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- (54) Title: HARQ CODEBOOK ENHANCEMENTS

ACK-overhead-
reduction-codebook:

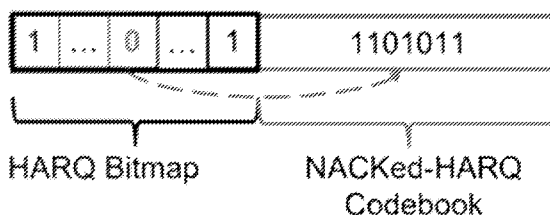


FIG. 2

(57) Abstract: Disclosed herein are systems, methods, and instrumentalities associated with HARQ overhead reduction. A WTRU may receive a transport block from a network device and determine a first HARQ feedback bit associated with the transport block (TB), wherein the first HARQ feedback bit may indicate an ACK or NACK. On a condition that the first HARQ feedback bit indicates the NACK, the WTRU may determine a second HARQ feedback bit for a code block group (CBG) associated with the TB. The WTRU may construct a HARQ codebook, wherein the HARQ codebook may include the first HARQ feedback bit in a first part of the HARQ codebook and wherein, on the condition that the first HARQ feedback bit indicates the NACK, the HARQ codebook may further include the second HARQ feedback bit in a second part of the HARQ codebook. The WTRU may then transmit the HARQ codebook to the network device.



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HARQ CODEBOOK ENHANCEMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/445,561, filed February 14, 2023, the contents of which is incorporated by reference herein.

BACKGROUND

[0002] Artificial Intelligence (AI)/Machine Learning (ML) models may be trained for improving the performance of a wireless communication system. A wireless transmit/receive unit (WTRU) may use these pre-trained AI/ML models for aspects of beam management such as beam prediction, beam selection, etc. The WTRU may also perform conventional measurements on channel conditions, beam and/or environment changes, link-adaptation parameters, etc. Therefore, it may be desirable to utilize the predictions and/or measurements made by the WTRU to further improve the performance of the wireless communication system, for example, with respect to hybrid automatic repeat request (HARQ) feedback.

SUMMARY

[0003] Disclosed herein are systems, methods, and instrumentalities associated with hybrid automatic repeat request (HARQ) feedback overhead reduction. According to embodiments of the present disclosure, a wireless transmit/receive unit (WTRU) may receive a transport block from a network device and determine a first hybrid automatic repeat request (HARQ) feedback bit associated with the transport block, wherein the first HARQ feedback bit may indicate a positive acknowledge (ACK) associated with the transport block (TB) or a negative acknowledgment (NACK) associated with the TB. On a condition that the first HARQ feedback bit indicates the NACK associated with the transport block, the WTRU may determine a second HARQ feedback bit for a code block group (CBG) associated with the transport block. The WTRU may construct a HARQ codebook, wherein the HARQ codebook may include the first HARQ feedback bit in a first part of the HARQ codebook and wherein, on the condition that the first HARQ feedback bit indicates the NACK associated with the TB, the HARQ codebook may further include the second HARQ feedback bit for the CBG in a second part of the HARQ codebook. The WTRU may then transmit the HARQ codebook to the network device.

[0004] In examples, the first part of the HARQ codebook may include a bitmap that comprises respective HARQ feedback bits associated with multiple TBs and wherein the first HARQ feedback bit may be included as a part of the bitmap. The bitmap may be ordered based on respective reception times of the multiple TBs or respective HARQ process identifiers associated with the multiple TBs. In examples, the

second part of the HARQ codebook may further include respective HARQ feedback bits for one or more CBGs associated with an NACKed transport block. In examples, the WTRU may be configured with multiple serving cells and the HARQ codebook may be constructed for the multiple serving cells.

[0005] In examples, the WTRU being configured to transmit the HARQ codebook to the network device may comprise the WTRU being configured to transmit the first part of the HARQ codebook to the network device via a first uplink transmission and transmit the second part of the HARQ codebook to the network device via a second uplink transmission. For example, the WTRU may receive a first plurality of uplink transmission resources from the network device in a first grant, and transmit the first part of the HARQ codebook to the network device using the first plurality of uplink transmission resources. The WTRU may also receive a second plurality of uplink transmission resources from the network device in a second grant, and transmit the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources.

[0006] In examples, the WTRU being configured to transmit the HARQ codebook to the network device may comprise the WTRU being configured to receive a first plurality of uplink transmission resources from the network device via a first grant, and transmit the first part of the HARQ codebook and a first portion of the second part of the HARQ codebook to the network device using the first plurality of uplink transmission resources. The WTRU may also receive a second plurality of uplink transmission resources from the network device via a second grant, and transmit a second portion of the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources. In this example, the WTRU may transmit an indication of the size of the second part of the HARQ codebook to the network device, and receive the first plurality of uplink transmission resources and the second plurality of uplink transmission resources after transmitting the indication.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1A is a system diagram illustrating an example communications system in which one or more disclosed embodiments may be implemented.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] FIG. 2 is a diagram illustrating example contents of a HARQ codebook as described herein.

DETAILED DESCRIPTION

[0012] 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.

[0013] 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 (WTRU), 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.

[0014] 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 (eNB), a

Home Node B, a Home eNode B, a gNode B (base station), 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.

[0015] 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.

[0016] 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).

[0017] 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).

[0018] 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).

[0019] 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).

[0020] 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., an eNB and a gNB).

[0021] 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.

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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.

[0029] 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.

[0030] 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.

[0031] 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).

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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 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)).

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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 is 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] In representative embodiments, the other network 112 may be a WLAN.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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).

[0050] 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).

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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).

[0055] 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).

[0056] 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.

[0057] 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.

[0058] 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.

[0059] 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.

[0060] 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.

[0061] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The UPF 184a, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0062] 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.

[0063] 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-b, UPF 184a-b, SMF 183a-b, DN 185a-b, and/or any other device(s) described herein, may be performed by one or more emulation devices (not shown). The emulation devices may be one or more devices configured to emulate one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0064] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all,

functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network. The emulation device may be directly coupled to another device for purposes of testing and/or may perform testing using over-the-air wireless communications.

[0065] 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.

[0066] Artificial intelligence (AI)/machine-learning (ML) may be used to improve an air interface such as beam management related functionalities associated with the air interface. The AI/ML technology may lay a foundation for improving the performance and/or reducing the complexity of multiple aspects of beam management, including beam prediction (e.g., in time and/or spatial domains for overhead and latency reduction), beam selection (e.g., to improve the accuracy of beam selection), and so forth.

[0067] Hybrid automatic repeat request (HARQ) feedback may include the transmission of an acknowledgment (ACK) or a non-acknowledgment (NACK) as a result of a WTRU verifying a correct or faulty reception of DL data, respectively. While the transmission of an NACK may trigger a retransmission of the data that was received with faulty content, the transmission of an ACK may impose overhead and/or latency to the overall communication system. This impact may be severe with a scheduler targeting a 10% block error rate (BLER) in eMBB systems or a much lower BLER (e.g., 10^{-5}) in URLLC systems. The lower BLER may result in a higher rate of ACK (e.g., 90% in eMBB and $1-10^{-5}$ in URLLC) that may become a bottleneck for overhead and latency reduction.

[0068] AI/ML models and/or channel measurements (e.g., performed based on long-term observations) may predict channel conditions, beam and/or environment changes, link-adaptation parameters, and so forth for a WTRU on a serving cell and/or with a selected beam. For example, the AI/ML models may predict if there is going to be a change in the conditions at or surrounding the WTRU that may result in more NACKs (e.g., faulty receptions due to degraded channel conditions) or more ACKs (e.g., less faulty receptions due to stable/fixed channel conditions).

[0069] The use of AI/ML models and/or measurements performed by a WTRU may lead to different WTRU behaviors, e.g., with respect to the calculation and/or transmission of ACK/NACK information bits and/or the generation of codebooks. The WTRU may determine the conditions, measurements, and/or reporting occasions for lowering ACK/NACK transmission overhead based on AI/ML models (e.g., including

the training, validation, activation, and/or deactivation of the AI/ML models) and/or measurements (e.g., such as channel state information (CSI) measurements). HARQ-ACK/NACK codebook generation and/or beam management (e.g., based on predictions made by AI/ML models or measurements performed by a WTRU) may be implemented.

[0070] When referred to herein, artificial intelligence (AI) may include behaviors learned and/or exhibited by machines (e.g., computing devices). Such behaviors may include, e.g., cognitive functions associated with sensing, reasoning, adapting and/or acting. When referred to herein, machine learning (ML) may include determining ways (e.g., algorithms) for solving a problem based on learning through experience (e.g., data). Machine learning may be considered a subset of AI. Different machine learning paradigms may be employed based on the nature of the data involved or feedback available to the learning. For example, a supervised learning approach may involve learning a function that maps an input to an output based on a labeled training dataset, wherein the training dataset may include paired data comprising an input and a corresponding output. An unsupervised learning approach may involve detecting patterns in the training data with no pre-existing labels. As an example of unsupervised learning, reinforcement learning may involve performing a sequence of actions in an environment to maximize a cumulative reward. In some examples, it may be possible to perform machine learning based on a combination of the above-mentioned approaches (e.g., based on supervised and unsupervised learning). For example, a semi-supervised learning approach may use a combination of labeled data and unlabeled data during the learning (e.g., during the training of an ML model). Such a semi-supervised learning approach may fall between unsupervised learning (e.g., without labeled training data) and supervised learning (e.g., with labeled training data).

[0071] When referred to herein, deep learning (DL) may include a class of machine learning techniques that may employ an artificial neural network (ANN) including a deep neural network (DNN). Such a DNN may receive an input that may be transformed (e.g., linearly transformed) and the DNN may pass the input through an activation function (e.g., a non-linear activation function) one or multiple times. The DNN may include multiple layers, wherein a (e.g., each) layer may include a transformation function (e.g., linear transformation function) and/or an activation function (e.g., a non-linear activation function). The DNN may be trained based on training data and/or back-propagation.

[0072] When referred to herein, AI/ML (or AIML) may include one or more of the learning or neural network training techniques described above.

