

DETERMINATION OF SUITABILITY FOR LP-WUS MONITORING IN RRC STATES OR LP-WUS CONFIGURATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States Provisional Patent Application No. 63/518,000 filed on August 7, 2023, the entire contents of which are incorporated herein by reference.

BACKGROUND

[0002] Low power-wake up signal (LP-WUS) monitoring may reduce power consumption of WTRUs and/or other small battery powered devices. A separate ultra-low power consumption receiver may monitor wake-up signals (WUSs) and/or trigger a main radio (MR). The MR may be dedicated for data and control signal transmission and/or reception.

[0003] A deep sleep state may be supported for the MR, for example, while the WTRU is in RRC IDLE and/or RRC INACTIVE states. The WTRU skipping monitoring PDCCH while in RRC CONNECTED state may also be supported.

SUMMARY

[0004] Systems and methods as described herein may include wireless transmit / receive unit (WTRU) determination of one or more RRC states and/or one or more LP-WUS configurations. A wireless transmit / receive unit (WTRU) may receive configuration information from a network that activates the WTRU to perform LP signal monitoring using a low power radio of the WTRU. The configuration information may indicate a threshold associated with a condition. The WTRU may receive an indication to determine suitability of the WTRU for low power (LP) signal monitoring. The WTRU may determine the suitability of the WTRU for LP signal monitoring based on the threshold associated with the condition. The WTRU may send a report indicating the determination.

[0005] The WTRU may determine the suitability of the WTRU for LP signal monitoring based on a state of the WTRU. The state of the WTRU may be a connected mode, an idle mode, or an inactive mode.

[0006] In an example, the WTRU may receive the configuration information via a main radio of the WTRU. The WTRU may receive the indication via the main radio of the WTRU. The WTRU may send the report via the main radio of the WTRU. The WTRU may receive the configuration via the main radio of the WTRU.

The WTRU may also monitor for low power signals via the low power radio of the WTRU in response to receiving the configuration from the network that activates the WTRU to perform LP signal monitoring.

[0007] In one embodiment, the condition may include any one or more of: LP signals, signals received by main radio (MR), beam quality of a beam associated with a main radio of the WTRU, beam quality of a beam associated with a low power radio of the WTRU, an activity of the WTRU, a mobility of the WTRU, a location of the WTRU, a coverage area of the low power radio of the WTRU, or a coverage gap between the low power radio of the WTRU and the main radio of the WTRU.

[0008] In another example, the indication may include a radio resource control (RRC) state for the WTRU to determine a suitability of the WTRU for LP signal monitoring.

[0009] In another embodiment, the configuration information may indicate a plurality of thresholds and a plurality of conditions. Each threshold of the plurality of thresholds may be associated with a radio resource control (RRC) state or a periodicity of a low power signal. The report may indicate, for each RRC state or periodicity of the low power signal, the suitability of the WTRU for LP signal monitoring.

[0010] The WTRU may receive a second indication to perform LP signal monitoring in a first radio resource control (RRC) state or with a first low power signal periodicity. The WTRU may also monitor an LP signal using a low power radio of the WTRU in accordance with the second indication.

[0011] The WTRU may determine that LP signal monitoring is not suitable when a mobility parameter is greater than a mobility threshold, an activity parameter is greater than an activity threshold, or a beam quality measure is less than a beam quality threshold.

[0012] The WTRU may determine that LP signal monitoring is suitable when a mobility parameter is less than a mobility threshold, an activity parameter is less than an activity threshold, or a beam quality measure is greater than a beam quality threshold.

[0013] The report may indicate the condition that is used to determine the suitability of the WTRU for LP signal monitoring.

BRIEF DESCRIPTION OF THE DRAWINGS

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

[0015] 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.

[0016] 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.

[0017] 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.

[0018] FIG. 2 is diagram illustrating an example receiver architecture of a WTRU utilizing low-power wake-up receiver.

DETAILED DESCRIPTION

[0019] 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.

[0020] 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 WTRU.

[0021] 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.

[0022] 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.

[0023] 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).

[0024] 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).

[0025] 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).

[0026] 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).

[0027] 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).

[0028] 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.

[0029] 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.

[0030] 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.

[0031] 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.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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).

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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)).

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] In representative embodiments, the other network 112 may be a WLAN.

[0053] 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.

[0054] 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.

[0055] 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.

[0056] 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).

[0057] 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).

[0058] 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.

[0059] 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.

[0060] 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.

[0061] 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).

[0062] 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).

[0063] 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.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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 WTRU IP address, managing PDU sessions, controlling policy enforcement and QoS,

providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0068] 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 184, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0069] 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.

[0070] 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.

[0071] 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.

[0072] 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.

[0073] FIG. 2 depicts an example receiver architecture of a WTRU using a low-power wake-up receiver. Low power-wake up signal (LP-WUS) monitoring may reduce power consumption of WTRUs and/or other small battery powered devices. A separate ultra-low power consumption receiver may monitor wake-up signals (WUSs) and/or trigger a main radio (MR). The MR may be dedicated for data and control signal transmission and/or reception, for example as shown in FIG. 2.

[0074] A deep sleep state for the MR may be supported, for example while the WTRU is in RRC IDLE and/or RRC INACTIVE states. The WTRU skipping monitoring physical downlink control channel (PDCCH) while in RRC CONNECTED state may also be supported.

[0075] Systems and methods as described herein may allow for power saving. A level of power saving achievable through LP-WUS monitoring may depend on selecting a (e.g., correct) LP-WUS monitoring configuration (e.g., MR in deep sleep state while WTRU is in RRC IDLE, WTRU skips monitoring PDCCH while MR is in RRC CONNECTED state, etc.), activating the low power wake up signal (LP-WUS) monitoring under (e.g., the right) conditions (e.g., WTRU activity level, WTRU mobility level, link quality level), and/or selecting (e.g., proper) LP-WUS monitoring setup (e.g., proper link/beam quality for LP-WUS monitoring), and so forth. Systems and methods as herein may pertain to selection of a (e.g., correct) LP-WUS monitoring configuration, selection of (e.g., right) conditions for activating LP-WUS monitoring, and/or selection of a (e.g., proper) beam(s)/link for LP-WUS monitoring.

[0076] The WTRU may determine the suitability and/or feasibility for LP-WUS monitoring, for example in different RRC states and/or LP-WUS configurations. WTRU determination of suitability and/or feasibility for LP-WUS monitoring in different RRC states may be based on a configured and/or indicated condition(s) and threshold(s), for example by the gNB.

[0077] The WTRU may receive a configuration (e.g., configuration information), for example from the gNB, for one or more conditions to meet for LP-WUS monitoring (e.g., monitoring low power synchronization signal (LP-SS), LP-WUS, LP-PDCCH via low power wake up radio (LP-WUR)). The WUS monitoring

conditions may include one or more of the link/beam quality, WTRU activity, WTRU mobility, location, LR coverage/LR-MR coverage gap (e.g., coverage gap between LR and MR), and/or etc.

[0078] A configuration (e.g., configuration information) may include one or more (e.g., any number) of thresholds (e.g., first threshold, second threshold, ..., kth threshold), for the LP-WUS monitoring conditions (e.g., for each condition). The kth threshold (e.g., for a particular condition) may be associated with a kth RRC state of the WTRU during LP-WUS monitoring (e.g., RRC IDLE, RRC INACTIVE, and RRC CONNECTED states) and/or LP-WUS configurations (e.g., LP-WUS periodicity) may be associated with LP-WUS monitoring.

[0079] The WTRU may receive an indication from the gNB for testing the suitability and/or feasibility of using LP-WUS monitoring with one or more RRC states and/or LP-WUS configuration (e.g., LP-WUS periodicity). The radio resource control (RRC) state(s) for which suitability and/or feasibility is tested may be determined by the WTRU based on for example, explicit indication(s) and/or an RRC state the WTRU is currently in (e.g., CONNECTED state). The indication may be received via one or more of a request for CSI-RS measurement and/or report for one or more beams associated with LR; a capability inquiry related to WUS monitoring; a specific TCI state activation; and/or an explicit indication (e.g., via MAC-CE, downlink control information (DCI), RRC).

[0080] The WTRU may determine the suitability and/or feasibility of monitoring LP-WUS in one or more (e.g., each) of the indicated one or more RRC states, for example based on the configured one or more conditions and the respective thresholds for each of the one or more RRC states.

[0081] For example, if the WTRU mobility > mobility threshold for kth RRC state, then LP-WUS monitoring may not be feasible/suitable for the kth RRC state. If the WTRU mobility < mobility threshold for kth RRC state, then LP-WUS monitoring may be feasible/suitable for the kth RRC state.

[0082] For example, if the WTRU activity level (e.g., number of SRs transmitted during a preconfigured time window) > activity threshold for kth RRC state, then LP-WUS monitoring may not be feasible/suitable for the kth RRC state. If the WTRU activity level < activity level threshold for the kth RRC state, then LP-WUS monitoring may be feasible/suitable for the kth RRC state.

[0083] For example, if the link quality > link quality threshold for kth RRC state, then LP-WUS monitoring may be feasible/suitable for the kth RRC state. If the link quality < link quality threshold for the kth RRC state, then LP-WUS monitoring may not be feasible/suitable for the kth RRC state.

[0084] The WTRU may report the suitability/feasibility of LP-WUS monitoring in (e.g., each of) the one or more RRC states, for example based on the suitability/feasibility determination. The report may include one

or more of an indication of feasible/suitable or not feasible/suitable (e.g., for each RRC state); and/or the conditions that do not meet the suitability/feasibility criteria (e.g., include separately for each RRC state), for example if not feasible/suitable for one or more conditions. The Suitability/feasibility report may be sent using one or more of a MAC-CE indication, via physical uplink control channel (PUCCH), via physical uplink shared channel (PUSCH), and/or via PRACH Tx.

