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BEAM MANAGEMENT FOR NEW RADIO

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ABSTRACT

A method and device for a wireless transmit/receive unit (WTRU). The WTRU may have a status that may determine whether or not to implement a beam selection process. When the status of the WTRU includes moving, then the beam selection process may be based on a predefined set of rules. When the status includes being stationary, then the beam selection process may determine if there is a beam indication in a semi-static downlink control information (DCI). In some instances, the beam selection process may determine there is no beam indication on the semi-static DCI, in which case the WTRU may check to see if there is preconfigured beam and use that beam if there is. If there is not preconfigured beam, depending on the quality of the downlink channel, the WTRU may use the downlink channel or the beam previously indicated by the DCI.

CLAIMS

What is claimed is:

1. A method for a wireless transmit/receive unit (WTRU), comprising:
determining the status of the WTRU; and
implementing a beam selection process based on the determining.
2. The method of claim 1, further comprising, on a condition that the status includes moving, then the beam selection process is based on a predefined rules.
3. The method of claim 1, wherein on a condition that the status includes being stationary, then the beam selection process determines if there is a beam indication in a semi-static downlink control information (DCI).
4. The method of claim 3, further comprising, on a condition that beam selection process determines there is not a beam indication on the semi-static DCI, determining if there is a preconfigured beam.
5. The method of claim 4, further comprising, on a condition that there is not a preconfigured beam, determining the quality of a downlink channel.
6. The method of claim 5, further comprising, on a condition that the quality of the downlink channel is good, using a beam the same as the downlink channel.
7. The method of claim 5, further comprising, on a condition that the quality of the downlink channel is bad, using a beam the same as a previously indicated DCI.

BEAM MANAGEMENT FOR NEW RADIO

BACKGROUND

[0001] In next generation mobile communications, applications such as enhanced mobile broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC) have been proposed. A wide range of spectrum bands ranging from 700 MHz to 80 GHz may be considered for a variety of deployment scenarios. These include both licensed and unlicensed spectrum.

SUMMARY

[0002] A method and device for use in a wireless transmit/receive unit (WTRU). The WTRU may have a status that may determine whether or not to implement a beam selection process. When the status of the WTRU includes moving, then the beam selection process may be based on a predefined set of rules. When the status includes being stationary, then the beam selection process may determine if there is a beam indication in a semi-static downlink control information (DCI). In some instances, the beam selection process may determine there is no beam indication on the semi-static DCI, in which case the WTRU may check to see if there is preconfigured beam and use that beam if there is. If there is not preconfigured beam, depending on the quality of the downlink channel, the WTRU may use the downlink channel or the beam previously indicated by the DCI.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] 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:

[0004] FIG. 1A is a system diagram illustrating an example communications system in which one or more disclosed embodiments may be implemented;

[0005] 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;

[0006] 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;

[0007] 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;

[0008] FIG. 2 is an example model of a TRP and WTRU antenna;

[0009] FIG. 3A is a diagram of an example slot structure for PDSCH beam indication;

[0010] FIG. 3B is a diagram of an example spatial QCL assumption update for NR-PDSCH reception;

[0011] FIG. 4 is a diagram of an example spatial QCL assumption update for NR-PDSCH reception;

[0012] FIG. 5 is a diagram of an example spatial QCL assumption update for NR-PDSCH reception;

[0013] FIG. 6 is an example procedure of determining the DL Rx beam before scheduling offset;

[0014] FIG. 7 is a diagram of example NR-PDCCH transmissions over multiple beams for robustness against beam pair link blocking;

[0015] FIG. 8 is a diagram of an example reference signal resources; and

[0016] FIG. 9 is a diagram of an example multiplexing beam report and part 2 of CSI type II reporting.

DETAILED DESCRIPTION

[0017] FIG. 1A is a diagram illustrating an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), zero-tail unique-word DFT-Spread OFDM (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0018] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a RAN 104/113, a CN 106/115, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that

the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d, any of which may be referred to as a “station” and/or a “STA”, may be configured to transmit and/or receive wireless signals and may include a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a subscription-based unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, a hotspot or Mi-Fi device, an Internet of Things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical device and applications (e.g., remote surgery), an industrial device and applications (e.g., a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. Any of the WTRUs 102a, 102b, 102c and 102d may be interchangeably referred to as a UE.

[0019] The communications systems 100 may also include a base station 114a and/or a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d to facilitate access to one or more communication networks, such as the CN 106/115, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a gNB, a NR NodeB, a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0020] The base station 114a may be part of the RAN 104/113, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals on one or more carrier frequencies, which may be referred to as a cell (not shown). These frequencies may be in licensed spectrum, unlicensed spectrum, or a combination of licensed and unlicensed spectrum. A cell may provide coverage for a wireless service to a specific geographical area that may be relatively fixed or that may change over time. The cell may 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.

[0021] 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).

[0022] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104/113 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 115/116/117 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink (DL) Packet Access (HSDPA) and/or High-Speed UL Packet Access (HSUPA).

[0023] 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).

[0024] 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).

[0025] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement multiple radio access technologies. For example, the base station 114a and the WTRUs 102a, 102b, 102c may implement LTE radio access and NR radio access together, for instance using dual connectivity (DC) principles. Thus, the air interface utilized by WTRUs 102a, 102b, 102c may be characterized by multiple types of radio access technologies and/or transmissions sent to/from multiple types of base stations (e.g., a eNB and a gNB).

[0026] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (WiFi)), IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global

System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

[0027] The base station 114b in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, an industrial facility, an air corridor (e.g., for use by drones), a roadway, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In an embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, LTE-A Pro, NR etc.) to establish a picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the CN 106/115.

[0028] The RAN 104/113 may be in communication with the CN 106/115, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. The data may have varying quality of service (QoS) requirements, such as differing throughput requirements, latency requirements, error tolerance requirements, reliability requirements, data throughput requirements, mobility requirements, and the like. The CN 106/115 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104/113 and/or the CN 106/115 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104/113 or a different RAT. For example, in addition to being connected to the RAN 104/113, which may be utilizing a NR radio technology, the CN 106/115 may also be in communication with another RAN (not shown) employing a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or WiFi radio technology.

[0029] The CN 106/115 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or the other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and/or the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired

and/or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104/113 or a different RAT.

[0030] 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.

[0031] 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.

[0032] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0033] 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.

[0034] 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.

[0035] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as NR and IEEE 802.11, for example.

[0036] 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).

[0037] 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.

[0038] 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.

[0039] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs and/or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, a Virtual Reality and/or Augmented Reality (VR/AR) device, an activity tracker, and the like. The peripherals 138 may include one or more sensors, the sensors may be one or more of a gyroscope, an accelerometer, a hall effect sensor, a magnetometer, an orientation sensor, a proximity sensor, a temperature sensor, a time sensor, a geolocation sensor, an altimeter, a light sensor, a touch sensor, a magnetometer, a barometer, a gesture sensor, a biometric sensor, and/or a humidity sensor.

[0040] The WTRU 102 may include a full duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for both the UL (e.g., for transmission) and downlink (e.g., for reception) may be concurrent and/or simultaneous. The full duplex radio may include an interference management unit 139 to reduce and or substantially eliminate self-interference via either hardware (e.g., a choke) or signal processing via a processor (e.g., a separate processor (not shown) or via processor 118). In an embodiment, the WTRU 102 may include a half-duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for either the UL (e.g., for transmission) or the downlink (e.g., for reception)).

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] In representative embodiments, the other network 112 may be a WLAN.

[0051] A WLAN in Infrastructure Basic Service Set (BSS) mode may have an Access Point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may have an access or an interface to a Distribution System (DS) or another type of wired/wireless network that carries traffic in to and/or out of the BSS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to respective destinations. Traffic between STAs within the BSS may be sent through the AP, for example, where the source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. The traffic between STAs within a BSS may be considered and/or referred to as peer-to-peer traffic. The peer-to-peer traffic may be sent between (e.g., directly between) the source and destination STAs with a direct link setup (DLS). In certain representative embodiments, the DLS may use an 802.11e DLS or an 802.11z tunneled DLS (TDLS). A WLAN using an Independent BSS (IBSS) mode may not have an AP, and the STAs (e.g., all of the STAs) within or using the IBSS may communicate directly with each other. The IBSS mode of communication may sometimes be referred to herein as an “ad-hoc” mode of communication.

[0052] When using the 802.11ac infrastructure mode of operation or a similar mode of operations, the AP may transmit a beacon on a fixed channel, such as a primary channel. The primary channel may be a fixed width (e.g., 20 MHz wide bandwidth) or a dynamically set width via signaling. The primary channel may be the operating channel of the BSS and may be used by the STAs to establish a connection with the AP. In certain representative embodiments, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) may be implemented, for example in 802.11 systems. For CSMA/CA, the STAs (e.g., every STA), including the AP, may sense the primary channel. If the primary channel is sensed/detected and/or determined to be busy by a particular STA, the particular STA may back off. One STA (e.g., only one station) may transmit at any given time in a given BSS.

[0053] 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.

[0054] Very High Throughput (VHT) STAs may support 20MHz, 40 MHz, 80 MHz, and/or 160 MHz wide channels. The 40 MHz, and/or 80 MHz, channels may be formed by combining contiguous 20 MHz channels. A 160 MHz channel may be formed by combining 8 contiguous 20 MHz channels, or by combining two non-contiguous 80 MHz channels, which may be referred to as an 80+80 configuration. For the 80+80 configuration, the data, after channel encoding, may be passed through a segment parser that may divide the data into two streams. Inverse Fast Fourier Transform (IFFT) processing, and time domain processing, may be done on each stream separately. The streams may be mapped on to the two 80 MHz channels, and the data may be transmitted by a transmitting STA. At the receiver of the receiving STA, the above described operation for the 80+80 configuration may be reversed, and the combined data may be sent to the Medium Access Control (MAC).

[0055] Sub 1 GHz modes of operation are supported by 802.11af and 802.11ah. The channel operating bandwidths, and carriers, are reduced in 802.11af and 802.11ah relative to those used in 802.11n, and 802.11ac. 802.11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV White Space (TVWS) spectrum, and 802.11ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.11ah may support Meter Type Control/Machine-Type Communications, such as MTC devices in a macro coverage area. MTC devices may have certain capabilities, for example, limited capabilities including support for (e.g., only support for) certain and/or limited bandwidths. The MTC devices may include a battery with a battery life above a threshold (e.g., to maintain a very long battery life).

[0056] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11n, 802.11ac, 802.11af, and 802.11ah, include a channel which may be designated as the primary channel. The primary channel may have a bandwidth equal to the largest common operating bandwidth supported by all STAs in the BSS. The bandwidth of the primary channel may be set and/or limited by a STA, from among all STAs in operating in a BSS, which supports the smallest bandwidth operating mode. In the example of 802.11ah, the primary channel may be 1 MHz wide for STAs (e.g., MTC type devices) that support (e.g., only support) a 1 MHz mode, even if the AP, and other STAs in the BSS support 2 MHz, 4 MHz, 8 MHz, 16 MHz, and/or other channel bandwidth operating modes. Carrier sensing and/or Network Allocation Vector (NAV) settings may depend on the status of the primary channel. If the primary channel is

busy, for example, due to a STA (which supports only a 1 MHz operating mode), transmitting to the AP, the entire available frequency bands may be considered busy even though a majority of the frequency bands remains idle and may be available.

[0057] In the United States, the available frequency bands, which may be used by 802.11ah, are from 902 MHz to 928 MHz. In Korea, the available frequency bands are from 917.5 MHz to 923.5 MHz. In Japan, the available frequency bands are from 916.5 MHz to 927.5 MHz. The total bandwidth available for 802.11ah is 6 MHz to 26 MHz depending on the country code.

[0058] FIG. 1D is a system diagram illustrating the RAN 113 and the CN 115 according to an embodiment. As noted above, the RAN 113 may employ an NR radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 113 may also be in communication with the CN 115.

[0059] The RAN 113 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 113 may include any number of gNBs while remaining consistent with an embodiment. The gNBs 180a, 180b, 180c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the gNBs 180a, 180b, 180c may implement MIMO technology. For example, gNBs 180a, 180b may utilize beamforming to transmit signals to and/or receive signals from the gNBs 180a, 180b, 180c. Thus, the gNB 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. In an embodiment, the gNBs 180a, 180b, 180c may implement carrier aggregation technology. For example, the gNB 180a may transmit multiple component carriers to the WTRU 102a (not shown). A subset of these component carriers may be on unlicensed spectrum while the remaining component carriers may be on licensed spectrum. In an embodiment, the gNBs 180a, 180b, 180c may implement Coordinated Multi-Point (CoMP) technology. For example, WTRU 102a may receive coordinated transmissions from gNB 180a and gNB 180b (and/or gNB 180c).

[0060] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using transmissions associated with a scalable numerology. For example, the OFDM symbol spacing and/or OFDM subcarrier spacing may vary for different transmissions, different cells, and/or different portions of the wireless transmission spectrum. The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using subframe or transmission time intervals (TTIs) of various or scalable lengths (e.g., containing varying number of OFDM symbols and/or lasting varying lengths of absolute time).

[0061] 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.

[0062] 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.

[0063] The CN 115 shown in FIG. 1D may include at least one AMF 182a, 182b, at least one UPF 184a, 184b, at least one Session Management Function (SMF) 183a, 183b, and possibly a Data Network (DN) 185a, 185b. While each of the foregoing elements are depicted as part of the CN 115, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0064] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N2 interface and may serve as a control node. For example, the AMF 182a, 182b may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, support for network slicing (e.g., handling of different PDU sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of NAS signaling, mobility management, and the like. Network slicing may be used by the AMF 182a, 182b in order to customize CN support for WTRUs 102a, 102b, 102c based on the types of services being utilized WTRUs 102a, 102b, 102c. For example, different

network slices may be established for different use cases such as services relying on ultra-reliable low latency (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for machine type communication (MTC) access, and/or the like. The AMF 162 may provide a control plane function for switching between the RAN 113 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-3GPP access technologies such as WiFi.

[0065] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 115 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 115 via an N4 interface. The SMF 183a, 183b may select and control the UPF 184a, 184b and configure the routing of traffic through the UPF 184a, 184b. The SMF 183a, 183b may perform other functions, such as managing and allocating UE IP address, managing PDU sessions, controlling policy enforcement and QoS, providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0066] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The UPF 184a, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0067] The CN 115 may facilitate communications with other networks. For example, the CN 115 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 115 and the PSTN 108. In addition, the CN 115 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers. In one embodiment, the WTRUs 102a, 102b, 102c may be connected to a local Data Network (DN) 185a, 185b through the UPF 184a, 184b via the N3 interface to the UPF 184a, 184b and an N6 interface between the UPF 184a, 184b and the DN 185a, 185b.

[0068] In view of Figures 1A-1D, and the corresponding description of Figures 1A-1D, one or more, or all, of the functions described herein with regard to one or more of: WTRU 102a-d, Base Station 114a-b, eNode-B 160a-c, MME 162, SGW 164, PGW 166, gNB 180a-c, AMF 182a-ab, UPF 184a-b, SMF 183a-b, DN 185a-b, and/or any other device(s) described herein, may be performed by one or more emulation devices (not shown). The emulation devices may be one or more devices configured to emulate

one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0069] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all, functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network. The emulation device may be directly coupled to another device for purposes of testing and/or may performing testing using over-the-air wireless communications.

[0070] 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.

[0071] In next generation mobile communications, applications such as enhanced mobile broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC) have been proposed. A wide range of spectrum bands ranging from 700 MHz to 80 GHz may be considered for a variety of deployment scenarios. These include both licensed and unlicensed spectrum.

[0072] For sub-6 GHz transmission, multiple antenna techniques such as Multiple Input Multiple Output (MIMO) transmission and its different types, e.g., Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO) techniques, may contribute significantly to the advancement of telecommunications. Different MIMO techniques may deliver different benefits such as providing diversity gain, multiplexing gain, beamforming, array gain, etc. In the cellular communication paradigm, and User Terminals (UTs) may communicate to a single central node, the use of MU-MIMO may increase the system throughput by facilitating the transmission of multiple data streams to different UTs at the same time on the same and/or overlapping set of resources in time and/or frequency. In the SU-MIMO case, the same central

node may transmit multiple data streams to the same UT rather than multiple UTs as it is the case for MU-MIMO.

[0073] Multiple antenna transmission at millimeter wave frequencies differ slightly from sub-6 GHz multiple antenna techniques. This is due to the different propagation characteristics at millimeter wave frequencies and the possibility of the base stations/WTRUs having a limited number of RF chains compared with antenna elements.

[0074] The massive antenna model may be configured as M_g antenna panels per vertical dimension and N_g antenna panels per horizontal dimension, wherein each antenna panel may be configured with N columns and M rows of antenna elements with or without polarization as shown in the FIG. 1. The timing and phase may be not be calibrated across panels although multiple panels may be equipped in the same eNB. The baseline massive antenna configuration may be different according to the operating frequency band as listed in Table 1.