[0073] A WTRU may transmit or receive a channel (e.g., a physical channel) or a reference signal according to at least one spatial domain filter. The term “beam” may be used interchangeably with the term “spatial domain filter.” The WTRU may transmit a physical channel or signal using the same spatial domain

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

[0074] The WTRU may perform a first transmission (e.g., a first physical channel or reference signal transmission) according to the same spatial domain filter as the spatial domain filter used for performing a second transmission. The first and second transmissions may be referred to as a “target” and a “reference” (or “source”) transmission, respectively. As such, the WTRU may be said to transmit the first (target) transmission according to a spatial relation with a reference to the second (reference) transmission.

[0075] A spatial relation may be configured (e.g., implicitly configured) via RRC signaling or via a MAC CE or DCI. For example, a WTRU may implicitly transmit a PUSCH and/or a DM-RS associated with the PUSCH according to the same spatial domain filter as a sounding reference signal (SRS) indicated by an SRS resource indicator (SRI) (e.g., received in DCI or configured via RRC signaling). As another example, a spatial relation may be configured via RRC signaling for an SRI or signaled by a MAC CE for a PUCCH. Such a spatial relation may be referred to as a beam indication.

[0076] The WTRU may receive a first (target) downlink channel or reference signal transmission according to the same spatial domain filter or spatial reception parameter(s) as a second (reference) downlink channel or reference signal transmission. An association may exist between a physical channel such as a PDCCH or PDSCH, and a DM-RS associated with the physical channel. In examples (e.g., when the first and second transmissions are both reference signals), such an association may exist when the WTRU is configured with a quasi-colocation (QCL) assumption type D between corresponding antenna ports. Such an association may be configured as a transmission configuration indicator (TCI) state. The WTRU may be indicated an association between a CSI-RS (or an SS block) and a DM-RS by an index to a set of TCI states configured via RRC signaling and/or signaled via a MAC CE. Such an indication may be referred to as a beam indication.

[0077] The term “TRP” (transmission and reception point) may be interchangeably used herein with the term “TP” (transmission point), “RP” (reception point), “RRH” (radio remote head), “DA” (distributed antenna), “BS” (base station), “sector,” and/or “cell” (e.g., a geographical cell area served by a BS). The term “multi-TRP” may be interchangeably used herein with the term “MTRP,” “M-TRP,” and/or “multiple TRPs.”

[0078] A WTRU may report channel state information (CSI), which may include one or more of a CSI-RS resource indicator (CRI), a SSB resource indicator (SSBRI), an indication of a panel used for reception at

the WTRU (such as a panel identity or group identity), measurements such as L1-RSRP and/or L1-SINR taken from an SSB or CSI-RS (e.g., cri-RSRP, cri-SINR, ssb-Index-RSRP, ssb-Index-SINR, etc.), a rank indicator (RI), a channel quality indicator (CQI), a precoding matrix indicator (PMI), a Layer Index (LI), and/or the like.

[0079] A WTRU may receive a synchronization signal/physical broadcast channel (SS/PBCH) block. The SS/PBCH block (SSB) may include a primary synchronization signal (PSS), a secondary synchronization signal (SSS), and/or a physical broadcast channel (PBCH) signal. The WTRU may monitor, receive, and/or attempt to decode an SSB during initial access, initial synchronization, radio link monitoring (RLM), cell search, cell switching, and so forth.

[0080] A WTRU may measure and report channel state information (CSI). A WTRU may receive CSI related configuration information (e.g., for a connection mode), which may include CSI report configuration information, CSI-RS resource set information, and/or NZP CSI-RS resource information. The CSI report configuration information may include one or more of a CSI report quantity (e.g., a Channel Quality Indicator (CQI), a Rank Indicator (RI), a Precoding Matrix Indicator (PMI), a CSI-RS Resource Indicator (CRI), a Layer Indicator (LI), etc.), a CSI report type (e.g., aperiodic, semi-persistent, or periodic), a CSI report codebook configuration (e.g., Type I, Type II, Type II port selection, etc.), or a CSI report frequency. A CSI-RS resource set may include one or more CSI resource settings such as NZP-CSI-RS resources for channel measurement, NZP-CSI-RS resources for interference measurement, CSI-IM resources for interference measurement, etc. NZP CSI-RS resources may include one or more of an NZP CSI-RS resource ID, a periodicity, an offset, QCL information, a TCI-state, or a resource mapping (e.g., number of ports, density, CDM type, etc.).

[0081] A WTRU may indicate, determine, or be configured with one or more reference signals. The WTRU may monitor, receive, and measure one or more parameters based on respective reference signals. For example, one or more of the following may apply and the parameters listed herein may be non-limiting examples of the parameters that may be included in reference signal measurements. Further, one or more (e.g., not all) of the parameters listed herein may be included in reference signal measurements, while other parameters may also be included in reference signal measurements.

[0082] An SS reference signal received power (SS-RSRP) may be measured based on one or more synchronization signals (e.g., demodulation reference signal (DM-RS) transmitted in a PBCH or SSS). Such a power may be determined as a linear average of the power contributions of multiple resource elements (REs) that may carry respective synchronization signals. In measuring the RSRP, power scaling for the reference signals may be applied. If an SS-RSRP is used for L1-RSRP, the measurement may be accomplished based on CSI reference signals in addition to the synchronization signals.

[0083] A CSI-RSRP may be determined based on a linear average of the power contributions of multiple resource elements (RE) that may carry respective CSI-RSs. The CSI-RSRP determination or measurement may be configured within measurement resources for one or more configured CSI-RS occasions.

[0084] An SS signal-to-noise ratio (SS-SINR) and/or an interference ratio (SS-SINR) may be measured based on one or more synchronization signals (e.g., a DM-RS in PBCH or SSS). One or both of these ratios may be determined as a linear average of the power contributions of multiple resource elements (REs) that may carry respective synchronization signals, divided by a linear average of the noise and interference power contributions by those REs. If an SS-SINR is used for L1-SINR, the noise and interference power measurement may be accomplished based on resources configured by higher layers.

[0085] A CSI-SINR may be measured based on a linear average of the power contributions of multiple resource elements (REs) that may carry respective CSI-RSs, divided by a linear average of the noise and interference power contributions of those REs. If a CSI-SINR is used for L1-SINR, the noise and interference power measurement may be accomplished based on resources configured by higher layers. Otherwise, the noise and interference power may be measured based on resources that may carry the respective CSI-RSs.

[0086] A received signal strength indicator (RSSI) may be measured based on an average of the total power contributions in configured OFDM symbols and/or bandwidth. The power contribution may be received from different resources (e.g., co-channel serving and non-serving cells, adjacent channel interference, thermal noise, and so forth).

[0087] A cross-layer interference received signal strength indicator (CLI-RSSI) may be measured based on an average of the total power contributions in configured OFDM symbols (e.g., of a configured time) and/or frequency resources. The power contribution may be received from different resources (e.g., cross-layer interference, co-channel serving and non-serving cells, adjacent channel interference, thermal noise, and so forth).

[0088] A sounding reference signal RSRP (SRS-RSRP) may be measured based on a linear average of the power contributions of resource elements (REs) that may carry respective SRSes.

[0089] A CSI report configuration (e.g., a CSI-ReportConfig information element) may be associated with a bandwidth part (BWP) (e.g., indicated by a BWP-Id). One or more of the following parameters may be configured: CSI-RS resources and/or CSI-RS resource sets for channel and interference measurement, a CSI-RS report type (e.g., periodic, semi-persistent, and aperiodic), a CSI-RS transmission periodicity for periodic and semi-persistent CSI reports, a CSI-RS transmission slot offset for periodic, semi-persistent and aperiodic CSI reports, a CSI-RS transmission slot offset list for semi-persistent and aperiodic CSI

reports, time restrictions for channel and interference measurements, report frequency band configuration information (e.g., wideband/subband CQI, PMI, and so forth), thresholds and modes of calculations for one or more reporting quantities (e.g., CQI, RSRP, SINR, LI, RI, etc.), codebook configuration information, group based beam reporting configuration information, a CQI table, a subband size, a non-PMI port indication, a port index; etc.

[0090] A CSI-RS resource set (e.g., configured via an NZP-CSI-RS-ResourceSet information element) may include one or more CSI-RS resources (e.g., configured via NZP-CSI-RS-Resource and/or CSI-ResourceConfig). A WTRU may be configured with one or more of the following regarding CSI-RS resources: a CSI-RS periodicity and slot offset for periodic and semi-persistent CSI-RS resources, a CSI-RS resource mapping that may define the number of CSI-RS ports, density, CDM-types, OFDM symbols, and/or subcarrier occupancy, the bandwidth part to which a configured CSI-RS is allocated, a reference to a TCI-State including QCL source RS(s) and/or the corresponding QCL type(s).

[0091] One or more of following may be associated with an RS resource set: an RS resource set ID, one or more RS resources for the RS resource set, a repetition indication (e.g., on or off), an aperiodic triggering offset (e.g., one of 0-6 slots), TRS information (e.g., true or false), etc.

[0092] One or more of following may be associated with an RS resource: an RS resource ID, a resource mapping (e.g., REs in a PRB), a power control offset (e.g., a value of -8, ..., 15), a power control offset with SS (e.g., -3 dB, 0 dB, 3 dB, 6 dB, etc.), a scrambling ID, a periodicity and offset, QCL information (e.g., based on a TCI state), etc.

[0093] A grant or assignment (e.g., transmitted via DCI) may indicate one or more of the following: a frequency allocation, an aspect of time allocation (e.g., such as a duration), a priority, a modulation and coding scheme, a transport block size, a number of spatial layers, a number of transport blocks, a TCI state, a CRI, an SRI, a number of repetitions, whether a repetition scheme is Type A or Type B, whether the grant is a configured grant type 1, type 2 or a dynamic grant, whether the assignment is a dynamic assignment or a semi-persistent scheduling (configured) assignment, a configured grant index or a semi-persistent assignment index, a periodicity of a configured grant or assignment, a channel access priority class (CAPC), other parameter(s) provided via DCI, by a MAC CE or by RRC signaling for the scheduling grant or assignment, etc.