[0085] The WTRU may receive an indication/configuration, for example from gNB/network, that indicates/activates use of LP-WUS monitoring.

[0086] The WTRU may receive an RRC release message from gNB indicating to go to RRC INACTIVE state. The release message may include an indication to use LP-WUS monitoring.

[0087] The WTRU may receive an indication from gNB while in RRC CONNECTED state to use LP-WUS monitoring while in CONNECTED state.

[0088] The WTRU may receive a non-access stratum (NAS) message indicating to use LP-WUS monitoring in RRC IDLE state.

[0089] The WTRU may use LP-WUS monitoring in an RRC state, for example based on the received indication from the gNB/Network.

[0090] The WTRU may monitor LP-SS and/or LP-WUS, for example while in the RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states). The WTRU may monitor and/or receive one or more DL signals (e.g., PDCCH), for example based on reception of the LP-WUS.

[0091] The WTRU may monitor LP-SS and/or LP-WUS, for example while in the RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states). The WTRU may monitor and/or receive one or more paging related signals (e.g., paging PDCCH/DCI, permanent equipment identifier (PEI)), for example based on reception of the LP_WUS.

[0092] Systems and methods as herein may include beam determination for LP-WUS monitoring. A WTRU may determine beam(s) for LP-WUS reception, for example by using a second set of BFR thresholds. There may be an assumption that MR and LR share the same RF hardware.

[0093] The WTRU may receive configuration information. The configuration may include a first set beam failure recovery (BFR) resources and/or a first set of BFR thresholds and/or a second set of thresholds. The configuration may include a first set beam failure recovery (BFR) resources and/or a first set of thresholds. The first set of thresholds may be associated with (e.g., regular) operation with a main radio (MR). The second set of thresholds may be associated with LP-WUS thresholds or BFR thresholds. The WTRU may determine whether to monitor and/or select a set of beams for a low power-wake up signal (LP-WUS) monitoring, for

example based on one or more measurements associated with the set of beams and the second set of thresholds. The WTRU may send a report message indicating the determination.

[0094] The WTRU may receive an indication message for determining whether to select the set of beams for LP-WUS monitoring. The configuration may include a second threshold and/or a second set of thresholds. The second threshold and/or second set of thresholds may be associated with beam failure detection. The second threshold and/or second set of thresholds may include one or more of an LP-WUS block error rate (BLER) threshold, an estimated LP-WUS BLER threshold, an estimated physical downlink control channel (PDCCH) BLER threshold, a reference signal receive power (RSRP) threshold, a beam selection threshold, and/or a beam failure indication (BFI) count threshold.

[0095] A WTRU may receive a configuration for a first set of BFR resources and/or a first set of BFR thresholds for regular operation with MR and/or a second set of thresholds (e.g., LP-WUS thresholds, BFR thresholds) to determine a beam for LP-WUS monitoring with LR. The first set of BFR resources may include one or more of a first set of beams (e.g., BFD RSs and/or PDCCH monitoring beam), a first set of candidate beams (e.g., BFR candidate beams), a first set of PRACH resources for beam failure indication, and/or etc. The first set of BFR thresholds may include one or more of first failure detection threshold(s) (e.g., first hypothetical PDCCH BLER threshold, a first failure detection RSRP threshold), a first new beam selection threshold, a first BFI max count, and/or etc. The second set of thresholds may include one or more of second failure detection threshold(s) (e.g., a hypothetical LP-WUS BLER threshold, second hypothetical PDCCH BLER threshold, a second failure detection RSRP threshold), a second new beam selection threshold, a second BFI max count, and/or etc.

[0096] The WTRU may receive an indication from the gNB for determining beams for LP-WUS monitoring. The WTRU may determine that there is no beam failure for UL/DL communication (i.e., while using the MR), for example based on the one or more beam measurements associated with the first set of beams and/or the first set of BFR thresholds. The WTRU may determine the suitability/unsuitability of the first set of beams for LP-WUS monitoring with LR, for example based on the one or more measurements associated with the one or more first set of beams and/or the second set of thresholds.

[0097] The WTRU may determine that the PDCCH monitoring beam is suitable for LP-WUS monitoring, for example if the hypothetical PDCCH BLER of a PDCCH monitoring beam < second hypothetical LP-WUS BLER threshold. The WTRU may determine that the PDCCH monitoring beam is not suitable for LP-WUS monitoring, for example if the hypothetical PDCCH BLER of a PDCCH monitoring beam > second hypothetical LP-WUS BLER threshold.

[0098] The WTRU may determine that the BFD RS is suitable for LP-WUS monitoring, for example if the RSRP of a BFD RS > second failure detection RSRP threshold. The WTRU may determine that the BFD RS beam is not suitable for LP-WUS monitoring, for example if the RSRP of a BFD RS < second failure detection RSRP threshold.

[0099] The WTRU may indicate to the gNB at least one (e.g., all) of the identified one or more beams (e.g., via PUCCH, PUSCH/MAC-CE or by transmitting using one or more preconfigured (e.g., second set of) PRACH resources), for example if the WTRU determines that one or more of the first set of beams are suitable for LP-WUS monitoring with LR.

[0100] The WTRU may select one or more beams out of the first set of candidate beams for LP-WUS monitoring, for example if the WTRU determines that there is no beam among the first set of beams that can be used for LP-WUS monitoring (by using the LR).

[0101] The WTRU may measure the beam quality (e.g., RSRP) of the first set of candidate beams. The WTRU may determine one or more beams for LP-WUS monitoring, for example based on the one or more measurements associated with one or more first set of candidate beams and/or the second new beam selection threshold. The WTRU may indicate to the gNB at least one (e.g., all) of the selected one or more beams (e.g., via PUCCH, PUSCH/MAC-CE or by transmitting using one or more preconfigured (third set of) PRACH resources). The WTRU may indicate to the gNB that no suitable beam is found for LP-WUS monitoring (e.g., via PUCCH, PUSCH, or by transmitting using a preconfigured PRACH resource), for example if the WTRU determines that there is no beam in both the first set of beams and first set of candidate beams that can be used for LP-WUS monitoring.

[0102] The WTRU may receive an indication and/or configuration from the gNB and/or the network that indicates/activates the use of LP-WUS monitoring. The WTRU may receive an indication and/or configuration of a set of beams for LP-WUS monitoring. The WTRU may receive the indication and/or activation after sending an indication of one or more selected or suitable beams (e.g., from the first set of beams or first candidate set of beams) for LP-WUS monitoring

[0103] The WTRU may receive an indication from gNB to use LP-WUS monitoring while in CONNECTED state and/or receive a confirmation indication (e.g., 1 bit indication), for example for using selected and indicated beams by the WTRU for LP-WUS monitoring.

[0104] The WTRU may receive an RRC release message from gNB. The RRC release message may indicate to go to RRC INACTIVE state. The release message may include an indication to use LP-WUS monitoring. The WTRU may receive a configuration and/or indication of a subset of beams (e.g., in a bit

map). The subset of beams may be from beams selected and/or indicated by the WTRU for LP-WUS monitoring.

[0105] The WTRU may use one or more of the indicated and/or configured beams. Additionally, or alternatively, the WTRU may monitor LP-WUS, for example for detecting wake up indications from the gNB.

[0106] The WTRU may monitor LP-SS and/or LP-WUS using one or more of the indicated/configured beams, for example while in LP-WUS monitoring in the RRC connected state. The WTRU may monitor and/or receive one or more DL signals (e.g., PDCCH), for example based on reception of the LP-WUS. The WTRU may determine a PDCCH monitoring resource (e.g., search space, and/or PDCCH monitoring occasion), for example based on a configured association between indicated/configured beams and PDCCH monitoring resources.

[0107] The WTRU may monitor LP-SS and/or LP-WUS using one or more of the beams indicated/configured, for example while in LP-WUS monitoring in the RRC IDLE or RRC INACTIVE state. The WTRU may monitor and/or receive one or more paging related signals (e.g., paging PDCCH/DCI, PEI), for example based on indication received on LP-WUS.

[0108] A WTRU may transmit and/or receive a physical channel and/or reference signal, for example according to at least one spatial domain filter. The term “beam” may be used to refer to a spatial domain filter.

[0109] The WTRU may transmit a physical channel and/or signal using the same spatial domain filter as the spatial domain filter used for receiving an RS (e.g., CSI-RS) and/or a SS block. The WTRU transmission may be referred to as “target”. The received RS and/or SS block may be referred to as “reference” and/or “source”. The WTRU may be said to transmit the target physical channel and/or signal according to a spatial relation with a reference to such RS and/or SS block.

[0110] The WTRU may transmit a first physical channel and/or signal according to the same spatial domain filter as the spatial domain filter used for transmitting a second physical channel and/or signal. The first and second transmissions may be referred to as “target” and “reference” or “source”, respectively. The WTRU may be said to transmit the first (e.g., target) physical channel and/or signal according to a spatial relation with a reference to the second (e.g., reference) physical channel or signal.

[0111] A spatial relation may be implicit, configured by RRC, and/or signaled by MAC CE and/or DCI. For example, a WTRU may implicitly transmit PUSCH and/or DM-RS of PUSCH according to the same spatial domain filter as an SRS indicated by an SRI indicated in DCI and/or configured by RRC. In another

example, a spatial relation may be configured by RRC for an SRS resource indicator (SRI) and/or signaled by MAC CE for a PUCCH. A (e.g., such) spatial relation may also be referred to as a “beam indication”.