At 4GHz	At 30GHz	At 70GHz
Dense urban and urban macro: $(M,N,P,M_g,N_g) = (8,8,2,1,1)$, $(d_V,d_H) = (0.8, 0.5)\lambda$	Dense urban and urban macro: $(M,N,P,M_g,N_g) = (4,8,2,2,2)$, $(d_V,d_H) = (0.5, 0.5)\lambda$, $(d_{g,V},d_{g,H}) = (2.0, 4.0)\lambda$	Dense urban: Baseline: $(M,N,P,M_g,N_g) = (8,16,2,2,2)$, $(d_V,d_H) = (0.5, 0.5)\lambda$, $(d_{g,V},d_{g,H}) = (4.0, 8.0)\lambda$
▪ A single panel ▪ 64 elements per Pol. ▪ Total 128 elements	▪ 4 panels ▪ 32 elements per Pol. ▪ Total 256 elements	▪ 4 panels ▪ 128 elements per Pol. ▪ Total 1024 elements

Table 1 Example of baseline massive antenna configuration for dense urban and urban macro

[0075] Precoding at millimeter wave frequencies may be digital, analog, or a hybrid of digital and analog. Digital precoding is precise and can be combined with equalization. It enables single user (SU), multi-user (MU), and multi-cell precoding and is similar to that used in sub 6 GHz, for example in IEEE 802.11n and beyond, and in 3GPP LTE and beyond. 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 complicate the use of digital beamforming. Analog beamforming may overcome the limited number of RF chains issue by using analog phase shifters on each antenna element. Such a technique may be used in IEEE 802.11ad during the Sector Level Sweep (which identifies the best sector), Beam Refinement (which refines the sector to an antenna beam), and beam tracking (which adjusts the sub-

beams over time to take into account any change in the channel) procedures. In hybrid beamforming, the precoder may be divided between analog and digital domains. Each domain may have precoding and combining matrices with different structural constraints (e.g., constant modulus constraint for combining matrices in the analog domain). This design may result in a compromise/balance between hardware complexity and system performance. Hybrid beamforming may be able to achieve digital precoding performance due to the sparse nature of channel and support multi-user/multi-stream multiplexing. Hybrid beamforming may also be limited by the number of RF chains, but this may not be an issue since mmWave channels may be sparse in the angular domain rendering this limitation potentially not as important.

[0076] In beam management for new radio, the use of higher band frequencies may imply that their propagation characteristics will influence the system design. As frequencies increase, the channel may experience higher path losses and more abrupt changes. In high frequency bands, a large-scale antenna array may be used to achieve high beamforming gain so as to compensate for the high propagation loss. The resulting coupling loss could be kept at a high level to support the desired data throughput or coverage. The use of a directional beam based communication may require an accurate beam pairing, and the correct beam direction may need to be associated with a real channel, in terms of angle of arrival and angle of departure in both azimuth and elevation. The correct beam direction should be dynamically adjusted with the channel change. Beam Management (BM) may cover a number of topics, such as: DL L1/L2 BM procedures for selection of TRP Tx/WTRU Rx beams are supported within one or multiple TRPs; 3 high level procedures (P-1, P-2, P-3) for beam selection, Tx beam refinement, Rx beam change; procedures that may involve TRP Tx and WTRU Rx beam sweep; WTRU-triggered mechanisms to recover from beam failure in NR environments; beam group based reporting and WTRU-specific configured BM; channel state information (CSI)-RS and/or synchronization signal (SS) block configuration for Tx and/or Rx beam sweeping for BM in NR environments; and/or at least one NW-controlled mechanism for beam management for UL transmission(s).

[0077] A common framework for PDSCH and PDCCH beam indication may be defined for NR. In this definition, the RRC may configure a set of M candidate Transmission Configuration Indication (TCI) states where each TCI state contains a reference to an RS Set comprising one or more DL RS index(-es), for purposes of providing QCL reference for either PDSCH or PDCCH reception. A TCI state acts as a pointer for the WTRU to determine which RS set or DL RS index the WTRU may need to use to determine its QCL references for the DM-RS ports associated with PDSCH and/or PDCCH.

[0078] For PDCCH reception, the QCL reference may be configured by signaling the association of either a CORESET or Search Space to a TCI state. The RS Set linked to the TCI state may provide the QCL reference for the PDCCH. NR may support dynamic beam indication for PDSCH. To facilitate such functionality, there may be an N-bit indicator state or TCI state field in the DL-related DCI field for PDSCH beam indication.

[0079] Concerning timing issues of beam indication for NR-PDSCH, for the case when at least spatial QCL is configured/indicated, NR supports the beam indication for NR-PDSCH as follows, if TCI field is present: the TCI field may always present in the associated DCI for NR-PDSCH scheduling irrespective of same-slot scheduling or cross-slot scheduling; when the scheduling offset $\geq$ threshold K, then NR-PDSCH may use the beam (spatial QCL parameter) indicated by the N-bit TCI field in the assignment DCI; when the scheduling offset $<$ threshold K, then NR-PDSCH may use a pre-configured/pre-defined/rule-based spatial assumption, but more details may be needed. For example, embodiments discussed herein may address the other QCL parameters that may be obtained from the N-bit TCI state field in the DCI. In another example, embodiments discussed herein may address how to update pre-configured/pre-defined spatial assumption (if applicable). Threshold K may be based on WTRU capability only if multiple candidate values of K are supported.

[0080] Concerning, DL Beam Indication for NR-PDCCH, NR-PDCCH transmissions may need to be robust against beam pair link blocking, where a WTRU may be configured to monitor NR-PDCCH on different beam pair link(s) in different NR-PDCCH OFDM symbols. Furthermore, the QCL configuration for NR-PDCCH may contain the information that provides a reference to a TCI state for a scenario where the QCL configuration/indication is on a per CORESET basis (e.g., the WTRU applies the QCL assumption on the associated CORESET monitoring occasions and all search space(s) within the CORESET utilize the same QCL) or a scenario where the QCL configuration/indication is on a per search space basis (e.g., the WTRU applies the QCL assumption on an associated search space and where there are multiple search spaces within a CORESET, the WTRU may be configured with different QCL assumptions for different search spaces). The indication of QCL configuration may be done by RRC or RRC + MAC CE, but details of the DCI may be addressed herein. Further, the design of the QCL configuration/indication for WTRU monitoring on NR-PDCCH over multiple different beam pair link(s) to reduce the overhead while providing robustness may also be discussed herein.

[0081] In one embodiment, there may be a DL beam indication for NR-PDSCH. An N-bit Transmission Configuration Indicator (TCI) field in DCI may be used to provide a spatial QCL reference to a

DL RS (e.g., CSI-RS or single side band (SSB) to aid in the demodulation of NR-PDSCH and/or NR-PDCCH. A given value of the indicator may be referred to as an indicator state, and it may be associated with an index of the DL RS (e.g., the index of CSI-RS or SSB). The DL RS index may be associated with the indicator state, either through explicit signaling (e.g., RRC or RRC and MAC-CE) or implicitly during a WTRU measurement (e.g., where the network configures a subset of DL RSs for measurement for a WTRU, and the WTRU establishes the association between a DL RS index and an indicator state based on measurement results).

[0082] When one NR-PDSCH scheduling assignment DCI carries one TCI field that provides the beam indication or spatial QCL reference indication for NR-PDSCH reception at a WTRU, it may need to consider the scheduling offset or scheduling delay of the corresponding NR-PDSCH allocation because a WTRU may take time to finish TCI decoding, RF tuning, and switching from current RX beam to the new RX beam if decoded TCI indicates that a new RX beam is needed.

[0083] The scheduling offset may present a certain period indicated as N symbols or time slots, depending on whether the corresponding NR-PDSCH allocation is scheduled in the same slot or a different slot as the scheduling assignment DCI. N may be an integer number that is no less than 1. The scheduling offset may be smaller, equal, or larger than a pre-specified or configured threshold K, which may be an estimated time duration that the WTRU needs to finish TCI decoding, RF tuning, and beam switching from a current RX beam to a new RX beam if a new RX beam is configured for NR-PDSCH.

[0084] The threshold value K may be an estimate time duration for a WTRU performing TCI decoding, RF tuning, and beam switching if a new RX beam is needed. The time length expressed by the threshold value K may depend on one or more of the following factors: WTRU capability; deployment scenarios, WTRU supported/used numerologies (i.e., where different values of K may be needed for different numerologies); WTRU service type such as eMBB, URLLC, MTC, or the like (e.g., URLLC may require smaller value of K than eMBB use case for a low latency requirement); and/or QoS requirements. The WTRU capabilities may include, but are not limited to, WTRU processing time for DCI reception and decoding (e.g., a different WTRU may have different decoding capability); WTRU processing time for beam switching; WTRU RF chain tuning time; number of panels equipped and used simultaneously/non-simultaneously; a WTRU only implementing a fixed Rx beam; and/or a WTRU reporting the WTRU capability to assist gNB or TRP to configure the appropriate scheduling offset or time offset for the reception and demodulation of NR-PDSCH. Deployment scenarios may include where the WTRU blind decoding time depends on frequencies used (e.g., WTRU may be configured with higher number of search

spaces when operates on higher frequencies). The deployment scenarios may also include where the beam switching time and RF turning time may be different when operating on higher frequencies.

[0085] Various approaches may be proposed to determine and configure the threshold value of K based on one or more factors mentioned above.

[0086] In one approach, K may be pre-specified and/or configured based on the same slot or cross slot scheduling. For example, for same slot scheduling, the value K may indicate the integer number of symbols. For cross slot scheduling, the value K may indicate the integer number of time slots. In the case a WTRU changes the time domain behavior from slot based scheduling to non-slot based scheduling, K may be configured and/or indicated dynamically. For example, non-slot based scheduling may be certain symbol duration, and K may be adjusted accordingly and indicated to the WTRU.

[0087] In another approach, a WTRU may be configured with multiple values of K, which may be pre-specified and configured for different types of service (e.g., URLLC or eMBB), and multiple Ks may be used simultaneously or alternatively. For example, a WTRU may support multiple types of service (e.g., URLLC, eMBB) simultaneously or alternatively, then multiple Ks may be accordingly configured for multiple services, which may be the same or different values.

[0088] As discussed here, the threshold value K may be decided by the network (gNB/TRP) and/or WTRU in a number of different methods. In one method, the WTRU may report necessary information to the network to assist the gNB/TRP to decide the threshold value K. The reported necessary information may include one or more of the following: WTRU capability, WTRU operating scenarios, WTRU currently used numerology, WTRU current use case, etc. The network may determine and configure the threshold K to the WTRU by higher layer signaling such as RRC message and/or MAC CE or L1 signaling such as DCI.

[0089] In another method, the WTRU may decide the value of K in a network controlled environment. For example, multiple Ks may be pre-specified based on the WTRU capability, WTRU category, numerology, use cases, or traffic type, etc. During the RRC connection, the network and WTRU may exchange the capability information and the WTRU may decide the threshold K value. Another example, the network may configure a WTRU with several optional values of K (each option may be bundled with possible conditions, such as when the value K is the nearest rounded integer milliseconds by combining TCI decoding time and beam switching time), and the WTRU may select or determine a value K from multiple K values based on network configurations. In this example, note that once the WTRU decides

K, the value of K may be informed to the network so that the network can schedule the subsequent NR-PDSCH allocation properly.

[0090] In another method, the threshold K may be pre-specified and/or configured to the same or common value for all WTRUs, a group of WTRUs, or WTRU-specified.

[0091] In another method, the same or different threshold K value may be configured to a WTRU based on one or more factors such as WTRU capability, WTRU operating scenarios, WTRU currently used numerology, WTRU current use case, etc. For example, if the WTRU implements one fixed Rx analog beam, or does not support Rx beam sweeping capability, the threshold K may not need to be configured or the WTRU may ignore it.

[0092] In one embodiment, there may be procedures to determine the threshold K. The beam indication for PDSCH may be based on a threshold for scheduling offset. Whether to use the spatial QCL indicated from the TCI state carried in the assignment DCI or follow the spatial QCL used for a CORESET with the lowest ID may be determined based on the scheduling offset and threshold Threshold-Sched-Offset. This threshold value may be determined based on one or more factors/methods as discussed herein, such as WTRU capability, numerology (subcarrier spacing), and the like. These factors/methods may be independently used or jointly used to determine the threshold Threshold-Sched-Offset.

[0093] In one scenario a table based implementation may be used to determine the threshold K. One or multiple tables may be specified so that the value of Threshold-Sched-Offset may be directly retrieved/decided based on the dimensions covered in the table(s). The specified table(s) may be common to a group of WTRUs (e.g., the WTRUs have similar capability or latency requirement or operating SCS) or WTRU specific. Table 2 and Table 3 are examples used for a table based scenario for determining threshold k.

Beam indication latency requirement (imposed by, e.g., service type, QoS, etc.)	Units	60khz SCS	120 khz SCS	60khz SCS	120 khz SCS	...
		CC1 / BWP1		CC2 / BWP2		
Low latency	Symbols or slots	Value 1	Value 4	Value 7	Value 10	
Medium latency	Symbols or slots	Value 2	Value 5	Value 8	Value 11	
High latency	Symbols or slots	Value 3	Value 6	Value 9	Value 12	

Table 2 Threshold-Sched-Offset value for baseline WTRU (WTRU category I)

Beam indication latency requirement	Units	60khz SCS	120 khz SCS	60khz SCS	120 khz SCS	...
		CC1 / BWP1		CC2 / BWP2		
Low latency	Symbols or slots	Value 13	Value 16	Value 19	Value 22	
Medium latency	Symbols or slots	Value 14	Value 17	Value 20	Value 23	
High latency	Symbols/slots	Value 15	Value 18	Value 21	Value 24	

Table 3 *Threshold-Sched-Offset* value for advanced WTRU (WTRU category II)

[0094] Multiple factors may be considered for the specific values found in the tables for *Threshold-Sched-Offset*. The value ranges for different factors in Tables 2 and 3 may be limited for easier illustration purposes. For example, two WTRU categories, three SCSs, and three delay requirements may be considered.

[0095] In Table 2, values are baseline values which may be supported by all WTRUs. Values in Table 2 may be arbitrary values but with a certain ordering relationship. For example, given the same other conditions (e.g., same WTRU, operating CC/BWP, latency requirement, etc.), for higher SCS, from 60 khz to 120 khz SCS, the value may be higher since the time length of 1 symbol/slot is smaller. The values for low latency and high latency in Table 2 may be the same or different for a given numerology, in case of a normal WTRU. If those values for high, medium, and low latency WTRUs are the same for all numerologies, then any two of them may be merged or ignored for the baseline WTRU and advanced WTRU.

[0096] In Table 3, for a given numerology and latency requirement, whether or not to support the value in Table II is reported as a WTRU capability. For a given numerology and latency, the value in Table 3 should be equal to or smaller than value in Table 2. All values may be pre-defined as fixed values.

[0097] A WTRU may follow the specified values defined in the tables and report the preferred *Threshold-Sched-Offset* value. A WTRU reported value is based on WTRU capability at a given carrier frequency, for each subcarrier spacing applicable to PDCCH reception (DCI decoding and obtain TCI information carried in the DCI) at this carrier frequency. The finally reported value *Threshold-Sched-Offset* may be up to WTRU. Due to a variety of reasons, a WTRU may dynamically be switching its operation capabilities. For example, for saving energy consumption, a WTRU may switch from advance mode to baseline mode. A WTRU may initiate or be indicated by NW (gNB/TRP) to work from above 6 GHz to below 6 GHz, and the supported SCS may be switching from 60/120 khz to 15/30 khz.

[0098] The definition of *Threshold-Sched-Offset* is essentially to address the different timing delays experienced by a WTRU when the WTRU performs DCI decoding, obtaining TCI information, and

beam switching. Given the same WTRU hardware capability, the WTRU may still report a different *Threshold-Sched-Offset* value for one or more reasons, such as: the configured number of search spaces and CORESET for a WTRU to monitor may be different (e.g., carrier frequency, aggregation level), and the time involved during DCI monitoring and decoding may be different; from the TCI field carried in DL DCI, a WTRU may need to check the activated TCI state table to find proper QCL information (e.g., RS(s) in the RS set), where the table checking and processing time may be different if the activated TCI table has invalid information; and/or the time delay needed for beam switching may depend on the carrier frequency/BWP used for PDCCH reception (e.g., the received signal may have different level of signal power difference between control and data channel, and the AGC gain may converge fast enough for beam switching within the same CC/BWP, but converge slowly for beam switching from a beam in CC1/BWP1 to a beam in CC2/BWP2).

[0099] In one scenario a formula based implementation may be used to determine the threshold K. As noted previously, the definition of *Threshold-Sched-Offset* is to address the different timing delay experienced by a WTRU when the WTRU performs the DCI decoding, obtaining TCI information, and beam switching.

[0100] For PDCCH blind decoding, different WTRUs with different hardware capability may take different timing delays to detect the format of PDCCHs (e.g., aggregations). Even for the same WTRU, different configurations of CORESET/Search Spaces may result in different processing timing consumption (e.g., a WTRU configured 5 SSs typically needs more time for DCI decoding than the same WTRU configured with 15 SSs, assuming the same number of CORESETs). In other words, the DCI decoding time may be a combined value depending on configurations and WTRU hardware capability. For beam switching, the timing delay may also depend on a combination of both WTRU implementations and configurations/operations (e.g., beam switching within the same or different CC/BWP). Therefore, the value *Threshold-Sched-Offset* for a WTRU operating on a BWP may be computed as:

$$[0101] \quad \text{Threshold} - \text{Sched} - \text{Offset} = \left\lceil \frac{D-d}{\text{symbol_length}} + \delta \right\rceil \text{symbols}$$

[0102] In the above formula, $\lceil \cdot \rceil$ is a ceiling (round up) function that converts the inside value to the next smallest integer that is larger than the inside value. The d is the time length between the last symbol of all the configured monitored CORESET or search spaces of a WTRU, as shown in the FIG. 3A. The D is the WTRU reported time length, which is the WTRU estimated time to complete the DCI decoding, obtain the TCI information, and potential beam switching if needed.

