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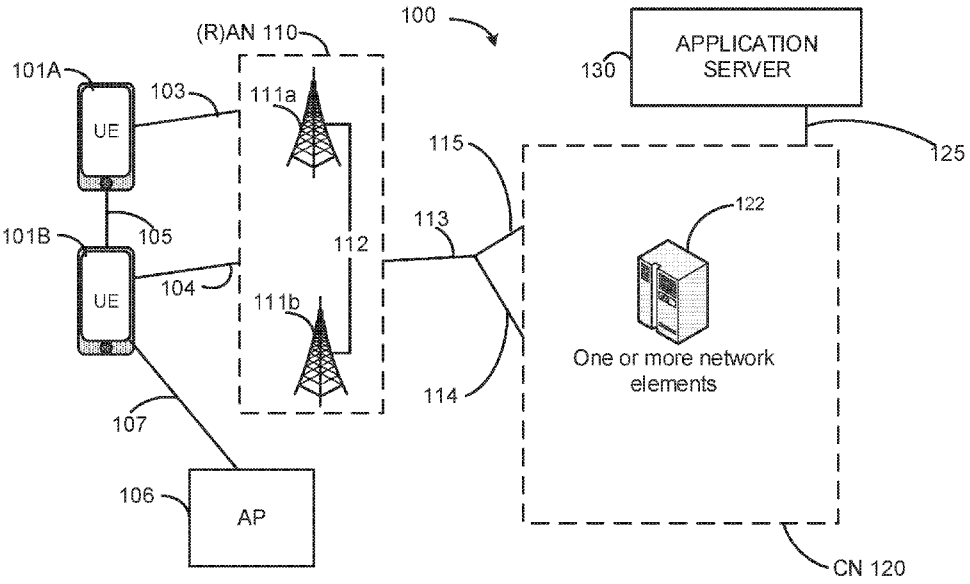


FIG. 1

(57) Abstract: Methods, systems, apparatus, and computer programs, for warning system notifications and acquisition. In one aspect, the method includes actions of receiving, by user equipment (UE) and from an access node, data indicating the presence of a PDSCH broadcast, configuring, by the UE and based on the received data, a narrowband (NB) to receive transport blocks in PDSCH, and receiving, by the UE, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information.

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NOTIFICATION AND ACQUISITION OF ETWS/CMAS IN CONNECTED MODE FOR UES IN CE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/824,149 filed March 26, 2019, the entirety of each of which is incorporated herein by reference.

BACKGROUND

[0001] Various implementations generally may relate to the field of wireless communications.

METHOD

[0002] According to innovative aspect of the present disclosure, a method for acquiring warning system information is disclosed. In one aspect, the method can include actions of receiving, by user equipment (UE) and from an access node, data indicating the presence of a PDSCH broadcast, configuring, by the UE and based on the received data, a narrowband (NB) to receive transport blocks in PDSCH, and receiving, by the UE and from the access node, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information.

[0003] Other versions include corresponding systems, apparatus, and computer programs to perform the actions of methods defined by instructions encoded on computer readable storage devices.

[0004] These and other versions may optionally include one or more of the following features. For instance, in some implementations, the UE is in coverage enhanced (CE) mode A or CE mode B.

[0005] In some implementations, the warning system information can include earthquake and tsunami warning system (ETWS) / commercial mobile alert system (CMAS) information.

[0006] In some implementations, the received data used to configure the narrowband (NB) includes dedicated RRC signaling, data broadcast in system information, or data indicated by PDCCH that schedules the PDSCH.

[0007] In some implementations, the PDSCH is broadcast in each narrowband.

[0008] In some implementations, periodicity, TBS size, or repetitions parameters are predefined. In other implementations, periodicity, TBS size, or repetitions parameters are configured via RRC or broadcast in system information.

[0009] In some implementations, the received data indicating presence of PDSCH broadcast is indicated by a PHY signal, a PDCCH scrambled with P-RNTI or SI-RNTI, a unicast PDSCH, RRC signaling, a MAC CE PDU, or unicast PDCCH in UESS.

[00010] In some implementations, the one or more transport blocks broadcast in PDSCH are prioritized over unicast transmissions. In some implementations, the UE is not required to receive unicast transmission for a predetermined amount of time.

