freq.
Time
x ms Cycle

FIG. 3

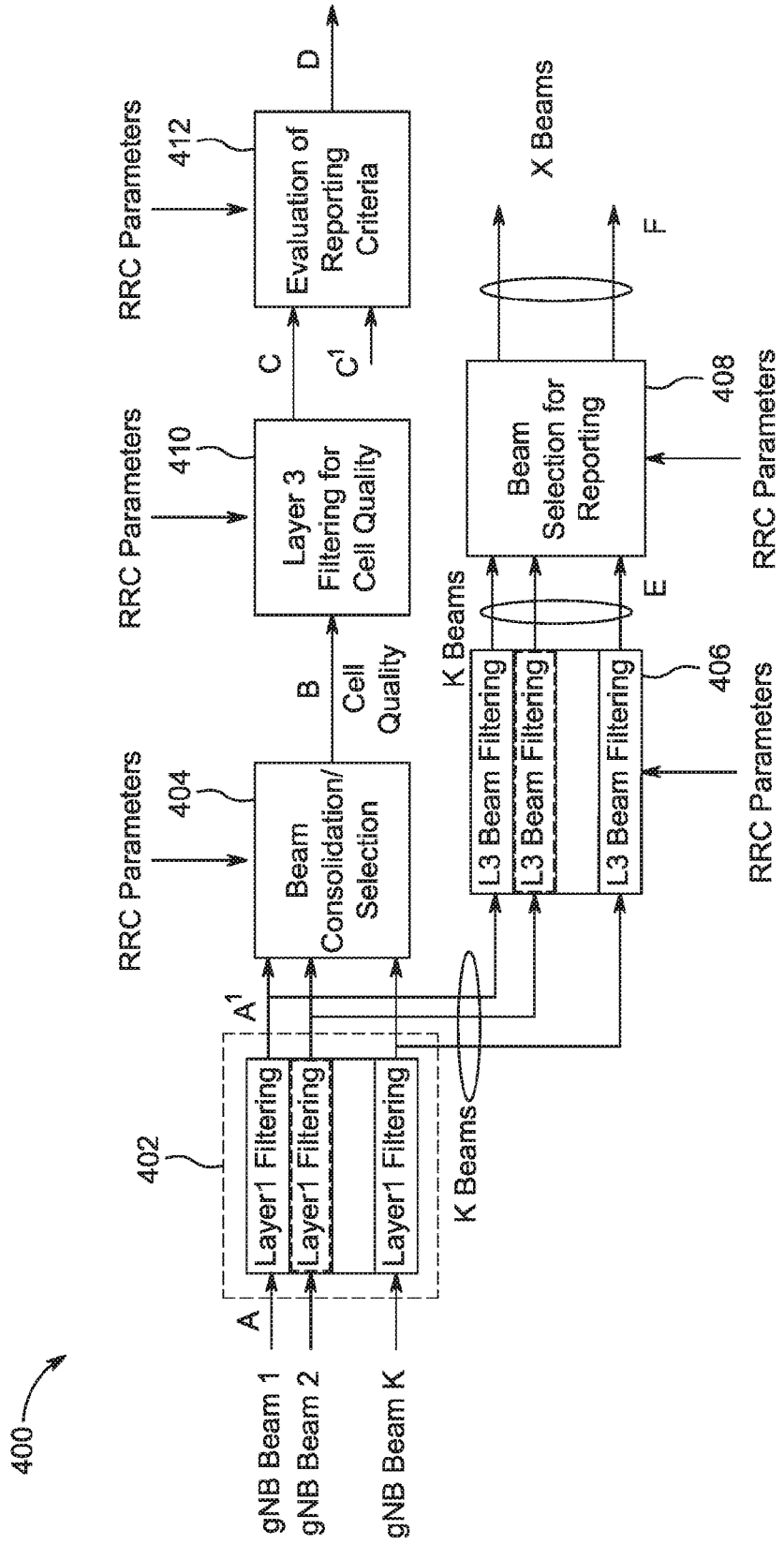

400
gNB Beam 1
gNB Beam 2
gNB Beam K
A
Layer1 Filtering
Layer1 Filtering
Layer1 Filtering
402
A1
K Beams
RRC Parameters
404
Beam Consolidation/ Selection
B
Cell Quality
RRC Parameters
410
Layer 3 Filtering for Cell Quality
C
C1
RRC Parameters
412
Evaluation of Reporting Criteria
D
K Beams
L3 Beam Filtering
L3 Beam Filtering
L3 Beam Filtering
406
RRC Parameters
E
Beam Selection for Reporting
408
RRC Parameters
X Beams
F

FIG. 4

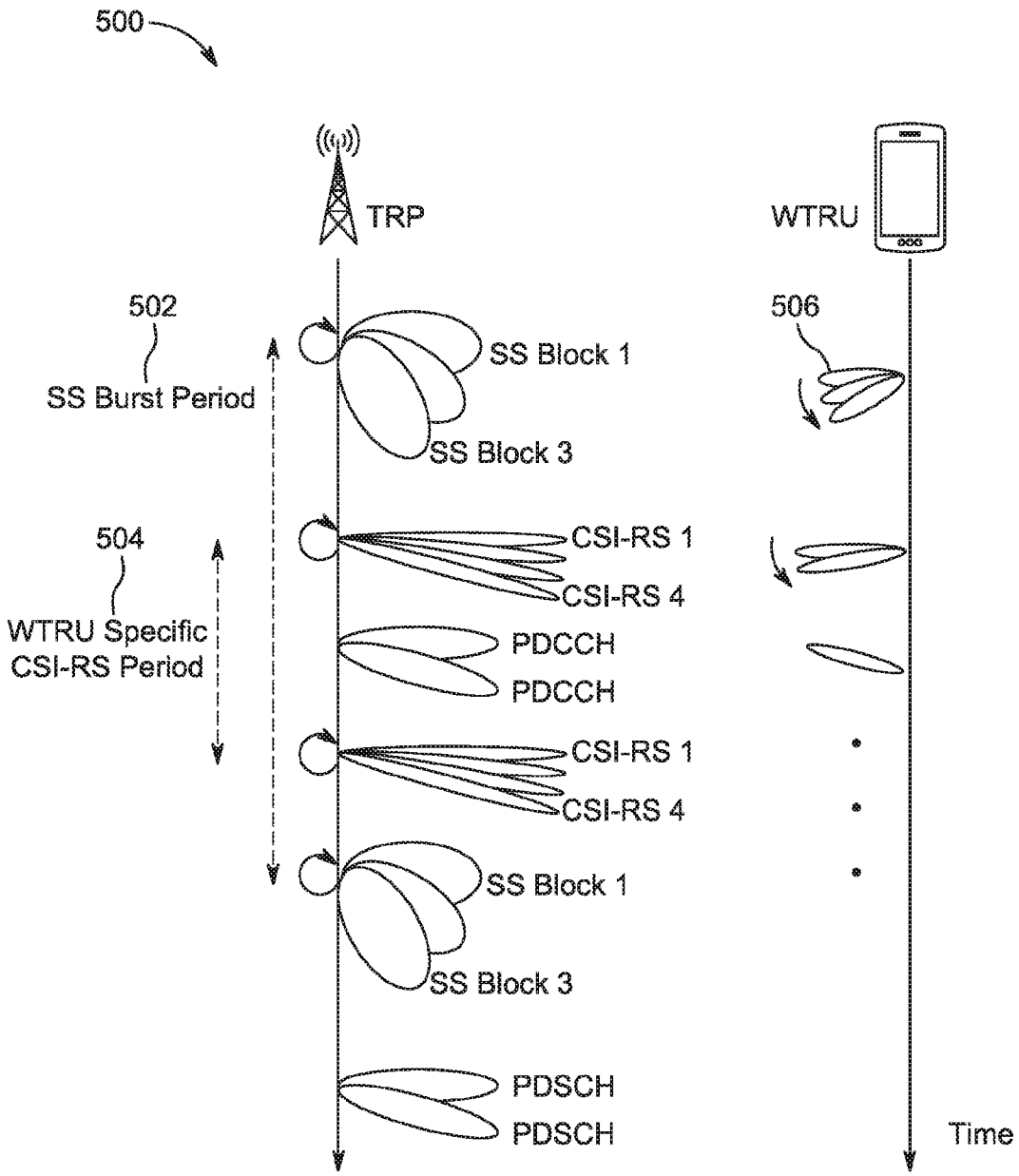

500
TRP
WTRU
502
SS Burst Period
SS Block 1
SS Block 3
506
504
WTRU Specific
CSI-RS Period
CSI-RS 1
CSI-RS 4
PDCCH
PDCCH
CSI-RS 1
CSI-RS 4
SS Block 1
SS Block 3
PDSCH
PDSCH
Time