[0112] The WTRU may receive a first (e.g., target) downlink channel or signal according to the same spatial domain filter or spatial reception parameter as a second (e.g., reference) downlink channel or signal. For example, an (e.g., such) association may exist between a physical channel (e.g., PDCCH and/or PDSCH) and its respective DM-RS. An (e.g., such) association may exist when the WTRU is configured with a quasi-colocation (QCL) assumption type D between corresponding antenna ports, for example at least when the first and second signals are reference signals. An (e.g., such) association may be configured as a TCI (transmission configuration indicator) state. A WTRU may indicate an association between a CSI-RS and/or SS block and a DM-RS, for example by an index to a set of TCI states configured by RRC and/or signaled by MAC CE. An (e.g., such) indication may be referred to as a “beam indication”.

[0113] Beam measurement and/or beam quality measurement and/or beam quality may refer one or more of the following parameters, for example measured and/or estimated and/or derived based on measurements performed for a beam or set of beams: RSRP, RSRQ, RSSI, SINR, CQI, RI, LI, PMI, CRI, AoA, AoD, Doppler spread, Doppler shift, Average Doppler, Delay spread, Average delay, and/or Channel occupancy.

[0114] Differential beam measurement and/or spatial-domain differential beam measurement of two beams is the different between the two beam measurements. For example, spatial-domain differential L1-RSRP of two beams may be the difference between L1-RSRPs the two beams.

[0115] Time-domain differential beam measurement of a beam may be the difference between beam measurements of the same beam at two time instances. For example, a time-domain differential L1-RSRP of a beam may be the difference between L1-RSRPs of the beam at two time instances.

[0116] LP-WUS monitoring may refer to one or more of monitoring, detecting, decoding, and/or receiving one or more signals associated with low-power wake up radio (LR). For example, the low-power synchronization signal (LP-SS) may help the LR to maintain time synchronization with the gNB. LP-WUS may indicate to the WTRU to perform one or more operations based on the content and/or presence of the signal. For example, upon the reception of LP-WUS, the WTRU may wake-up the MR of the WTRU for PDCCH monitoring. In another example, upon the reception of LP-WUS, a group of WTRUs may wake up the MR at their next DRX on duration for paging PDCCH/DCI reception or reception paging early indication (PEI). The MR and LR may share the radio frequency hardware. The WTRU may receive LP-WUS by using

the MR. The WTRU may receive configuration information via a main radio of the WTRU. The WTRU may receive indication via the main radio of the WTRU.

[0117] A WTRU may determine the suitability and/or feasibility for LP-WUS monitoring, for example in different RRC states and/or LP-WUS configurations. The WTRU may determine the suitability and/or feasibility for LP-WUS monitoring in different RRC states and/or LP-WUS configurations based on a configured and/or indicated conditions and/or thresholds by the gNB. The WTRU may receive configurations indicating a threshold associated with a condition. The WTRU may receive a configuration from the gNB for one or more conditions to meet for LP-WUS monitoring (e.g., monitoring LP-SS, LP-WUS, and/or LP-PDCCH via LP-WUR) or low power signal monitoring. The WUS monitoring conditions may include one or more of the link/beam quality, WTRU activity, WTRU mobility, location, low-power wake up radio (LR) coverage/LR-MR coverage gap (e.g., coverage gap between LR and MR), and/or etc. A configuration may include a first threshold, second threshold, ..., kth threshold, for example for the LP-WUS monitoring conditions (e.g., for each condition). The kth threshold (e.g., for a particular condition) may be associated with kth RRC state of the WTRU during LP-WUS monitoring (e.g., RRC IDLE, RRC INACTIVE, and/or RRC CONNECTED states) and/or condition (e.g., LP-WUS periodicity).

[0118] The WTRU may receive an indication from the gNB for testing the suitability and/or feasibility of using LP-WUS monitoring with one or more RRC states and/or LP-WUS configurations (e.g., LP-WUS periodicity). The RRC state(s) for which suitability/feasibility should be tested may be determined by the WTRU based on one or more of an explicit indication and/or an RRC state the WTRU is currently in (e.g., CONNECTED state), or based on threshold associated with conditions. A suitability of the WTRU for LP signal monitoring may be based on a state of the WTRU. The CONNECTED state may be a connected mode, an idle mode, or an inactive mode. An indication may be received via one or more of a request for CSI-RS measurement and/or report for one or more beams associated with LR; a capability inquiry related to WUS monitoring; a (e.g., specific) TCI state activation; and/or an explicit indication (e.g., via MAC-CE, DCI, and/or RRC).

[0119] The WTRU may determine the suitability and/or feasibility of monitoring LP-WUS in each of the indicated one or more RRC states, for example based on the configured one or more conditions and/or the respective thresholds for each of the one or more RRC states.

[0120] LP-WUS monitoring may not be feasible/suitable for the kth RRC state, for example if the WTRU mobility > mobility threshold for kth RRC state. LP-WUS monitoring may be feasible/suitable for the kth RRC state, for example if the WTRU mobility < mobility threshold for kth RRC state.

[0121] LP-WUS monitoring may not be feasible/suitable for the kth RRC state, for example if the WTRU activity level (e.g., number of SRs transmitted during a preconfigured time window) > activity threshold for kth RRC state. LP-WUS monitoring is feasible/suitable for the kth RRC state, for example if the WTRU activity level < activity level threshold for the kth RRC state.

[0122] LP-WUS monitoring may be feasible/suitable for the kth RRC state, for example if the link quality > link quality threshold for kth RRC state. LP-WUS monitoring may not be feasible/suitable for the kth RRC state, for example if the link quality < link quality threshold for the kth RRC state.

[0123] The WTRU may report the suitability/feasibility of LP-WUS monitoring in one or more (e.g., each) of the one or more RRC states and/or LP-WUS configurations (e.g., LP-WUS periodicity), for example based on the suitability/feasibility determination. A report may include one or more of an indication of feasible/suitable or not feasible/suitable (e.g., for each RRC state); conditions that do not meet the suitability/feasibility criteria may be indicated in the report (e.g., include separately for each RRC state), for example if not feasible/suitable for one or more conditions. A Suitability/feasibility report may be sent using one or more of a MAC-CE indication, via PUCCH, via PUSCH, and/or via PRACH Tx. The report may indicate the determined suitability of the WTRU for LP signal monitoring. The WTRU may send the report via the main radio of the WTRU. The WTRU may receive configuration via the main radio of the WTRU. The WTRU may monitor for low power signals via the low power radio of the WTRU in response to receiving the configuration from the network that activates the WTRU to perform LP signal monitoring.

[0124] Assistance information for determining LP-WUS configurations (e.g., periodicity of LP-WUS) may include one or more of LP signals, signals received by main radio (MR), WTRU activity level, beam quality measurements of one or more beams, LR coverage (a coverage area of the low power radio of the WTRU), a coverage gap between the low power radio of the WTRU and the main radio of the WTRU, WTRU mobility (e.g., speed of movement, direction of movement), and/or WTRU location. The WTRU may receive an indication and/or configuration from gNB/network that indicates/activates use of LP-WUS monitoring. The configuration may activate the WTRU to perform LP signal monitoring using a low power radio of the WTRU. The WTRU may receive an RRC release message from gNB indicating to go to RRC INACTIVE state. The release message may include an indication to use LP-WUS monitoring. The WTRU may receive an indication from gNB while in RRC CONNECTED state to use LP-WUS monitoring while in CONNECTED state. The WTRU may receive a NAS message, for example indicating to use LP-WUS monitoring in RRC IDLE state.

[0125] The WTRU may use LP-WUS monitoring in an RRC state, for example based on the received indication from the gNB/Network. The WTRU may monitor LP-SS and/or LP-WUS, for example while in the RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states). The WTRU may monitor and/or receive one or more DL signals (e.g., PDCCH), for example based on reception of the LP-WUS. The WTRU may monitor LP-SS and/or LP-WUS, for example while in the RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states). The WTRU may monitor and/or receive one or more paging related signals (e.g., paging PDCCH/DCI, PEI), for example based on reception of the LP_WUS.

[0126] A WTRU may be configured to monitor one or more LP-WUS and/or related signals (e.g., LP-SS), for example via a LR and/or using the MR radio frequency (RF) hardware (e.g., when the LR and MR shares RF hardware). The WTRU may be configured to monitor one or more LP-WUS and/or related signals while the WTRU is in different RRC states. For example, a WTRU may be configured to monitor LP-WUS while in RRC CONNECTED state. The WTRU may (e.g., then) skip receiving one or more PDCCHs (e.g., all) until/unless indicated by a LP-WUS received via low-power wake up radio (LR) to wake up the main receive (MR) and/or decode such PDCCHs. In another example, a WTRU may be configured to monitor LP-WUS while the WTRU is in RRC IDLE state or RRC INACTIVE states as herein. The WTRU may (e.g., then) skip one or more paging messages from the gNB/network until/unless indicated by a LP-WUS received via LR to wake up the MR and receive such paging messages. One or more LP-WUS and/or related signals (e.g., LP-SS) and/or LP-WUR may be configured differently. For example, a LP-WUS/LP-WUR may be configured with one or more of different periodicity (e.g., a first periodicity, a second periodicity, and/or etc.), different subcarrier spacing (SCS) values, different bandwidths, different carrier frequency, different configurations related to MR operation in the event of not receiving one or more configured/scheduled LP-WUSs (e.g., wake-up MR or MR does not wake up), and/or different configurations related to LR operation in the event of not receiving one or more configured/scheduled LP-WUSs (e.g., LR increases monitoring frequency/LR reducing monitoring periodicity).