[0094] A DCI indication may indicate one or more of the following: an explicit indication provided via a DCI field or via an RNTI used to mask the CRC of a PDCCH transmission, or an implicit indication that may be implied by a property such as a DCI format, a DCI size, a coreset or search space, an aggregation level, a first resource element of the received DCI (e.g., an index of a first control channel element), where a mapping between the property and its value may be provided via RRC signaling or a MAC CE.

[0095] When referred to herein, an RS may include one or more of an RS resource, an RS resource set, an RS port, an RS port group, an SSB, a CSI-RS, an SRS, a DM-RS, a TRS, a position reference signal (PRS), or a phase tracking reference signal (PTRS). When referred to herein, a reference signal may include a sounding reference signal (SRS), a channel state information-reference signal (CSI-RS), a demodulation reference signal (DM-RS), a phase tracking reference signal (PTRS), or a synchronization signal block (SSB). When referred to herein, a channel may include a PDCCH, a PDSCH, a Physical uplink control channel (PUCCH), a physical uplink shared channel (PUSCH), a physical random access channel (PRACH), etc. The terms signal, channel, and message (e.g., as in DL or UL signal, channel, or message) may be used interchangeably herein. The term RS resource set may be interchangeably used herein with the term RS resource or beam group. The term beam reporting may be interchangeably used herein with the term CSI measurement, CSI reporting, or beam measurement. When described herein, a beam resource prediction technique may be applied to beam resources that may belong to a single cell or multiple cells, a single or multiple TRPs, etc. The term CSI reporting may be used interchangeably herein with the term CSI measurement, beam reporting, or beam measurement. The term RS resource set may be used interchangeably herein with the term beam group. When used herein, the term HAORAP (HARQ-ACK overhead reduction procedure) may refer to techniques, solutions and/or procedures associated with reducing the overhead associated with HARQ-ACK transmissions in some examples. The techniques described in the examples related to activating, deactivating, and/or applying a HAORP may also be used in other procedures, actions, services, functions, events, etc. The term "HARQ-ACK overhead reduction procedure" or "HAORP" may include procedures, actions, services, functions, events, and/or the like.

[0096] A WTRU may be configured with one or more resource allocations for uplink transmissions (e.g., data channels) in one or more transmission occasions. For example, for a control channel transmission (e.g., PUCCH), a resource allocation or configuration may include one or more settings or parameters, such as a starting PRB, a second hop starting PRB, a number of PRBs, a number of slots, a starting symbol index, a PUCCH format, a cyclic shift, an orthogonal cover code (OCC) configuration, and/or the like that may be indicated based on a PUCCH resource index or indicator (e.g., such as a *PUCCH-ResourceId*).

[0097] In examples, for a downlink (shared) channel transmission (e.g., PDSCH) configured by semi-static indications (e.g., SPS PDSCH configured by *SPS-Config*), the WTRU may determine or be configured with an associated PUCCH resource index or indicator that the WTRU may use to send corresponding control information (e.g., HARQ-ACK, CSI report, etc.). For instance, the time resources (e.g., slots) for the transmission of a HARQ-ACK in a respective PUCCH may be defined based on one or more RRC-configured parameters (e.g., a K1 defined via *dl-DataToUL-ACK* of *PUCCH-Config* in *BWP-*

UplinkDedicated), or activated via DCI (e.g., format 1_1 or 1_2 with a *PDSCH-to-HARQ_feedback* timing indicator field).

[0098] In examples, for an uplink shared channel transmission (e.g., PUSCH), a resource allocation or configuration may be indicated based on one or more settings or parameters, such as time resources (e.g., *timeDomainAllocation*), frequency resources (e.g., *frequencyDomainAllocation*), a periodicity, a repetition, etc. For example, for a PUSCH transmission corresponding to a first configured grant (e.g., Type 1) or for a PUSCH transmission corresponding to a second configured grant (e.g., Type 2) and activated by DCI, a resource allocation may be provided by one or more parameters (e.g., via *ConfiguredGrantConfig* in *BWP-UplinkDedicated* and/or an activating UL grant received via DCI).

[0099] For a PUSCH transmission corresponding to an UL grant (e.g., a dynamic grant), a time domain resource assignment (TDRA) (e.g., received in DCI) may indicate a slot offset (e.g., K2 via a indexed row), a start and length indicator (e.g., SLIV), a start symbol and/or allocation length, a PUSCH mapping type, the number of slots for a transport block size (TBS) determination, and/or the number of repetitions for the PUSCH transmission.

[0100] A WTRU may be configured with one or more PUCCH resource sets, including one or more PUCCH resources. In examples, PUCCH resource configure parameters may include a PUCCH resource index, an index for a first PRB, an index for a first PRB for frequency hopping, a PUCCH format, a starting symbol index, a number of symbols, a number of PRBs, and/or the like.

[0101] A WTRU may be configured with a PUCCH resource indicator (PRI) field (e.g., via DCI). In examples, the PRI may be indicated by one or more bits (e.g., up to three bits), where the PRI may map to a set of PUCCH resource indices corresponding to multiple (e.g., up to eight) PUCCH resources provided by a PUCCH resource set. The WTRU may use the PRI to determine the resource allocation to be used for a PUCCH transmission.

[0102] A WTRU may receive configuration information regarding the time and/or frequency resources for transmitting HARQ ACK/NACK feedback. The HARQ ACK/NACK timing for the reception of a downlink signal and/or channel may be configured, for example, by one or more higher layer parameters (e.g., K1). In examples, a K1 parameter may indicate an index in a table specified by an RRC parameter (e.g., *dl-DataToUL-ACK* in *PUCCH-Config*), as shown below in the non-limiting examples of parameters that may be included in PUCCH configuration information. One or more of the shown parameters may be included. The number of bits and/or choices for each parameter are merely examples and other numbers of bits and/or choices may be included.

PUCCH-Config ::= SEQUENCE {

...

resourceToAddModList SEQUENCE (SIZE (1..maxNrofPUCCH-Resources)) OF PUCCH-Resource

dl-DataToUL-ACK SEQUENCE (SIZE (1..8)) OF INTEGER (0..15) Optional

...

}

maxNrofPUCCH-Resources INTEGER ::= 128

[0103] A WTRU may receive one or more reference signals and/or channel transmissions (e.g. in the downlink). The WTRU may receive configuration information associated with generating one or more HARQ-ACK information bits and/or HARQ-ACK codebooks. In an example, the WTRU may report HARQ-ACK information for one or more PDSCH receptions, one or more PDCCH (e.g., DCI) receptions, one or more TCI state updates, a PDSCH transmission without a corresponding PDCCH, a PDCCH transmission indicating a SPS PDSCH release, and/or the like. The WTRU may report the HARQ-ACK information bits in a HARQ-ACK codebook (e.g., Type-1, Type-2, Type-3, etc.) that the WTRU may transmit in a slot indicated by a timing indicator (e.g., a PDSCH-to-HARQ feedback timing indicator field in a corresponding DCI format). In an example, the WTRU may determine if the resources for a HARQ-ACK report are mapped to a PUCCH or PUSCH.

[0104] The WTRU may determine $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O_{ACK}-1}^{ACK}$ HARQ-ACK information bits for a total number of O_{ACK} HARQ-ACK information bits. The WTRU may be configured with one or more HARQ-ACK codebook indices for multiplexing the corresponding HARQ-ACK information bits (e.g., per SPS PDSCH configuration).

[0105] The WTRU may determine the total number of transport blocks (TBs) or code block groups (CBGs) to be received based on one or more configurations and/or one or more DCI (e.g., comprising a grant) indications received by the WTRU. In an example, the WTRU may be indicated or configured to receive one or more PDSCH downlink transmissions. The WTRU may use a total downlink assignment index (DAI) field in a UL grant DCI to determine the total number of TBs or CBGs to be received.

[0106] One or more codebooks may be enhanced for HARQ overhead reduction. A WTRU may determine to enable, use, or activate a HAORP (e.g., based on AI/ML models and/or an indication from a base station) for a time duration (T_{HAORP}). The WTRU may determine to generate and/or use a codebook for HARQ feedback transmissions. The codebook may include TB-based HARQ feedback bits (e.g., in a first part of the codebook) followed by CBG-based HARQ feedback bits or partial CBG-based HARQ feedback bits (e.g., in a second part of the codebook). When referred to herein, "partial CBG-based HARQ feedback" may mean HARQ feedback for a subset of CBGs (e.g., not all CBGs) received by the WTRU

(e.g., the subset of CBGs for which a corresponding TB has been NACKed). To generate such a codebook, the WTRU may determine the PDSCH(s) and/or PDCCH(s) for which a HARQ-ACK/NACK transmission is to be included in the codebook. The determination may be made, for example, based on respective values of K1 and/or respective time limits associated with the PDSCH(s) and/or PDCCH(s). For instance, a K1 value may indicate the offset between the DL slot in which a DL transmission is scheduled and the UL slot in which HARQ ACK/NACK feedback for the DL transmission should be sent. As such, HARQ ACKs/NACKs scheduled in the same set of UL resources (e.g., as indicated by K1 values) may indicate to the WTRU that those HARQ ACKs/NACKs can be merged in a single codebook.

[0107] The codebook (e.g., comprising TB-based HARQ feedback bits followed by partial CBG-based HARQ feedback bits) may include two parts. The first part may be a compressed part or version (e.g., TB-based) comprising HARQ information bits associated with one or more PDCCH/PDSCH receptions (e.g., the first part of the codebook is compressed in the sense that TB-based HARQ feedback includes fewer bits than CBG-based HARQ feedback). In examples, the first part of the codebook may include a bitmap corresponding to one or more HARQ processes, wherein each bit of the bitmap may represent a TB-based HARQ information bit for a PDCCH/PDSCH received during a configured and/or determined time interval (T_{HAORP}) (e.g., each bit of the bitmap may be calculated based on a logical AND of multiple (e.g., all) HARQ-ACK bits associated with a HARQ process or a TB). The WTRU may generate HARQ information for (e.g., only for) transport block(s) associated with the PDSCH, for (e.g., only for) an SPS PDSCH release, or for (e.g., only for) a TCI state update. The order of bits in the aforementioned bitmap may be based on the reception times (e.g., according to semi-static configurations or DAI in dynamic configurations) of the PDCCH/PDSCH transmissions for which the HARQ feedback is provided, or based on the HARQ process indices associated with the PDCCH/PDSCH transmissions for which the HARQ feedback is provided (e.g., the bits of the bitmap may be arranged in an ascending order from MSB to LSB according to the HARQ process indices). Multiple PDSCH transmissions may be associated with the same HARQ process, so the order of the bitmap may be different depending on whether the order is based on reception times or HARQ process indices. For each bit of the bitmap, a value of 1 may indicate an ACK while a value of 0 may indicate a NACK.