FIG. 5

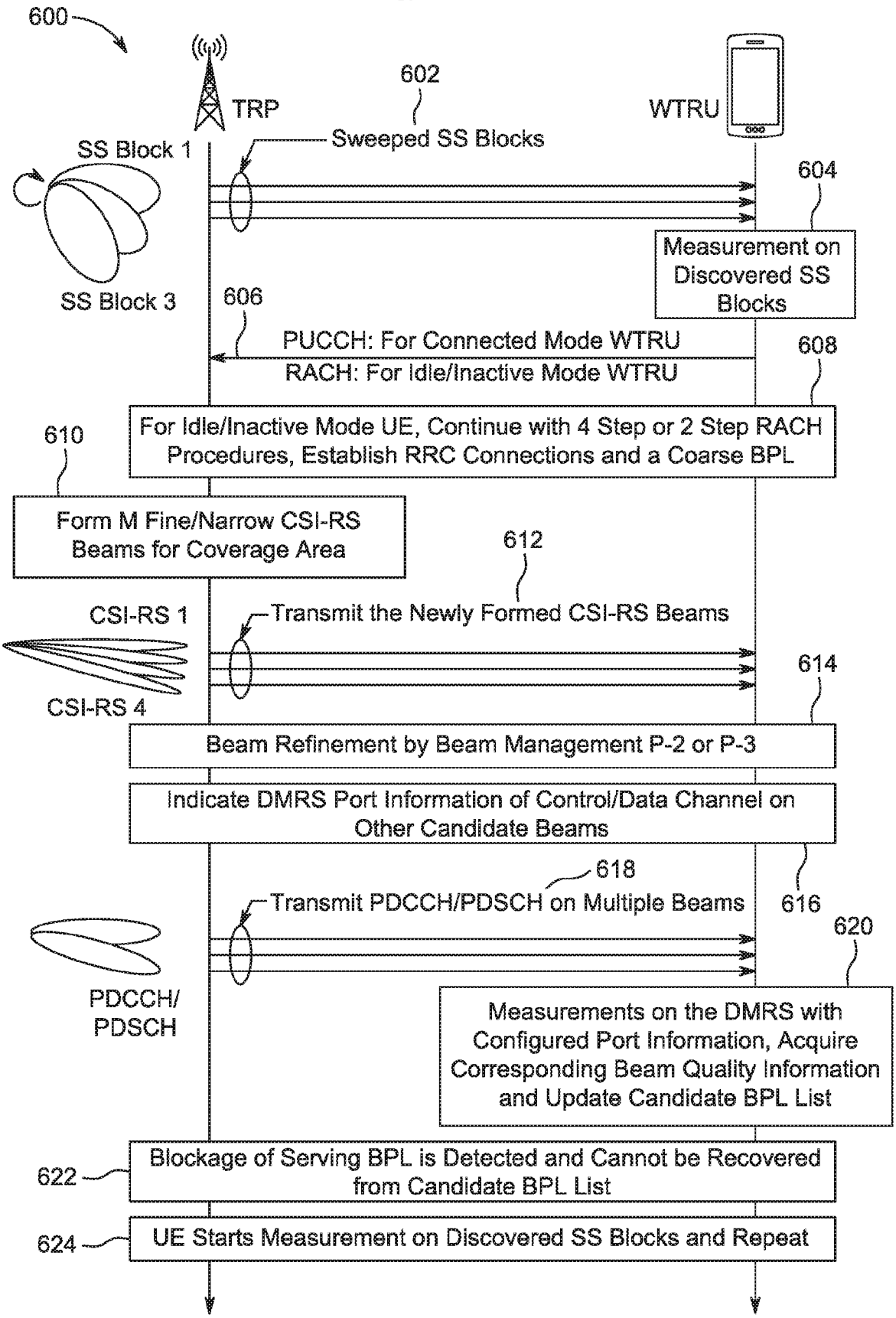

600
TRP
602
Sweeped SS Blocks
WTRU
SS Block 1
SS Block 3
604
Measurement on Discovered SS Blocks
606
PUCCH: For Connected Mode WTRU
RACH: For Idle/Inactive Mode WTRU
608
610
For Idle/Inactive Mode UE, Continue with 4 Step or 2 Step RACH Procedures, Establish RRC Connections and a Coarse BPL
Form M Fine/Narrow CSI-RS Beams for Coverage Area
612
Transmit the Newly Formed CSI-RS Beams
CSI-RS 1
CSI-RS 4
614
Beam Refinement by Beam Management P-2 or P-3
Indicate DMRS Port Information of Control/Data Channel on Other Candidate Beams
618
Transmit PDCCH/PDSCH on Multiple Beams
616
620
PDCCH/ PDSCH
Measurements on the DMRS with Configured Port Information, Acquire Corresponding Beam Quality Information and Update Candidate BPL List
622
Blockage of Serving BPL is Detected and Cannot be Recovered from Candidate BPL List
624
UE Starts Measurement on Discovered SS Blocks and Repeat

FIG. 6

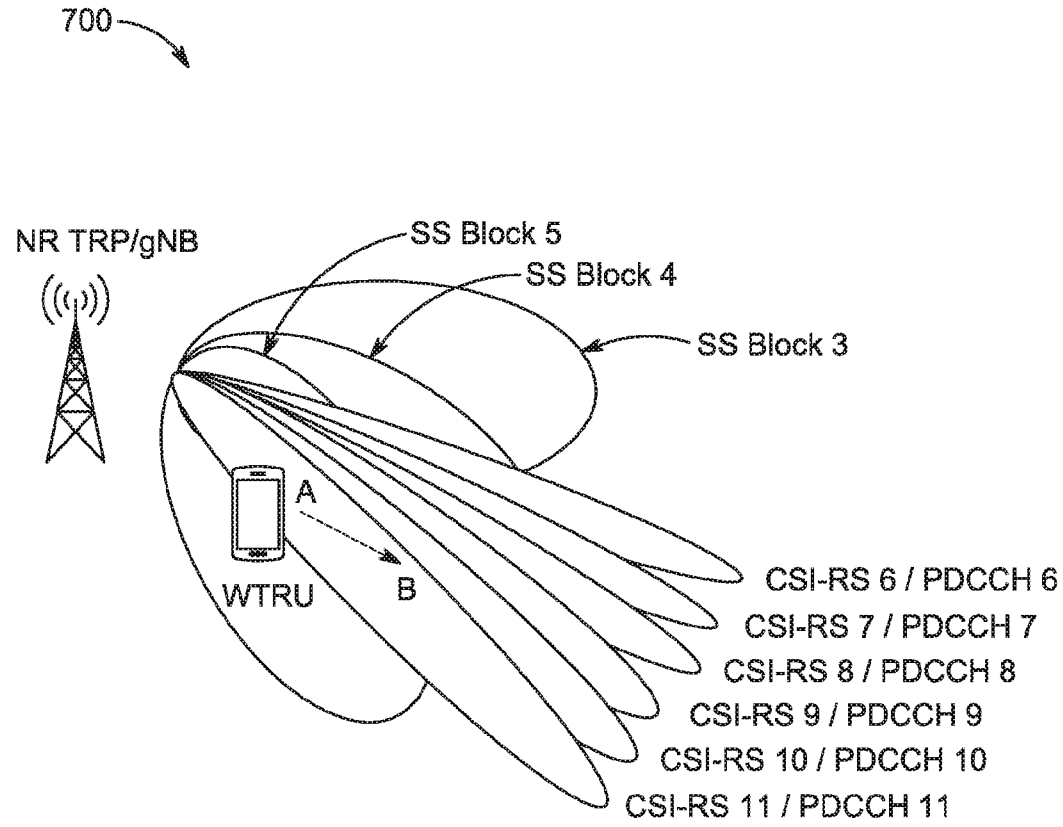

700
NR TRP/gNB
SS Block 5
SS Block 4
SS Block 3
A
B
WTRU
CSI-RS 6 / PDCCH 6
CSI-RS 7 / PDCCH 7
CSI-RS 8 / PDCCH 8
CSI-RS 9 / PDCCH 9
CSI-RS 10 / PDCCH 10
CSI-RS 11 / PDCCH 11