[0103] The beam switching time may just be an WTRU estimation before the completion of DCI decoding and obtaining the TCI information, since the WTRU is unaware of whether beam switching is needed (e.g., if PDCCH and PDSCH reception use the same beam then beam switching is unnecessary) or how much time for beam switching is needed (e.g., the spatial angle between the old and new beam, whether BWP switching is needed during the process of beam switching). The beam switching time may be equal to 0 if no beam switching is needed or non-zero value if beam switching is needed. The time to obtain TCI information may depend on WTRU implementation (e.g., cache access to read TCI table) and reported as part of D . The WTRU reported value D may be based on μ of Table 4 that corresponds to the subcarrier spacing of the downlink with which the PDSCH was transmitted.

[0104] $\text{Symbol}_{\text{length}}$ is the time length of each symbol within a slot on a BWP, and δ is the offset value to compensate/adjust the threshold value considering other factors/methods as discussed herein.

μ	PDCCH decoding time [symbols]
0 (e.g., 30 khz)	Value 1
1 (e.g., 60 khz)	Value 2
2 (e.g., 120 khz)	Value 3

Table 4 Processing time delay for PDCCH processing capability 1

[0105] In one scenario, there may be WTRU procedures for PDSCH reception. The WTRU may report its WTRU capability (e.g., WTRU estimated time duration for performing DCI decoding, obtaining TCI information, RF tuning and beam switching if a new RX beam is needed, such as the value of D in the proposed formula in section 4.1.2.2) to assist the gNB or TRP to configure the appropriate scheduling offset or time offset for the reception and demodulation of NR-PDSCH.

[0106] The WTRU may receive the scheduling offset information for PDSCH reception/demodulation after decoding the DCI from the received PDCCH. The WTRU may determine the *Threshold-Sched-Offset* based on the table based approach or the formula based solution approach as described herein.

[0107] The WTRU may determine the beam (or spatial QCL parameter) for PDSCH reception based on the following rule, which depends on whether the received scheduling offset information from DCI is larger or smaller than the determined *Threshold-Sched-Offset* (threshold K): If the scheduling offset $<$ threshold K , then the PDSCH uses the beam indicated by the default TCI state that corresponds to the TCI state used for control channel QCL indication for the lowest CORESET ID in that slot; If the scheduling offset $\geq$ threshold K , then the PDSCH uses the beam (spatial QCL parameter) indicated by the N -bit TCI field in the assignment DCI.

[0108] The WTRU may switch to a different beam which is determined from the previous step, if the WTRU uses different beam for PDCCH reception and PDSCH reception. Otherwise, the WTRU does not switch beams. The WTRU may receive PDSCH after applying the determined beam.

[0109] A *Threshold-Sched-Offset* (e.g., threshold K) value may be determined based on the number of TCI states configured. For example, if the number of TCI states configured is less than a first threshold, a first *Threshold-Sched-Offset* value may be used; if the number of TCI states configured is greater than the first threshold and less than a second threshold, a second *Threshold-Sched-Offset* value may be used; if the number of TCI states configured is greater than the second threshold, a third *Threshold-Sched-Offset* value may be used, wherein the thresholds may be predefined, configured, or determined based on one or more of system parameters and/or UE parameters. The second threshold may be larger than the first threshold. The third threshold may be larger than the second threshold.

[0110] A *Threshold-Sched-Offset* value may be determined based on a number of transmitted SS blocks within a SS burst, wherein the number of transmitted SS blocks may be the number of actually transmitted SS blocks which may be indicated in a broadcasting signal.

[0111] In one embodiment, if a NR-PDSCH is scheduled and transmitted over a new beam before the WTRU decodes DCI/TCI and switches to a new needed Rx beam, the first few symbols of the NR-PDSCH allocation may be buffered improperly and thus the subsequent data decoding may be impaired. If the scheduling offset of corresponding NR-PDSCH (indicated by the scheduling assignment DCI) is equal or bigger than the threshold value K, NR-PDSCH may use the beam (spatial QCL assumption) indicated by the N-bit TCI in the assignment DCI. If the scheduling offset of corresponding NR-PDSCH (indicated by the scheduling assignment DCI) is smaller than the threshold value K, the WTRU may apply the proper Rx beam from the starting symbol of the scheduled NR-PDSCH to avoid loss of the NR-PDSCH symbols which are scheduled before the threshold value K. There may be various approaches to determine the proper Rx beam applied by the WTRU and used for NR-PDSCH before the beam (spatial QCL parameter) indicated by the TCI in the associated DCI or in the assignment DCI.

[0112] In one approach the beam may be pre-configured. For example, a specific beam may be pre-configured so that the WTRU may always switch to the pre-configured beam to buffer the first few symbols of NR-PDSCH. The information concerning whether a WTRU must switch to that beam and for how long a WTRU needs to receive and buffer on that specific beam, may be pre-configured and known to the WTRU in advance. The pre-configured beam may be WTRU specific (e.g., RRC signaling), may be common to a group of WTRUs (e.g., depends on WTRU use case, WTRU capability category, etc.), or all

WTRUs within a cell/TRP. The pre-configured beam may be configured to a WTRU through higher layer signaling such as RRC, obtained by a WTRU through system information via broadcast, or specifically requested. The preconfigured beam may be set as a default beam once configured initially and reconfigured at a later time as needed.

[0113] In another approach the beam may be pre-defined. Instead of knowing a proper Rx beam in advance (e.g., pre-configured beam, default beam, etc.), a WTRU may apply a proper Rx beam by following pre-defined mechanisms. There may be one or more of these pre-defined mechanisms. One mechanism may use the same beam as a WTRU receives the scheduling DCI (NR-PDCCH) in the same slot.

[0114] Another mechanism may use the same beam as a WTRU receives the NR-PDCCH or/and NR-PDSCH in previous slots. For example, assuming the current slot is X, a WTRU may use the same beam used in the previous slot Y for NR-PDCCH or/and NR-PDSCH, where the $Y \leq X$ and the slot difference is $\beta = X - Y$, and the value of β may be configurable.

[0115] Another mechanism may use a beam configured by higher layer signaling (e.g., MAC-CE and/or RRC). To reduce the higher layer involvement and overhead, this higher layer signaling may not always be needed. For example, a WTRU may be configured to use a proper Rx beam that will be continuously used in future NR-PDSCH transmissions. Note this mechanism may only or may not only indicate a Rx beam for a WTRU to receive NR-PDSCH symbols before the threshold value K.

[0116] Another mechanism may use a semi-persistent beam. TX/RX beam for NR-PDSCH may not change dynamically and quickly that it is needed to indicate the beam in every NR-PDSCH scheduling. The spatial QCL assumption (or a beam) sent to a WTRU at time/slot t1 may be reused by the WTRU to receive all subsequent scheduled NR-PDSCH allocations until a specific condition is satisfied. Note that the spatial QCL assumption may be indicated to the WTRU by using DCI/TCI which has low overhead, or higher layer signaling which has high reliability. A specific condition may be one or more of the following: the same spatial QCL assumption (or a beam) is only reused to receive N subsequent scheduled NR-PDSCH allocations, where N may be configurable or/and carried together with the QCL indication; a timer may be configured with each spatial QCL assumption, and when the timer is expired, the spatial QCL assumptions becomes invalid; a new spatial QCL assumption is indicated/configured, which may directly overwrite the old spatial QCL assumption.

[0117] In another approach the beam may be determined based on one or more rules. A WTRU may obtain proper Rx beam information based on pre-defined rules. Note that the defined rules may be

triggered by associated parameters (e.g., WTRU speed, WTRU traffic load, currently used numerology, etc.), and each triggered rule may lead to the beam changes within a specific beam determination mechanism (e.g., switch from one preconfigured beam to another reconfigured beam) or across different beam determination mechanisms (e.g., from semi-persistent beam to NR-PDCCH beam or last NR-PDSCH beam). There may be one or more rules. For example, a WTRU uses a preconfigured beam initially, but switches to use semi-persistent beam as the WTRU moves around. The persistence duration may be related to the WTRU's moving speed and configured/indicated as a certain period or a timer in DCI or MAC-CE or RRC message. For a high speed WTRU, the smaller period or shorter timer may be used. For a low speed WTRU, the larger period or longer timer may be used. Once the WTRU receives the spatial QCL assumption indicated in a DCI, it may be used for the reception of NR-PDSCH for a certain period, until the timer is expired, or a new DCI with beam indication is received. In another example, for a high speed case, a WTRU may use wide beam and a single fix Rx beam (e.g., omni beam). Alternatively, the WTRU may use the same beam for NR-PDCCH reception to receive NR-PDSCH to reduce configuration/indication overhead. In another example, a WTRU may switch the operation from slot based mode to non-slot based mode. In slot based mode, the WTRU may use the same Rx beam to receive NR-PDSCH as to receive the CORESET or NR-PDCCH. In non-slot based mode, the WTRU may use the Rx beam indicated by one previous DCI containing beam indication, e.g., last DCI with beam indication or the Rx beam for the reception of last NR-PDSCH.

[0118] In one embodiment, for PDSCH, the QCL reference may be dynamically indicated by a TCI field in DCI. For PDCCH, the QCL reference may be semi-statically configured by a reference to a particular TCI state. DL RS in the RS Set used for spatial QCL purposes may be dynamically initialized and updated based on WTRU measurements and reports.

[0119] Spatial QCL assumptions may need to be updated due to various reasons, such as WTRU mobility, WTRU rotation, WTRU traffic load, beam congestion status, beam blockage, change of WTRU active band width part(s), and/or change of WTRU active Component Carrier (s). The spatial QCL assumption update may be explicit, implicit, or event triggered.

[0120] In the event of an explicit update, the update may contain a reference to a periodic or semi-persistent DL RS (e.g., CSI-RS or SSB), which may be updated and sent by the network based on the latest WTRU beam measurement reporting by either RRC or RRC + MAC-CE signaling. This explicit update may be network initiated or WTRU initiated.

[0121] In the event of an implicit update, the update may be achieved by the network (TRP/gNB) including signaling (e.g., DCI) that triggers an aperiodic beam measurement on a periodic, semi-persistent, or aperiodic DL RS (e.g., CSI-RS or SSB). Upon receiving the measurement trigger, the WTRU may know that it should update the QCL reference in the pre-defined mechanisms or rule based beam determinations.

[0122] In the event of a triggered update, one example trigger may be where the WTRU experiences a larger traffic loading and traffic congestion on beam, so the pre-defined beam may not sustain capacity requirements, e.g., WTRU cannot use the same beam for receiving NR-PDCCH. The update may be triggered by other events.

[0123] In one embodiment, there may be several methods for a spatial QCL assumption update for NR-PDSCH reception before TCI decoding and beam switching. In this embodiment, it may be assumed that the WTRU is pre-configured with a beam X to receive the NR-PDSCH symbols scheduled before the WTRU finishes DCI decoding and obtain the TCI and spatial QCL information during a transition period (TP) before the beam indicated by the N-bit TCI field in the assignment DCI is applied. The TP is needed for NR-PDSCH reception and may indicate the time for WTRU DCI/TCI decoding, RF tuning, and beam switching if a new Rx beam is scheduled for NR-PDSCH. Due to various reasons, such as WTRU rotation/movement or beam blockage, the QCL reference used for TP may become invalid (e.g., the pre-configured beam X may be blocked). The following methods may recover and/or update the QCL reference for NR-PDSCH reception during TP and/or the subsequent scheduled NR-PDSCH(s) reception.

[0124] FIG. 3B shows an example method of spatial QCL assumption update for NR-PDSCH reception. In this method, the network (e.g., gNB or TRP) may send an explicit update to the WTRU with new QCL reference (e.g., WTRU could use the same beam as the beam used to receive the assignment DCI (NR-PDCCH)). As shown in the FIG. 3B, the spatial QCL assumption update for NR-PDSCH reception may have the gNB send an explicit update spatial QCL assumption to the WTRU based on the latest WTRU beam measurement reporting. Alternatively, the WTRU may detect beam failure on the pre-configured beam and request the gNB to send explicit update spatial QCL assumption for the reception of NR-PDSCH during TP.

[0125] FIG. 4 shows another example method of spatial QCL assumption update for NR-PDSCH reception. In this method, an event triggered update may be used for spatial QCL assumption for NR-PDSCH reception. Based on a certain pre-specified or configured event triggering (e.g., PDCCH beam congestion), the WTRU may automatically decide a new QCL reference according to previously configured rules (e.g., the rule may be configured by the network in earlier time, e.g., RRC configuration). As illustrated

in Figure 3, the second exemplary spatial QCL assumption update for NR-PDSCH reception is that the WTRU may use the same beam as the one used to receive the last NR-PDSCH allocation as long as this beam has L1-RSRP, SINR, or BLER above a certain configurable threshold during the last or previous measurement(s). The WTRU may send feedback of the determined beam to the gNB.

[0126] FIG. 5 shows another example method of spatial QCL assumption update for NR-PDSCH reception. In this method, a gNB may use an implicit method to recover and update the WTRU's QCL reference for NR-PDS. As shown in the FIG. 5, the spatial QCL assumption update for NR-PDSCH reception may assume the QCL reference used for the TP becomes invalid (e.g., the pre-configured beam may be blocked). Then the gNB may send a trigger signaling (e.g., via RRC, MAC-CE and/or DCI) to the WTRU with or without a specifically configured RS resources (e.g., certain aperiodic CSI-RS resources specifically configured for the WTRU to recover from an invalid QCL reference). With this trigger signaling, the WTRU may perform beam measurement and reporting on aperiodic RS resources (e.g. CSI-RS) and make a proper update of the QCL reference which may then be used to receive future NR-PDSCH allocations which are scheduled during the TP. The updated QCL reference may be sent to the network (e.g., WTRU sends the updated QCL reference as feedback to the network), so that the network may use the updated QCL reference to transmit NR-PDSCH allocation within the TP. It may also be possible that the updated QCL reference is applied for NR-PDCCH and/or NR-PDSCH as well in an implicit manner or in an explicit manner. In case of the implicit manner, the WTRU may apply the updated QCL reference directly for the following NR-PDCCH in subsequent slots, and/or NR-PDSCH in the current slot which may include within and/or outside the TP of NR-PDSCH, or subsequent slots. In the case of the explicit manner, the WTRU may rely on explicit signaling to extend the updated QCL reference for PDSCH allocation within the TP to NR-PDCCH or/and NR-PDSCH in subsequent slots. Alternatively, the third solution may be extended to become a hybrid solution by combining the explicit and implicit update of a spatial QCL reference or assumption for the reception of NR-PDCCH and/or NR-PDSCH.

[0127] In one embodiment, after a WTRU correctly decodes TCI/DCI, it may apply the Rx beam (spatial QCL parameter) indicated in the TCI field in the associated DCI or in the assignment DCI for the reception and demodulation of a scheduled NR-PDSCH. Alternatively, the WTRU may continue applying the beam used during TP to the subsequent scheduled NR-PDSCH. Alternatively, the WTRU may use the same beam as the WTRU receives the scheduling DCI (NR-PDCCH) in the same slot. Alternatively, the WTRU may use the same beam as the WTRU receives the NR-PDCCH or/and NR-PDSCH in the previous

slots. Alternatively, the WTRU may determine the proper RX beam used for NR-PDSCH after TCI/DCI decoding by one or any combination of the methods discussed herein.

[0128] If the WTRU incorrectly decodes TCI/DCI, the decoding error of current NR-PDCCH may result in failures in the reception of NR-PDSCH, so the WTRU may continue applying the beam used during TP to the following NR-PDSCH. Alternatively, the WTRU may determine the proper RX beam used for NR-PDSCH after TCI/DCI decoding by one or any combination of the methods disclosed herein.

[0129] In one embodiment, a WTRU may be RRC configured with M TCI states per cell, per TRP, or per BWP, depending on the WTRU capability. Before one of the RRC configured TCI states is used/indicated by the DCI carrying the TCI indication (TCI/DCI), a subset (e.g., up to 8) of the RRC configured M TCI states may be selected and activated by the MAC-CE. If the value M, number of RRC configured TCI states, is larger than the largest supported subset size (e.g., 8), a selection message or command such as MAC-CE may be used. However, if the value of M is equal to or smaller than a certain size, such as 8, there may be several optional procedures for WTRU to carry out.

[0130] In a first option, a WTRU may still wait for an activation/selection command such as a MAC-CE. For example, if M = 7, MAC-CE may be still needed to select a smaller number, such as 2, to reduce the possible overhead for the WTRU to monitor beam indication. In one use case, if the number of activated TCI states is small enough (e.g., smaller than 4), a smaller number of the activated TCI states information may be stored in CPU cache, with lower latency and low power during TCI state data access.

[0131] In a second option there may be no need to select/activate a subset of TCI states, so a WTRU may not need to wait for a selection/activation command such as MAC-CE.

[0132] In a third option a TCI state selection/activation timer may be defined/specified and configured by a higher layer message (e.g., RRC message) and/or indicated in system information. If a WTRU does not receive the selection/activation command within the timer, the WTRU may assume that the selection/activation command is not needed and all the M configured TCI states may be treated as activated.

[0133] When beam failure occurs previously configured and activated TCI states may become invalid for the time duration until the reconfiguration and reactivation (if reactivation is needed) of the TCI states; the default TCI may be defined for a WTRU's reception for PDSCH and/or PDCCH.