[00011] In some implementations, the method can further include receiving, by the UE, one or more second transport blocks in unicast while also receiving the one or more transport blocks broadcast PDSCH using an NB switching gap that is defined for parallel reception of unicast transport blocks and broadcast transport blocks.

[00012] In some implementations, the received data indicating the presence of a PDSCH broadcast includes scheduling information of SIB1-BR or SIB10, SIB11, or SIB12.

[00013] In some implementations, the UE is configured to monitor PDCCH for waring system information.

[00014] In some implementations, the UE is not required to monitor PDCCH for warning system information.

[00015] In some implementations, the method can further include receiving or transmitting DCI having DCI format 6-2 with a flag to indicate paging or direct indication differentiation. In such Implementations, the flag = 0 to indicate direct indication or the flag = 1 to indicate paging.

[00016] In some implementations, the DCI includes direct indication information to provide an indication of warning system information.

[00017] In some implementations, the DCI includes scheduling information for SIB1-BR or SIB10/11/12.

[00018] In some implementations, the method further includes after receiving the warning system information: transmitting, to the access node, an indication that the UE has finished receiving the warning system information and is ready for unicast transmission/reception.

[00019] In some implementations, the indication is transmitted in an RRC message, a MAC CE PDU, a scheduling request, a CQI or SRS report, or HARQ feedback.

[00020] In some implementations, method further includes receiving an RRC connection release message during reception of warning system information, and completing reception of warning system information before completing release of connection.

[0002] These and other aspects of the present disclosure are discussed in more detail in the detailed description below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[00021] Figure 1 illustrates an example architecture of a system of a network.

[00022] Figure 2 illustrates an example architecture of a system including a first CN.

[00023] Figure 3 illustrates an architecture of a system including a second CN.

[00024] Figure 4 illustrates an example of infrastructure equipment.

[00025] Figure 5 illustrates an example of a platform.

[00026] Figure 6 illustrates example components of baseband circuitry and radio front end modules (RFEM).

[00027] Figure 7 illustrates various protocol functions that may be implemented in a wireless communication device.

[00028] Figure 8 illustrates components of a core network.

[00029] Figure 9 is a block diagram illustrating components of a system to support NFV.

[00030] Figure 10 is a block diagram illustrating components able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

[00031] Figure 11 illustrates an example of prioritizing broadcast PDSCH over unicast transmission.

[00032] Figure 12 illustrates an example of scheduling PDSCH after receiving notification at a PO.

[00033] Figure 13A is a MAC CE PDU that can be used to provide scheduling information of SIB1-BR.

[00034] Figure 13B is another example of a MAC CE PDU that can be used to provide scheduling information of SIB1-BR.

[00035] Figure 13C is another example of a MAC CE PDU that can be used to provide scheduling information of SIB1-BR.

[00036] Figure 14 is a flowchart of an example of a process for warning system information notification and acquisition.

[00037] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[00038] The present disclosure is directed towards downlink control information (DCI), radio resource control (RRC) and medium access control (MAC) coverage enhancement (CE) based

methods, systems, data structures, and computer programs for ETWS/CMAS notification and its acquisition in connected mode such as RCC Connected mode. ETWS/CMAS acquisition can include, for example, system information update notification/acquisition.

[00039] Use of DCI, RRC, and MAC CE techniques for ETWS/CMAS notification and acquisition can be particularly advantageous for non-bandwidth reduced low complexity (BL) user equipment (UE) or UE in CE, as such UE are not required to monitor the UE specific search space (USS) and common search space (CSS) machine type communication physical downlink control channel (MPDCCH) (type-1 and type-2) simultaneously when in connected mode. As a result, these UEs do not monitor for MPDCCH with cyclical redundancy check (CRC) scrambled with paging radio temporary identifier (P-RNTI) to receive any paging message or direct indication of system information (SI) update or Public Warning System (PWS) messages (e.g., ETWS/CMAS) in connected mode. Currently, if network wants to send the ETWS/CMAS notification to UEs operating in CE mode, then it will have to release all the UEs to IDLE mode and send the notification using direct indication message in MPDCCH with CRC scrambled with P-RNTI in the paging occasion. After receiving the notification, UE has to acquire the latest SIB10/11/12. This method would incur additional signaling overhead, delay, radio resources and UE power consumption in receiving the notification. This can also disrupt unicast traffic.