[0108] The second part of the codebook described herein may include HARQ feedback bits and/or codebooks for (e.g., only for) HARQ processes that are NACKed in the first part of the codebook (e.g., in the bitmap described herein), as illustrated by FIG. 4. One or more of the following operations may be performed with respect to the second part of the codebook. For a HARQ process associated with a transport block (e.g., for PDCCH monitoring occasion m or for SPS PDSCH receptions on serving cell c), if the corresponding HARQ feedback bit in the first part of the codebook (e.g., the bitmap) indicates an ACK,

the WTRU may not multiplex HARQ-ACK information bits corresponding to the transport block in the second part of the codebook. Further, if the WTRU is provided with PDSCH-CodeBlockGroupTransmission, the WTRU may not multiplex HARQ-ACK information bits corresponding to CBGs of the ACKed transport block in the codebook. If the corresponding HARQ information bit in the first part of the codebook (e.g., the bitmap) indicates a NACK, the WTRU may generate HARQ feedback bits for the transport block in the second part of the codebooks (e.g., one HARQ feedback bit per CBG associated with the NACKed TB), and may do so on a per HARQ process basis (e.g., the HARQ generation for one HARQ process may be separate from another HARQ process). In examples, the WTRU may construct the codebook (e.g., comprising TB-based HARQ bits followed by partial CBG-based HARQ bits) by concatenating the determined HARQ-ACK bits and/or codebooks (e.g., in an ascending order of HARQ process IDs or reception times). The codebook may be constructed per serving cell, or for multiple (e.g., all) of the serving cells, configured for the WTRU.

[0109] The first part and the second part of the codebook (e.g., the first part comprises TB-based HARQ feedback, and the second part comprises partial CBG-based HARQ feedback) may be transmitted separately (e.g., in two parts) based on one or more of the following. A TB-based (e.g., which may be referred to herein as Type 2 or Type II) HARQ codebook and a partial CBG-based (e.g., which may be referred to herein as Type 3 or Type III) codebook may be combined. The WTRU may be configured with first PUCCH resources (e.g., via a grant DCI) to send HARQ feedback. The WTRU may send the first part of the codebook (e.g., the TB-based bitmap) using the configured first PUCCH resources. Subsequently, the WTRU may receive a request from a base station to perform a transmission (e.g., a one-shot transmission as described herein) of the second part of the codebook (e.g., partial CBG-based HARQ feedback). In examples, the request from the base station may indicate second PUCCH resources for performing the one-shot transmission. In examples, the request from the base station may indicate a corresponding bitmap (e.g., bitmap #1, #2, etc.). In examples, the request from the base station may include a request for HARQ codebook Type 3.

[0110] The WTRU may be configured with PUCCH resources (e.g., via a grant DCI) to send HARQ feedback. The PUCCH resources may include enough resources for transmitting the TB-based HARQ bitmap described herein (e.g., the first part of the codebook), followed by resources only enough for transmitting a subset (e.g., N CBG-based HARQ transmissions) of the information contained in the second part of the codebook. If the number of CBG-based HARQ transmissions in the second part of the codebook is lower than N, the WTRU may send the first and second parts of the code book using the indicated PUCCH resources. If the number of CBG-based HARQ transmissions in the second part of the codebook is higher than N, the WTRU may send the first part of the codebook and the first N CBG-based

HARQ transmissions of the second part of the codebook using the configured PUCCH resources (e.g., the remaining CBG-based HARQ transmissions of the second part of the codebook may not be sent with the configured PUCCH resources). Later, the WTRU may receive a request (e.g., a Type 3 HARQ codebook request) from the base station to send the remaining CBG-based HARQ transmissions. The base station may retransmit the data for the HARQ processes, PDSCHs, and/or PDCCHs NACKed in the first part of the codebook (e.g., in the bitmap) and for which CBG-based HARQs have not yet been transmitted. The value of N may be determined and/or reported by the WTRU (e.g., based on AI/ML prediction models). The value of N may also be determined and configured (e.g., for the WTRU) by the base station.

[0111] A WTRU may be configured (e.g., by a base station) to generate and/or transmit an enhanced codebook associated with HARQ feedback (referred to herein as a HARQ-ACK codebook). Such a HARQ-ACK codebook may be based on TB-based HARQ feedback, followed by CBG-based (e.g., partial CBG-based) HARQ feedback. The WTRU may be configured to generate and/or transmit the HARQ-ACK codebook to enable, use, or activate a HAORP, as described herein. In an example, the WTRU may receive an indication to include one or more ACK/NACK (e.g., information bits) in the HARQ-ACK codebook associated with one or more of the following entities, processes, parameters, and/or configurations. These entities, processes, parameters, and/or configurations are non-limiting examples of the entities, processes, parameters, and/or configurations that may be used for generating information bits for the HARQ-ACK codebook. One or more of these entities, processes, parameters, and/or configurations may be included. Other entities, processes, parameters, and/or configurations may also be included. The entities, processes, parameters, and/or configurations may include one or more HARQ processes, one or more component carriers (CC) associated with a PUCCH group, one or more SPS PDSCH receptions configured for one or more serving cells, in one or more active BWPs, over one or more DL slots for SPS PDSCH receptions (e.g., configured to be multiplexed in a corresponding PUCCH), one or more CBG-level ACKs/NACKs for a CC with CBG-level transmission configured, one or more configured (e.g., SPS) PDSCH receptions, SPS PDSCH releases, or TCI state updates, one or more group DCI formats (e.g., DCI with CRC scrambled by a G-RNTI or a G-CS-RNTI, high priority group DCI, etc.), the detection of one or more DCI formats (e.g., associated with TCI state updates) with or without a scheduling PDSCH reception, etc.

[0112] The WTRU may report, suggest, or indicate the use of the HARQ-ACK codebook (e.g., TB-based HARQ followed by CBG-based HARQ). The WTRU may determine, indicate, or report a time window (e.g., T_{HAORP}) for using the HARQ-ACK codebook. The WTRU may receive an indication (e.g., from the base station) to enable the use of the HARQ-ACK codebook and/or the time window for using the HARQ-ACK codebook. The WTRU may receive the indication via DCI, a MAC-CE, and/or RRC signaling from the base

station. The time window included in the indication for using the HARQ-ACK codebook may be the same as the time window recommended by the WTRU or be changed by the base station (e.g., based on the WTRU's recommendation).

[0113] In examples, the WTRU may receive a confirmation message, an activation indication, and/or the time window associated with the use of the HARQ-ACK codebook as part of HARQ-ACK configuration information (e.g., in the PDCCH), or as a separate message or indication (e.g., which may be received via DCI, MAC-CE, RRC, etc.).

[0114] In examples, the WTRU may be configured to generate the HARQ-ACK codebook for (e.g., only for) DL transmissions (e.g., PDCCH, PDSCH, etc.) whose grant indication (e.g., received via DCI) includes a confirmation message or an indication to activate the use of the HARQ-ACK codebook.

[0115] In examples, the WTRU may be configured to generate the HARQ-ACK codebook for multiple (e.g., all) DL transmissions (e.g., PDCCH, PDSCH, etc.) received from the time of the indication to the end of the configured time window (e.g., T_{HAORP}).

[0116] In examples, the confirmation message or indication may include an indication (e.g., a flag or bit field) to activate/deactivate or enable/disable the use of the HARQ-ACK codebook (e.g., via a flag indication in DCI, MAC-CE, RRC, etc.). In examples, the confirmation message or indication may indicate serving cells, component carriers, and/or HARQ processes for an indicated serving cell that may be associated with the HARQ-ACK codebook. In examples, the confirmation message or indication may include the time window (e.g., T_{HAORP}) for using or applying the HARQ-ACK codebook.

[0117] In examples, the WTRU may generate the HARQ-ACK codebook for multiple (e.g., all) of the DL transmission for which the HARQ-ACK codebook is activated and/or for which corresponding HARQ-ACK feedback is configured to be transmitted in the same (UL) resources (e.g., as indicated by K1 values). For instance, the WTRU may receive a number of (e.g., N) DL transmissions (e.g., PDCCH, PDSCH, etc.) for which HARQ-ACK configuration information may indicate that the same time and/or frequency resources (e.g., as indicated by K1 values) may be used to send HARQ-ACK feedback. The WTRU may then generate the HARQ-ACK codebook for these (e.g., N) received DL transmissions.

[0118] To determine the number of DL transmissions associated with the HARQ-ACK codebook, the WTRU may consider DL transmissions received from the time HARQ-ACK codebook generation was activated to the end of a pre-configured time gap (e.g., $T_{\text{HARQ-K1-gap}}$) for using configured (UL) resources (e.g., PUCCH resources) to send the HARQ-ACK codebook (e.g., the time gap may be between reception of the DL transmissions and transmission of the HARQ-ACK codebook using the configured UL resources). In examples, the WTRU may not expect to receive UL resources for HARQ-ACK feedback transmission (e.g., PUCCH resources) within such a time gap (e.g., $T_{\text{HARQ-K1-gap}}$).

[0119] The WTRU may generate one or more HARQ-ACK information bits for a (e.g., each) HARQ process ID, where a (e.g., each) HARQ information bit in the codebook may represent an ACK/NACK for a received DL transmission (e.g., one bit per TB or CBG) corresponding to the HARQ process ID. In an example, $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O_{ACK}-1}^{ACK}$ may indicate the HARQ-ACK information bits for a total number O_{ACK} of HARQ-ACK information bits for the corresponding HARQ process ID. In an example, for a received PDSCH, the corresponding HARQ-ACK information bits may represent TB-based or CBG-based HARQ information bits. In an example, for a received SPS PDSCH release or a received TCI state update, the HARQ information bits may indicate the ACK/NACK of the reception of the corresponding message.