[0134] For PDCCH reception after beam failure, the WTRU may monitor a dedicated control channel resource sets (CORESETs) during beam failure recovery. When the WTRU is reconfigured by a gNB to another CORESET for receiving dedicated PDCCH and activated by MAC-CE with a TCI state if the

configured CORESET has $K > 1$ configured TCI states, the WTRU may then monitor the new configured CORESET based on the activated TCI state. Alternatively, instead of reconfiguration and reactivation, the WTRU may be re-indicated by gNB to another TCI state(s) by MAC-CE before beam failure.

[0135] During initial RRC configuration or subsequent RRC reconfigurations, a WTRU may be configured with updated TCI states, and those configured/reconfigured/updated TCI states may need to be activated by subsequent MAC-CE commands. During the period between RRC configuration/reconfiguration/update of the TCI states and subsequent MAC-CE activation of the TCI states, a default/fallback spatial QCL reference may be needed for PDCCH reception. There may be several options to accomplish this.

[0136] In a solution, the TCI activated and used before RRC reconfiguration/update of TCI states may still be activated and used for PDCCH until the reception and application of the new MAC-CE activation/deactivation/reactivation command.

[0137] In another solution, one specific new RRC configured/reconfigured/updated TCI states may be used for PDCCH reception. For example, the lowest entry of the new RRC states is used.

[0138] In another solution, the most recent TCI state (and the included DL RS) activated by MAC-CE in any of the existing CORESETS may be used for QCL spatial reference for PDCCH reception until the reception and application of the new MAC-CE activation/deactivation/reactivation command. If the most recent activated TCI state (or DL RSs) is more than one, the DL RS activated for a specific CORESET may be used. For example, the DL RS for the CORESET with lowest CORESET ID may be used, wherein the lowest CORESET ID may be the lowest CORESET ID number except '0' and/or the lowest CORESET ID within the CORESETs in the same bandwidth part (BWP).

[0139] Once the TCI state for PDCCH reception is determined (TCI reconfiguration and reactivation for PDCCH) as described herein, the TCI states for PDSCH reception may also be needed; there may be one or more scenarios that address this.

[0140] In one scenario, the WTRU may assume DMRS of PDSCH is spatial QCL'ed with the DL RS of the WTRU-identified candidate beam in the beam failure recovery request. In this case, TCI states may not be needed, by using the assumed QCL relation (RX beam) with the DL RS of the WTRU-identified candidate beam in the beam failure recovery request for the PDSCH reception.

[0141] In another scenario, if the TCI states reconfiguration and activation/selection for PDSCH is completed, the WTRU may rely on the DCI/TCI message for PDSCH reception. In this case, if the offset between the reception of the DL DCI and the corresponding PDSCH is equal to or greater than a threshold

Threshold-Sched-Offset, the WTRU may use the TCI indicated in the DCI; if the offset is smaller than the threshold Threshold-Sched-Offset, the WTRU may assume that the antenna ports of one DM-RS port group of PDSCH of a serving cell are quasi co-located based on the TCI state used for PDCCH quasi-collocation indication of the lowest CORESET-ID in the latest slot in which one or more CORESETs are configured for the WTRU.

[0142] In another scenario, if the TCI states reconfiguration is completed but the activation/selection for PDSCH is not completed, the WTRU may not rely on the indication of TCI by DCI because the RRC configured TCI states may still not be activated. In this case, the WTRU may use the same TCI state that is activated for PDCCH reception. Alternatively, the WTRU may use the default TCI state corresponding to, for example, the first TCI state in the RRC configured PDSCH TCI states, or the same TCI state for PDSCH reception from the previous or latest reception

[0143] In one embodiment, one or more control channel resource sets (CORESETs) may be configured for a WTRU to monitor and each CORESET may be configured with one or more QCL (Quasi-collocation) parameters (e.g., spatial Rx parameters) which may be used to indicate or determine an associated downlink signal (e.g., CSI-RS or SS block) for downlink beam indication. Hereafter, a QCL association between a downlink channel (e.g., CORESET, PDCCH, PDSCH) and a downlink reference signal (e.g., CSI-RS, SS block) may be used to indicate which downlink beam or receiver beam to use for the downlink channel reception. If one or more downlink channels use the same beam, then one or more downlink channels may be associated (e.g., QCL-ed) with the same downlink reference signal (e.g., CSI-RS, SS block). The WTRU may be configured to monitor one or more CORESETs in a slot, where the one or more CORESETs in a slot may be associated with a same downlink beam (e.g., a same CSI-RS resource or a same SS block). If the one or more CORESETs are associated with the same downlink beam (e.g., associated with the same downlink reference signal), the CORESETs may be configured in the same or different time locations, wherein the CORESETs may be located, allocated, transmitted, or monitored in different frequency locations when the CORESETs are configured in the same time location (e.g., a same OFDM symbol). Alternatively, the one or more CORESETs in a slot may be associated with a different downlink beam (e.g., different CSI-RS resources or SS blocks). If the one or more CORESETs are associated with a different downlink beam, the CORESETs may be configured in different time location within a slot (e.g., symbol or symbol group) or across different slots.

[0144] As a default beam for a NR-PDSCH reception, a WTRU may be configured with the same beam with its associated CORESET, where a default beam may be used if the scheduling offset k is

smaller than a threshold, and/or a default beam may be used for a period where a WTRU receive its associated DCI. Such a period may be predefined, configured, or implicitly determined based on one or more system parameters (e.g., subcarrier spacing, slot length, number of symbols for scheduling, etc.). When a WTRU uses a default beam to receive a NR-PDSCH and the default beam is the same beam as its associated CORESET, the WTRU may use or assume one or more QCL parameters for NR-PDSCH that may be the same as the one or more of QCL parameters for its associated CORESET.

[0145] In one approach, if multiple CORESETs are configured to monitor for NR-PDSCH scheduling and the CORESETs are associated with the same beam (e.g., the CORESETs are QCL-ed with the same downlink reference signal), the default beam for a NR-PDSCH reception may be based on the beam used for CORESETs. The offset value between a CORESET and its associated NR-PDSCH may be the same irrespective of the CORESET number in which the WTRU received the scheduling DCI.

[0146] In another approach, if the CORESETs are associated with more than one beam (e.g., QCL-ed with more than one downlink signals or downlink reference signals), the default beam for a NR-PDSCH reception may be based on one or more scenarios. In one scenario, a reference CORESET may be defined or determined within the configured CORESETs, wherein the QCL parameters (or a subset of QCL parameters) for the reference CORESET may be used as a default beam for the NR-PDSCH reception. For example, the QCL parameters for NR-PDSCH reception may be the same as the QCL parameters of the reference CORESET. The QCL assumption for the reference CORESET (e.g., spatial Rx parameter) may be reused for the NR-PDSCH reception in the slot. Also, the reference CORESET may be different in each slot. For example, a first CORESET in the configured CORESETs may be used or determined as the reference CORESET in a slot and a second CORESET in the configured CORESETs may be used or determined as the reference CORESET in another slot. When the reference CORESET is changed across slots, the reference CORESET may be cyclically switched among the configured CORESETs. Additionally, the reference CORESET may be a predefined location within the configured CORESETs irrespective of the slot, and the configured CORESETs may be different based on the slot number.

[0147] In another scenario, the CORESET located in the latest time location (e.g., closest to the NR-PDSCH region) within the configured CORESETs may be used or determined as a reference CORESET. The scheduling offset between a CORESET and its associated NR-PDSCH may be different based on the CORESET type. For example, if a WTRU receives a DCI for NR-PDSCH scheduling in a reference CORESET, a first scheduling offset may be used; if the WTRU receives a DCI for NR-PDSCH

scheduling in a CORESET which is not the reference CORESET (non-reference CORESET), a second scheduling offset may be used. The second scheduling offset may be longer than the first scheduling offset. For example, when a WTRU receives a DCI for NR-PDSCH scheduling in a reference CORESET in a slot #n, the WTRU may receive, decode, and/or attempt to decode the scheduled NR-PDSCH in the slot #n. If a WTRU receives a DCI for NR-PDSCH scheduling in a non-reference CORESET, the WTRU may receive, decode, and/or attempt to decode the scheduled NR-PDSCH in the slot #n+x, where x may be predefined, configured, indicated, and/or reported as a WTRU capability.

[0148] In another scenario, the reference CORESET within the CORESETs configured may be configured via a higher layer signaling.

[0149] In another scenario, the reference CORESET within the configured CORESETs may be determined implicitly based on at least one of following: system parameters (e.g., numerology, cell-ID, etc.); WTRU-specific parameters (e.g., WTRU-ID (e.g., C-RNTI), scrambling ID, etc.); and/or timing/location parameters (e.g., slot number, frame number, radio frame number, bandwidth part number, etc.).

[0150] In another approach, a TCI field may not be present in the reference CORESET while the TCI field may be present in other configured CORESETs if more than one beam is used for multiple CORESETs. In such an approach, the WTRU may assume that the NR-PDSCH scheduled via a DCI which may be received in the reference CORESET may be the same beam (e.g., QCL-ed with same downlink reference signal) as the reference CORESET. Further, the WTRU may assume that the NR-PDSCH scheduled via a DCI which may be received in other configured CORESETs may be a different beam (e.g., QCL-ed with a different downlink reference signal) with the reference CORESET.

[0151] As discussed herein, the schemes of determining an Rx beam before the scheduling offset include using a pre-configured beam, using a pre-defined beam, using a rule based beam determination, or updating spatial QCL assumption may be jointly or hybrid applied via some pre-determined order. One example may be the rule based beam determination has the highest priority, the pre-configured beam has the second highest priority, the pre-defined beam has a third highest priority, etc.

[0152] FIG. 6 shows an example procedure for determining the DL Rx beam before the scheduling offset. In the example, the WTRU may first check if it is in some special conditions (e.g., moving, rotation). If so, it may use the rule-based scheme. Otherwise, it may check if there is any semi-statically configured Rx beam. If so, it may use the semi-statically configured Rx beam. Otherwise, it may check if there is any pre-configured (via upper layers like RRC) or pre-defined Rx beam. If so, it may use

that Rx beam. Otherwise, it decides if the DL data channel is in good condition. If so, it uses the same or similar Rx beam as NR-PDSCH. Otherwise, it may use the same beam as indicated in previous DCI.

[0153] In one embodiment, to support robustness against beam pair link blocking, a WTRU may be configured to monitor NR-PDCCH on different beam pair link(s) (BPLs) in different NR-PDCCH OFDM symbols. For the purpose of NR-PDCCH reception, the CORESET and search space configuration may include a reference to one TCI state. In other words, the QCL configuration for NR-PDCCH may contain the information which provides a reference to a TCI state. The DL RS index linked to that TCI state may provide a QCL reference for the NR-PDCCH DMRS reception during a monitoring occasion for that CORESET and search space. A WTRU may apply a QCL assumption on the associated CORESET monitoring occasions where all search space(s) within the CORESET utilize the same QCL assumption. A WTRU may also apply the QCL assumption on an associated search space. This could mean that in a case where there are multiple search spaces within a CORESET, the WTRU may be configured with different QCL assumptions for different search spaces.

[0154] If multiple candidate beam pair links are configured for NR-PDCCH, a WTRU may be configured with one CORESET and multiple search spaces within the CORESET where the QCL assumption is on a per search space basis. Alternatively, the WTRU may be configured with multiple CORESETs, where the QCL assumptions is on a per CORESET basis (i.e., all the search spaces within one CORESET share the same spatial QCL assumptions).

[0155] For robustness against beam pair link blocking, a WTRU may support multiple QCL references (associated with multiple candidate beams) for NR-PDCCH monitoring, and the WTRU may be configured with multiple search spaces associated different Tx beams. If a QCL reference is on a per search space basis, the multiple configured search spaces of the WTRU may be from the same CORESET or different CORESETs. However, if the QCL reference is on a per CORESET basis, the multiple configured search spaces may be from different CORESETs.

[0156] In one example, the primary serving beam of a WTRU may work properly, and the other candidate NR-PDCCH monitoring beams may be a waste of resources or overhead. In order to reduce the possible negative impact on spectral efficiency, the multiple configured search spaces may have different monitoring periodicity, where the search space(s) associated with the primary serving beam(s) may always be transmitted if NR-PDCCH is necessary, and other search space(s) associated with the back-up beam(s) may be transmitted less frequently. A pre-specified or semi-static configured time domain pattern may be introduced to configure WTRU monitoring of NR-PDCCH with multiple beams or multiple QCL association.

The monitoring periodicities for multiple search spaces may be different: the periodicity of the primary serving beam may be shorter than the periodicity of the secondary serving beam or neighboring beam.

[0157] In a case where the QCL configuration/indication for NR-PDCCH is on a per CORESET basis, the WTRU may apply the QCL assumption on the associated CORESET monitoring occasions. All search space(s) within the CORESET may utilize the same QCL. The different CORESETs may correspond to different BPLs, and each one may be linked to a different TCI state. The secondary serving beam or neighboring beam may be activated or deactivated by MAC-CE to facilitate the purpose of a longer monitoring periodicity for WTRU power saving.

[0158] To facilitate the configuration and indication of WTRU monitoring of NR-PDCCH with multiple beams or multiple QCL reference for multiple CORESETs, the MAC-CE may use signaling to activate or deactivate multiple semi-persistent CSI-RS resources inside a resource set so that only activated CSI-RS resources may be used for TCI state for monitoring of NR-PDCCH. The deactivated CSI-RS resources may not be monitored. The monitoring periodicities for multiple CORESETs may be different: the periodicity of the primary serving beam may be shorter than the periodicity of the secondary serving beam or neighboring beam.

[0159] FIG. 7 shows an example where a WTRU may be configured with multiple QCL associations configuration for NR-PDCCH monitoring, where the monitoring periodicities for multiple search spaces may be different: the periodicity of the primary serving beam may be shorter than the periodicity of the secondary serving beam or neighboring beam (e.g., $T_{\text{Secondary}}$ is twice as long as the T_{Primary} in this example). The NR-PDCCH monitoring over the primary serving beam may always be present, while the NR-PDCCH monitoring over the other two candidate beams may take turns to be present. With more frequent monitoring of the primary serving beam and alternative monitoring of the secondary serving beams, the overhead and power consumption may be reduced while robustness of multiple NR-PDCCH monitoring may be obtained.

[0160] As blind decoding of search spaces may lead to large latency and huge power consumption, one method to reduce the overhead could be some indication to the WTRU that may directly skip some NR-PDCCH monitoring instances even if they are present. For example, based on the SNR value, BLER value, or L1-RSRP from recent beam measurements, the WTRU may know the quality status of the primary serving beam and whether the NR-PDCCH reception/decoding over the primary serving beam succeeds or not. In addition, if NR-PDCCH reception/decoding is successful at one slot, the monitoring of other candidate search spaces in the next slot or next M slots may be skipped, where the

value of M may be a configurable value or the value of M may be evaluated based on some pre-defined rules (e.g., the threshold value of the quality of the primary serving beam). Alternatively, the optimization of monitoring multiple search spaces may be part of beam management procedures, where periodic and/or aperiodic beam measurement and reporting may help decide whether NR-PDCCH monitoring may be skipped or not. The indication of skipping NR-PDCCH monitoring may be contained in a field of DCI, and the NR-PDCCH monitoring over the primary serving beam may be confirmed with the help of HARQ ACK/NACK feedback.

[0161] In some embodiments there may be procedures for the configuration of the DL reference signal for beam management. In some scenarios for both CSI acquisition and beam management, an aperiodic Resource Setting(s) may contain more than one CSI-RS Resource set. Additionally, for a beam management use case, there may be support for a configuration of up to $S=16$ CSI-RS resource sets per resource setting and $K_s=1\sim 64$ CSI-RS resources per resource set.

[0162] In one scenario for beam sweeping purposes, there may be one or multiple CSI-RS resources transmitted within a time slot. Note that each CSI-RS resource may occupy a single OFDM symbol, and the total number of available OFDM symbols within a time slot may not be enough to transmit all the configured resources within one CSI-RS Resource set. In such a scenario with dynamic number of CSI-RS resources, the embodiments discussed herein may address the design for CSI-RS resource allocation schemes for different types of CSI-RS transmissions (e.g., periodic, semi-persistent, aperiodic, and the like) to realize efficient beam management.

[0163] In one scenario for beam indication purpose, each TCI state may associate with one RS set, wherein one or multiple RS IDs may be included, which establishes the QCL association between the TCI state and the RS ID(s). In such a scenario, the embodiments discussed herein may address the QCL association between the TCI state and reference signal resources.

[0164] In one embodiment concerning the configuration of a DL reference signal for beam management, there may be multi-slot configuration of CSI-RS resources. For beam management, a resource setting may contain more than one CSI-RS resource set (i.e., $S \geq 1$ resource sets are configured to one resource setting), each of which may consist of $K_s \geq 1$ CSI-RS resources. For beam sweeping purposes, one CSI-RS resource within a time slot may occupy a single OFDM symbol. If the total number of available OFDM symbols within a time slot is not enough to transmit all the configured resources within one CSI-RS Resource set, multi-slot configuration may be used.