[00040] To address these problems, the present disclosure provides DCI, RRC and MAC CE based options for PWS (e.g., ETWS/CMAS) notification for BL UEs or UEs in CE to acquire PWS (e.g., ETWS/CMAS) information. Though aspects of the present disclosure are particularly advantageous for BL UEs or UE in CE, the present disclosure is not so limited. Instead, techniques of the present disclosure area also applicable to non BL UEs in connected mode as well. In addition, aspects of the present disclosure described herein are also applicable to provide system information change/update, EAB parameter change/update notification or acquisition, or both, in connected mode. The two actions to consider in connected mode include 1) mechanism to receive the ETWS/CWAS notification and 2) mechanism to acquire the ETWS/CWAS information.

[00041] Figure 1 illustrates an example architecture of a system 100 of a network, according to some implementations of the present disclosure. The following description is provided for an

example system 100 that operates in conjunction with the LTE system standards and 5G or NR system standards as provided by 3GPP technical specifications. However, the example implementations are not limited in this regard and the described implementations may apply to other networks that benefit from the principles described herein, such as future 3GPP systems (e.g., Sixth Generation (6G)) systems, IEEE 802.16 protocols (e.g., WMAN, WiMAX, etc.), or the like.

[00042] As shown by Figure 1, the system 100 includes UE 101a and UE 101b (collectively referred to as "UEs 101" or "UE 101"). In this example, UEs 101 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as consumer electronics devices, cellular phones, smartphones, feature phones, tablet computers, wearable computer devices, personal digital assistants (PDAs), pagers, wireless handsets, desktop computers, laptop computers, in-vehicle infotainment (IVI), in-car entertainment (ICE) devices, an Instrument Cluster (IC), head-up display (HUD) devices, onboard diagnostic (OBD) devices, dashtop mobile equipment (DME), mobile data terminals (MDTs), Electronic Engine Management System (EEMS), electronic/engine control units (ECUs), electronic/engine control modules (ECMs), embedded systems, microcontrollers, control modules, engine management systems (EMS), networked or "smart" appliances, MTC devices, M2M, IoT devices, and/or the like.

[00043] In some implementations, any of the UEs 101 may be IoT UEs, which may comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as M2M or MTC for exchanging data with an MTC server or device via a PLMN, ProSe or D2D communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[00044] The UEs 101 may be configured to connect, for example, communicatively couple, with a RAN 110. In implementations, the RAN 110 may be an NG RAN or a 5G RAN, an E-

UTRAN, or a legacy RAN, such as a UTRAN or GERAN. As used herein, the term "NG RAN" or the like may refer to a RAN 110 that operates in an NR or 5G system 100, and the term "E-UTRAN" or the like may refer to a RAN 110 that operates in an LTE or 4G system 100. The UEs 101 utilize connections (or channels) 103 and 104, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[00045] In this example, the connections 103 and 104 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a GSM protocol, a CDMA network protocol, a PTT protocol, a POC protocol, a UMTS protocol, a 3GPP LTE protocol, a 5G protocol, a NR protocol, and/or any of the other communications protocols discussed herein. In implementations, the UEs 101 may directly exchange communication data via a ProSe interface 105. The ProSe interface 105 may alternatively be referred to as a SL interface 105 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[00046] The UE 101b is shown to be configured to access an AP 106 (also referred to as "WLAN node 106," "WLAN 106," "WLAN Termination 106," "WT 106" or the like) via connection 107. The connection 107 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 106 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 106 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below). In various implementations, the UE 101b, RAN 110, and AP 106 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 101b in RRC_CONNECTED being configured by a RAN node 111a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 101b using WLAN radio resources (e.g., connection 107) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 107. IPsec tunneling may include encapsulating the entirety of original IP packets and adding a new packet header, thereby protecting the original header of the IP packets.