[0120] As described herein, the HARQ-ACK codebook may include at least two parts. The first part of the HARQ-ACK codebook may be a compressed part or version of HARQ-ACK information bits and/or HARQ-ACK codebook(s) associated with one or more received DL transmissions. In an example, the WTRU may be configured to generate the HARQ-ACK codebook for a received PDSCH. The WTRU may calculate, generate, and/or determine the first part of the HARQ-ACK codebook corresponding to the PDSCH according to the HARQ-ACK information bits and/or codebook that may be generated based on an acknowledged or not-acknowledged (e.g., faulty) reception of transport block(s) for the PDSCH. The WTRU may receive a PDSCH that may include one or more code block groups (CBGs) associated with a transport block, and the WTRU may calculate, determine, and/or report HARQ-ACK information bits for the transport block in the first part of the HARQ-ACK codebook.

[0121] The WTRU may generate the first part of the HARQ-ACK codebook as a bitmap, where each bit in the bitmap may be calculated based on TB-based HARQ-ACK feedback corresponding to a HARQ process ID, as illustrated by FIG. 2. The order of the bits in the bitmap may be based on HARQ process IDs and/or reception times of the transport blocks for which the HARQ feedback is being provided. With the HARQ process ID based ordering, HARQ bits corresponding to the HARQ process indices may be mapped in an ascending order from MSB to LSB of the bitmap based on the HARQ process indices. Each bit in the bitmap may correspond to a HARQ process ID (e.g., one bit may be generated for each TB associated with the HARQ process ID) and the length of the bitmap may be equal to the number of HARQ process IDs associated with the DL transmissions for which the HARQ feedback is being provided. With the reception time based ordering, each bit in the bitmap may correspond to a HARQ-ACK information bit associated with a HARQ process ID, and the order of the bits may be based on the reception times of the DL transmissions for which the HARQ feedback is being provided.

[0122] In an example, each bit of the bitmap described herein may include a first value (e.g., 1, indicating an ACK) or a second value (e.g., 0, indicating a NACK). In an example, the WTRU may be configured to generate the HARQ-ACK codebook based on the reception of a number of (e.g., N) DL

transmissions (e.g., PDCCH, PDSCH, etc.), where the HARQ-process IDs for the DL transmissions may be indicated (implicitly or explicitly) in respective grant messages. The WTRU may generate HARQ-ACK information bits for the received DL transmissions using the TB-based HARQ-ACK mechanism described herein. The WTRU may generate the bitmap in a first part of the HARQ-ACK codebook, where the size of the bitmap may be equal to the total number of received HARQ process IDs (each bit in the bitmap may correspond to the reception of a DL transmission associated with a configured HARQ process ID). The WTRU may be configured to order the bits in the bitmap based on the reception times of the DL transmissions or based on the HARQ process IDs associated with the DL transmissions.

[0123] The WTRU may compress the bitmap included in the first part of the HARQ-ACK codebook. In an example, the WTRU may be configured with a compression rate for the bitmap. In an example, the WTRU may determine the compression rate for the bitmap based on an acceptable rate of error (e.g., BLER) that may be received as part of the configuration information regarding the HARQ-ACK codebook. The WTRU may use a higher compression rate for scenarios with higher acceptable error rates (e.g., eMBB) and may use a lower compression rate for scenarios with lower acceptable error rates (e.g., URLLC). The base station may decompress the compressed first part of the HARQ-ACK codebook to determine the first part of the HARQ-ACK codebook (e.g., to determine the bitmap described herein).

[0124] The WTRU may generate the second part of the HARQ-ACK codebook using the CBG-based HARQ feedback mechanism described herein (e.g., partial CBG-based HARQ transmission or reporting mechanism). For example, the WTRU may generate and report CBG-based HARQ feedback for (e.g., only for) a PDSCH transmission for which TB-based HARQ information bit(s) in the first part (e.g., bitmap) of the HARQ-ACK codebook indicates a NACK (e.g., as illustrated by FIG. 2). In examples, for a HARQ process associated with a transport block for PDCCH monitoring occasion m or for SPS PDSCH receptions on serving cells c , if a corresponding bit in the first part of the HARQ-ACK codebook (e.g., in the bitmap described herein) indicates an ACK, the WTRU may not multiplex a HARQ-ACK information bit corresponding to the transport block in the second part of the HARQ-ACK codebook. In examples, if the WTRU is configured with CBG-based HARQ transmission (e.g., via *PDSCH-CodeBlockGroupTransmission*), the WTRU may not multiplex HARQ-ACK information bits corresponding to the CBGs of the transport block in the second part of the HARQ-ACK codebook. In examples, if a corresponding bit in the first part (e.g., bitmap) of the HARQ-ACK codebook indicates NACK, the WTRU may generate HARQ-ACK bits and/or codebooks for the corresponding HARQ process and/or CBGs in the second part of the HARQ-ACK codebook by concatenating the determined HARQ-ACK bits and/or codebooks (e.g., in an ascending order based on the HARQ process IDs, based on the reception times of the DL transmissions, etc.).

[0125] The WTRU may determine an association between the HARQ-ACK information bits in the first part (e.g., bitmap) of the HARQ-ACK codebook and the (e.g., concatenated) HARQ-ACK bits and/or codebooks in the second part (e.g., CBG-based) of the HARQ-ACK codebook. The WTRU may determine the association based on a corresponding HARQ-ACK process ID between the two parts. The WTRU may determine the order of the generated and/or reported HARQ-ACK information bits in the second part (e.g., CBG-based HARQ-ACK) of the HARQ-ACK codebook to follow the order of the HARQ-ACK bits in the first part (e.g., bitmap) of the HARQ-ACK codebook, where the HARQ-ACK codebooks and/or information bits may be included in the second part (e.g., CBG-based HARQ-ACK) of the HARQ-ACK codebook if (e.g., only if) a corresponding HARQ-ACK bit in the first part (e.g., bitmap) of the HARQ-ACK codebook indicates an NACK.

[0126] If the base station receives the HARQ-ACK codebook described herein, the base station may check the first part of the codebook and determine faulty DL transmissions based on the TB-based NACK bits included in the first part (e.g., bitmap) of the codebook. Based on the NACK bits in the first part of the HARQ-ACK codebook, the base station may decode the CBG-based HARQ-ACK information bits or codebooks included in the second part of the HARQ-ACK codebook (e.g., in the same order as the NACK indications or bits included in the first part of the HARQ-ACK codebook).

[0127] A WTRU may be configured to transmit the HARQ-ACK codebook described herein (e.g., a new or enhanced HARQ-ACK codebook) in multiple (e.g., two) parts or steps. The WTRU may provide HARQ ACK/NACK feedback with first information, second information, and third information. In examples, the first information may include ACK/NACK information for certain HARQ process indices. For instance, the WTRU may generate (e.g., as part of the first information) a bitmap in which a (e.g., each) bit may represent an ACK/NACK for a HARQ process. The bit may be calculated based on an AND function on multiple (e.g., all) HARQ-ACK bits corresponding to the HARQ process. In examples, the second information may include HARQ ACK bits and/or codebooks for (e.g., only for) HARQ processes that may be NACKed in the first information. In examples, the second information may include HARQ ACK bits associated with CBG(s) for (e.g., only for) the HARQ processes NACKed in the first information. In examples, the second information may include HARQ bits and/or codebooks for (e.g., only for) HARQ processes NACKed in the first information, and the third information may include HARQ bits for CBGs associated with (e.g., only with) TBs NACKed in the second information. In this way, the HARQ codebook described herein may be constructed in a hierarchical manner.

[0128] The WTRU may report the HARQ ACK/NACK information in one or more uplink (UL) (e.g., PUCCH and/or PUSCH) transmissions. For example, the HARQ ACK/NACK information may be transmitted in a same slot or in different slots. Resources for the HARQ ACK/NACK transmission may be

configured and/or indicated via RRC signaling, a MAC CE, and/or DCI (e.g., a WTRU-specific DCI for scheduling one or more PUSCHs or a group DCI).

[0129] In examples, the WTRU may report the HARQ ACK/NACK information in a single UL transmission. For example, the WTRU may report the first information and the second information described herein in a single UL transmission (e.g., a single UL signal and/or channel). In these examples, the payload size of the first information may be based on the number of HARQ processes reported. The payload size of the second information may be based on a predetermined or preconfigured number of bits. For example, the payload size of the second information may be based on the number of HARQ processes multiplied by a maximum number of bits associated with each HARQ process.

[0130] In examples, the WTRU may report the HARQ ACK/NACK information in multiple parts (e.g., in two or more UL transmissions). For example, the WTRU may report the first information described herein as a first part using a first resource, the second information described herein as a second part using a second resource, and the third information described herein as a third part using a third resource. The payload size of the first information may be based on the number of HARQ codebooks reported. The payload size of the second information may be determined based on a number of bits associated with NACKed HARQ processes in the first information. For example, the payload size of the second information may be based on the number of NACKed HARQ processes * the number of bits associated with each NACKed HARQ codebook. The payload size of the second information and/or the third information may be determined based on the number of bits associated with NACKed TBs in the first or second information. For example, the payload size of the second or third information may be based on the number of NACKed TBs * the number of bits for each NACKed TB (e.g., the number of CBGs for each NACKed TB).

[0131] The configuration or indication of resources for transmitting the first part, the second part, or the third part of the HARQ ACK/NACK information may be different. For example, UL resources for the first part may be semi-statically configured (e.g., via RRC and/or MAC CE), while UL resources for the second part may be dynamically indicated (e.g., via a DCI indication of an UL resource from one or more UL resources semi-statically configured via RRC and/or MAC CE). The number of configured or indicated UL resources may be different for the first part, the second part, and the third part. For example, the number of UL resources for the first part may be one resource while the number of UL resources for the second part may be two or more resources. The WTRU may select an UL resource from the two or more configured resources based on one or more of a modulation scheme, a coding rate, an interference level, a channel quality (e.g., one or more of SINR, RSRP, CQI, etc.), a number of NACKed processes and/or NACKed TBs, and/or the like.