[0165] A WTRU may be configured with multi-symbol and multi-slot CSI-RS transmissions. For periodic CSI-RS transmissions, a WTRU may be configured to measure a single CSI-RS resource set (e.g., multiple resource sets may be configured to a WTRU, while only one resource set is configured to be measured at a time). The configuration of periodic CSI-RS transmission may include the transmission periodicity (e.g., once every X slots), symbol location (e.g., the 1st, 2nd symbol of each slot since the transmission of the first CSI-RS resource until all resources within a resource set are transmitted), slot location (e.g., depending on the total number of resources and the number of symbols configured for CSI-RS transmissions within each slot), mapped antenna port, and the like. Some parameters (e.g., transmission periodicity) in the configuration may have the same values across different CSI-RS resources within the configured CSI-RS resource set. Some parameters (e.g., symbol location) may have flexible values which are depending on resources' index within a resource set.

[0166] For semi-persistent CSI-RS transmissions, the network may support signaling in MAC CE or RRC to select single CSI-RS resource set for the WTRU to measure. During the activation/deactivation of a CSI-RS resource set, the WTRU may dynamically determine the symbol locations and slot locations of the corresponding K_s CSI-RS resources, within the selected CSI-RS resource set, from configured parameters (e.g., such as symbol offset and slot offset values). The symbol offset and slot offset values may be the same or different for different CSI-RS resources. Also, the offset values may not change when the selected CSI-RS resource set is transmitted for each repetition within the semi-persistent duration.

[0167] For aperiodic CSI-RS transmissions, which are typically used for urgent conditions (e.g., WTRU rotations, etc.), the network may support signaling in DCI, for low latency purposes, to select and trigger the transmission of one CSI-RS resource set. The aperiodic CSI-RS triggering offset X may be a configurable value (e.g., X may be defined in units of slots). If the aperiodic CSI-RS triggering offset X is defined per resource, the symbol location and slot location of each CSI-RS resource within a resource set may be already known (e.g., the offset value is at the symbol level and symbol location is known to a WTRU) or derived (e.g., some DCI fields may carry slot/symbol location information in the form of bitmap, etc.) by a WTRU. If the aperiodic CSI-RS triggering offset X is defined per resource set, the symbol location and slot location of each CSI-RS resource within a resource set may need to be derived by a WTRU specifically. Note that this derivation may be based on the default symbol offset value and slot offset value (e.g., values configured during higher layer configurations of resource settings), explicitly higher layer configured parameters (e.g., RRC explicitly signaled symbol and slot locations), and/or carried within the

same DCI triggering signaling (e.g., some DCI fields may carry slot/symbol location information in the form of bitmap, etc.).

[0168] Concerning different types of CSI-RS transmissions (e.g., periodic, semi-persistent, aperiodic), the CSI-RS resources in a set may occupy or not occupy adjacent symbols. If some CSI-RS resources occupy adjacent symbols, those resources may form a scheduling group. As discussed herein, a CSI-RS resource set may consist of one or multiple scheduling group. For each scheduling group, only one piece of symbol/slot location information may be need, and the resources within the same scheduling group may be transmitted in a time division multiplexing (TDM) manner.

[0169] In some cases, a WTRU may be configured with one or more resource settings, that is one more resource sets in each resource settings, and the configuration of each resource set may contain an information element (IE) indicating whether repetition is “on/off”. If the repetition is “on”, a WTRU may assume the network (TRP/gNB) maintains the same TX beam. In this scenario, if the WTRU performs DL RX beam sweeping (e.g., P3), the WTRU may need know the symbol/location of each resource transmitted within the resource set (e.g., if the CSI-RS resources within a resource are not transmitted in adjacent symbols). Alternatively, the WTRU may only need to know the starting symbol/slot location and the ending symbol/slot location when the network transmits the whole resource set. Alternatively, if the WTRU does not perform DL RX beam sweeping, the WTRU may only need to know the starting symbol/slot location when the network transmits the whole resource set. This means the WTRU may not need to measure all the resources within a resource set (e.g., since those resources are all transmitted on the same beam).

[0170] If the repetition is “off”, a WTRU may assume the network (TRP/gNB) performs the DL TX beam sweeping. In this scenario, the WTRU may or may not perform DL RX beam sweeping (e.g., P1 and P2). In either situation, the WTRU may need to know the symbol/location of each resource transmitted within the resource set, and the above procedure(s) may be used to achieve resource configuration as discussed herein.

[0171] In one embodiment concerning the configuration of a DL reference signal for beam management, a WTRU may report the desired amount of CSI-RS resources. With this assistance information (i.e., WTRU reported desired amount of resources), the network may configure the WTRU with CSI-RS configurations. For periodic and semi-persistent CSI-RS transmissions, the WTRU may perform repeated (semi-persistent is also a type of repeated transmissions) beam measurement and reporting, hereafter the same design as the above solution may be used. In this case, since the network knows the desired amount of CSI-RS resources a WTRU may measure, the network may configure a more efficient

periodic beam reporting (e.g., the reporting periodicity is configured according to the enough number of CSI-RS resources that have been transmitted).

[0172] For aperiodic CSI-RS transmissions, with the assistance information, the network may configure a precise amount of CSI-RS resources for a WTRU (i.e., as the WTRU reported desired amount). In this case, the WTRU would know the number of resources being transmitted before a resource set is DCI triggered to be measured. The slot/symbol location information may be simplified or reused for each triggered aperiodic CSI-RS transmission. For example, when a WTRU is triggered to measure aperiodic CSI-RS transmission in X slots where X is the triggering offset, if the WTRU reported that Y resources are desired, with only one value such as a symbol interval Z (e.g., every 1 or 2 symbols, a resource is transmitted), the WTRU would know that the i -th resource may be transmitted in the $i * Z/7$ slot and $i * Z\%7$ symbol.

[0173] In one embodiment, there may be QCL indication for CSI-RS. For DL beam management, the reference signal aperiodic CSI-RS may be dynamically triggered so that flexibility and efficiency can be achieved. If the time domain offset between the reception of the triggering message that triggers one or multiple sets of CSI-RS resource(s) (e.g., aperiodic), and the first symbol of the transmitted CSI-RS resource(s) is larger than the WTRU capability (e.g., similar to the threshold K defined for PDSCH reception and WTRU capability as in section 4.1), the WTRU may have enough time to obtain the spatial QCL reference (e.g., the beam) for receiving the triggered CSI-RS resources, if spatial QCL reference is included in the triggering message/state. However, if the time domain offset is less than the WTRU capability, a new solution may be needed. In other words, if beam management reference signal such as aperiodic CSI-RS resources are scheduled with an offset less than the WTRU capability, the spatial QCL reference in the triggering state (e.g., for each AP-CSI-RS resource associated with each triggering state, QCL configuration is provided through an association with one of the M candidate TC1 states by RRC which is used for PDSCH reception as defined in section 4.1) cannot be used by the WTRU, and a default/fallback spatial QCL reference may be needed.

[0174] One possible solution is that the WTRU assumes that the triggered CSI-RS resources are quasi-co-located with the QCL-TypeD (e.g., spatial QCL parameter) with the same DL RS assumed for the reception of PDSCH in the same slot where the triggered CSI-RS resources is scheduled. In other words, if the triggered CSI-RS is scheduled with an offset less than the WTRU capability, the WTRU may use the same beam to receive the CSI-RS resources as the WTRU receives the PDSCH in the same slot. This solution may mean that the spatial QCL reference(s) carried in the triggering message or indicated by the

triggering message (e.g., triggering message indicates a TCI state and the TCI states indicates an spatial QCL reference) overrides the WTRU assumptions (e.g., where the WTRU assumes that the same beam used for PDSCH reception in the same slot is used for CSI-RS reception).

[0175] In another solution, a WTRU may ignore the triggered CSI-RS resource if an offset between the associated PDCCH and the triggered CSI-RS resource is less than a threshold, wherein the offset may be determined based on time locations of the last symbol of the associated PDCCH and the first symbol of the CSI-RS resource. The threshold may be *Threshold-Sched-Offset*. The WTRU may not report triggered CSI associated with the triggered CSI-RS resource when the WTRU ignores the triggered CSI-RS resource due to the offset.

[0176] In one embodiment concerning the configuration of a DL reference signal for beam management, there may be an association of TCI State with Reference Signal (RS) resources. A network (e.g., TRP/gNB) may send a RRC message(s) to configure multiple TCI states to a WTRU and the network may activate (e.g., use MAC-CE to select) part or all of the configured TCI states. Each TCI state may be RRC configured with one RS set as a QCL reference.

[0177] When a WTRU performs beam measurement and reporting, the WTRU may measure the L1-RSRP of the configured RS resources. Then the configured/activated TCI states may be used by the network to achieve beam indication based on WTRU reported beam measurement results. The association between the RS resources and TCI states may be proposed to map WTRU reported beam measurement results and network indicated TCI state.

[0178] The RS resources may be SSB resources or CSI-RS resources. For CSI-RS resource, it may be for periodic transmission, aperiodic transmission, or semi-persistent transmissions. For periodic CSI-RS transmissions, the spatial QCL of the transmitted CSI-RS resources may be configured through a reference (e.g., TCI state index) to a configured TCI state.

[0179] For aperiodic CSI-RS transmissions, the spatial QCL of all aperiodic CSI-RS resources (e.g., NZP-CSI-RS/ZP-CSI-RS based IMR) may first be RRC configured through association with the configured TCI states. Next, when part or all of the aperiodic CSI-RS resources are DCI triggered for WTRU aperiodic beam measurement and reporting, the spatial QCL of those transmitted aperiodic CSI-RS resources may be indicated through DCI (e.g., AP-CSI-report-triggering state indication) as well.

[0180] For semi-persistent CSI-RS transmissions, the spatial QCL for the transmitted CSI-RS semi-persistent resources may be indicated in the same MAC-CE message that activates the SP- CSI-RS.

In other words, the spatial QCL of semi-persistent CSI-RS may be configured through RRC, and then activated/deactivated through MAC-CE.

[0181] For SSB transmissions, the spatial QCL of the transmitted SSB resources may be provided by RRC configurations through references (e.g., TCI state index) to configured TCI states. This RRC configuration may be done at the same time when the WTRU is initially (e.g., right after WTRU initial access) RRC configured with multiple TCI states or later RRC update of the TCI states.

[0182] Note that when MAC-CE is used to select up to 2^N TCI states out of all the configured TCI states, it may also be used to configure on what RS resources a WTRU should perform beam measurement and reporting.

[0183] The spatial QCL relations of RS resources may be included in a TCI table. Also, there may be or may not be the same RS resources in terms of the spatial QCL with multiple TCI states. If the same RS resource(s) have spatial QCL with multiple TCI states, it may mean that these TCI states are similar in terms of QCL assumptions (e.g., DL beams associated with those TCI states are geographically close to each other and have similar spatial QCL assumptions).

[0184] Table 5 shows an example of a TCI state table. It shows that multiple RS IDs may be configured for a single TCI state. Each RS ID may be associated with a RS type which is associated with a RS resource. Note that the RS resource may overlap across multiple TCI states in the table. For example, the periodic CSI-RS resource 0 is configured for both TCI state 0 and TCI state 2 in the table.

TCI State	RS ID	RS type	RS Resource
0	0	Periodic	0
	1	Aperiodic	4
	2	Semi-persistent	3
	3	SSB	2
1	0	Periodic	2
	1	Aperiodic	2
	2	Semi-persistent	1
	3	SSB	3
2	0	Periodic	0
	1	Aperiodic	1
	2	Semi-persistent	3
	3	SSB	2

Table 5 – Example of TCI state table

[0185] In one embodiment, there may be one or more beam reporting prioritization of various schemes. Beam reporting prioritization may not only solve WTRU transmission issues when different reporting collides, but may also improve the reporting efficiencies in terms of energy consumption, signaling, overhead/latency, and system operation robustness. Based on the WTRU specifically configured CSI-RS resources (e.g., periodic, semi-persistent, or aperiodic resources), the WTRU may perform different types of beam reporting accordingly (e.g., periodic, semi-persistent, or aperiodic). Prioritization of beam reporting may be based on one or more conditions/use cases, such as latency, energy consumption, robustness, redundancy control, internal collisions, and/or external collisions.

[0186] In the case of latency, for some WTRU use cases, such as URLLC or high speed mobility, beam reporting may be performed more often to compensate for the fast-changing radio environment and delayed beam reporting may contain invalid beam measurement results. Different parts of each beam reporting and/or different instances of beam reporting may be prioritized to achieve low overhead and efficient (e.g., only the most important portion of beam reporting content) beam reporting with lower latency.

[0187] In the case of energy consumption, beam measurement reporting content may be reduced to save energy consumption for low mobility WTRUs (e.g., static or low speed WTRUs) or WTRUs with lower remaining battery.

[0188] In the case of robustness, X beams may be used for PDCCH and PDSCH transmission, but a WTRU may report Y beams (e.g., where $Y > X$) during beam reporting. The extra reported beams may provide robustness/flexibilities in cases such as sudden beam blockage, beam congestions, or the like.

[0189] In the case of redundancy control, there may be a cost for more reported beams than needed. A WTRU may report at most 4 Tx beams and corresponding L1-RSRP, but only part of them may be used for subsequent PDCCH and PDSCH transmission. If the beam quality is relatively stable (e.g., static WTRU, open wide radio environment), only the needed number of beams may be reported to reduce potentially unnecessary redundancy.

[0190] In the case of internal collisions, two reports may be said to collide if the time occupancy of the physical channels scheduled to carry the two reports (e.g., both reports are carried on PDCCH, or one report is on PDCCH and the other one is on PDSCH) overlap in at least one OFDM symbol and are transmitted on the same carrier. For NR supported different types of beam reporting, the internal collisions may refer to collisions among different types of beam reporting (e.g., the collisions of aperiodic beam reporting and semi-persistent/periodic beam reporting) and between beam reporting intended for PUSCH and PUCCH.

[0191] In the case of external collisions, in addition to beam reporting, a WTRU may also support CSI reporting and SRS transmission. With limited capacity on PUCCH and PUSCH, a WTRU may only support one or a subset of UL transmissions (e.g., Beam reporting, CSI reporting and SRS transmissions are transmitted on UL resources configured by gNB). Therefore, the predefined or configured beam reporting priority and dropping rules may be needed.

[0192] In one embodiment, beam reporting may be prioritized according to beam reporting content. For example, the minimum number of beams to be reported may be determined and assigned the highest priority. The value of this minimum number may be directly configurable, and depend on the actual number of beams simultaneously used for subsequent PDCCH and PDSCH transmission. The value of the minimum number may also depend on WTRU capability (e.g., WTRU panel). The value of the minimum number may also depend on a configurable threshold value (e.g., only the beams with L1-RSRP above a threshold value Y).

[0193] In another example, an extra number of beams may be determined and assigned lower priorities. A WTRU may be configured to report at most 4 beams, but only 1 beam with measured L1-RSRP above an L1-RSRP threshold may exist. For robustness/flexibility purposes (e.g., for off-loading purposes, the gNB may not use one beam for subsequent PDSCH transmissions even though the beam is reported to

have the highest L1-RSRP), a WTRU may assign priority 1 to the second reported beam, and priority 2 and 3 to the third and fourth reported beams, where priority 1 is higher than priority 2 and 3.

[0194] In another example, a measured beam may be determined to be the minimum reported beam or an extra reported beam. One purpose for beam reporting may be for beam pair link (BPL) establishment for subsequent PDCCH/PDSCH transmissions. Therefore, the beams that have the best quality indicated by beam measurement may be the minimum reported beams.

[0195] In considering criteria to evaluate beam quality for PDCCH beam training, beam quality stability/reliability may be a primary concern while beamforming gain may be a secondary concern. For example, beams that are measured on periodic SSB resources (e.g., SSB based beams may be available both at initial access and connected mode, and have larger beam width and more reliable availability), or beams that have lower variations in terms of L1-RSRP values measured in recent configurable value of time window, may be selected as minimum reported beams with higher priority.

[0196] In considering criteria to evaluate beam quality for PDSCH beam training, beam quality stability/reliability may be considered just as with criteria for PDCCH, but for PDSCH potential beamforming gain may be more important so that enough transmission capacity is able to meet the WTRU data transmission's requirements. For example, given some distribution probability statistics of recently measured L1-RSRP values within a configurable time window, a beam selected as a minimum reported beam for PDCCH transmissions may satisfy that:

$$\frac{\sum_{i=0}^{N/2} RSRP_i}{\frac{N}{2}-1} < Th_1, \sqrt{\frac{\sum_{i=1}^N (RSRP_i - \overline{RSRP})}{N-1}} < Th_2.$$

[0197] Where $N/2$ is the lower half of all measured L1-RSRP values of a specific beam within a configurable time window, and $\overline{RSRP}$ is the mean of all measured L1-RSRP within the same time window. Therefore, the first equation may mean that if a beam's average L1-RSRP value of the lower half of all measured value is bigger than a threshold value Th_1 , this beam's quality may be sufficient for operation. The second equation may mean that if the standard deviation of all measured L1-RSRP values of a beam within the same time window is smaller than a threshold value Th_2 , this beam's quality may be sufficiently stable for operation.

[0198] Similarly, a beam selected as a minimum reported beam for PDSCH transmissions may satisfy:

$$\frac{\sum_{i=0}^{N/2} RSRP_i}{\frac{N}{2}-1} < Th_3, \sqrt{\frac{\sum_{i=1}^N (RSRP_i - \overline{RSRP})}{N-1}} < Th_4.$$

[0199] Note that, the threshold value Th_3 and Th_4 may be the same or different from Th_1 and Th_2 . For example, a PDSCH beam may require a higher worse case L1-RSRP value ($Th_3 > Th_1$), but tolerate higher stand derivation value ($Th_2 > Th_4$).