[00047] The RAN 110 can include one or more AN nodes or RAN nodes 111a and 111b (collectively referred to as "RAN nodes 111" or "RAN node 111") that enable the connections 103

and 104. As used herein, the terms "access node," "access point," or the like may describe equipment that provides the radio baseband functions for data and/or voice connectivity between a network and one or more users. These access nodes can be referred to as BS, gNBs, RAN nodes, eNBs, NodeBs, RSUs, TRxPs or TRPs, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). As used herein, the term "NG RAN node" or the like may refer to a RAN node 111 that operates in an NR or 5G system 100 (for example, a gNB), and the term "E-UTRAN node" or the like may refer to a RAN node 111 that operates in an LTE or 4G system 100 (e.g., an eNB). According to various implementations, the RAN nodes 111 may be implemented as one or more of a dedicated physical device such as a macrocell base station, and/or a low power (LP) base station for providing femtocells, picocells or other like cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells.

[00048] In some implementations, all or parts of the RAN nodes 111 may be implemented as one or more software entities running on server computers as part of a virtual network, which may be referred to as a CRAN and/or a virtual baseband unit pool (vBBUP). In these implementations, the CRAN or vBBUP may implement a RAN function split, such as a PDCP split wherein RRC and PDCP layers are operated by the CRAN/vBBUP and other L2 protocol entities are operated by individual RAN nodes 111; a MAC/PHY split wherein RRC, PDCP, RLC, and MAC layers are operated by the CRAN/vBBUP and the PHY layer is operated by individual RAN nodes 111; or a "lower PHY" split wherein RRC, PDCP, RLC, MAC layers and upper portions of the PHY layer are operated by the CRAN/vBBUP and lower portions of the PHY layer are operated by individual RAN nodes 111. This virtualized framework allows the freed-up processor cores of the RAN nodes 111 to perform other virtualized applications. In some implementations, an individual RAN node 111 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 1). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 4), and the gNB-CU may be operated by a server that is located in the RAN 110 (not shown) or by a server pool in a similar manner as the CRAN/vBBUP. Additionally or alternatively, one or more of the RAN nodes 111 may be next generation eNBs (ng-eNBs), which are RAN nodes that provide E-UTRA user plane and control plane protocol terminations toward the UEs 101, and are connected to a 5GC (e.g., CN 320 of

Figure 3) via an NG interface (discussed infra).

[00049] In V2X scenarios one or more of the RAN nodes 111 may be or act as RSUs. The term "Road Side Unit" or "RSU" may refer to any transportation infrastructure entity used for V2X communications. An RSU may be implemented in or by a suitable RAN node or a stationary (or relatively stationary) UE, where an RSU implemented in or by a UE may be referred to as a "UE-type RSU," an RSU implemented in or by an eNB may be referred to as an "eNB-type RSU," an RSU implemented in or by a gNB may be referred to as a "gNB-type RSU," and the like. In one example, an RSU is a computing device coupled with radio frequency circuitry located on a roadside that provides connectivity support to passing vehicle UEs 101 (vUEs 101). The RSU may also include internal data storage circuitry to store intersection map geometry, traffic statistics, media, as well as applications/software to sense and control ongoing vehicular and pedestrian traffic. The RSU may operate on the 5.9 GHz Direct Short Range Communications (DSRC) band to provide very low latency communications required for high speed events, such as crash avoidance, traffic warnings, and the like. Additionally or alternatively, the RSU may operate on the cellular V2X band to provide the aforementioned low latency communications, as well as other cellular communications services. Additionally or alternatively, the RSU may operate as a Wi-Fi hotspot (2.4 GHz band) and/or provide connectivity to one or more cellular networks to provide uplink and downlink communications. The computing device(s) and some or all of the radiofrequency circuitry of the RSU may be packaged in a weatherproof enclosure suitable for outdoor installation, and may include a network interface controller to provide a wired connection (e.g., Ethernet) to a traffic signal controller and/or a backhaul network.

[00050] Any of the RAN nodes 111 can terminate the air interface protocol and can be the first point of contact for the UEs 101. In some implementations, any of the RAN nodes 111 can fulfill various logical functions for the RAN 110 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[00051] In implementations, the UEs 101 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 111 over a multicarrier

communication channel in accordance with various communication techniques, such as, but not limited to, an OFDMA communication technique (e.g., for downlink communications) or a SC-FDMA communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the implementations is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[00052] In some implementations, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 111 to the UEs 101, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[00053] According to various implementations, the UEs 101 and the RAN nodes 111 communicate data (for example, transmit and receive) data over a licensed medium (also referred to as the "licensed spectrum" and/or the "licensed band") and an unlicensed shared medium (also referred to as the "unlicensed spectrum" and/or the "unlicensed band"). The licensed spectrum may include channels that operate in the frequency range of approximately 400 MHz to approximately 3.8 GHz, whereas the unlicensed spectrum may include the 5 GHz band.