[0127] Suitability/feasibility of an RRC state and/or LP-WUS configuration for LP-WUS monitoring by a WTRU may depend on different conditions the WTRU is experiencing and/or has experienced. The indication may include an RRC state for the WTRU to determine a suitability of the WTRU for LP signal monitoring. The information about/status of (e.g., some of) the conditions of the WTRU may be readily available at the gNB. Information about/status of some of these conditions may be typically known by the WTRU and/or most updated information/status may be available at the WTRU (e.g., most of the time). For example, the DL buffer status and/or availability of pending HARQ feedbacks may be readily known by the

gNB. In another example, one or more of the WTRU activity (e.g., number of SRs transmitted in a preconfigured time window), WTRU mobility (e.g., speed, direction of movement), beam quality, radio link quality, location, LR coverage, LR-MR coverage gap and so forth, may be known (e.g., only known) by the WTRU. Additionally, or alternatively, most current information/status may be known by the WTRU. There may be consideration of one or more conditions, for example to determine appropriate RRC states and/or LP-WUS/LP-WUR configurations.

[0128] A WTRU may use one or more of the following solutions to determine the suitability/feasibility of LP-WUS monitoring with different RRC states and/or LP-WUS/LP-WUR configurations. The WTRU may be equipped with one or more receivers. A first receiver (e.g., main receiver) may receive a first type of signals and a second receiver (e.g., low-power receiver) may receive a second type of signals. The first type of signals may include signals dedicated for the first receiver and used for data transmission and the second type of signals may include signals dedicated to keep connection with the network and/or allow the first receiver to be in inactive mode and/or sleep mode for power saving. Herein, the first receiver may be referred to as main receiver (MR) and the second receiver may be referred to as low-power wake-up receiver (LP-WUR), low power receiver (LR), or secondary receiver (SR). The second type of signals may be at least one of LP-WUS, LP-SS, and LP-PDCCH. The one or more second type of signals may be common referred to as LP-WUS.

[0129] A WTRU may indicate the suitability and/or feasibility of reception of the second type of signals (e.g., signals dedicated for LP-WUR) based on one or more predefined and/or configured conditions. Herein, the condition may be referred to as a monitoring condition. The WTRU may determine to monitor the second type of signals when the one or more predefined and/or configured conditions are met for monitoring and/or a gNB indicates and/or configures the WTRU to monitor the second type of signals.

[0130] A WTRU may receive a configuration (or configuration information) and/or may be configured with one or more of the following. The configuration information may indicate a plurality of thresholds and a plurality of conditions. There may be one or more conditions to test for suitability or feasibility (e.g., which may herein be referred to as suitability) of LP-WUS monitoring. The configuration information may indicate a threshold associated with a condition. Each threshold of the plurality of thresholds may be associated with an RRC state or a periodicity of a low power signal. A WTRU may receive one or more signals from the gNB via LP-WUR. One or more signals received via LP-WUR may include LP-WUSs. LP-WUSs may indicate the MR to perform one or more of start receiving/detecting/monitoring for signals from the gNB and/or other transmitters (e.g., relays, WTRUs, so forth), and/or receiving supporting signals (e.g.,

synchronization signals for LP-WUR/MR). The LP-WUS monitoring conditions may include one or more of WTRU activity, WTRU mobility, beam quality, LR coverage, LR-MR coverage gap, and/or radio link quality.

[0131] WTRU activity may include the WTRU computing/determining its level of activity based on one or more operations/signal transmissions performed in a time window (e.g., a configured time duration in the immediate past). For example, the WTRU may count the number of scheduling requests (SRs) the WTRU transmitted to the gNB in a preconfigured time window. In another example, the WTRU may count the number of PDCCHs and/or PDSCHs it received in a preconfigured time window.

[0132] WTRU mobility may include one or more of the speed of the WTRU, direction of movement (e.g., compared to a reference direction, e.g., direction towards the gNB), the number of times WTRU changed its direction of movement beyond a preconfigured angle in a time window (e.g., a configured time duration in the immediate past), and/or change in the direction of movement compared to a reference direction (e.g., the direction of movement at x ms/slots in the immediate past).

[0133] The location of the WTRU may include the distance between WTRU and the serving node (e.g., gNB, relay, repeater, RRH). In another example, the absolute geographical location/region the WTRU may be located.

[0134] Beam quality may include the WTRU configured to measure and/or compare the beam quality measurements associated with one or more beams (e.g., BFR candidate beams, BFD RSs) with one or more preconfigured thresholds.

[0135] LR coverage may include the WTRU measuring the beam quality/radio signal strength by using a second receiver (e.g., LR) and/or measuring/estimating/determining the distance between the WTRU and the serving node (e.g., gNB, relay, RRH). The WTRU may (e.g., subsequently) compare the signal strength and distance between WTRU and the serving node (e.g., by using a lookup table), for example to determine the LR coverage by using additional details of LP-WUR/LP-WUS capabilities and/or LP-WUS transmitter at the WTRU (e.g., BW, minimum radio, LP-WUS transmit power). Alternatively, or additionally, the WTRU may determine LR coverage based on a measurement from a first receiver (e.g., MR)

[0136] LR-MR coverage gap may include the WTRU measuring the beam quality measurement of one or more beams or signal strength measurements by using LR and MR. The WTRU may compute the difference between the beam quality measurement and/or radio signal strength measurements between LR and MR. The difference between the beam quality and/or radio signal strengths may be compared against preconfigured threshold(s) to determine the suitability of LP-WUS monitoring.

[0137] Radio link quality may include the radio signal strength and/or number of times the radio signal strength falls below a preconfigured threshold value in a preconfigured time window.

[0138] The WTRU may be configured with one or more thresholds for one or more conditions (e.g., each condition), for example to be tested for determining suitability of LP-WUS monitoring (e.g., first threshold, second threshold, ..., kth threshold, where k is an integer ≥ 1). For example, first WTRU activity threshold, second WTRU activity threshold, ..., kth WTRU activity threshold may be associated with LP-WUS monition condition WTRU activity. The kth threshold (e.g., for a WTRU mobility or WTRU activity) may be associated with a RRC state of the WTRU during LP-WUS monitoring (e.g., RRC IDLE state, RRC INACTIVE state, and/or RRC CONNECTED state) and/or one or more additional configuration associated with LP-WUS/LP-WUR (e.g., which may herein be referred to as LP-WUS configuration). The LP-WUS configurations may include one or more of LP-WUS periodicity, configuration related to MR operation in the event of not receiving one or more LP-WUS (e.g., wake-up MR or MR does not wake up), and/or so forth.

[0139] The one or more thresholds may be determined based on one or more of periodicity of a second type of signals (e.g., LP-WUS, LP-SSB, etc.) and/or repetition number of a second type of signals.

[0140] The WTRU may determine the suitability and/or feasibility of LP-WUS monitoring. The WTRU may receive an indication and/or configuration from the gNB for determining/testing the suitability of using LP-WUS monitoring. The indication/configuration may include one or more RRC states (e.g., RRC IDLE state, RRC INACTIVE state, RRC CONNECTED state) and/or one or more LP-WUS configuration (e.g., LP-WUS periodicity), for example for which the suitability of LP-WUS monitoring need to be determined/tested.

[0141] The WTRU may receive the indication for testing the suitability for LP-WUS monitoring via one or more of a request for performing CSI-RS measurement and/or reporting associated measurements for one or more beams/beam resource set associated with LR; a capability inquiry related to LP-WUS monitoring; activation of one or more preconfigured TCI states; and/or an explicit indication.

[0142] A request for performing CSI-RS measurement and/or reporting associated measurements for one or more beams/beam resource set associated with LR may include, for example, the WTRU receiving a request for CSI-RS measurement report and/or beam measurement report where CSI-RS resources or beams are associated with LR. The WTRU may determine that in addition to performing CSI measurement and reporting, the WTRU may be expected to test the suitability of LP-WUS monitoring, for example based on the preconfigured association between the CSI-RS resources/beams with LR. The report may indicate, for each RRC state or periodicity of the low power signal, the suitability of the WTRU for LP signal monitoring.

[0143] A capability inquiry related to LP-WUS monitoring may include for example, the WTRU receiving a capability inquiry which requests the WTRU to report one or more capabilities (e.g., supported BW) associated with LP-WUS/LP-WUR. The WTRU may interpret the reception of capability inquiry as an implicit indication for testing the suitability of LP-WUS monitoring.

[0144] Activation of one or more preconfigured TCI states may include for example, the WTRU receiving an indication for activating one or more preconfigured TCI states (e.g., via PDCCH indication, MAC-CE indication). The WTRU may interpret the activation of the one or more preconfigured TCI states as an implicit indication for testing the suitability of LP-WUS monitoring. The WTRU may receive another indication to perform LP signal monitoring in an RRC state or with a first low power signal periodicity. The WTRU may monitor an LP signal using a low power radio of the WTRU in accordance with this another indication.

[0145] An explicit indication may be made via one or more of MAC-CE indication, a DCI indication, and/or RRC signaling.

[0146] The WTRU may receive the indication and/or configuration for RRC states and/or LP-WUS configurations for which the suitability of LP-WUS monitoring may be tested by explicit indication (e.g., RRC signaling, and/or MAC-CE indication and/or DCI indication). Alternatively, or additionally, the WTRU may determine the RRC states for which the suitability should be tested for LP-WUS monitoring based on an implicit indication. For example, the WTRU may determine/test the suitability of LP-WUS monitoring with the current RRC state (e.g., RRC state of the WTRU when it receives indication/configuration from the WTRU for determining/testing the suitability of LP-WUS monitoring). In another example, the WTRU may determine one or more RRC states based on a preconfigured association between a first RRC state (e.g., current RRC state) and second RRC states (e.g., RRC states to be tested for the suitability/feasibility of LP-WUS monitoring). For example, the WTRU may be preconfigured with two RRC state association configurations including {First RRC State: RRC CONNECTED, Second RRC States: RRC CONNECTED, RRC INACTIVE, RRC IDLE} and {First RRC State: RRC INACTIVE, Second RRC States: RRC INACTIVE, RRC IDLE}. In the example configuration, based on the current RRC state, the WTRU may determine the first RRC state. Based on the configured RRC state association configurations between the first and the second RRC states, the WTRU may determine the set of RRC states for which the suitability of LP-WUS monitoring need to be tested. For example, if the WTRU determined that its first RRC state is RRC CONNECTED, the WTRU may test the suitability of LP-WUS monitoring with RRC CONNECTED, RRC

INACTIVE and/or RRC IDLE states. In another example, if the first RRC state was determined to be RRC INACTIVE state, the WTRU may test the suitability of LP-WUS monitoring with RRC IDLE state.