[0200] In one alternative, the minimum reported beams may be determined by ranking the L1-RSRP values, from current measurement or averaged among multiple measurements recently, of all the measured beams and selecting the highest values. For example, a gNB may use the same beam for subsequent PDCCH and PDSCH transmissions for a WTRU to reduce the beam management effort.

[0201] In another alternative, a RSRQ and/or RSSI value may be used instead of RSRP values or jointly considered to rank beam qualities.

[0202] During the beam training process, the cost of beam switching (e.g., DL TX beam, or DL RX beam, or both) may be significantly different from time to time. For example, intra-TRP beams switching, if the radio front end of gNB is deployed on a TRP, may be faster and easier than inter-TRP beam switching, if a gNB manages multiple TRPs, since data may need to be forwarded from one TRP to another one. Similarly, inter-gNB beam switching may incur more overhead and delay than intra-gNB beam switching because control plane traffic such as handover signaling, higher layer negotiations, and data plane traffic such as data path reestablishment and data forwarding may be involved, and even core network signaling may be also needed (e.g., WTRU service subscription check, etc.).

[0203] Based on these various considerations of beam reporting prioritization based on content, beam selections and prioritizations may follow one or more rules. Beams may be selected as a minimum reported beam according to a first rule, then according to a second rule if the first rule is the same, and so forth for any number of rules. Some examples of rules may comprise one or more of the following: a beam's measurement quantity (e.g., L1-RSRP) is above a threshold value Th_x (i.e., a beam is usable); a beam belongs to the same TRP as the current serving beam(s); a beam's measurement quantity (e.g., L1-RSRP) is above a threshold value Th_y (i.e., a beam is not only useable (L1-RSRP above Th_x) but also sufficiently good enough (L1-RSRP above Th_y), where $Th_y > Th_x$); a beam belongs to the same cell/gNB; and/or a beam's average measurement quantity among recent Y measurement results.

[0204] In one embodiment, beam reporting may be prioritized according to one or more pre-defined or specified and/or configured beam reporting conditions and/or beam reporting rules. In one case, the beam(s) with the highest L1-RSRP value changes may be reported with the highest priority. Alternatively, the X new beams (i.e., the new beams that have not been previously reported), may be reported with the highest priority.

[0205] In another case, if the beams reported in the current report are partially or completely the same as the last report, the beam ID(s) may have lower priority, and the L1-RSRP values may have higher priority. If the L1-RSRP values of the reported beams are similar or within a configurable offset range (e.g., 1 dB higher or smaller), the whole beam reporting may be assigned with a lower priority because the current beam report is similar to the previous report and may not need to be transmitted if UL resource is limited, or the whole beam may be consolidated as a simplified version (e.g., contains a short-fixed value 00 to indicate that similar L1-RSRP value as last reporting, instead of L1-RSRP values, to reduce the overhead).

[0206] In another case, if a battery-constrained WTRU indicates a low remaining battery level, a WTRU may assign the best X ($X \geq 1$) beams with the highest priority, even though the WTRU's capability may support Y ($Y \geq X$) beams simultaneously without battery power constraint which may be indicated by battery saving mode, for example.

[0207] In another case, as the DL active bandwidth part (BWP) for a WTRU changes dynamically, the frequency band and corresponding beam property (e.g., attenuation, path loss may lead to beam quality) may change accordingly, and the beam reporting frequency and payload may also change as well.

[0208] In another case, as the UL active BWP for a WTRU changes dynamically, the PUCCH/PUSCH resources for beam reporting may change dynamically as well. The beam reporting content may need to be prioritized so that the overhead fits the available UL resources and the beam reporting content may need to be specified per UL BWP candidate.

[0209] In one embodiment, there may be WTRU procedures to support beam reporting prioritization. A WTRU may perform prioritized beam reporting based on the beam prioritization schemes as discussed herein. The WTRU may determine whether the required UL resources (PUCCH/PUSCH resources) for planned UL transmissions (e.g., different types of CSI reporting, beam reporting, SRS transmissions) are overlapping in a slot or not. Overlapping, as discussed herein, may be related to beam reporting. For example, overlapping within different types of beam reporting, or overlapping between beamforming reporting and CSI reporting, or between beamforming reporting and SRS transmissions. If none of the UL resources overlap with each other in time, beam reporting may be transmitted according to other concerns (e.g., energy consumptions, latency requirements). Specifically, for beam reporting, a WTRU may be configured with a certain priority threshold value, the different parts of beam reporting content which have priority values higher than the configured priority value may be transmitted. Alternatively, the priority threshold value may be dynamically indicated via MAC-CE or DCI messages.

[0210] FIG. 8 is a diagram of an example reference signal resources. Beam reporting may be a full/wide DL BWP band measurement so that the measurement results may reflect a full DL BWP band of beam quality. In some cases, existing reference signal resources used for beam measurement reporting may not cover a full DL BWP band, and additional reference signal resources may need to be configured and transmitted. One example is shown in FIG. 8 where the reference signal resources transmitted on beam 1 and beam 2 at the slot x are not able to cover a full band of the current active DL BWP. For beam measurement reporting, the WTRU have two options.

[0211] In the first option, after beam measurement at the slot x, WTRU may not send beam reporting but may wait until the slot y, when combined reference signal resources at slot x and slot y provide a full band measurement. Note that the RS resources on symbol 1 and symbol 2 at the slot x may be QCL-ed (e.g., transmitted on the same beam) with the RS resources on symbol 1 and symbol 2 at the slot y, respectively.

[0212] In the second option, the WTRU may send the beam report right after the beam measurement when slot x is completed.

[0213] For the two options, the first option may provide more accurate beam measurement results but may experience higher beam report delay, while the second option may have lower delay of beam report, but may not provide as accurate beam measurement results. In some cases, which require lower beam reporting latency such as URLLC, the WTRU may prefer the second option due to its lower delay of the beam report, and report the sub-band beam measurement reports right after slot x, which provides at least a rough reference for gNB DL beam selection. After slot y, the WTRU may still send a beam report, but the report content may be assigned with a lower priority because the previous report may already be accurate enough for DL beam selection.

[0214] If at least two UL transmissions overlap at least partially in time, the different parts of the beam reporting may be ranked in a priority order. If the at least two overlapping UL transmissions include more than one beam reporting, for example, aperiodic beam reporting and periodic beam reporting, the internal collisions of beam reporting may be handled first before ranking. For this handling, if more than one beam reporting is of the same type, for example, two semi-persistent beam reports, they may be consolidated into one single beam reporting. For example, the WTRU may determine one set of minimum reported beams from multiple sets of the minimum reported beams from multiple beam reports, and report one value for each selected beam. The same behavior may be applied to the set of extra reported beams.

[0215] After the consolidation of same types of beam reporting, if there are still at least two overlapping beam reports, all beam reports may be dropped except the one with the highest priority. The priority of different types of beam reporting may be defined and specified and/or configured (e.g., by RRC message) to follow an order, for example: beam reporting contained in beam failure recover request; aperiodic beam reporting; semi-persistent beam reporting on PUSCH; semi-persistent beam reporting on PUCCH; and/or periodic beam reporting. After these prioritizations, at most one beam reporting may be left for the UL transmissions, and the WTRU may rank the different parts of the remaining beam reporting in a priority order.

[0216] The same consolidation process may be applied to SRS transmissions and CSI reporting as well. After the consolidation, at most one CSI reporting and at most one SRS transmission may be left for the UL transmissions.

[0217] Based on the ranked priority order of different parts of the beam reporting, for the overlapping UL transmissions, the different parts may be dropped based on the following order, or any variation of the following order, including less or more than is listed: periodic or semi-persistent SRS; Periodic CSI reporting; Periodic beam reporting; semi-persistent CSI reporting on PUCCH; semi-persistent CSI reporting on PUSCH; semi-persistent beam reporting on PUCCH; semi-persistent beam reporting on PUSCH; aperiodic SRS; and then aperiodic CSI reporting or beam reporting.

[0218] After the parts are dropped (e.g., using the aforementioned order) the remaining part may be the beam reporting contained in a beam failure recover request (if this type of beam reporting exists), which may have the highest priority. It may have the highest priority because when beam recovery happens, the triggered aperiodic transmissions may not be valid anymore. Also, the BPL between the WTRU and network may have to be recovered first before the reporting may be transmitted. In case transmissions on PUSCH are dropped (e.g., SRS), dropping can be partial in time domain. For example, only those OFDM symbols that collide with the PUCCH (e.g., aperiodic beam reporting on PUCCH) need to be dropped.

[0219] Additionally, in the event two UL transmissions have the same transmission configuration, for example, periodic beam reporting and periodic CSI reporting, there should be no ambiguity (i.e., periodic CSI reporting should be dropped first) based on the aforementioned example dropper order. The only ambiguity may be between aperiodic CSI reporting and aperiodic beam reporting, which may be addressed in one or more manners.

[0220] In a first manner, one report may be dropped. This report may be based on one or more factors, such as: If the content of this beam report is similar to a previous beam report, this beam report may be dropped, where the similarity may be a function of difference of the L1-RSRP values in the current report and previous report; If the content of this beam report consists of beams from the same TRP and different TRP, or the same cell/gNB and different cell/gNB, when the measurement quantities (e.g., L1-RSRP) of the beams belonging to the serving TRP/gNB/cell are similar (i.e., offset value is within a configurable threshold) as the beams reported in a previous report, and also if the measurement quantities of these beams may be already above a certain threshold value (i.e., indicating that these beams are good enough), this beam report may be dropped; and if the previous two factors are not met, the CSI reporting may be skipped in this slot and scheduled in a following slot that has enough UL resources.

[0221] In a second manner, the beam report may and the CSI report may be consolidated so that both of them may be multiplexed and reported, as shown in the example of FIG. 9. If aperiodic beam report is multiplexed with aperiodic CSI reporting, both reports may be transmitted on PUSCH or long PUCCH. If the aperiodic CSI support type I, where type 1 CSI may contain only subband CSI, and if the beam report is based on full/wide band measurements, the beam reporting may be put before part 1 of the CSI report. During transmission, as much content as possible may be selected from part 1 first then part 2 without exceeding the maximum number of bits supported by the available PUSCH resources, and the rest of the CSI report may be dropped. If the beam report is based on partial band measurements, the beam report may still be put before part 1 of the CSI report, but during the transmission, the part 1 of the same or adjacent sub-band (i.e., close to the beam report measured partial band) CSI may be selected.

[0222] If the aperiodic CSI supports type II CSI, the beam report may be placed before the part 1 or before the wideband CSI, as shown in FIG. 9. During transmission, as much content of the part 2 CSI as possible may be selected from the highest priority first without exceeding the maximum number of bits supported by the available PUSCH resources, and the rest of the CSI report may be dropped. Also shown in the FIG. 9, Part 2 of CSI type II may be skipped level by level beginning with the lowest priority level until the highest priority level is reached. When beam reporting is based on partial band measurement, the sub-band CSI that is closest to the beam measurement based partial band may be assigned as priority 1 (i.e., the highest priority among all sub-band CSI). Note that part 1 may be updated according to actual number of information bits transmitted from part 2, and the size of part 1 may have a fixed payload size and contains RI, CQI, and an indication of the number of non-zero wideband amplitude coefficients per layer for the Type II CSI.

[0223] When the higher layer parameter ReportQuantity is configured with one of the values 'CRI/RSRP' or 'SSBRI/RSRP', the CSI report may comprise a single part, and may be transmitted followed by beam report.

[0224] In a third manner, if the aperiodic CSI report supports type I CSI, the CSI report may be dropped; if the aperiodic CSI report supports type II CSI, both CSI report and beam report may be multiplexed and transmitted. The multiplexing methods may apply the similar procedures as in the second manner. Alternatively, if beam reporting is based on partial band beam measurements, and the partial band is overlapping with the subband reported by the type I CSI of the CSI report, the CSI report may be kept and multiplexed with the beam report

[0225] In one embodiment, beam reporting prioritization may be grouped based on the beam reporting prioritization rules as discussed herein. In order to flexibly meet different WTRU requirements (e.g., energy consumption, latency, service type, feedback capacity limit, etc.), a WTRU may support scalable beam reporting (or different beam reporting classes) based on different grouping criteria or rules. Grouping criteria or rules may be based on one or any combination of the following: beam reporting payload size; processing delay/latency; WTRU computation complexity; short term measurement or long term weighted average; frequency band and/or the number of BWP; beam from the same or different TRPs or gNBs or cells (e.g., serving or neighboring cells); and/or the like.

[0226] Three example implementation of grouping based beam report prioritization or beam report classes are shown in Table 6, Table 7, and Table 8 respectively.

[0227] Note that in Table 6, if the differential RSRP value is used, the corresponding reference value may be carefully specified. For example, 4 bits may be used to represent differential RSRP values, and only 16 states may be allowed to be represented by the 4- bits (e.g., 0000 to 1111). In this case, one state of the 16 states (e.g., the state 1111) may be used to indicate that the corresponding differential RSRP is out of range. Therefore, for differential L1-RSRP reporting, when the largest L1-RSRP is reported as out of range, the maximal value of 7-bit representation may be used as the reference value for calculating differential L1-RSRP value of remaining L1-RSRP values. Alternatively, another specific value of 7-bit representation may be used as the reference, for example, the highest value of remaining RSRP values which has 7-bit or 4-bit representation. Alternatively, the upper bound of the range may be used as the reference value. For example, the upper bound of the range of all reported L1-RSRP values (e.g., all reported values are in the range of [-140, -15], and the -15 is the upper bound which becomes the reference value). Or the upper bound of 4-bit representation may be the reference. For example,

considering that 4 bit represents 16 states and 2 dB as step size, when minimum reported value is -100, the upper bound of 4-bit representation may be -70 (e.g., 15 states).

Beam report classes	Definition	Notes
Base layer	The best x beam(s) within the same TRP/gNB/cell as the serving beam(s)	1. Only beam ID(s). 2. L1-RSRP value(s) are only reported when they are above certain threshold value.
Enhancement layer 1	The L1-RSRP values of the beams contained in the base layer	Differential or absolute L1-RSRP values
Enhancement layer 2	Besides the x serving beam(s), the best y beam(s) in neighbouring TRP(s)/cell(s).	The value of x and y may be same or different.

Table 6 – Example of scalable content of group based beam reporting

Beam report classes	Definition	Notes
Low latency	The best x beam(s) measured within the last y time slot within the active BWP band (e.g., SS block + CSI-RS independent L1-RSRP reporting)	The value of x and/or y may be pre-defined or specified and/or configurable. For example, x and y may be equal to 4 and 1 respectively.
Medium latency	The best x beam(s) measured within the last y time slot within the active BWP band and two adjacent BWP bands (e.g., SS block + CSI-RS independent L1-RSRP reporting)	Same as above and the additional measured BWP bands may be also configurable
High latency	The best x beam(s) measured within the last z time slots within three alternative BWP bands (e.g., SS block + CSI-RS joint L1-RSRP reporting)	The value of x and/or z may be pre-defined or specified and/or configurable, where z may be larger than y to indicate High latency beam report class. For example, x and z may be equal to 4 and 2 respectively.

Table 7 – Example of scalable latency of group based beam reporting

Beam report classes	Definition	Notes
Low payload size	Only the beam ID(s) of the minimum reported beams	The reporting order of the beam IDs may represent the order of the associated L1-RSRP value.
Medium payload	Beam ID(s) + L1-RSRP values(s) of the minimum reported beams	
High payload	Beam ID(s) + L1-RSRP values(s) of the minimum reported beams + y extra reported beams	It may also be used for candidate beam selection for beam failure recovery.

Table 8 – Example of scalable payload size of group based beam reporting

[0228] 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.