FIG. 7

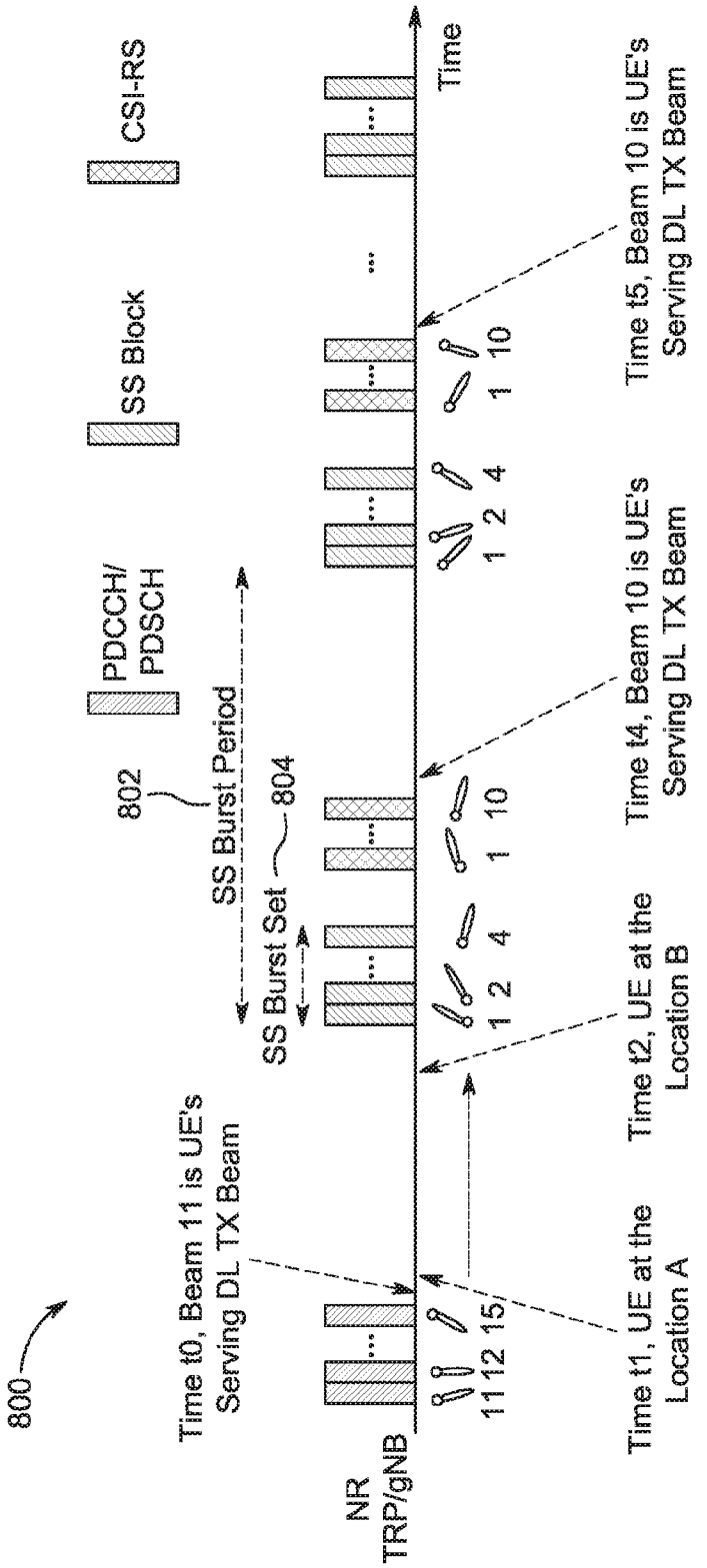

800
NR TRP/gNB
Time t0, Beam 11 is UE's Serving DL TX Beam
Time t1, UE at the Location A
Time t2, UE at the Location B
Time t4, Beam 10 is UE's Serving DL TX Beam
Time t5, Beam 10 is UE's Serving DL TX Beam
11 12 15
1 2 4
1 10
802
SS Burst Period
804
SS Burst Set
PDCCH/ PDSCH
SS Block
CSI-RS
Time

FIG. 8

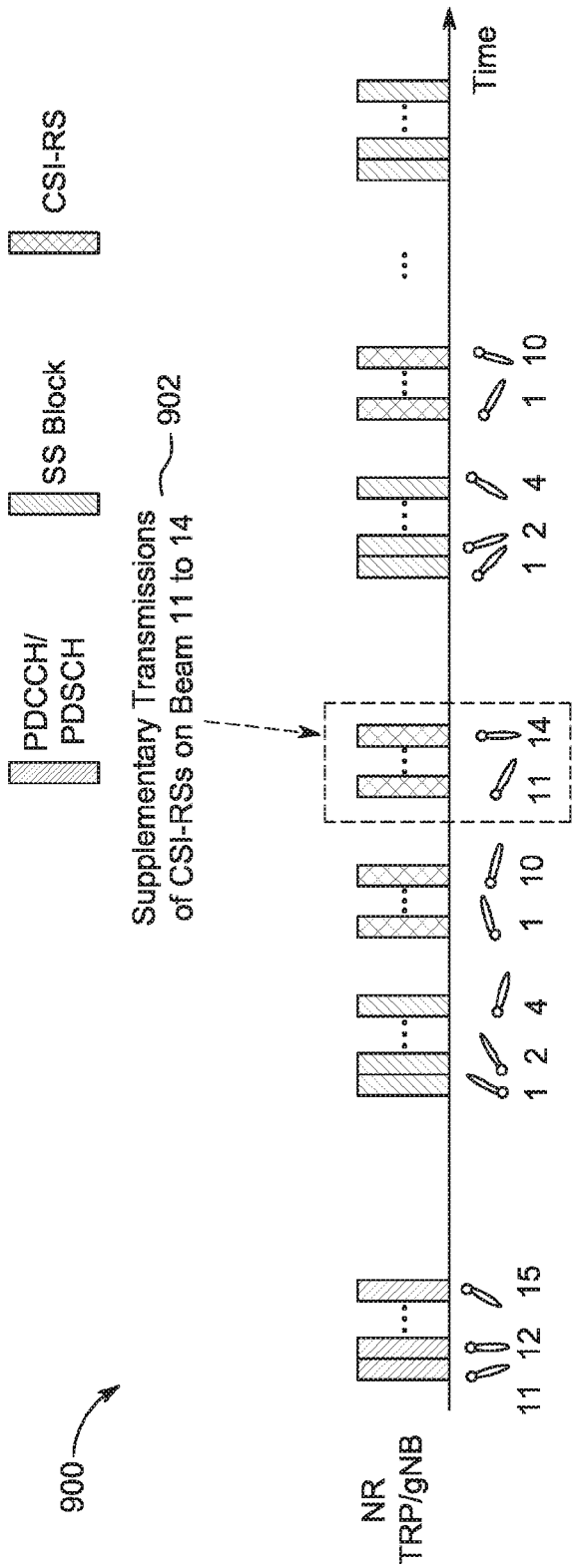

900
NR
TRP/gNB
11 12 15
1 2 4
1 10
11 14
Supplementary Transmissions
of CSI-RSs on Beam 11 to 14
902
PDCCH/
PDSCH
SS Block
CSI-RS
Time