[0147] The WTRU may determine the thresholds associated with each one or more conditions to be tested for determining/testing the suitability of LP-WUS monitoring based on the RRC states and/or LP-WUS configuration. For example, to determine the suitability for first RRC state and/or LP-WUS configuration, the WTRU may test one or more conditions for LP-WUS monitoring associated with the first set of thresholds (e.g., WTRU activity) against the first set of preconfigured thresholds. In another example, to determine the suitability for kth RRC state and/or LP-WUS configuration, the WTRU may test one or more conditions associated with kth set of thresholds (e.g., WTRU activity, location) against the kth set of preconfigured thresholds.

[0148] In an example configuration, an nth set of thresholds may be configured with a threshold on WTRU mobility. The WTRU may measure its mobility (e.g., WTRU measures its speed based on location estimates at two different time instances) and may compare against the threshold on WTRU mobility configured via nth set of thresholds. The WTRU may determine that the LP-WUS monitoring is not suitable with the nth RRC state and/or LP-WUS configuration, for example if the WTRU mobility > mobility threshold for nth RRC state and/or LP-WUS configuration. The WTRU may determine that the LP-WUS monitoring is suitable with the nth RRC state and/or LP-WUS configuration, for example if the WTRU mobility < mobility threshold for nth RRC state and/or LP-WUS configuration.

[0149] In a second example configuration, nth set of thresholds may be configured with a threshold on WTRU activity. The WTRU may measure its activity (e.g., by calculating the number of SRs transmitted in a preconfigured time window) and may compare against the threshold on WTRU activity configured via nth set of thresholds. The WTRU may determine that the LP-WUS monitoring is not suitable with the nth RRC state and/or LP-WUS configuration, for example if the WTRU activity > activity threshold for nth RRC state and/or LP-WUS configuration. The WTRU may determine that the LP-WUS monitoring is suitable with the nth RRC state and/or LP-WUS configuration, for example if the WTRU activity < activity threshold for nth RRC state and/or LP-WUS configuration. The WTRU may determine that LP signal monitoring is not suitable when a mobility parameter is greater than a mobility threshold, an activity parameter is greater than an activity threshold, or a beam quality measure is less than a beam quality threshold. The WTRU may determine that LP signal monitoring is suitable when a mobility parameter is less than a mobility threshold, an activity parameter is less than an activity threshold, or a beam quality measure is greater than a beam quality threshold.

[0150] In a third example configuration, nth set of thresholds may be configured with a threshold on beam quality. The WTRU may measure beam quality of one or more beams WTRU is configured with (e.g., by measuring the beam quality associated with BFD-RSs) and may compare against the threshold on beam quality configured via nth set of thresholds. The WTRU may determine that the LP-WUS monitoring is suitable for the nth RRC state and/or LP-WUS configuration, for example if the measured beam quality associated with one or more beams > beam quality threshold for nth RRC state and/or LP-WUS configuration. The WTRU may determine that the LP-WUS monitoring is not suitable with the nth RRC state and/or LP-WUS configuration, for example if measured beam quality associated with one or more beams < activity threshold for nth RRC state and/or LP-WUS configuration. The WTRU may determine that LP signal monitoring is not suitable when a mobility parameter is greater than a mobility threshold, an activity parameter is greater than an activity threshold, or a beam quality measure is less than a beam quality threshold. The WTRU may determine that LP signal monitoring is suitable when a mobility parameter is less than a mobility threshold, an activity parameter is less than an activity threshold, or a beam quality measure is greater than a beam quality threshold.

[0151] The WTRU may report the suitability of LP-WUS monitoring in one or more (e.g., each) RRC states and/or LP-WUS monitoring configuration, for example based on the suitability determined by the WTRU. For example, the WTRU may indicate the suitability of LP-WUS monitoring with one or more (e.g., each) RRC state and/or LP-WUS monitoring configuration via PUCCH indication, MAC-CE indication, RRC signaling (e.g., indicated as a bit map where a bit value 1 may indicate the RRC state and/or LP-WUS configuration corresponding to the bit is suitable. The bit value 0 may indicate the RRC state and/or LP-WUS configuration corresponding to the bit is NOT suitable). In another example, the WTRU may receive a configuration indicating the association between the RRC state and/or LP-WUS configuration (e.g., each RRC state and/or LP-WUS configuration) and a set of PRACH resources from the gNB (e.g., via MAC-CE indication, RRC signaling). The WTRU may indicate the suitability of one or more RRC state and/or LP-WUS configuration by transmitting one or more PRACH resources corresponding to the RRC state and/or LP-WUS configuration determined to be suitable. The suitability/feasibility report associated with RRC states and/or LP-WUS configuration may also include one or more of the following. The report may indicate the condition used to determine the suitability of the WTRU for LP signal monitoring.

[0152] The WTRU may report the conditions that the WTRU did not meet (e.g., WTRU mobility, location), for example for (e.g., each) RRC states and/or LP-WUS configurations the WTRU determined that LP-WUS

monitoring is NOT feasible. The WTRU may use one or more of RRC signaling, MAC-CE indication and/or DCI indication.

[0153] The WTRU may report assistance information for determining LP-WUS monitoring condition/configuration/parameters (e.g., bandwidth, SCS, modulation, coding rate, and/or so forth). The assistance information may include one or more of WTRU activity level, beam quality measurements of one or more beams, LR coverage, WTRU mobility (e.g., speed of movement, direction of movement), and/or WTRU location. The gNB may use one or more of the assistance information reported to determine one or more of the conditions/configurations/parameters associated with LP-WUS.

[0154] The WTRU may determine the priority for each RRC state and/or LP-WUS configuration determined to be suitable. The WTRU may be configured with (e.g., additional) priority determining parameters (e.g., WTRU mobility, beam quality) and/or priority determining thresholds. For example, the WTRU may determine that LP-WUS monitoring while the WTRU is in RRC IDLE and/or RRC INACTIVE is suitable. The WTRU may determine that RRC INACTIVE state has higher priority over RRC IDLE state for LP-WUS monitoring, for example if the WTRU mobility (speed) > a preconfigured priority determining threshold for RRC IDLE. The WTRU may determine that RRC IDLE state has higher priority over RRC INACTIVE state for LP-WUS monitoring, for example if the WTRU mobility (speed) < the preconfigured priority determining threshold for RRC IDLE. The WTRU may indicate the determined priority of each RRC state to the gNB (e.g., via PUCCH indication, MAC-CE indication, and/or RRC signaling)

[0155] The WTRU may receive an indication and/or configuration from the gNB or the network (e.g., from core network (CN) via non access stratum (NAS) signaling), for example to start to using LP-WUS monitoring. The WTRU may receive an indication and/or configuration via RRC signaling, MAC-CE indication, and/or DCI indication (e.g., via a DCI scrambled with a preconfigured RNTI (e.g., a dedicated RNTI for signaling related to LP-WUS monitoring), for example from the gNB.

[0156] The WTRU may receive an RRC release message from gNB indicating to go to RRC INACTIVE state. The release message may include an indication to use LP-WUS monitoring. The WTRU may go to RRC INACTIVE state and/or start monitoring LP-WUS by using LR.

[0157] The WTRU may receive an indication from gNB while in RRC CONNECTED state to use LP-WUS monitoring while in CONNECTED state. The WTRU may stay in RRC CONNECTED state and/or start monitoring LP-WUS by using LR.

[0158] The WTRU may receive a NAS message indicating the WTRU to use LP-WUS monitoring in RRC IDLE state. The WTRU may go to RRC IDLE state and/or start monitoring LP-WUS by using LR.

[0159] The WTRU may use the LP-WUS monitoring in an RRC state and/or LP-WUS configuration, for example based on the received indication and/or configuration from the gNB (e.g., via DCI indication, MAC-CE indication, RRC signaling) and/or the network (e.g., NAS signaling). In an example, based on the one or more of the signals receives via LR (e.g., LP-SS, LP-WUS), the WTRU may wake up the MR for monitoring/detecting/receiving one or more signals/channels/indications/configurations (e.g., PDCCH, PDSCH, and/or so forth). In another example, based on the one or more of the signals receives via LR (e.g., LP-SS, LP-WUS), the WTRU may refrain from waking up the MR. In another example, based on the one or more of the signals receives via LR (e.g., LP-SS, LP-WUS) the WTRU may skip monitoring one or more (e.g., a preconfigured or indicated number of) future LP-WUS monitoring occasions.

[0160] The WTRU may monitor LP-SS and/or LP-WUS, for example while the WTRU is in an RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states). Based on the reception of the LP-WUS, the WTRU may monitor and/or receive one or more DL signals (e.g., PDCCH). While the WTRU is in an RRC state (e.g., RRC CONNECTED, RRC IDLE, RRC INACTIVE states) for example, the WTRU may monitor LP-SS and/or LP-WUS. Based on reception of the LP_WUS, the WTRU may monitor and/or receive one or more paging related signals (e.g., paging PDCCH/DCI, and/or paging early indication (PEI)).

[0161] There may be beam determination for LP-WUS monitoring. A WTRU may determine one or more beams for LP-WUS reception by using a second set of BFR thresholds. It may be assumed that MR and LR share the same RF hardware.