[0132] The same or different UL resources may be used to transmit the first, second, and third information described herein. For example, the WTRU may transmit the first information in a first transmission using a first resource, the second information in a second transmission using a second resource, and the third information in a third transmission using a third resource. The WTRU may determine whether or not to transmit the first information, the second information, and the third information using the same resource(s). For example, if one or more parameters have values less than a threshold (e.g., which may be configured or indicated via one or more of RRC, MAC CE, or DCI and/or reported by the WTRU), the WTRU may use the same resource(s) to transmit two or more of the first information, the second information, or the third information. Otherwise, the WTRU may use different resources to transmit the information. The one or more parameters may include one or more of a number of failed HARQ codebooks, a number of failed TBs, a number of failed CBGs, a number of HARQ codebooks to be reported, a number of TBs to be reported (e.g., determined based on NACKed HARQ codebooks), a number of CBGs to be reported (e.g., based on NACKed TBs), etc.

[0133] Codebook generation may be enhanced to support HARQ-ACK overhead reduction. A WTRU may determine to enable/disable, use/stop using, or activate/deactivate a HAORP (e.g., based on an AI/ML model prediction, a measurement, or an explicit indication from gNB), for a determined time duration (T_{HAORP}). The WTRU may receive one or more transmissions for which it is configured to report a HARQ-ACK/NACK. When generating a codebook (e.g., a new codebook), the WTRU may determine the PDSCHs and/or PDCCHs for which a HARQ-ACK transmission may be included in the codebook based on their respective K1 values (e.g., mapping to the same PUCCH resources) and/or respective time limits. The WTRU may determine to use a two-part codebook (e.g., TB-based HARQ feedback followed by CBG-based HARQ feedback including partial CBG-based HARQ feedback) for the HARQ-ACK feedback. The WTRU may build the two-part codebook in one or more of the following manners.

[0134] The two-part codebook (e.g., TB-based HARQ feedback followed by partial CBG-based HARQ feedback) may be formed based on two sets of HARQ bits. The first set of HARQ bits may include a compressed set or version (e.g., TB-based) of HARQ information bits that may correspond to one or more PDCCH/PDSCH receptions. The first set of HARQ bits may include a bitmap associated with one or more HARQ processes, in which a (e.g., each) HARQ bit in the bitmap may represent a TB-based HARQ information bit for a received PDCCH/PDSCH in a configured and/or determined time interval (T_{HAORP}). For example, a (e.g., each) HARQ bit may be calculated based on a logical AND function of multiple (e.g., all) HARQ bits corresponding to a HARQ process. The WTRU may generate HARQ information for (e.g., only for) a transport block in the PDSCH, for (e.g., only for) an SPS PDSCH release, or for (e.g., only for) a TCI state update. The order of bits in the bitmap may be based on reception times (e.g., based on the order in

which the PDCCHs/PDSCHs are received in time as indicated by semi-static configurations or downlink assignment indexes (DAIs) in dynamic configurations). The order of the bitmap may be based on HARQ process IDs or indices (e.g., the bits may be ordered in an ascending order from MSB to LSB of the bitmap in accordance with the corresponding HARQ process indices). For a (e.g., each) HARQ bit of the bitmap, a value of 1 may indicate an ACK and a value of 0 may indicate a NACK.

[0135] The second set of HARQ bits may include HARQ bits and/or codebooks for (e.g., only for) the HARQ-processes that were NACKed in the first set of HARQ bits. For example, for a HARQ process associated with a transport block for PDCCH monitoring occasion m or for SPS PDSCH receptions on serving cell c , if the corresponding bit in the first set of HARQ bits indicates an ACK, the WTRU may not include HARQ information bits corresponding to the transport block in the second set of HARQ bits of the two-part codebook. If the WTRU is configured with *PDSCH-CodeBlockGroupTransmission* (or a similar parameter), the WTRU may not multiplex HARQ information bits corresponding to the CBGs of the transport block in the second set of HARQ-ACK bits of the two-part codebook. If the WTRU is not configured with *PDSCH-CodeBlockGroupTransmission* (or a similar parameter) and if the corresponding bit in the first set of HARQ-ACK bits indicates a NACK, the WTRU may include one or more HARQ information bits corresponding to the transport block (e.g., for CBGs of the transport block) in the set of HARQ bits of the two-part codebook. The WTRU may determine the second set of HARQ bits, for example, by concatenating the relevant HARQ information bit(s) (e.g., based on an ascending or descending order of the corresponding process IDs or reception times associated with a transport block).

[0136] The WTRU may determine the two-part codebook (e.g., a TB-based HARQ followed by a partial CBG-based HARQ) by concatenating the first set of HARQ bits and the second set of HARQ bits. The two-part codebook may be constructed per serving cell or for multiple (e.g., all) serving cells configured for the WTRU.

[0137] The WTRU may transmit the two-part codebook in one or more of the following manners. In a first manner of transmission, the first set of HARQ bits and the second set of HARQ bits in the two-part codebook (e.g., a TB-based HARQ followed by a partial CBG-based HARQ) may be transmitted in two parts or steps. For example, the two-part codebook may include a TB-based Type 2 HARQ codebook combined with a partial CBG-based Type 3 codebook. The WTRU may receive a configuration of first resources (e.g., PUCCH resources indicated via grant DCI) for sending HARQ feedback and the WTRU may send the first set of HARQ bits of the two-part codebook (e.g., the TB-based bitmap) using the configured first PUCCH resources. The WTRU may subsequently receive a grant from a base station indicating second PUCCH resources for performing a transmission (e.g., a one-shot transmission) of the second set of HARQ bits of the two-part codebook.

[0138] In a second manner of transmission, the WTRU may receive a configuration of PUCCH resources for sending a HARQ feedback (e.g., via a grant DCI). The PUCCH resources may include enough resources for transmission of the first set of HARQ bits and only N bits of the second set of HARQ bits. If the size of the second set of HARQ bits is smaller than N, the WTRU may send the first and second sets of HARQ bits in the indicated/configured PUCCH resources. If the size of the second set of HARQ bits is more than N, the WTRU may send the first set of HARQ bits and the first N bits of the second set of HARQ bits with the indicated/configured PUCCH resources. The WTRU may (e.g., later) receive a request for a Type 3 HARQ codebook from the base station (e.g., to send the remaining portion of the second set of HARQ bits), and/or a grant of resources for the Type 3 HARQ codebook. In response, the WTRU may transmit the requested Type 3 HARQ codebook (e.g., the remaining portion of the second set of HARQ bits) to the base station using the grant of resources. The value of N may be determined and/or reported by the WTRU (e.g., based on AI/ML prediction models). The value of N may be determined and/or configured by the base station.

[0139] Although features and elements described above are described in particular combinations, each feature or element may be used alone without the other features and elements of the preferred embodiments, or in various combinations with or without other features and elements. Although the implementations described herein may consider 3GPP specific protocols, it is understood that the implementations described herein are not restricted to this scenario and may be applicable to other wireless systems. For example, although the solutions described herein consider LTE, LTE-A, New Radio (NR) or 5G specific protocols, it is understood that the solutions described herein are not restricted to this scenario and are applicable to other wireless systems as well.

[0140] The processes described above may be implemented in a computer program, software, and/or firmware incorporated in a computer-readable medium for execution by a computer and/or processor. Examples of computer-readable media include, but are not limited to, electronic signals (transmitted over wired and/or wireless connections) and/or computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as, but not limited to, internal hard disks and removable disks, magneto-optical media, and/or optical media such as compact disc (CD)-ROM disks, and/or digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, terminal, base station, RNC, and/or any host computer.

CLAIMS

What is claimed is:

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

a processor configured to:

receive a transport block from a network device;

determine a first hybrid automatic repeat request (HARQ) feedback bit associated with the transport block, wherein the first HARQ feedback bit indicates a positive acknowledge (ACK) associated with the transport block (TB) or a negative acknowledgment (NACK) associated with the TB;

on a condition that the first HARQ feedback bit indicates the NACK associated with the transport block, determine a second HARQ feedback bit for a code block group (CBG) associated with the transport block;

construct a HARQ codebook, wherein the HARQ codebook includes the first HARQ feedback bit in a first part of the HARQ codebook and wherein, on the condition that the first HARQ feedback bit indicates the NACK associated with the TB, the HARQ codebook further includes the second HARQ feedback bit for the CBG in a second part of the HARQ codebook; and

transmit the HARQ codebook to the network device.

2. The WTRU of claim 1, wherein the first part of the HARQ codebook includes a bitmap that comprises respective HARQ feedback bits associated with multiple TBs and wherein the first HARQ feedback bit is a part of the bitmap.

3. The WTRU of claim 2, wherein the bitmap is ordered based on respective reception times of the multiple TBs or respective HARQ process identifiers associated with the multiple TBs.

4. The WTRU of claim 1, wherein the second part of the HARQ codebook further includes respective HARQ feedback bits for one or more additional CBGs associated with the transport block.

5. The WTRU of claim 1, wherein the WTRU is configured with multiple serving cells and wherein the HARQ codebook is constructed for the multiple serving cells.

6. The WTRU of claim 1, wherein the processor being configured to transmit the HARQ codebook to the network device comprises the processor being configured to transmit the first part of the HARQ codebook

to the network device via a first uplink transmission and transmit the second part of the HARQ codebook to the network device via a second uplink transmission.

7. The WTRU of claim 6, wherein the processor being configured to transmit the HARQ codebook to the network device comprises the processor being configured to:

- receive a first plurality of uplink transmission resources from the network device in a first grant; transmit the first part of the HARQ codebook to the network device using the first plurality of uplink transmission resources;

- receive a second plurality of uplink transmission resources from the network device in a second grant; and

- transmit the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources.

8. The WTRU of claim 1, wherein the processor being configured to transmit the HARQ codebook to the network device comprises the processor being configured to:

- receive a first plurality of uplink transmission resources from the network device via a first grant; transmit the first part of the HARQ codebook and a first portion of the second part of the HARQ codebook to the network device using the first plurality of uplink transmission resources;

- receive a second plurality of uplink transmission resources from the network device via a second grant; and

- transmit a second portion of the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources.