FIG. 9

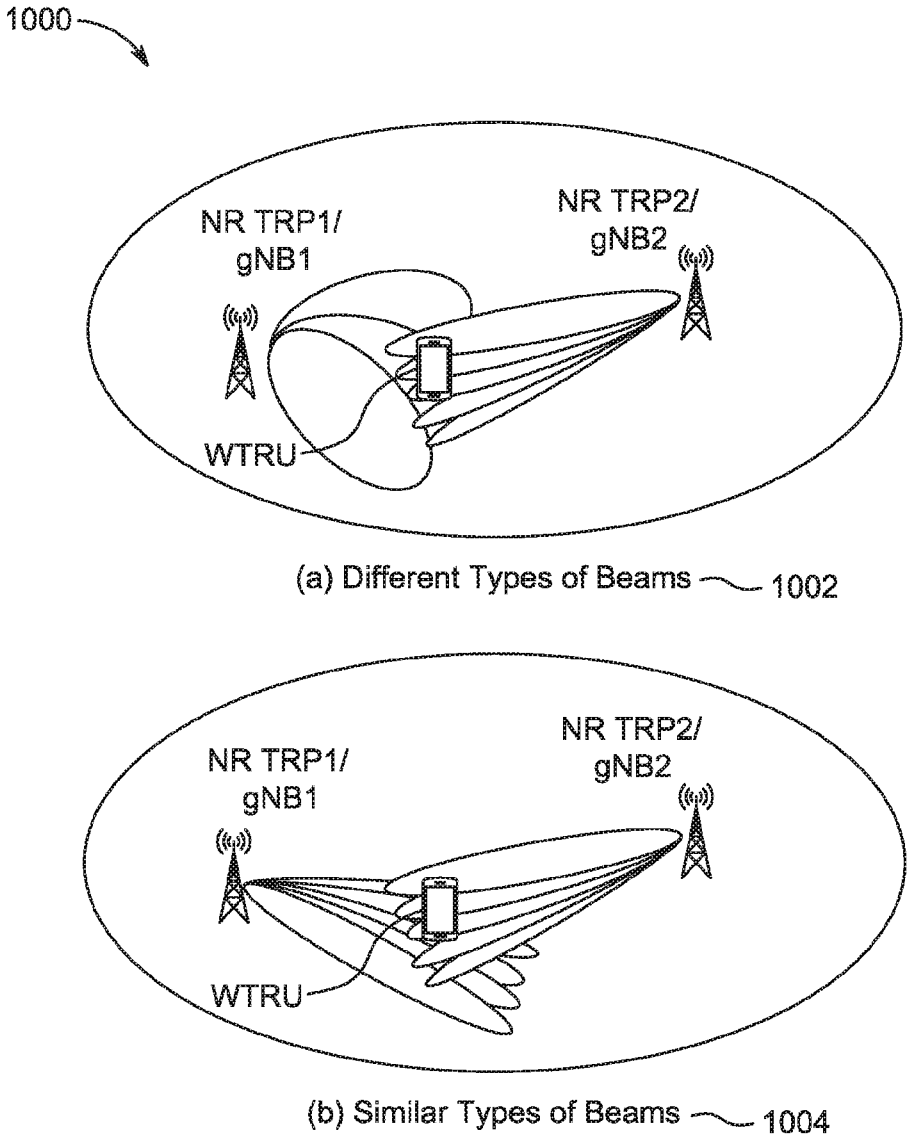

1000
NR TRP1/
gNB1
NR TRP2/
gNB2
WTRU
(a) Different Types of Beams
1002
NR TRP1/
gNB1
NR TRP2/
gNB2
WTRU
(b) Similar Types of Beams
1004

FIG. 10

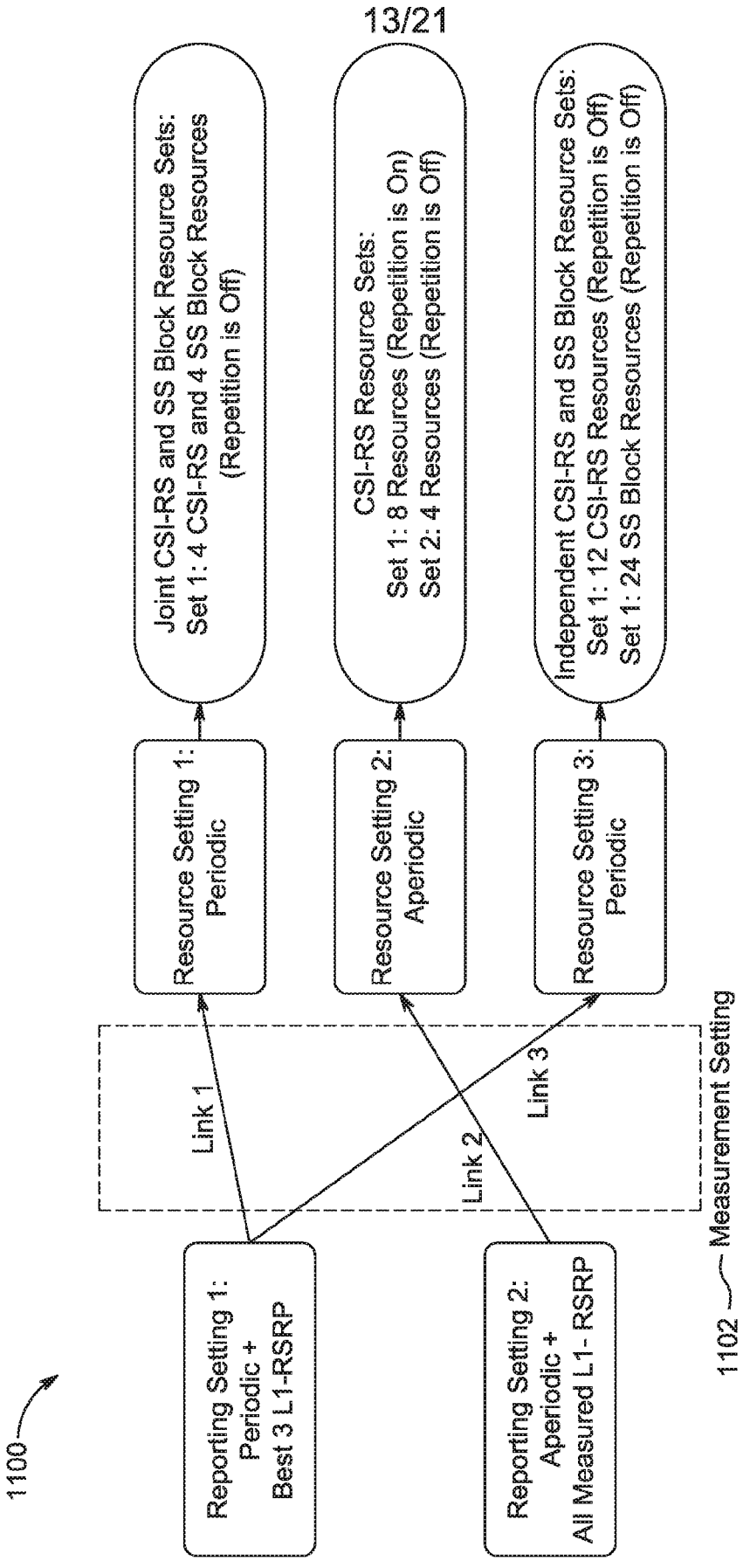

1100
Reporting Setting 1:
Periodic +
Best 3 L1-RSRP
Reporting Setting 2:
Aperiodic +
All Measured L1- RSRP
Link 1
Link 2
Link 3
1102
Measurement Setting
Resource Setting 1:
Periodic
Resource Setting 2:
Aperiodic
Resource Setting 3:
Periodic
Joint CSI-RS and SS Block Resource Sets:
Set 1: 4 CSI-RS and 4 SS Block Resources
(Repetition is Off)
CSI-RS Resource Sets:
Set 1: 8 Resources (Repetition is On)
Set 2: 4 Resources (Repetition is Off)
Independent CSI-RS and SS Block Resource Sets:
Set 1: 12 CSI-RS Resources (Repetition is Off)
Set 1: 24 SS Block Resources (Repetition is Off)