[0162] The WTRU may receive a configuration for a first set of BFR resources and/or first set of BFR thresholds for regular operation with MR and/or a second set of thresholds (e.g., LP-WUS thresholds, BFR thresholds), for example to determine a beam for LP-WUS monitoring with LR. The first set of BFR resources may include one or more of a first set of beams (e.g., BFD RSs and/or PDCCH monitoring beam), a first set of candidate beams (e.g., BFR candidate beams), a first set of PRACH resources for beam failure indication, and/or etc. The first set of BFR thresholds may include one or more of first failure detection thresholds (e.g., first hypothetical PDCCH BLER threshold, a first failure detection RSRP threshold), a first new beam selection threshold, a first BFI max count, etc. The second set of thresholds may include one or more second failure detection thresholds (e.g., a hypothetical LP-WUS BLER threshold, second hypothetical PDCCH BLER threshold, a second failure detection RSRP threshold), a second new beam selection threshold, a second BFI max count, etc.

[0163] The WTRU may receive an indication from the gNB for determining beams for LP-WUS monitoring. The WTRU may determine that there is no beam failure for UL/DL communication (i.e., while using the

MR), for example based on the one or more beam measurements associated with the first set of beams and first set of BFR thresholds.

[0164] The WTRU may determine the suitability/unsuitability of the first set of beams for LP-WUS monitoring with LR, for example based on the one or more measurements associated with the one or more first set of beams and the second set of thresholds. The WTRU may determine that the PDCCH monitoring beam is suitable for LP-WUS monitoring, for example if the hypothetical PDCCH BLER of a PDCCH monitoring beam < second hypothetical LP-WUS BLER threshold. The WTRU may determine that the PDCCH monitoring beam is not suitable for LP-WUS monitoring, for example if the hypothetical PDCCH BLER of a PDCCH monitoring beam > second hypothetical LP-WUS BLER threshold. The WTRU may determine that the BFD RS is suitable for LP-WUS monitoring, for example if the RSRP of a BFD RS > second failure detection RSRP threshold. The WTRU may determine that the BFD RS beam is not suitable for LP-WUS monitoring, for example if the RSRP of a BFD RS < second failure detection RSRP threshold.

[0165] The WTRU may indicate to the gNB at least one (e.g., all) of the identified one or more beams (e.g., via PUCCH, PUSCH/MAC-CE or by transmitting using one or more preconfigured second set of PRACH resources), for example if the WTRU determines that one or more of the first set of beams are suitable for LP-WUS monitoring with LR. The WTRU may select one or more beams out of the first set of candidate beams for LP-WUS monitoring, for example if the WTRU determines that there is no beam among the first set of beams that can be used for LP-WUS monitoring (e.g., by using the LR).

[0166] The WTRU may measure the beam quality (e.g., RSRP) of the first set of candidate beams. The WTRU may determine one or more beams for LP-WUS monitoring, for example based on the one or more measurements associated with one or more first set of candidate beams and the second new beam selection threshold.

[0167] The WTRU may indicate to the gNB at least one (e.g., all) of the selected one or more beams (e.g., via PUCCH, PUSCH/MAC-CE or by transmitting using one or more preconfigured (third set of) PRACH resources). The WTRU may indicate to the gNB that no suitable beam is found for LP-WUS monitoring (e.g., via PUCCH, PUSCH, or by transmitting using a preconfigured PRACH resource), for example if the WTRU determines that there is no beam in both the first set of beams and first set of candidate beams that can be used for LP-WUS monitoring.

[0168] The WTRU may receive an indication and/or configuration from the gNB and/or the network that indicates and/or activates the use of LP-WUS monitoring. The WTRU may receive an indication and/or configuration of a set of beams for LP-WUS monitoring. The WTRU may receive the indication and/or

activation, for example after sending an indication of one or more selected or suitable beams (e.g., from the first set of beams or first candidate set of beams) for LP-WUS monitoring. The WTRU may receive an indication from gNB to use LP-WUS monitoring while in a CONNECTED state and/or receive a confirmation indication (e.g., 1 bit indication), for example for using selected and indicated beams by the WTRU for LP-WUS monitoring. The WTRU may receive an RRC release message from gNB indicating to go to RRC INACTIVE state. The release message may include an indication to use LP-WUS monitoring. The WTRU may receive a configuration and/or indication of a subset of beams (e.g., in a bit map). The subset of beams may be from beams selected and/or indicated by the WTRU for LP-WUS monitoring.

[0169] The WTRU may use one or more of the indicated and/or configured beams and/or monitor LP-WUS for detecting wake up indications from the gNB. The WTRU may monitor LP-SS and/or LP-WUS using one or more of the indicated and/or configured beams, for example While in LP-WUS monitoring in the RRC connected state. Based on reception of the LP-WUS, for example, the WTRU may monitor and/or receive one or more DL signals (e.g., PDCCH). The WTRU may determine a PDCCH monitoring resource (e.g., search space, and/or PDCCH monitoring occasion), for example based on a configured association between indicated and/or configured beams and PDCCH monitoring resources. While in LP-WUS monitoring in the RRC IDLE or RRC INACTIVE state, for example, the WTRU may monitor LP-SS and/or LP-WUS using one or more of the beams indicated/configured. Based on indication received on LP-WUS, for example, the WTRU may monitor and/or receive one or more paging related signals (e.g., paging PDCCH/DCl, and/or PEI).

[0170] There may be beam quality monitoring and/or radio link monitoring. A WTRU may use/receive and/or be configured with one or more sets of reference signals per BWP, for example for monitoring and/or detecting the beam failure detection. For example, the term q_0 may be used for the beam failure detection set. The beam failure detection sets may include one or more reference signals. The reference signals may be CSI-RS resource configuration indexes and/or SS/PBCH block (SSB) indexes. The reference signals included in beam failure detection RS sets may be the same as the reference signals configured/used/received for Radio Link Monitoring (RLM).

[0171] The WTRU may determine the respective RS sets, for example if a WTRU is not provided and/or configured with beam failure detection RS sets for a BWP. For example, the WTRU may determine the RS signals to be included in a beam failure detection RS set for a BWP based on the periodic CSI-RS resource configuration indexes that the WTRU uses for monitoring PDCCH in the respective CORESETs as indicated by TCI-state.

[0172] The WTRU may measure the reference signals included in beam failure detection RS sets and/or estimate radio link quality accordingly. The WTRU may use one or more thresholds/ranges for monitoring and/or estimating the radio link quality. For example, out-of-sync threshold (e.g., Q_{out}) and/or in-sync threshold (e.g., Q_{in}) may be used. The thresholds Q_{out} and/or Q_{in} may be used for estimating the quality of the radio link and/or respective beam(s). The terms Q_{out} and Q_{in} may be used to represent one or more attributes and parameters and the respective values.

[0173] The threshold Q_{out} may be used to determine the radio link and/or beam quality for which, for example the signal transmission may not be reliably received, corresponding to out-of-sync block error rate (BLER_{out}). Alternatively, or additionally, threshold Q_{in} may be used to determine the radio link and/or beam quality for which, for example the signal transmission may be received reliably, corresponding to in-sync block error rate (BLER_{in}). The BLER_{out} and/or BLER_{in} may be explicitly determined by gNB.

[0174] In case BLER_{out} and/or BLER_{in} are not explicitly determined by gNB, they may be estimated based on one or more parameters. For example, the WTRU may use, receive, or be configured with PDCCH transmission parameters for performing the out-of-sync and/or in-sync evaluations. In an example, the number of control OFDM symbols, aggregation level, ratio of hypothetical PDCCH RE energy to average SSS RE energy, ratio of hypothetical PDCCH DMRS energy to average SSS RE energy, BWP in number of PRBs, subcarrier spacing, and so forth may be used for determining the BLER_{out} and/or BLER_{in} thresholds.

[0175] There may be beam failure detection. A WTRU may monitor the beam failure detection RS sets in active BWPs. The WTRU may (e.g., further) estimate the beam and/or radio link quality. The WTRU may report the out-of-sync and/or in-sync status. In an example, a WTRU may measure the radio link quality (e.g., L1-RSRP) for SSB(s) and/or CSI-RS(s) in corresponding beam failure detection RS set. The WTRU may (e.g., then) compare the measurement with respective thresholds to determine, indicate, and/or detect if beam failure instance (BFI) has happened.

[0176] The WTRU may indicate, determine, and/or be configured with one or more beam failure detection (BFD) counters. The WTRU may detect the beam failure by counting BFI indications. The WTRU may indicate, determine, and/or be configured with one or more of BFI_Counter, BFI_Max_Count, BFD_Timer, and/or BFI_Counter. A BFI_Counter may be used for counting the number of BFIs, which for example may be set to 0 initially and/or incremented per BFI detection. A BFI_Max_Count may include a maximum value for the BFI_Counter that, for example may trigger the beam failure detection. A BFD_Timer may start with the first BFI detection. If the timer expires before the BFI_Counter reaches the BFI_Max_Count, the beam

failure detection procedure may be stopped. The parameters herein are a non-limiting example of the parameters that may be included and/or used in beam failure detection. One or more of these parameters may be included. Other parameters may be included.

[0177] In an example, if BFI has happened, the WTRU starts or restarts BFD_Timer and adds BFI_Counter by 1. If BFI_Counter reaches the BFI_Max_Count, the WTRU may trigger a BFD event and/or may initiate a beam failure recovery (BFR) procedure.

[0178] There may be beam failure recovery. A WTRU may determine, indicate, and/or trigger a beam failure recovery, for example based on the beam failure detection event. The WTRU may indicate, determine, and/or be configured with one or more of BFR_Timer, RSRP_Threshold, candidateBeamRSList, power ramping, and/or random access. A BFR_Timer may start with beam a failure recovery procedure. An RSRP_Threshold may be for RSRP used in beam failure recovery. A candidateBeamRSList may include a list of candidate beam reference signal indexes to be monitored, measured, and/or selected during the beam failure recovery. Power ramping may include parameters including one or more of a power ramping step, a received preamble target power, and/or so forth. Random access may include PRACH parameters including one or more of a preamble index, SSB per RACH occasion, random access response window, PRACH configuration index, random access occasions and SSBs association mask index, and/or so forth. The above parameters are a non-limiting example of the parameters that may be included in beam failure detection. One or more of those parameters may be included. Other parameters may be included.