[00054] To operate in the unlicensed spectrum, the UEs 101 and the RAN nodes 111 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 101 and the RAN nodes 111 may perform one or more known medium-sensing operations and/or carrier-sensing operations in order to determine whether one or more channels in the unlicensed

spectrum is unavailable or otherwise occupied prior to transmitting in the unlicensed spectrum. The medium/carrier sensing operations may be performed according to a listen-before-talk (LBT) protocol.

[00055] LBT is a mechanism whereby equipment (for example, UEs 101 RAN nodes 111, etc.) senses a medium (for example, a channel or carrier frequency) and transmits when the medium is sensed to be idle (or when a specific channel in the medium is sensed to be unoccupied). The medium sensing operation may include CCA, which utilizes at least ED to determine the presence or absence of other signals on a channel in order to determine if a channel is occupied or clear. This LBT mechanism allows cellular/LAA networks to coexist with incumbent systems in the unlicensed spectrum and with other LAA networks. ED may include sensing RF energy across an intended transmission band for a period of time and comparing the sensed RF energy to a predefined or configured threshold.

[00056] Typically, the incumbent systems in the 5 GHz band are WLANs based on IEEE 802.11 technologies. WLAN employs a contention-based channel access mechanism, called CSMA/CA. Here, when a WLAN node (e.g., a mobile station (MS) such as UE 101, AP 106, or the like) intends to transmit, the WLAN node may first perform CCA before transmission. Additionally, a backoff mechanism is used to avoid collisions in situations where more than one WLAN node senses the channel as idle and transmits at the same time. The backoff mechanism may be a counter that is drawn randomly within the CWS, which is increased exponentially upon the occurrence of collision and reset to a minimum value when the transmission succeeds. The LBT mechanism designed for LAA is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions, respectively, may have an LAA contention window that is variable in length between X and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for LAA. In one example, the minimum CWS for an LAA transmission may be 9 microseconds (μs); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[00057] The LAA mechanisms are built upon CA technologies of LTE-Advanced systems. In

CA, each aggregated carrier is referred to as a CC. A CC may have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five CCs can be aggregated, and therefore, a maximum aggregated bandwidth is 100 MHz. In FDD systems, the number of aggregated carriers can be different for DL and UL, where the number of UL CCs is equal to or lower than the number of DL component carriers. In some cases, individual CCs can have a different bandwidth than other CCs. In TDD systems, the number of CCs as well as the bandwidths of each CC is usually the same for DL and UL.

[00058] CA also comprises individual serving cells to provide individual CCs. The coverage of the serving cells may differ, for example, because CCs on different frequency bands will experience different pathloss. A primary service cell or PCell may provide a PCC for both UL and DL, and may handle RRC and NAS related activities. The other serving cells are referred to as SCells, and each SCell may provide an individual SCC for both UL and DL. The SCCs may be added and removed as required, while changing the PCC may require the UE 101 to undergo a handover. In LAA, eLAA, and feLAA, some or all of the SCells may operate in the unlicensed spectrum (referred to as "LAA SCells"), and the LAA SCells are assisted by a PCell operating in the licensed spectrum. When a UE is configured with more than one LAA SCell, the UE may receive UL grants on the configured LAA SCells indicating different PUSCH starting positions within a same subframe.

[00059] The PDSCH carries user data and higher-layer signaling to the UEs 101. The PDCCH carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 101 about the transport format, resource allocation, and HARQ information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 101b within a cell) may be performed at any of the RAN nodes 111 based on channel quality information fed back from any of the UEs 101. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 101.

[00060] The PDCCH uses CCEs to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets,

which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as REGs. Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the DCI and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[00061] Some implementations may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some implementations may utilize an EPDCCH that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more ECCEs. Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an EREGs. An ECCE may have other numbers of EREGs in some situations.