FIG. 11

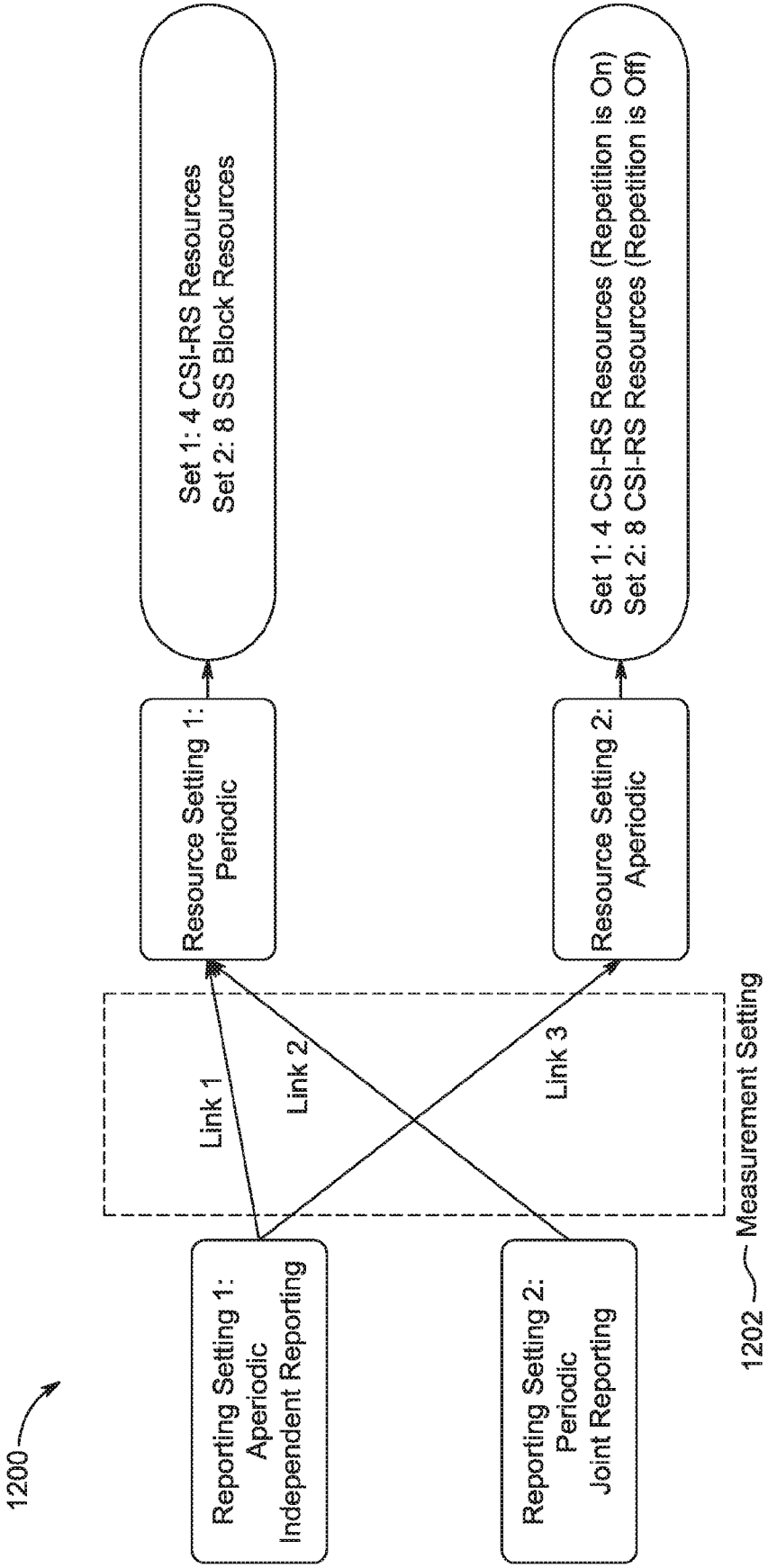

1200
Reporting Setting 1:
Aperiodic
Independent Reporting
Reporting Setting 2:
Periodic
Joint Reporting
Link 1
Link 2
Link 3
Measurement Setting
1202
Resource Setting 1:
Periodic
Resource Setting 2:
Aperiodic
Set 1: 4 CSI-RS Resources
Set 2: 8 SS Block Resources
Set 1: 4 CSI-RS Resources (Repetition is On)
Set 2: 8 CSI-RS Resources (Repetition is Off)

FIG. 12

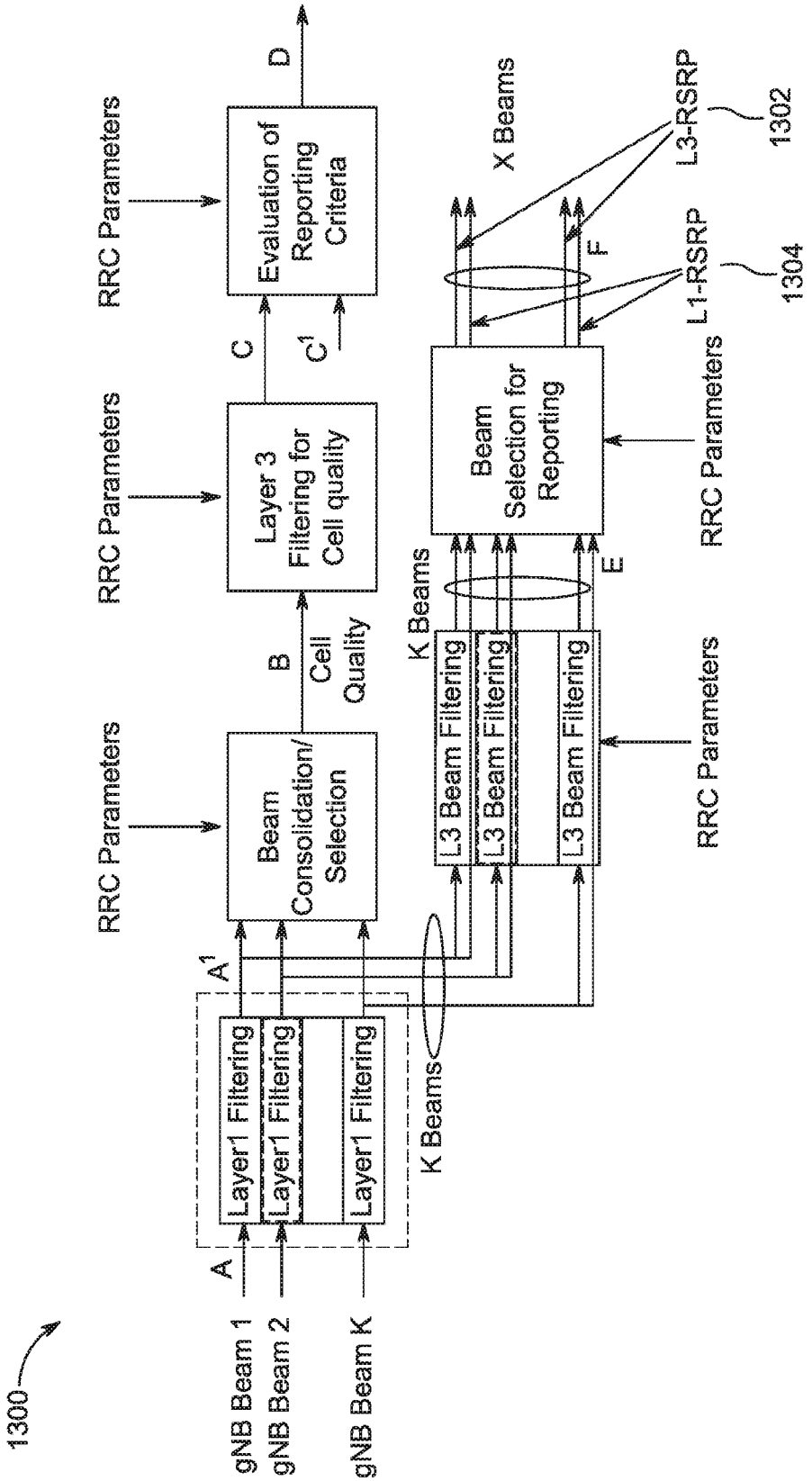

1300
gNB Beam 1
gNB Beam 2
gNB Beam K
A
A1
Layer1 Filtering
Layer1 Filtering
Layer1 Filtering
K Beams
B
Cell Quality
C
C1
D
E
F
K Beams
X Beams
L3 Beam Filtering
L3 Beam Filtering
L3 Beam Filtering
Beam Consolidation/ Selection
Layer 3 Filtering for Cell quality
Evaluation of Reporting Criteria
Beam Selection for Reporting
RRC Parameters
RRC Parameters
RRC Parameters
RRC Parameters
RRC Parameters
L3-RSRP
1302
L1-RSRP
1304