[0179] A WTRU may use, receive, and/or be configured with one or more sets of reference signals per BWP for monitoring, measuring, and/or selecting as the resources for the beam failure recovery. For example, the term q1 may be used for the beam failure recovery set. The beam failure recovery sets may include one or more reference signals. The reference signals may include one or more of CSI-RS resource configuration indexes, SS/PBCH block (SSB) indexes, and/or so forth. In an example, the reference signals included in beam failure recovery RS sets may be based on candidateBeamRSList (e.g., configured as part of a BFR procedure)a.

[0180] A WTRU may initiate a beam failure recovery based on random-access procedure. In an example, the WTRU may configure the random-access parameters, start the BFR_Timer, and/or apply the power ramping parameters. The WTRU may monitor and/or measure one or more of the reference signals from the candidateBeamRSList. The WTRU may determine if at least one of the SSBs has SS-RSRP above respective RSRP_Threshold amongst the SSBs in candidateBeamRSList. The WTRU may additionally, or alternatively, determine if at least one of the CSI-RSs has CSI-RSRP above respective RSRP_Threshold

amongst the CSI-RSs in candidateBeamRSList. The WTRU may (e.g., then) select the respective reference signal as the new candidate beam (NCB) and/or random-access resource for BFR procedure. For example, the term q_new may be used to present the new selected beam and/or random-access resource. The WTRU may perform PRACH transmission in respective random-access resources. Additionally, or alternatively, the WTRU may perform PRACH transmission according to spatial relation(s) with the periodic CSI-RS resource configuration and/or with an associated SS/PBCH block and/or QCL-ed with index q_new .

[0181] The PRACH preamble transmission may be based on contention-free PRACH transmission that is subject to the WTRU being provided and/or configured with a preamble (e.g., index) for the PRACH transmission. The PRACH preamble transmission may be based on a contention-based PRACH transmission, for which for example, the WTRU may select a (e.g., random) PRACH preamble (e.g., index) from a set of available preambles (e.g., indexes) for the PRACH transmission.

[0182] A WTRU may determine, identify, and/or be configured with one or more CORESETs corresponding to the random-access procedure for the respective beam failure recovery. In an example, the WTRU may monitor PDCCH in a search space set, for example for detection of a DCI format with respective CRC scrambled with a Radio Network Identifier (e.g., C-RNTI or MCS-C-RNTI). The WTRU may determine the same antenna port quasi-collocation parameters as the ones associated with index q_new for monitoring the PDCCH in a search space set and/or receive the corresponding PDSCH. The WTRU may trigger a link failure detection and/or follow with link failure recovery (LFR) procedures, for example if BFR_Timer has expired and/or beam failure recovery procedure has not been accomplished successfully.

[0183] A WTRU may receive one or more configuration information, which may include on a first set of BFR configurations and a second set of BFR configurations. The WTRU may use the first set of BFR configurations for a first mode of operation and/or the second set of BFR configurations for a second mode of operation. For example, the first mode of operation may be for regular operation with MR and/or the second mode of operation may be to determine a beam for LP-WUS monitoring with LR.

[0184] In an example, the first set of BFR configuration information may include one or more first thresholds and/or maximum values for one or more parameters, timers, counters, and/or etc. For example, the first set of BFR configuration information may include a first hypothetical PDCCH BLER threshold, a first failure detection RSRP threshold, a first new beam selection RSRP threshold, a first BFI max count, and/or etc. In another example, the first set of BFR configuration information may include indications on one or more first beam resources. For example, the first beam resources may include a first set of BFD RS

beams, a first set of PDCCH monitoring beams, a first set of candidate beams (e.g., BFR candidate beams), a first set of PRACH resources for beam failure indication, and/or etc.

[0185] In an example, the second set of BFR configuration information may include one or more thresholds and/or maximum values for one or more parameters, timers, counters, and/or etc. For example, the second set of BFR configuration information may include a second hypothetical PDCCH BLER threshold, a second failure detection RSRP threshold, a second new beam selection RSRP threshold, a second BFI max count, and/or etc.

[0186] A WTRU may receive an indication from the gNB to determine one or more beam resources for LP-WUS monitoring. The WTRU may use the first beam resources indicated in the first set of BFR configuration to determine the (e.g., best) beams for LP-WUS monitoring. In an example, the WTRU may use one or more beam resources from the first set of BFD RS beam resources. In another example, the WTRU may use one or more beam resources from the first set of PDCCH monitoring beam resources.

[0187] The WTRU may measure one or more parameters, for example based on the first beam resources. The WTRU may measure RSRP based on one or more of the received RSs from the first set of BFD RS beam resources. The WTRU may measure the (e.g., hypothetical) PDCCH BLER for one or more beam resources, for example from the first set of PDCCH monitoring beam resources.

[0188] The WTRU may compare the measured parameters with the first set of thresholds and/or determine that the measured parameters for the first beam resources are within the acceptable range. In an example, the WTRU may determine that the measured RSRP based on one or more received RSs from the first set of BFD RS beam resources are larger than corresponding first failure detection RSRP threshold. In another example, the WTRU may determine that the measured hypothetical PDCCH BLER for one or more beam resources from the first set of PDCCH monitoring beam resources are lower than the corresponding first hypothetical PDCCH BLER threshold. The WTRU may determine that the first beam resources are suitable for UL/DL communications while using MR and that there is no beam failure detected.

[0189] The WTRU may compare one or more measured parameters, for example based on the first beams with one or more corresponding second thresholds to determine if the first beams are suitable for LP-WUS monitoring. In an example, the WTRU may determine that the measured RSRP based on one or more received RSs from the first set of BFD RS beam resources is larger than corresponding second failure detection RSRP threshold. The WTRU may determine that the respective beam resources are suitable for LP-WUS monitoring. In another example, the WTRU may determine that the measured RSRP based on one or more received RSs from the first set of BFD RS beam resources is smaller than

corresponding second failure detection RSRP threshold. The WTRU may determine that the respective beam resources are not suitable for LP-WUS monitoring.

[0190] In an example, the WTRU may determine that the measured hypothetical PDCCH BLER for one or more beam resources from the first set of PDCCH monitoring beam resources are lower than the corresponding second hypothetical PDCCH BLER threshold. The WTRU may determine that the respective beam resources are suitable for LP-WUS monitoring. In another example, the WTRU may determine that the measured hypothetical PDCCH BLER for one or more beam resources from the first set of PDCCH monitoring beam resources are higher than the corresponding second hypothetical PDCCH BLER threshold. As such, the WTRU may determine that the respective beam resources are not suitable for LP-WUS monitoring.

[0191] A WTRU may determine that one or more of the first beam resources are suitable for LP-WUS monitoring with LR. The WTRU may send an indication (e.g., to a gNB) to indicate at least one of the determined beam resources. In an example, the WTRU may send the indication via PUCCH, PUSCH, UCI, MAC-CE, as part of a CSI report, and/or by transmitting using one or more (pre)configured (e.g., second set of) PRACH resources.

[0192] A WTRU may determine that none of the first beam resources are suitable and none of them can be used for LP-WUS monitoring by using the LR. The WTRU may select one or more beams from the first set of candidate beams. The WTRU may measure one or more parameters, for example based on the selected beams. In an example, the WTRU may measure RSRP based on the received RS according to the selected beams. The WTRU may compare the measured parameters with one or more second thresholds. In an example, the WTRU may compare the measured RSRP with the second new beam selection RSRP threshold. If, for example, the measured parameters are within the acceptable range (e.g., measured RSRP higher than the second RSRP threshold), the WTRU may report the selected beam resources (e.g., to a gNB). In an example, the WTRU may send the indication via PUCCH, PUSCH, UCI, MAC-CE, as part of a CSI report, and/or by transmitting using one or more (pre)configured (e.g., third set of) PRACH resources.

[0193] The WTRU may determine that neither the first beam resources nor the first candidate beam resources are suitable and none of them can be used for LP-WUS monitoring by using the LR. In an example, the WTRU may determine that none of the first beam resources from the first set of BFD RS beam resources are suitable for LP-WUS monitoring by using the LR. In another example, the WTRU may determine that none of the first beam resources from the first set of PDCCH monitoring beam resources are

suitable for LP-WUS monitoring by using the LR. In another example, the WTRU may determine that none of the first candidate beam resources are suitable for LP-WUS monitoring by using the LR. As such, the WTRU may send an indication (e.g., to a gNB) indicating that no suitable beam resources were found for LP-WUS monitoring. The WTRU may send the indication via PUCCH, PUSCH, UCI, MAC-CE, as part of a CSI report, and/or by transmitting using one or more (pre)configured PRACH resources.

[0194] A beam in a first beam resource set for LR may be associated with a beam in a beam resource set for MR. For example, a beam in the first beam resource set may be QCL-ed with a beam in a beam resource set for MR. The beam resource set for MR may be used for beam failure detection for MR and/or a new candidate beam detection for MR. A beam in a beam resource set for MR may be used as a source beam for a beam in a first (or a second) beam resource set for LR.