* * *

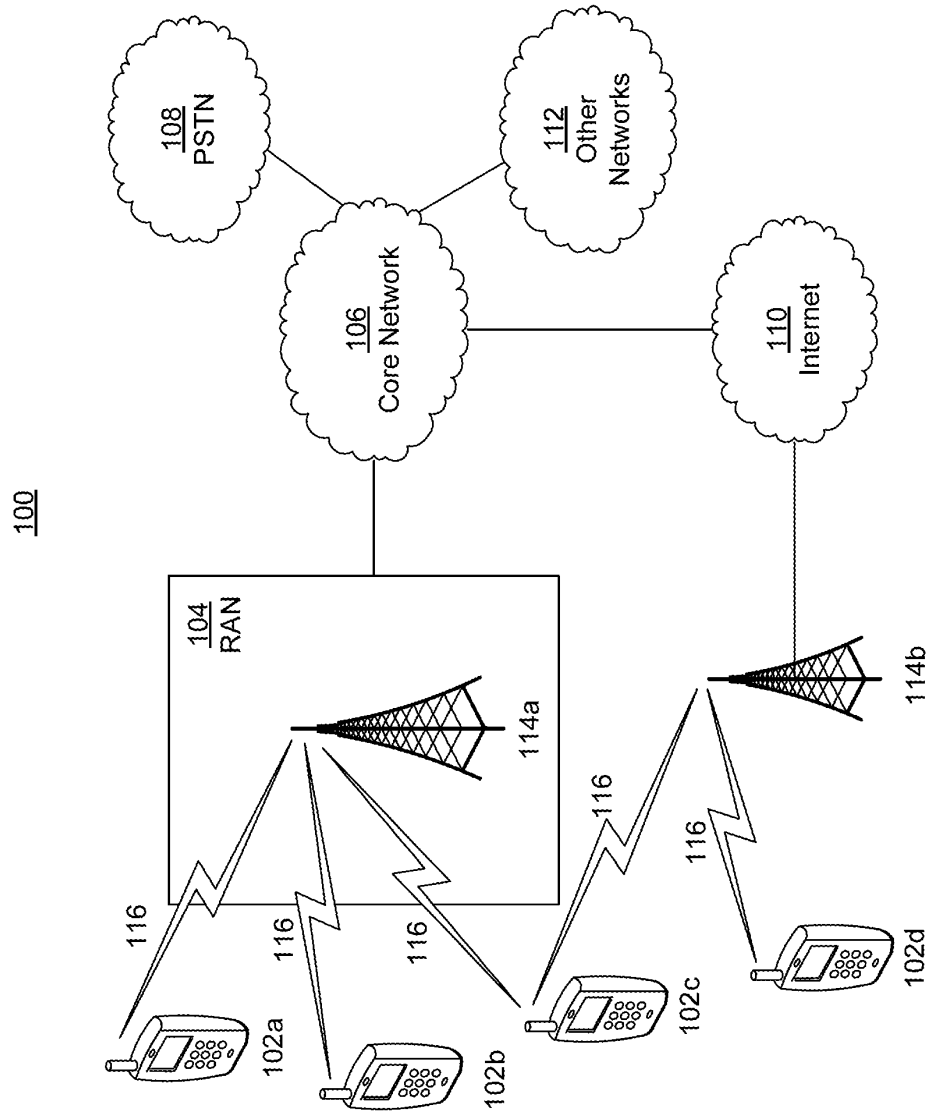
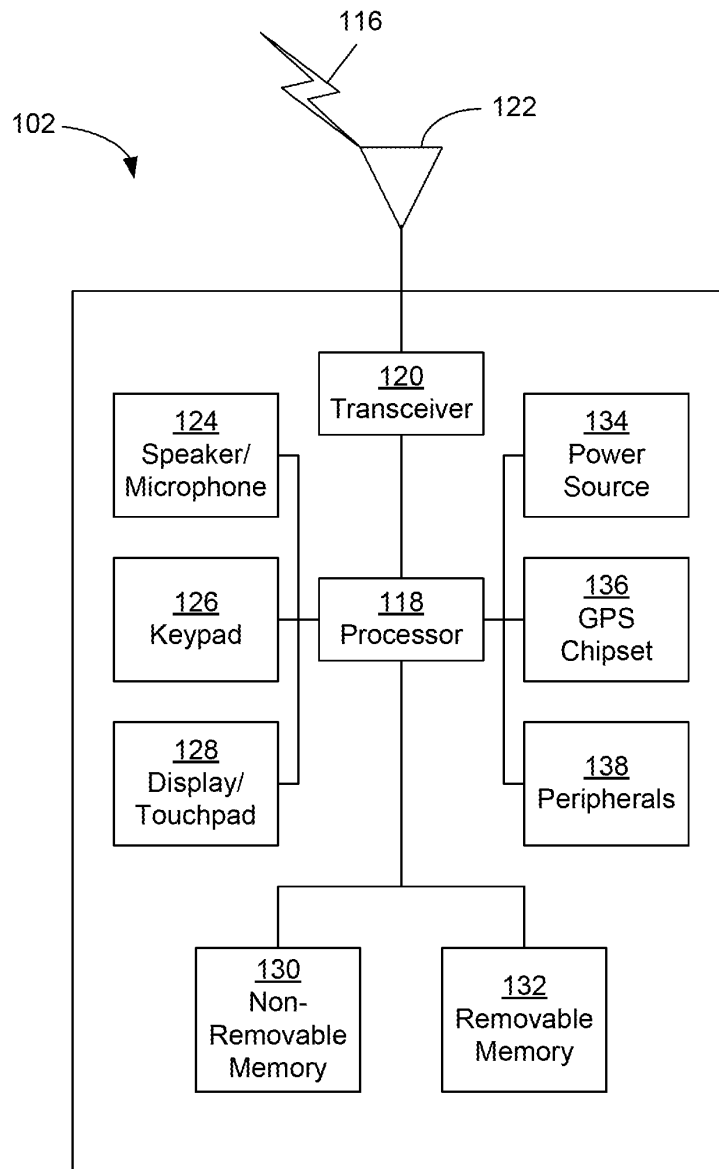


FIG. 1A

**FIG. 1B**

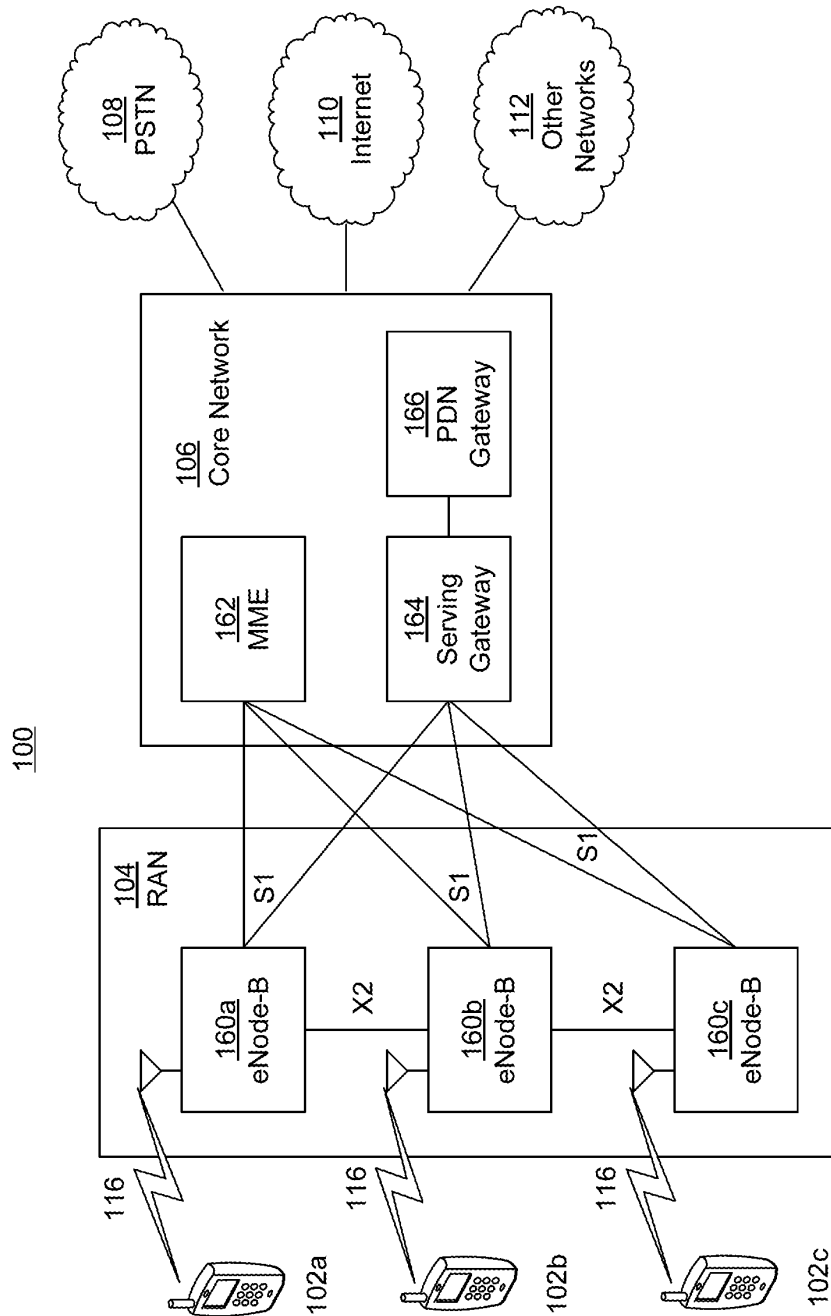


FIG. 1C

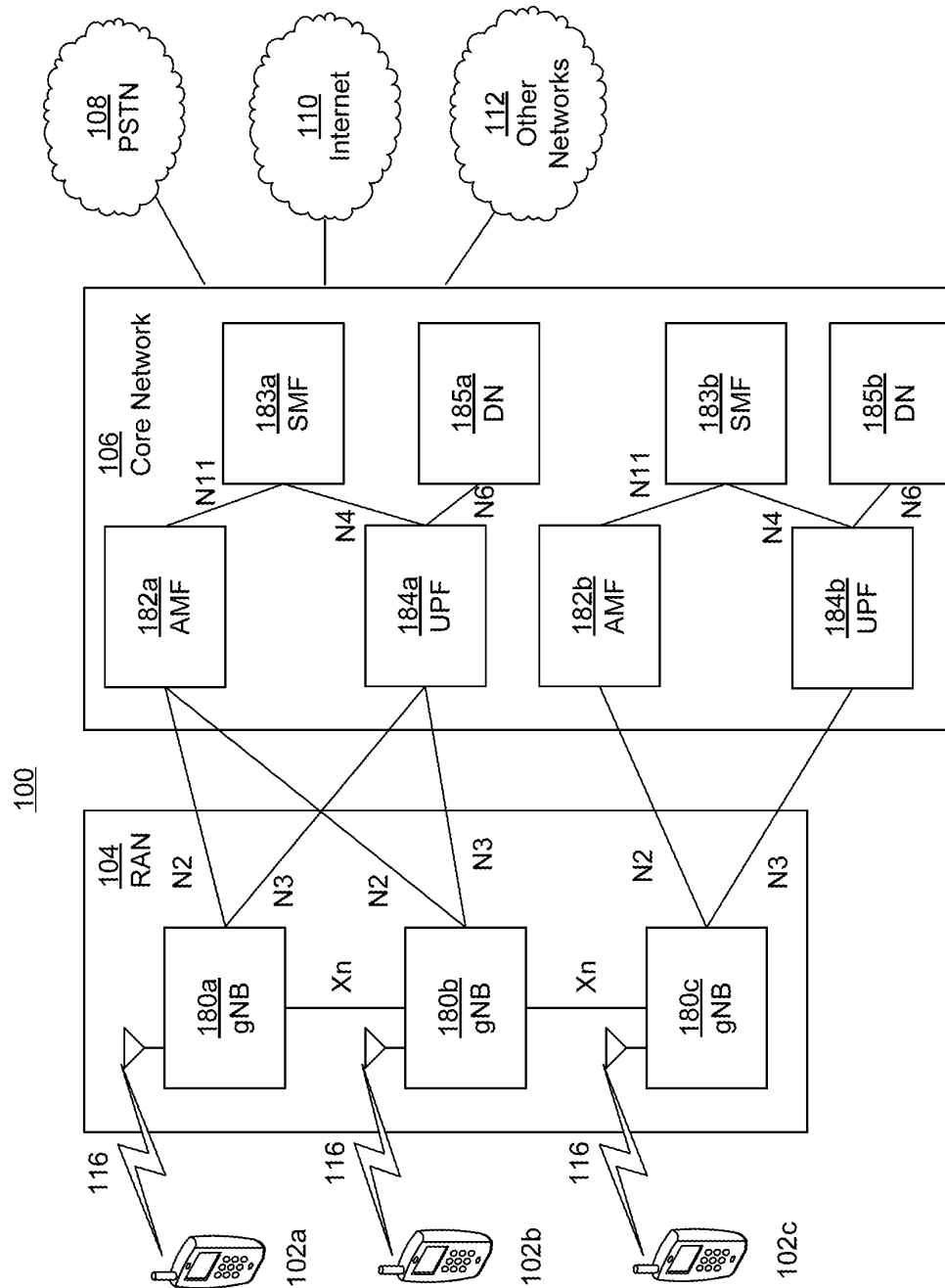


FIG. 1D

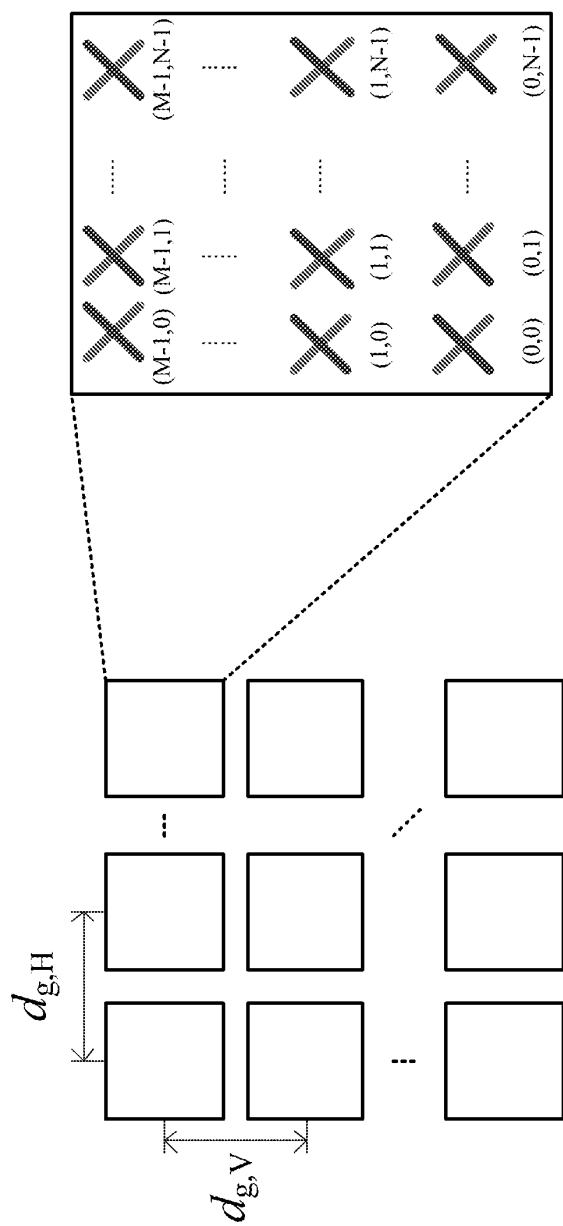


FIG. 2

The last symbol of all the configured
monitored CORESETs/SSs

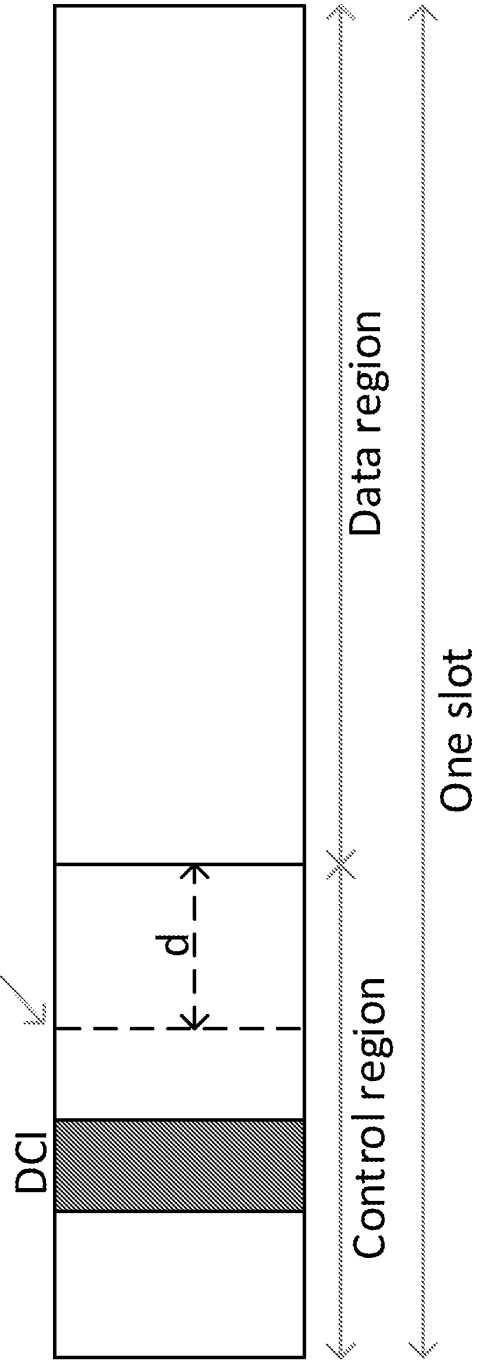


FIG. 3A

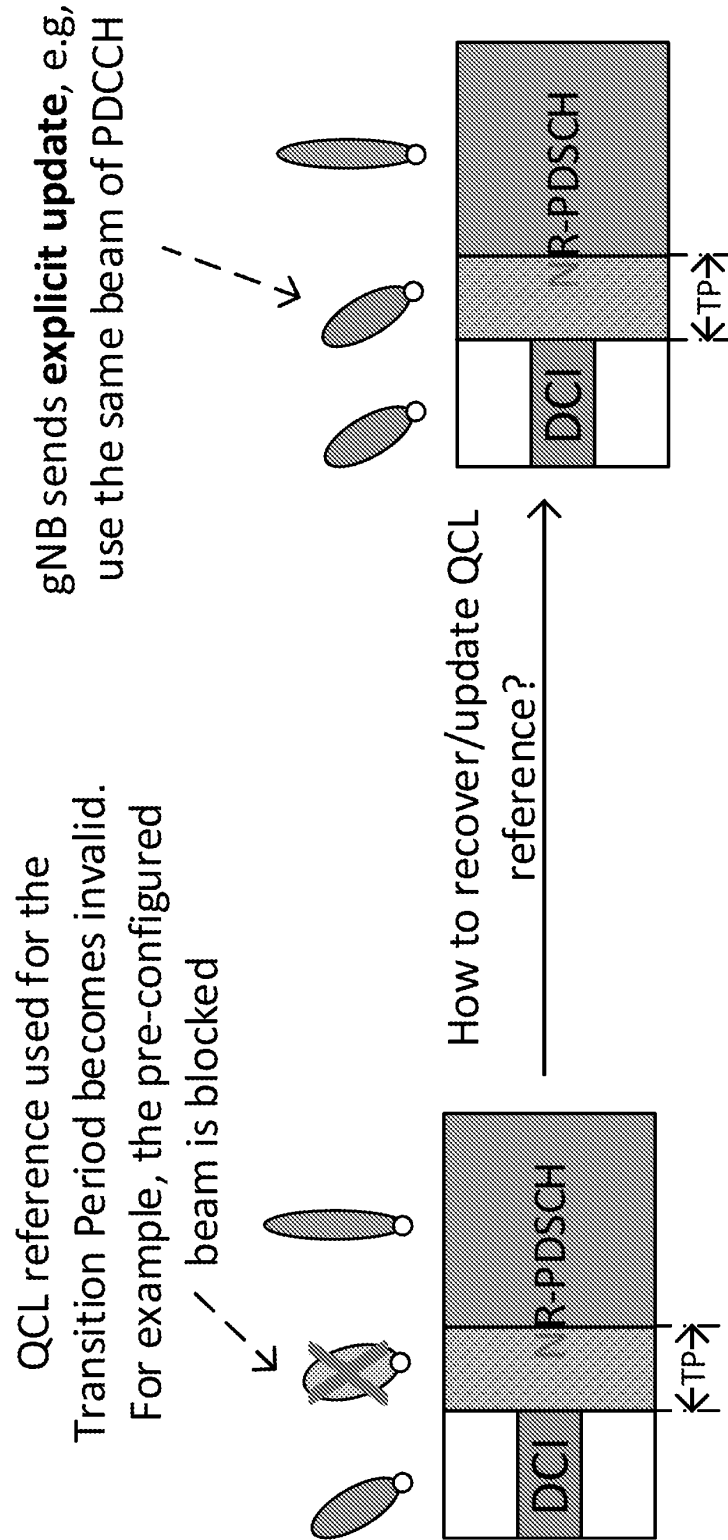


FIG. 3B

UE may determine a beam based on configured rules and then feedback the beam to gNB, e.g., use last PDSCH beam which has LS-RSRP above a threshold