FIG. 13

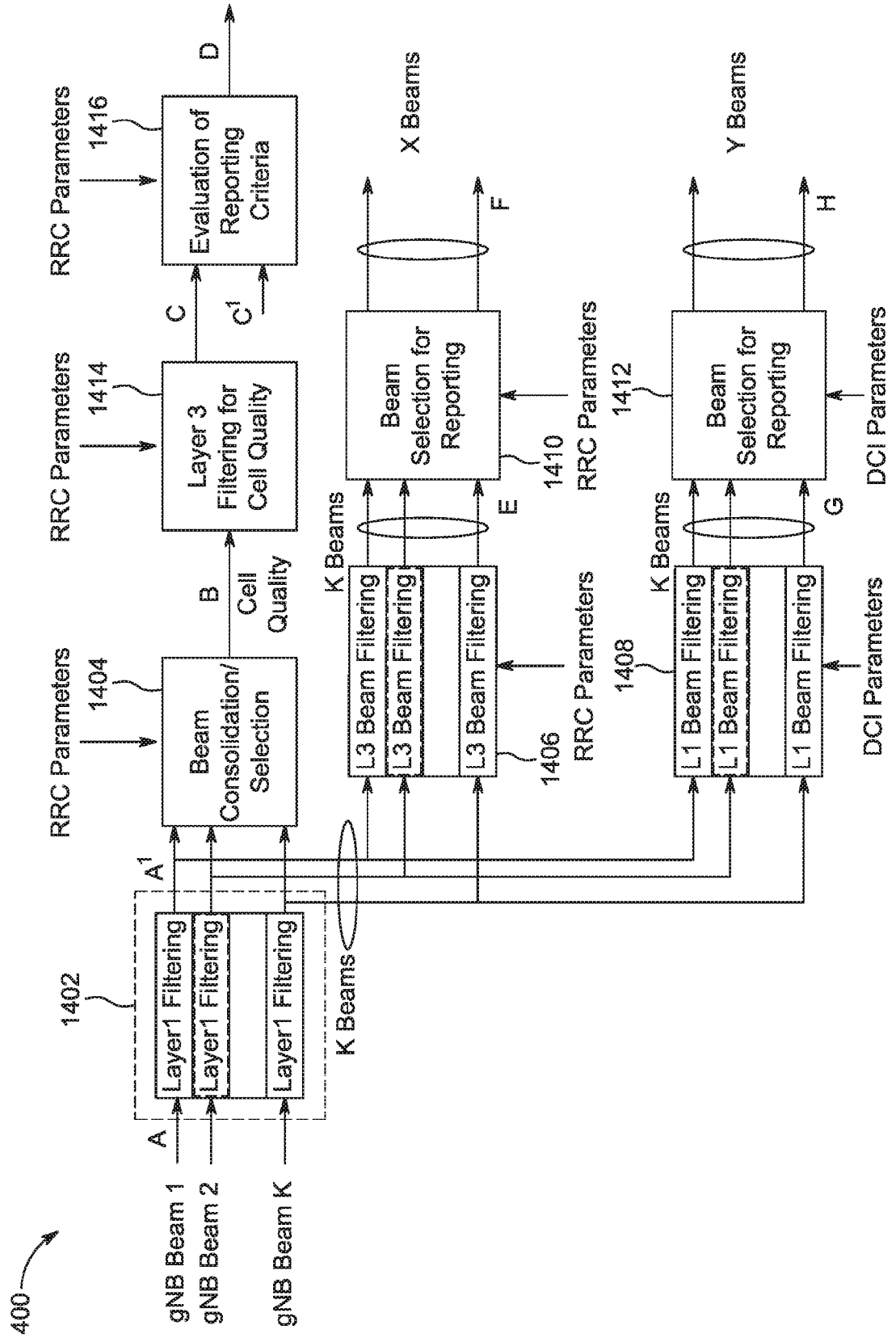

1400
gNB Beam 1
gNB Beam 2
gNB Beam K
A
A1
1402
Layer1 Filtering
Layer1 Filtering
Layer1 Filtering
K Beams
RRC Parameters
1404
Beam Consolidation/ Selection
B
Cell Quality
RRC Parameters
1414
Layer 3 Filtering for Cell Quality
C
C1
RRC Parameters
1416
Evaluation of Reporting Criteria
D
K Beams
L3 Beam Filtering
L3 Beam Filtering
L3 Beam Filtering
1406
RRC Parameters
Beam Selection for Reporting
1410
E
X Beams
F
RRC Parameters
1408
K Beams
L1 Beam Filtering
L1 Beam Filtering
L1 Beam Filtering
DCI Parameters
Beam Selection for Reporting
1412
G
Y Beams
H
DCI Parameters