[00062] The RAN nodes 111 may be configured to communicate with one another via interface 112. In implementations where the system 100 is an LTE system (e.g., when CN 120 is an EPC 220 as in Figure 2), the interface 112 may be an X2 interface 112. The X2 interface may be defined between two or more RAN nodes 111 (e.g., two or more eNBs and the like) that connect to EPC 120, and/or between two eNBs connecting to EPC 120. In some implementations, the X2 interface may include an X2 user plane interface (X2-U) and an X2 control plane interface (X2-C). The X2-U may provide flow control mechanisms for user data packets transferred over the X2 interface, and may be used to communicate information about the delivery of user data between eNBs. For example, the X2-U may provide specific sequence number information for user data transferred from a MeNB to an SeNB; information about successful in sequence delivery of PDCP PDUs to a UE 101 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 101; information about a current minimum desired buffer size at the SeNB for transmitting to the UE user data; and the like. The X2-C may provide intra-LTE access mobility functionality, including context transfers from source to target eNBs, user plane transport control, etc.; load management functionality; as well as inter-cell interference coordination functionality.

[00063] In implementations where the system 100 is a 5G or NR system (e.g., when CN 120 is an 5GC 320 as in Figure 3), the interface 112 may be an Xn interface 112. The Xn interface is defined between two or more RAN nodes 111 (e.g., two or more gNBs and the like) that connect to 5GC 120, between a RAN node 111 (e.g., a gNB) connecting to 5GC 120 and an eNB, and/or between two eNBs connecting to 5GC 120. In some implementations, the Xn interface may include an Xn user plane (Xn-U) interface and an Xn control plane (Xn-C) interface. The Xn-U may provide non-guaranteed delivery of user plane PDUs and support/provide data forwarding and flow control functionality. The Xn-C may provide management and error handling functionality, functionality to manage the Xn-C interface; mobility support for UE 101 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 111. The mobility support may include context transfer from an old (source) serving RAN node 111 to new (target) serving RAN node 111; and control of user plane tunnels between old (source) serving RAN node 111 to new (target) serving RAN node 111. A protocol stack of the Xn-U may include a transport network layer built on Internet Protocol (IP) transport layer, and a GTP-U layer on top of a UDP and/or IP layer(s) to carry user plane PDUs. The Xn-C protocol stack may include an application layer signaling protocol (referred to as Xn Application Protocol (Xn-AP)) and a transport network layer that is built on SCTP. The SCTP may be on top of an IP layer, and may provide the guaranteed delivery of application layer messages. In the transport IP layer, point-to-point transmission is used to deliver the signaling PDUs. In other implementations, the Xn-U protocol stack and/or the Xn-C protocol stack may be same or similar to the user plane and/or control plane protocol stack(s) shown and described herein.

[00064] The RAN 110 is shown to be communicatively coupled to a core network—in this implementation, core network (CN) 120. The CN 120 may comprise a plurality of network elements 122, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 101) who are connected to the CN 120 via the RAN 110. The components of the CN 120 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In some implementations, NFV may be utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums

(described in further detail below). A logical instantiation of the CN 120 may be referred to as a network slice, and a logical instantiation of a portion of the CN 120 may be referred to as a network sub-slice. NFV architectures and infrastructures may be used to virtualize one or more network functions, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[00065] Generally, the application server 130 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS PS domain, LTE PS data services, etc.). The application server 130 can also be configured to support one or more communication services (e.g., VoIP sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101 via the EPC 120.

[00066] In implementations, the CN 120 may be a 5GC (referred to as "5GC 120" or the like), and the RAN 110 may be connected with the CN 120 via an NG interface 113. In implementations, the NG interface 113 may be split into two parts, an NG user plane (NG-U) interface 114, which carries traffic data between the RAN nodes 111 and a UPF, and the S1 control plane (NG-C) interface 115, which is a signaling interface between the RAN nodes 111 and AMFs. Implementations where the CN 120 is a 5GC 120 are discussed in more detail with regard to Figure 3.