[0195] There may be LP-WUS monitoring using the determined beams. A WTRU may receive a configuration of one or more of a first set of RS resources, a second RS resource set, a first set of TCI states, a second set of TCI states, and/or a CSI report. A first set of RS resources may include for example, RSs associated with one or more candidate beams for BFR. A first set of TCI-states may include, for example, TCI-state(s) associated with one or more RS resources of the second RS resource set. A second set of TCI-states may include, for example, TCI-state(s) associated with one or more signals/channels (E.g., PDCCH, e.g., PDSCH). A CSI-Report may include a configuration of resources for CSI-reporting (e.g., periodic/aperiodic)

[0196] The WTRU may measure one or more RSs associated with the first RS resource set, for example based on the received configuration. The WTRU may measure one or more RSs associated with the second RS resource set, for example based on the received configuration. Additionally, or alternatively, the WTRU may measure one or more RSs associated with the second RS resource set using one or more TCI-states from the first set of TCI-states. The WTRU may determine one or more RS quality/beam-quality measurements, for example based on the measurement(s) of RSs. The one or more RS quality/beam-quality measurements may include one or more of an L1-RSRPs/CQI/SINR/RSSI/LOS probability of the RSs associated with the first RS resource set and/or an L1-RSRPs/CQI/SINR/RSSI/LOS probability of the RSs associated with the second RS resource set.

[0197] The WTRU may send an indication of one or more RSs (e.g., via configured CSI-Report), for example based on the determined RS/beam-quality values. The WTRU may indicate CRI/Beam ID of one or more RSs with the highest quality (e.g., highest L1-RSRP/LOS probability) out of the measured RSs (e.g., all measured RSs). The WTRU may indicate CRI/Beam ID of one or more RSs the highest quality out

of the measured RSs (e.g., all measured RSs) associated with the first RS resource set and/or one or more RSs with the highest quality out of the measured RSs (e.g., all measured RSs) associated with the second RS resource set.

[0198] The WTRU may report one or more of the associated RS measurements (e.g., L1-RSRP). The WTRU (e.g., while the WTRU is in CONNECTED state, e.g., when WTRU's main radio (MR) is in ON state) may receive a configuration/indication of a connection state change (e.g., CONNECTED to RRC INACTIVE) and/or of one or more RSs/beams, for example based on the WTRU report. The WTRU may receive 1-bit confirmation from the gNB for the WTRU indicated RSs/beams. The WTRU may receive a bitmap-based indication from the gNB indicating a subset of WTRU indicated RSs/beams. The WTRU may receive a configuration of a third set of RS resources. The WTRU may receive a RRC release message from the gNB (e.g., to indicate activation of RRC INACTIVE/RRC IDLE state). Alternatively, or additionally, the WTRU may receive a configuration/indication of RSs/beams (e.g., 1-bit indication/bitmap-based indication).

[0199] The WTRU may attempt to (e.g., determine to) detect/search for/monitor LP-WUS using one or more Rx beams/Rx spatial filters associated with RSs (or Tx beams), for example indicated by the gNB. The WTRU may perform beam sweep of Rx beams associated with the gNB-indicated RSs, for example to monitor LP-WUS and/or LP-SS.

[0200] The WTRU may monitor/attempt to detect LP-WUS and/or LP-SS in the RRC CONNECTED state. The WTRU may determine a monitoring resource for one or more DL signals (e.g., PDCCH/PDSCH), for example based on the reception/detection of LP-WUS and/or LP-SS. For example, the WTRU may determine a PDCCH monitoring resource (e.g., PDCCH search space, PDCCH monitoring occasion) using a TCI-state from the second set of TCI-states (e.g., using the TCI-state associated with the Rx beam/Rx spatial filter used to receive/detect the LP-WUS/LP-SS).

[0201] The WTRU may monitor/attempt to detect LP-WUS and/or LP-SS in the RRC IDLE or RRC INACTIVE state. The WTRU may monitor/search for and/or detect/receive one or more paging signals (e.g., paging PDCCH, paging DCI, PEI), for example based on the reception/detection of LP-WUS and/or LP-SS. For example, the WTRU may monitor and/or receive a paging signal using a TCI-state from the second set of TCI-states (e.g., using the TCI-state associated with the Rx beam/Rx spatial filter used to receive/detect the LP-WUS/LP-SS).

CLAIMS:

1. A wireless transmit / receive unit (WTRU) comprising:
a processor and memory, wherein the processor and memory are configured to:
receive configuration information from a network that activates the WTRU to perform low power (LP) signal monitoring using a low power radio of the WTRU, wherein the configuration information indicates a threshold associated with a condition, and wherein the condition is associated with LP signal monitoring;
receive an indication to determine a suitability of the WTRU for LP signal monitoring;
determine the suitability of the WTRU for LP signal monitoring based on the threshold associated with the condition; and
send a report that indicates the determined suitability of the WTRU for LP signal monitoring.
2. The WTRU of claim 1, wherein the processor and memory are configured to receive the configuration information via a main radio of the WTRU, receive the indication via the main radio of the WTRU, and send the report via the main radio of the WTRU; and
wherein the processor and memory are configured to:
monitor for low power signals via the low power radio of the WTRU in response to receiving the configuration information from the network that activates the WTRU to perform LP signal monitoring.
3. The WTRU of claim 1, wherein the condition comprises any one or more of: beam quality of a beam associated with a main radio of the WTRU, beam quality of a beam associated with a low power radio of the WTRU, an activity of the WTRU, a mobility of the WTRU, a location of the WTRU, a coverage area of the low power radio of the WTRU, or a coverage gap between the low power radio of the WTRU and the main radio of the WTRU.
4. The WTRU of claim 1, wherein the indication comprises a radio resource control (RRC) state for the WTRU to determine the suitability of the WTRU for LP signal monitoring.
5. The WTRU of claim 1, wherein the configuration information indicates a plurality of thresholds and a plurality of conditions, wherein each threshold of the plurality of thresholds is associated with a radio

resource control (RRC) state or a periodicity of a low power signal, and wherein the report indicates, for each RRC state or periodicity of the low power signal, the suitability of the WTRU for LP signal monitoring.

6. The WTRU of claim 1, wherein the processor and memory are configured to:
 - receive a second indication to perform LP signal monitoring in a first radio resource control (RRC) state or with a first low power signal periodicity; and
 - monitor an LP signal using a low power radio of the WTRU in accordance with the second indication.
7. The WTRU of claim 1, wherein the processor and memory are configured to:
 - determine that LP signal monitoring is not suitable when a mobility parameter is greater than a mobility threshold, an activity parameter is greater than an activity threshold, or a beam quality measure is less than a beam quality threshold.
8. The WTRU of claim 1, wherein the processor and memory are configured to:
 - determine that LP signal monitoring is suitable when a mobility parameter is less than a mobility threshold, an activity parameter is less than an activity threshold, or a beam quality measure is greater than a beam quality threshold.
9. The WTRU of claim 1, wherein the report indicates the condition that is used to determine the suitability of the WTRU for LP signal monitoring.
10. A method performed by a wireless transmit / receive unit (WTRU), the method comprising:
 - receiving configuration information from a network that activates the WTRU to perform low power (LP) signal monitoring using a low power radio of the WTRU, wherein the configuration information indicates a threshold associated with a condition, and wherein the condition is associated with LP signal monitoring;
 - receiving an indication to determine a suitability of the WTRU for LP signal monitoring;
 - determining the suitability of the WTRU for LP signal monitoring based on the threshold associated with the condition; and
 - sending a report that indicates the determined suitability of the WTRU for LP signal monitoring.

11. The method of claim 10, further comprising:
receiving the configuration information via a main radio of the WTRU, receiving the indication via the main radio of the WTRU, and sending the report via the main radio of the WTRU; and
further comprising:
monitoring for low power signals via the low power radio of the WTRU in response to receiving the configuration information from the network that activates the WTRU to perform LP signal monitoring.
12. The method of claim 11, wherein the condition comprises any one or more of: beam quality of a beam associated with a main radio of the WTRU, beam quality of a beam associated with a low power radio of the WTRU, an activity of the WTRU, a mobility of the WTRU, a location of the WTRU, a coverage area of the low power radio of the WTRU, or a coverage gap between the low power radio of the WTRU and the main radio of the WTRU.
13. The method of claim 11, wherein the indication comprises a radio resource control (RRC) state for the WTRU to determine the suitability of the WTRU for LP signal monitoring.
14. The method of claim 11, wherein the configuration information indicates a plurality of thresholds and a plurality of conditions, wherein each threshold of the plurality of thresholds is associated with a radio resource control (RRC) state or a periodicity of a low power signal, and wherein the report indicates, for each RRC state or periodicity of the low power signal, the suitability of the WTRU for LP signal monitoring.
15. The method of claim 11, further comprising:
receiving a second indication to perform LP signal monitoring in a first radio resource control (RRC) state or with a first low power signal periodicity; and
monitoring an LP signal using a low power radio of the WTRU in accordance with the second indication.
16. The method of claim 11, further comprising:

determining that LP signal monitoring is not suitable when a mobility parameter is greater than a mobility threshold, an activity parameter is greater than an activity threshold, or a beam quality measure is less than a beam quality threshold.

17. The method of claim 11, further comprising:

determining that LP signal monitoring is suitable when a mobility parameter is less than a mobility threshold, an activity parameter is less than an activity threshold, or a beam quality measure is greater than a beam quality threshold.

18. The method of claim 11, wherein the report indicates the condition that is used to determine the suitability of the WTRU for LP signal monitoring.

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

a processor and memory, wherein the processor and memory are configured to:

receive configuration information from a network that activates the WTRU to perform low power (LP) signal monitoring using a low power radio of the WTRU, wherein the configuration information indicates a threshold associated with a condition, and wherein the condition is associated with LP signal monitoring;

determine a suitability of the WTRU for LP signal monitoring based on a state of the WTRU and the threshold associated with the condition; and

send a report that indicates the determined suitability of the WTRU for LP signal monitoring.

20. The WTRU of claim 19, wherein the state of the WTRU is a connected mode, an idle mode, or an inactive mode.