FIG. 14

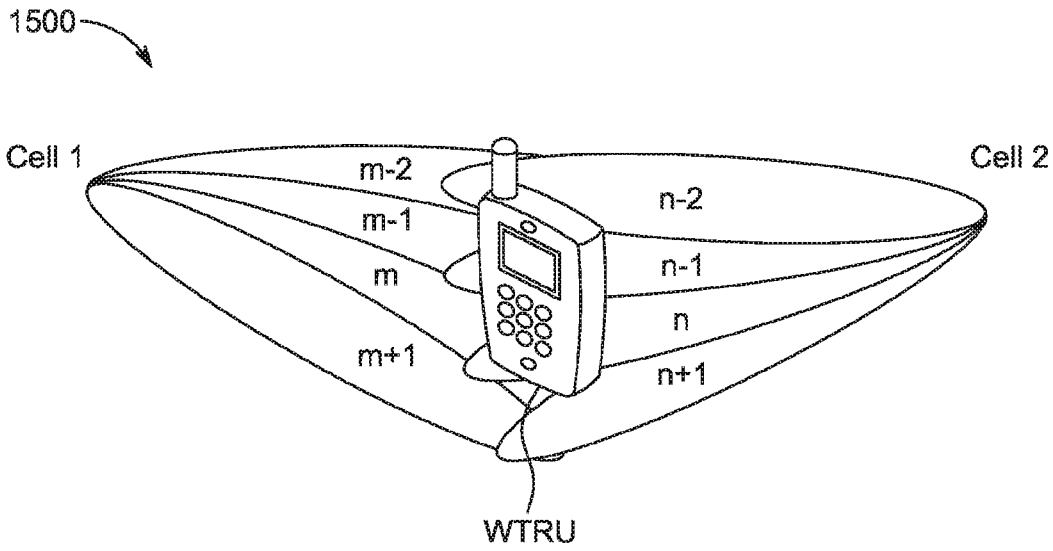


FIG. 15

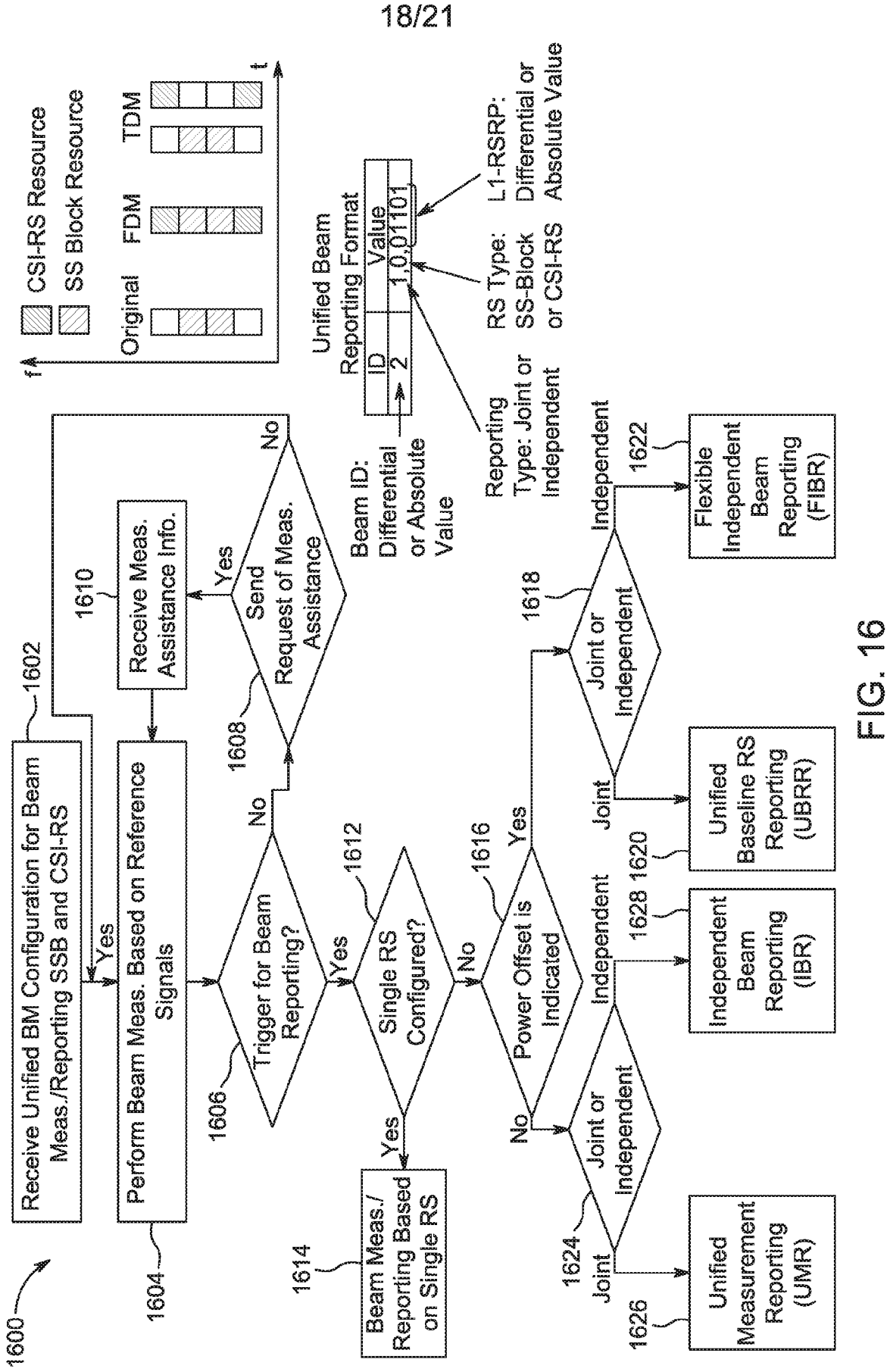

1600
Receive Unified BM Configuration for Beam Meas./Reporting SSB and CSI-RS
1602
Yes
Perform Beam Meas. Based on Reference Signals
1604
1606
Trigger for Beam Reporting?
No
Yes
1608
Send Request of Meas. Assistance
No
Yes
1610
Receive Meas. Assistance Info.
1612
Single RS Configured?
No
Yes
1614
Beam Meas./ Reporting Based on Single RS
1616
Power Offset is Indicated
Yes
No
1618
Joint or Independent
Joint
Independent
1620
Unified Baseline RS Reporting (UBRR)
1622
Flexible Independent Beam Reporting (FIBR)
1624
Joint or Independent
Joint
Independent
1626
Unified Measurement Reporting (UMR)
1628
Independent Beam Reporting (IBR)
f
t
CSI-RS Resource
SS Block Resource
Original
FDM
TDM
Unified Beam Reporting Format
ID
Value
2
1,0,01101
Beam ID: Differential or Absolute Value
Reporting Type: Joint or Independent
RS Type: SS-Block or CSI-RS
L1-RSRP: Differential or Absolute Value

FIG. 16

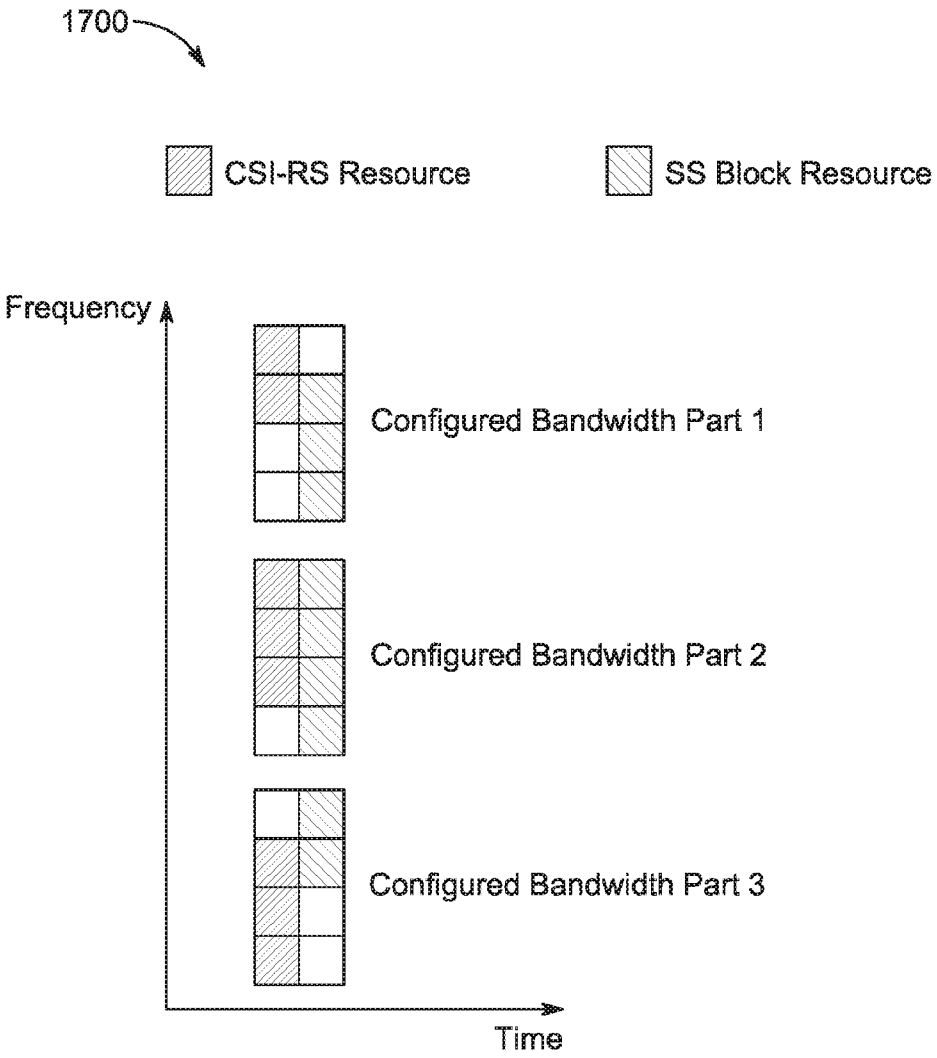

1700
CSI-RS Resource
SS Block Resource
Frequency
Configured Bandwidth Part 1
Configured Bandwidth Part 2
Configured Bandwidth Part 3
Time

FIG. 17

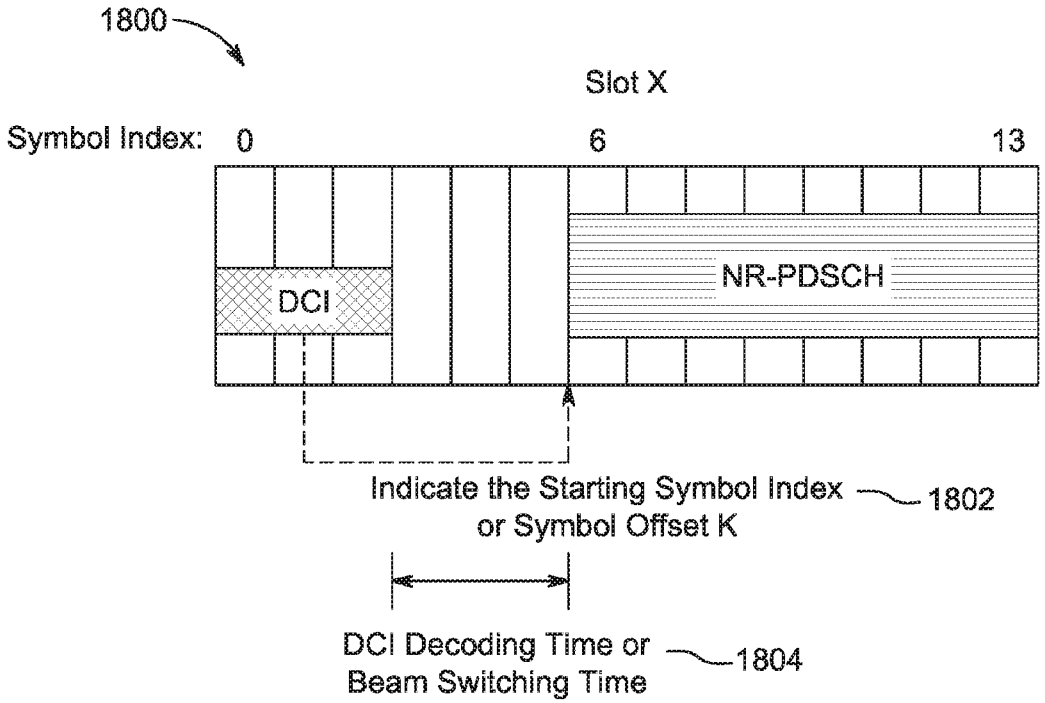

1800
Slot X
Symbol Index: 0
6
13
DCI
NR-PDSCH
Indicate the Starting Symbol Index or Symbol Offset K
1802
DCI Decoding Time or Beam Switching Time
1804