[00067] In implementations, the CN 120 may be a 5G CN (referred to as "5GC 120" or the like), while in other implementations, the CN 120 may be an EPC). Where CN 120 is an EPC (referred to as "EPC 120" or the like), the RAN 110 may be connected with the CN 120 via an S1 interface 113. In implementations, the S1 interface 113 may be split into two parts, an S1 user plane (S1-U) interface 114, which carries traffic data between the RAN nodes 111 and the S-GW, and the S1-MME interface 115, which is a signaling interface between the RAN nodes 111 and MMEs.

[00068] Figure 2 illustrates an example architecture of a system 200 including a first CN, according to some implementations of the present disclosure. Figure 2 illustrates an example architecture of a system 200 including a first CN 220, in accordance with various implementations. In this example, system 200 may implement the LTE standard wherein the CN 220 is an EPC 220 that corresponds with CN 120 of Figure 1. Additionally, the UE 201 may be the same or similar as the UEs 101 of Figure 1, and the E-UTRAN 210 may be a RAN that is the same or similar to the RAN 110 of Figure 1, and which may include RAN nodes 111 discussed previously. The CN 220 may comprise MMEs 221, an S-GW 222, a P-GW 223, a HSS 224, and a SGSN 225.

[00069] The MMEs 221 may be similar in function to the control plane of legacy SGSN, and may implement MM functions to keep track of the current location of a UE 201. The MMEs 221 may perform various MM procedures to manage mobility aspects in access such as gateway selection and tracking area list management. MM (also referred to as "EPS MM" or "EMM" in E-UTRAN systems) may refer to all applicable procedures, methods, data storage, etc. that are used to maintain knowledge about a present location of the UE 201, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 201 and the MME 221 may include an MM or EMM sublayer, and an MM context may be established in the UE 201 and the MME 221 when an attach procedure is successfully completed. The MM context may be a data structure or database object that stores MM-related information of the UE 201. The MMEs 221 may be coupled with the HSS 224 via an S6a reference point, coupled with the SGSN 225 via an S3 reference point, and coupled with the S-GW 222 via an S11 reference point.

[00070] The SGSN 225 may be a node that serves the UE 201 by tracking the location of an individual UE 201 and performing security functions. In addition, the SGSN 225 may perform Inter-EPC node signaling for mobility between 2G/3G and E-UTRAN 3GPP access networks; PDN and S-GW selection as specified by the MMEs 221; handling of UE 201 time zone functions as specified by the MMEs 221; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 221 and the SGSN 225 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[00071] The HSS 224 may comprise a database for network users, including subscription-

related information to support the network entities' handling of communication sessions. The EPC 220 may comprise one or several HSSs 224, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 224 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 224 and the MMEs 221 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 220 between HSS 224 and the MMEs 221.

[00072] The S-GW 222 may terminate the S1 interface 113 ("S1-U" in Figure 2) toward the RAN 210, and routes data packets between the RAN 210 and the EPC 220. In addition, the S-GW 222 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The S11 reference point between the S-GW 222 and the MMEs 221 may provide a control plane between the MMEs 221 and the S-GW 222. The S-GW 222 may be coupled with the P-GW 223 via an S5 reference point.

[00073] The P-GW 223 may terminate an SGi interface toward a PDN 230. The P-GW 223 may route data packets between the EPC 220 and external networks such as a network including the application server 130 (alternatively referred to as an "AF") via an IP interface 125 (see e.g., Figure 1). In implementations, the P-GW 223 may be communicatively coupled to an application server (application server 130 of Figure 1 or PDN 230 in Figure 2) via an IP communications interface 125 (see, e.g., Figure 1). The S5 reference point between the P-GW 223 and the S-GW 222 may provide user plane tunneling and tunnel management between the P-GW 223 and the S-GW 222. The S5 reference point may also be used for S-GW 222 relocation due to UE 201 mobility and if the S-GW 222 needs to connect to a non-collocated P-GW 223 for the required PDN connectivity. The P-GW 223 may further include a node for policy enforcement and charging data collection (e.g., PCEF (not shown)). Additionally, the SGi reference point between the P-GW 223 and the packet data network (PDN) 230 may be an operator external public, a private PDN, or an intra operator packet data network, for example, for provision of IMS services. The P-GW 223 may be coupled with a PCRF 226 via a Gx reference point.