9. The WTRU of claim 8, wherein the processor is further configured to transmit an indication of a size of the second part of the HARQ codebook to the network device, and wherein the first plurality of uplink transmission resources and the second plurality of uplink transmission resources are received after the transmission of the indication.

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

- receiving a transport block from a network device;

- determining a first hybrid automatic repeat request (HARQ) feedback bit associated with the transport block, wherein the first HARQ feedback bit indicates a positive acknowledge (ACK) associated with the transport block (TB) or a negative acknowledgment (NACK) associated with the TB;

on a condition that the first HARQ feedback bit indicates the NACK associated with the transport block, determining a second HARQ feedback bit for a code block group (CBG) associated with the transport block;

constructing a HARQ codebook, wherein the HARQ codebook includes the first HARQ feedback bit in a first part of the HARQ codebook and wherein, on the condition that the first HARQ feedback bit indicates the NACK associated with the TB, the HARQ codebook further includes the second HARQ feedback bit for the CBG in a second part of the HARQ codebook; and

transmitting the HARQ codebook to the network device.

11. The method of claim 10, wherein the first part of the HARQ codebook includes a bitmap that comprises respective HARQ feedback bits associated with multiple TBs and wherein the first HARQ feedback bit is a part of the bitmap.

12. The method of claim 11, wherein the bitmap is ordered based on respective reception times of the multiple TBs or respective HARQ process identifiers associated with the multiple TBs.

13. The method of claim 10, wherein the second part of the HARQ codebook further includes respective HARQ feedback bits for one or more additional CBGs associated with the transport block.

14. The method of claim 10, wherein the WTRU is configured with multiple serving cells and wherein the HARQ codebook is constructed for the multiple serving cells.

15. The method of claim 10, wherein transmitting the HARQ codebook to the network device comprises transmitting the first part of the HARQ codebook to the network device via a first uplink transmission and transmitting the second part of the HARQ codebook to the network device via a second uplink transmission.

16. The method of claim 15, wherein transmitting the HARQ codebook to the network device comprises:
receiving a first plurality of uplink transmission resources from the network device in a first grant;
transmitting the first part of the HARQ codebook to the network device using the first plurality of uplink transmission resources;

receiving a second plurality of uplink transmission resources from the network device in a second grant; and

transmitting the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources.

17. The method of claim 10, wherein transmitting the HARQ codebook to the network device comprises:

receiving a first plurality of uplink transmission resources from the network device via a first grant;
transmitting the first part of the HARQ codebook and a first portion of the second part of the HARQ codebook to the network device using the first plurality of uplink transmission resources;

receiving a second plurality of uplink transmission resources from the network device via a second grant; and

transmitting a second portion of the second part of the HARQ codebook to the network device using the second plurality of uplink transmission resources.

18. The method of claim 17, further comprising transmitting an indication of a size of the second part of the HARQ codebook to the network device, wherein the first plurality of uplink transmission resources and the second plurality of uplink transmission resources are received after the transmission of the indication.