FIG. 18

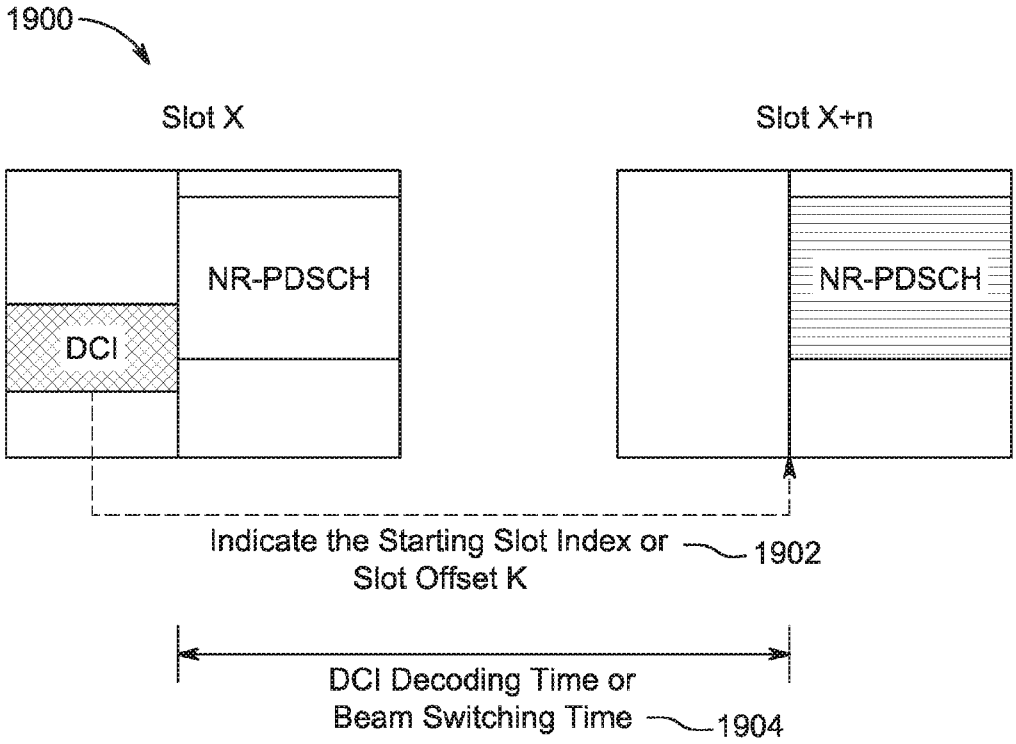

1900
Slot X
Slot X+n
NR-PDSCH
DCI
NR-PDSCH
Indicate the Starting Slot Index or Slot Offset K
1902
DCI Decoding Time or Beam Switching Time
1904

FIG. 19

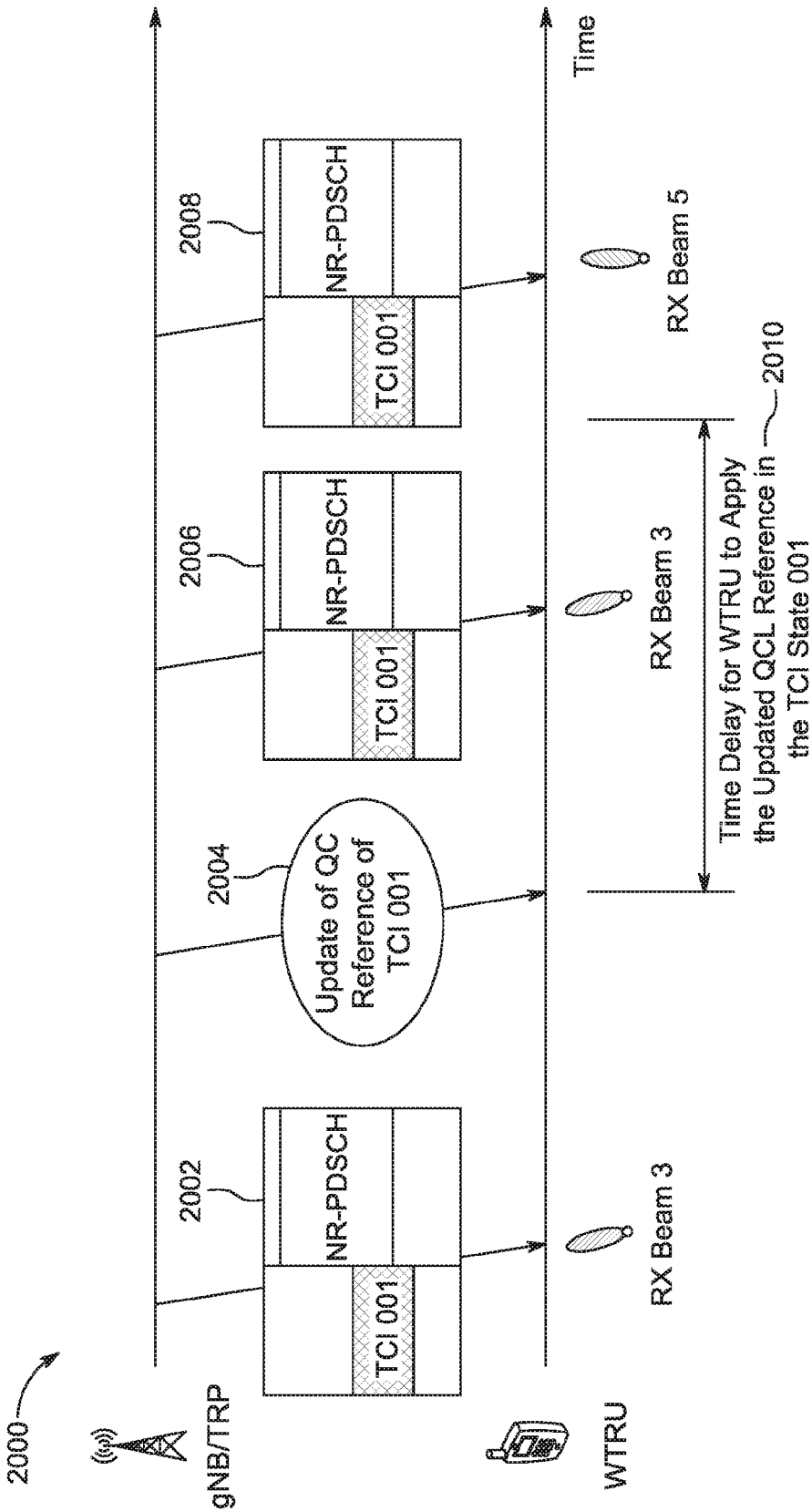

2000
gNB/TRP
WTRU
Time
2002
NR-PDSCH
TCI 001
RX Beam 3
2004
Update of QC Reference of TCI 001
2006
NR-PDSCH
TCI 001
RX Beam 3
2008
NR-PDSCH
TCI 001
RX Beam 5
Time Delay for WTRU to Apply the Updated QCL Reference in the TCI State 001
2010

FIG. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/037498

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/Q6
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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	VIVO: "Di scussion on beam management for NR MIMO" , 3GPP DRAFT; R1-17O0274_DI SCUSSION ON BEAM MANAGEMENT FOR NR MIMO, 3RD GENERATION PARTNERSHI P PROJECT (3GPP) , MOBI LE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTI POLIS CEDEX ; FRANC , vol . RAN WG1 , no. Spokane, USA; 20170116 - 20170120 16 January 2017 (2017-01-16) , XP051207812 , Retri eved from the Internet: URL: http://www.3gpp.org/ftp/Meeti ngs_3GPP_ SYNC/RANl/Docs/ [retri eved on 2017-01-16] page 1 - page 5 f i gures 1-4 table 1 -/--	1-20

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

X See patent family annex.

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 August 2018	29/10/2018

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

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/037498

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/184613 A2 (INTERDIGITAL PATENT HOLDINGS [US]) 12 December 2013 (2013-12-12) paragraph [0097] - paragraph [0098] paragraph [0113] - paragraph [0115] paragraph [0131] - paragraph [0139] paragraph [0168] paragraph [0199] paragraph [0212] - paragraph [0215] paragraph [0252] - paragraph [0256]	1-20

1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/037498

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		CN 108111196 A	01-06-2018
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		JP 2015523013 A	06-08-2015
		KR 20150027194 A	11-03-2015
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		US 2013322376 Al	05-12-2013
		US 2017238323 Al	17-08-2017
		WO 2013184613 A2	12-12-2013