QCL reference used for the Transition Period becomes invalid. For example, the pre-configured beam is blocked

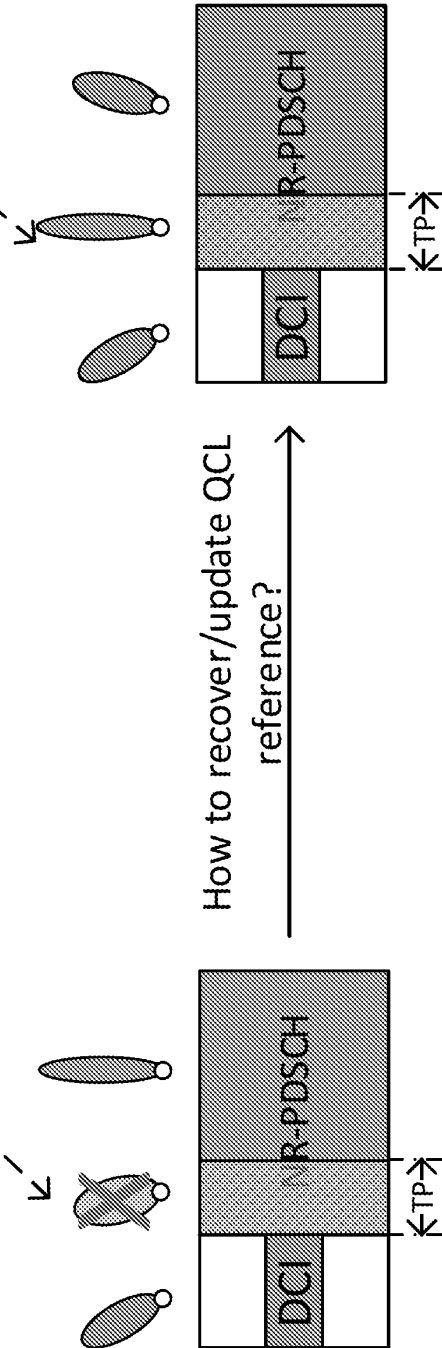


FIG. 4

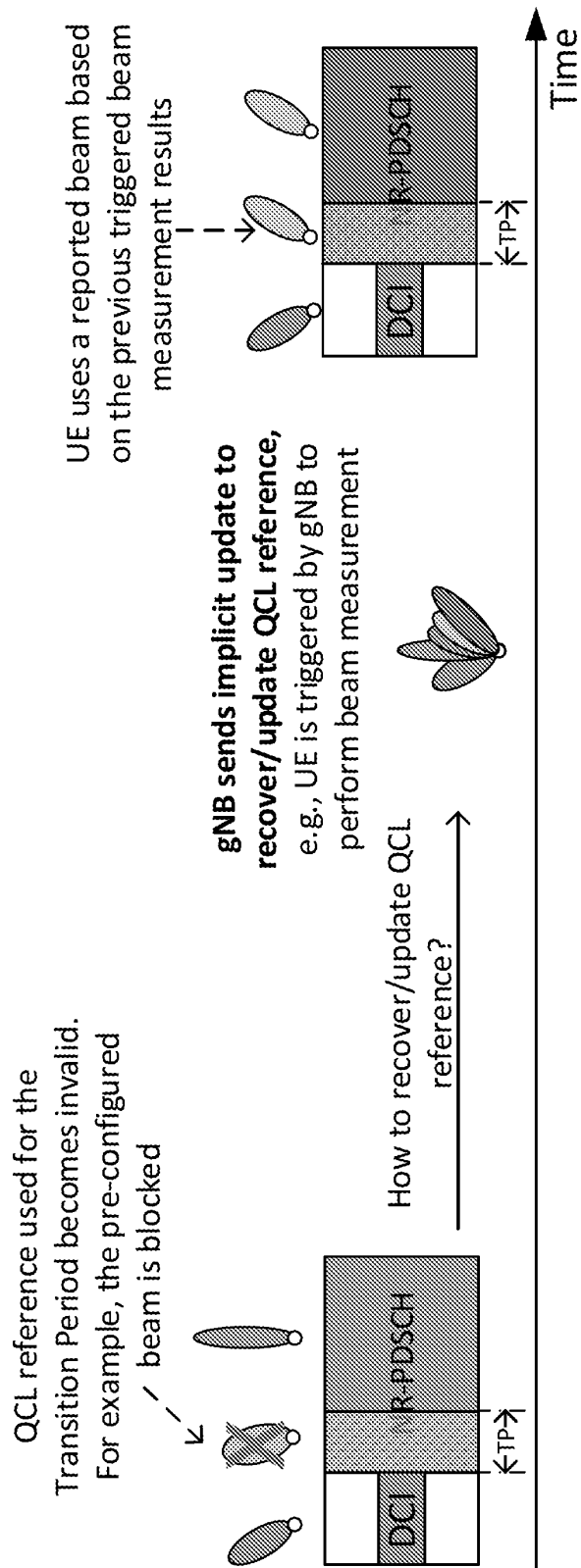


FIG. 5

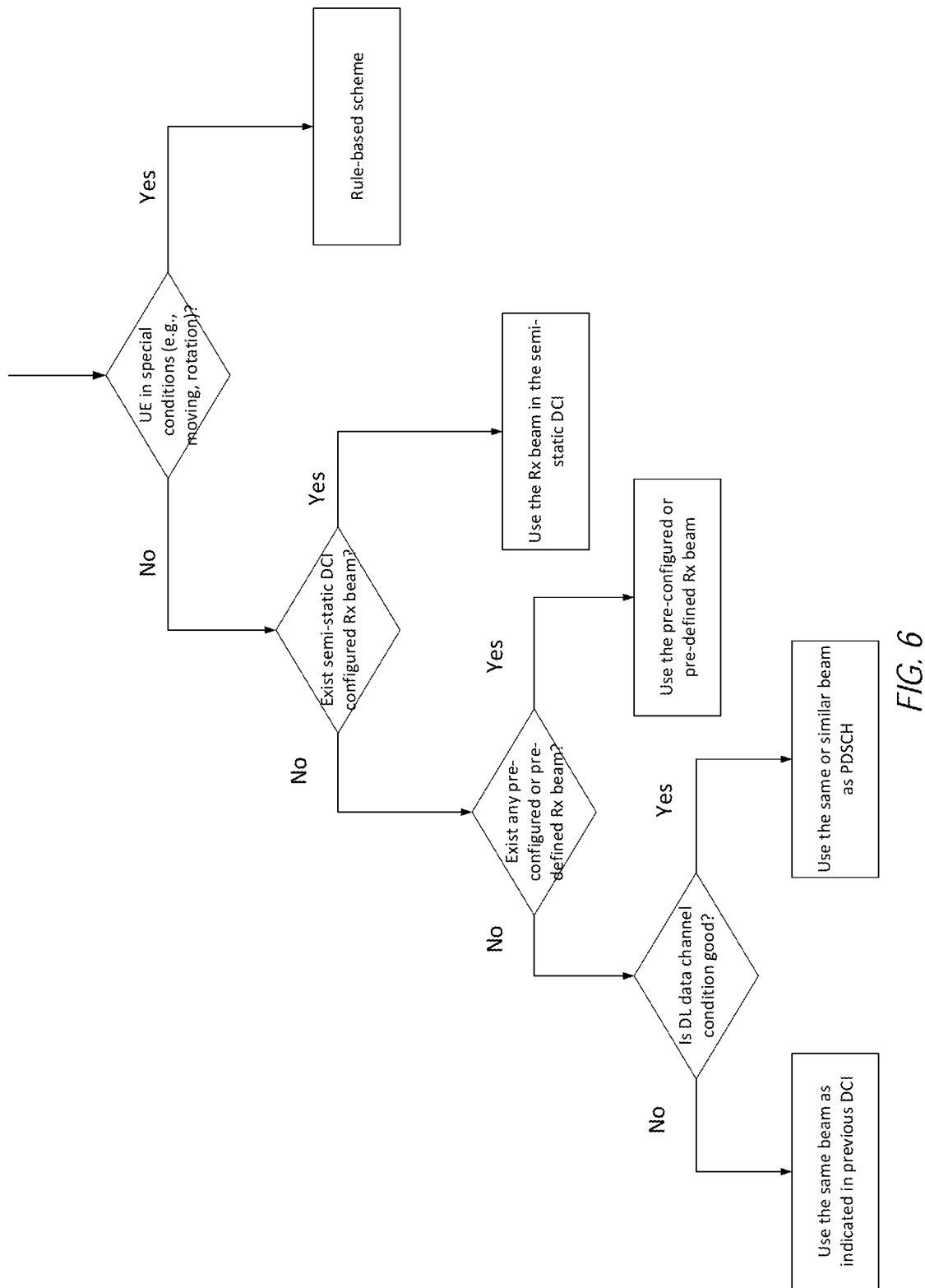


FIG. 6

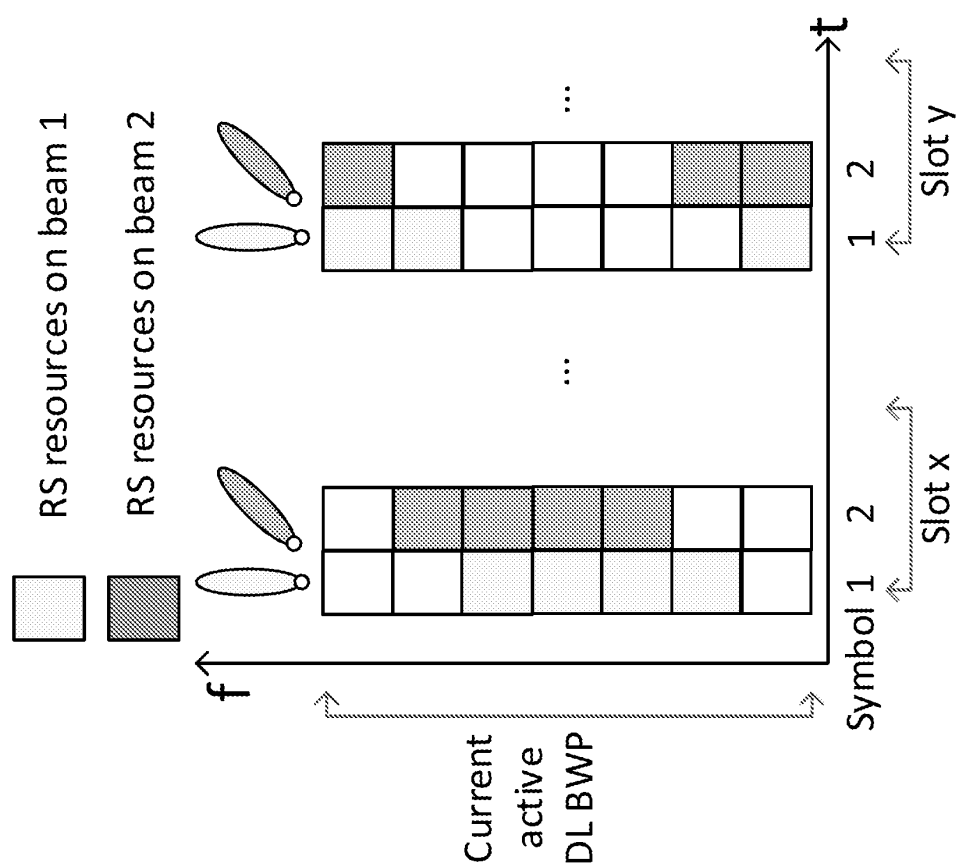


FIG. 8

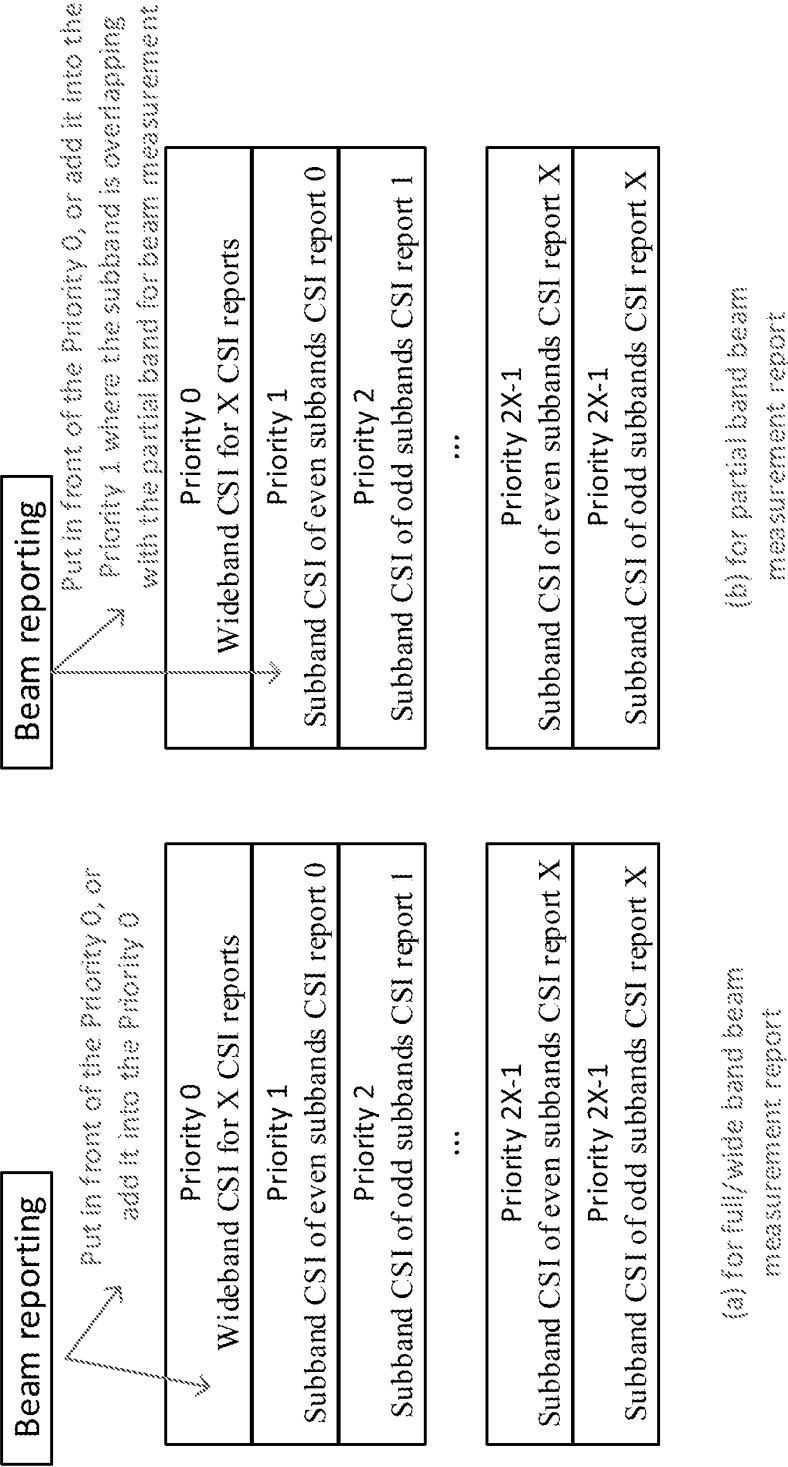


FIG. 9