100

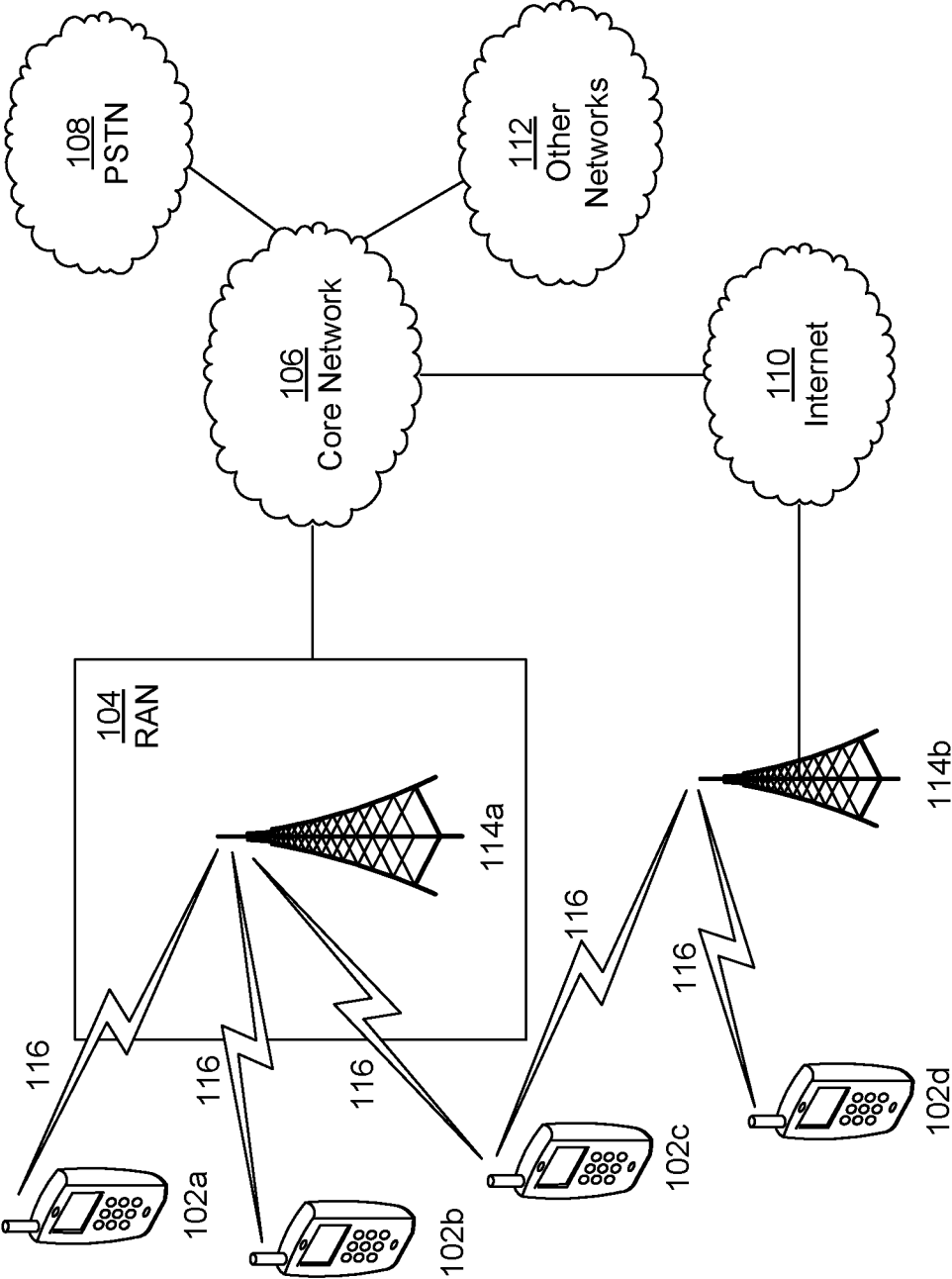


FIG. 1A

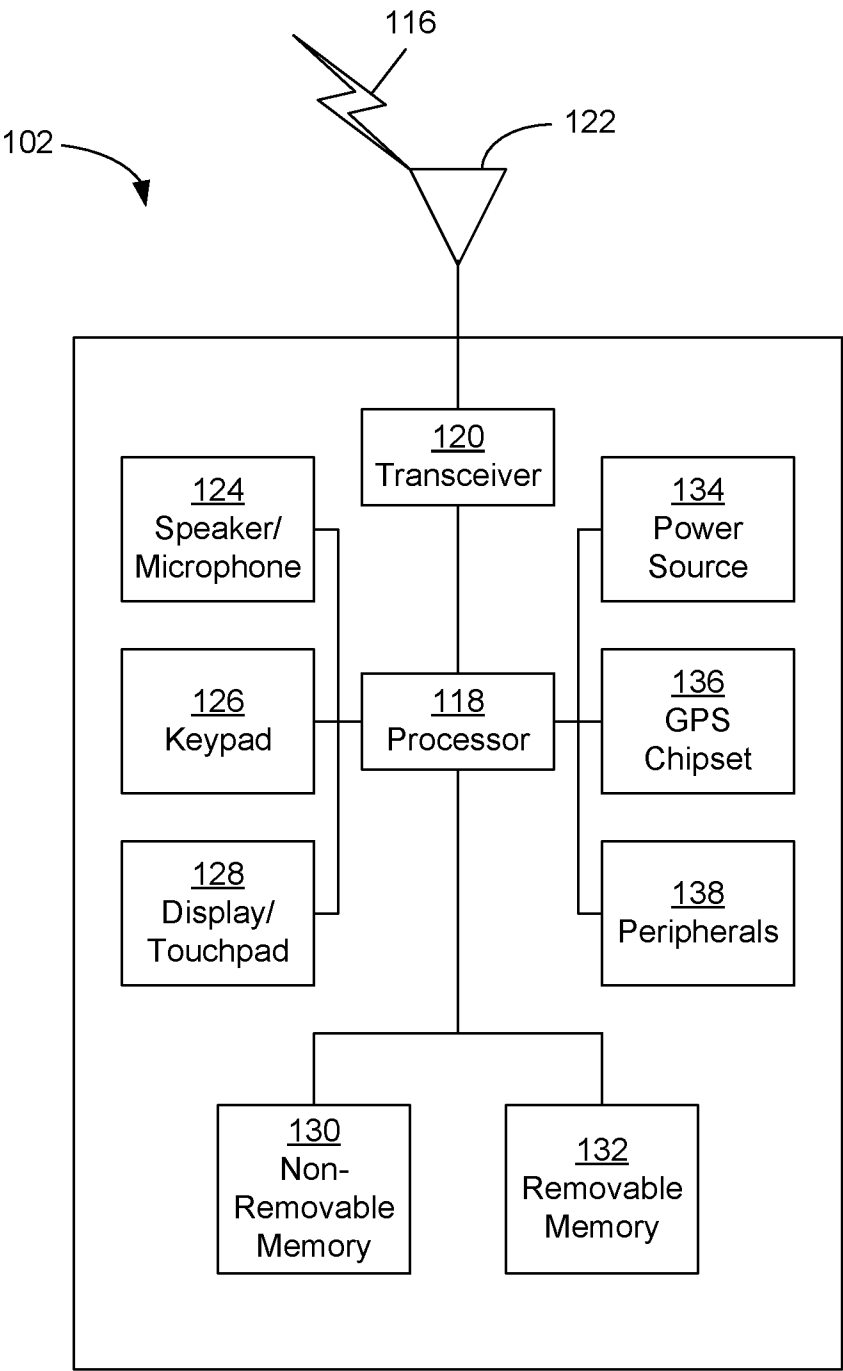


FIG. 1B

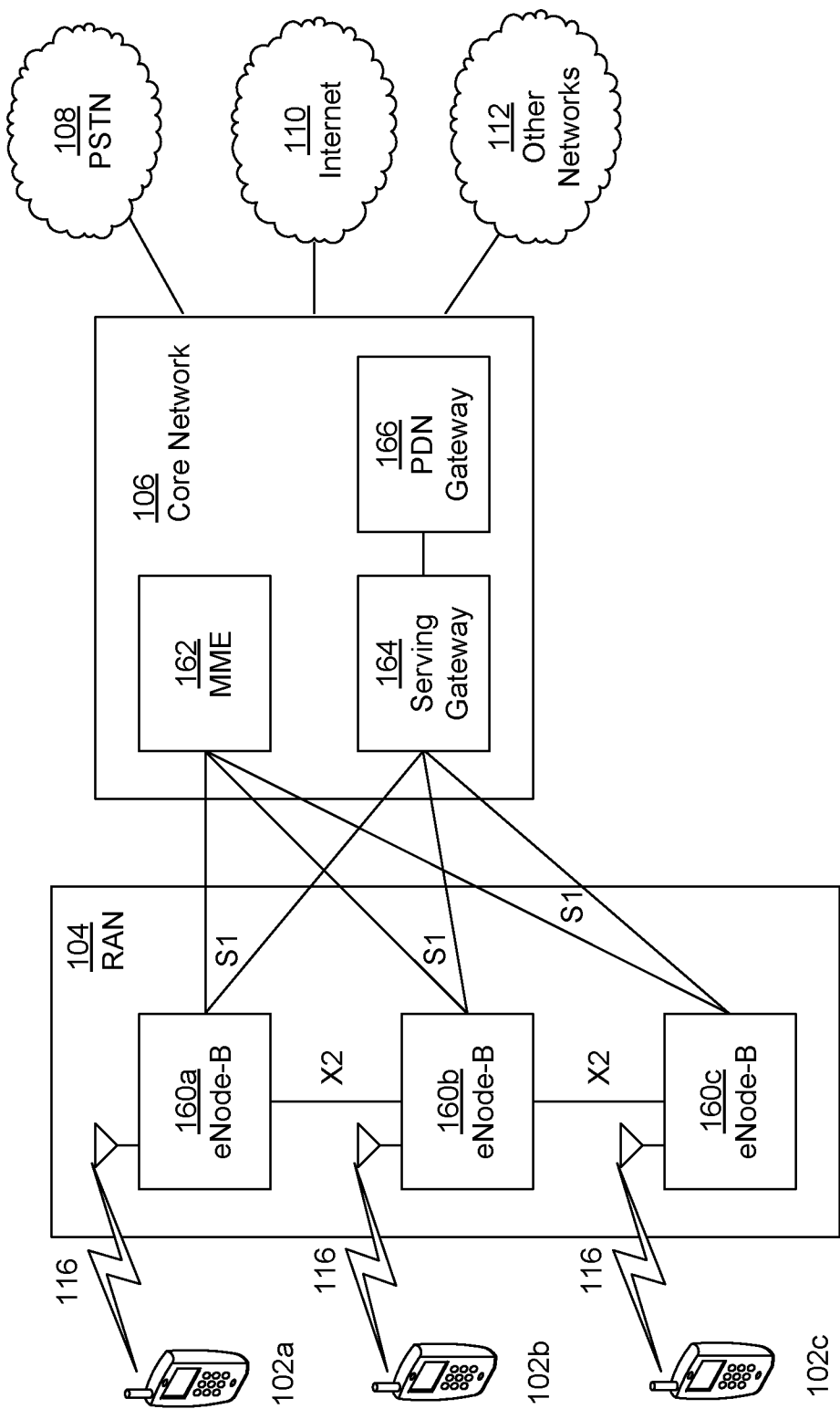


FIG. 1C

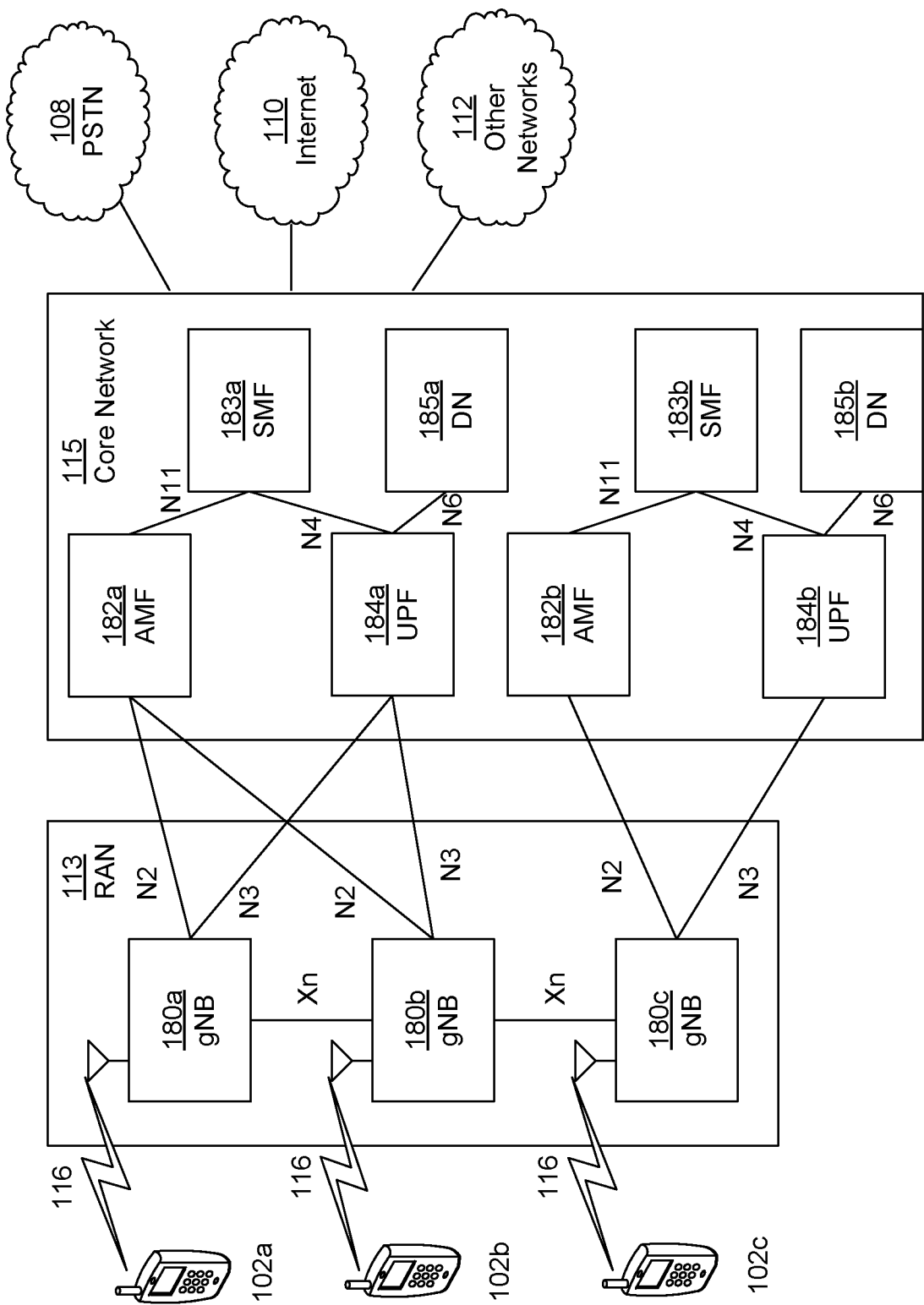


FIG. 1D

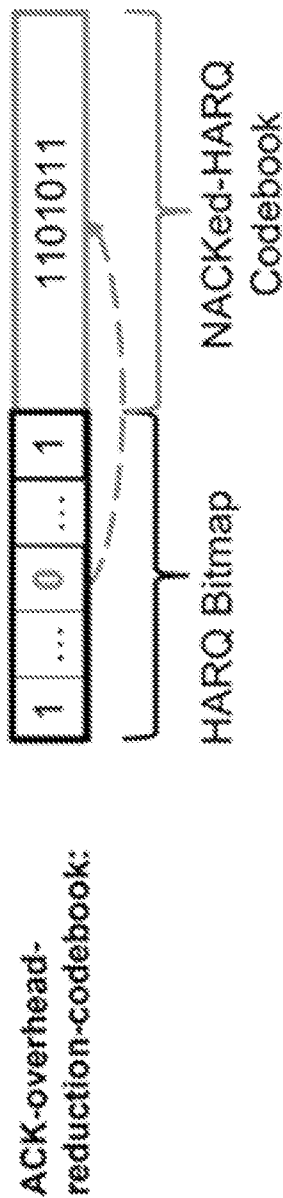


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/015666

A. CLASSIFICATION OF SUBJECT MATTER INV. H04L1/1607 H04L1/1822 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H04L Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 11 224 056 B2 (QUALCOMM INC [US]) 11 January 2022 (2022-01-11)	1-4, 6-8, 10-13, 15-17
A	column 25, line 62 - column 31, line 18; figures 4-7	9, 18
X	US 2021/176011 A1 (LEI HAIPENG [CN]) 10 June 2021 (2021-06-10) paragraphs [0049] - [0060]; figures 4, 5	1-5, 10-14
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 3 June 2024		Date of mailing of the international search report 14/06/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Marjanovic, Djordje

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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