[00074] PCRF 226 is the policy and charging control element of the EPC 220. In a non-roaming scenario, there may be a single PCRF 226 in the Home Public Land Mobile Network (HPLMN) associated with a UE 201's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE 201's IP-CAN session, a Home PCRF (H-PCRF) within an HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 226 may be communicatively coupled to the application server 230 via the P-GW 223. The application server 230 may signal the PCRF 226 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 226 may provision this rule into a PCEF (not shown) with the appropriate TFT and QCI, which commences the QoS and charging as specified by the application server 230. The Gx reference point between the PCRF 226 and the P-GW 223 may allow for the transfer of QoS policy and charging rules from the PCRF 226 to PCEF in the P-GW 223. An Rx reference point may reside between the PDN 230 (or "AF 230") and the PCRF 226.

[00075] Figure 3 illustrates an architecture of a system 300 including a second CN, according to some implementations of the present disclosure. The system 300 is shown to include a UE 301, which may be the same or similar to the UEs 101 and UE 201 discussed previously; a (R)AN 310, which may be the same or similar to the RAN 110 and RAN 210 discussed previously, and which may include RAN nodes 111 discussed previously; and a DN 303, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 320. The 5GC 320 may include an AUSF 322; an AMF 321; a SMF 324; a NEF 323; a PCF 326; a NRF 325; a UDM 327; an AF 328; a UPF 302; and a NSSF 329.

[00076] The UPF 302 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 303, and a branching point to support multi-homed PDU session. The UPF 302 may also perform packet routing and forwarding, perform packet inspection, enforce the user plane part of policy rules, lawfully intercept packets (UP collection), perform traffic usage reporting, perform QoS handling for a user plane (e.g., packet filtering, gating, UL/DL rate enforcement), perform Uplink Traffic verification (e.g., SDF to QoS flow mapping), transport level packet marking in the uplink and downlink, and perform downlink packet buffering and downlink data notification triggering. UPF 302 may include an uplink

classifier to support routing traffic flows to a data network. The DN 303 may represent various network operator services, Internet access, or third party services. DN 303 may include, or be similar to, application server 130 discussed previously. The UPF 302 may interact with the SMF 324 via an N4 reference point between the SMF 324 and the UPF 302.

[00077] The AUSF 322 may store data for authentication of UE 301 and handle authentication-related functionality. The AUSF 322 may facilitate a common authentication framework for various access types. The AUSF 322 may communicate with the AMF 321 via an N12 reference point between the AMF 321 and the AUSF 322; and may communicate with the UDM 327 via an N13 reference point between the UDM 327 and the AUSF 322. Additionally, the AUSF 322 may exhibit an Nausf service-based interface.

[00078] The AMF 321 may be responsible for registration management (e.g., for registering UE 301, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 321 may be a termination point for the N11 reference point between the AMF 321 and the SMF 324. The AMF 321 may provide transport for SM messages between the UE 301 and the SMF 324, and act as a transparent proxy for routing SM messages. AMF 321 may also provide transport for SMS messages between UE 301 and an SMSF (not shown by Figure 3). AMF 321 may act as SEAF, which may include interaction with the AUSF 322 and the UE 301, receipt of an intermediate key that was established as a result of the UE 301 authentication process. Where USIM based authentication is used, the AMF 321 may retrieve the security material from the AUSF 322. AMF 321 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 321 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 310 and the AMF 321; and the AMF 321 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.

[00079] AMF 321 may also support NAS signalling with a UE 301 over an N3 IWF interface. The N3IWF may be used to provide access to untrusted entities. N3IWF may be a termination point for the N2 interface between the (R)AN 310 and the AMF 321 for the control plane, and may

be a termination point for the N3 reference point between the (R)AN 310 and the UPF 302 for the user plane. As such, the AMF 321 may handle N2 signalling from the SMF 324 and the AMF 321 for PDU sessions and QoS, encapsulate/de-encapsulate packets for IPSec and N3 tunnelling, mark N3 user-plane packets in the uplink, and enforce QoS corresponding to N3 packet marking taking into account QoS requirements associated with such marking received over N2. N3IWF may also relay uplink and downlink control-plane NAS signalling between the UE 301 and AMF 321 via an N1 reference point between the UE 301 and the AMF 321, and relay uplink and downlink user-plane packets between the UE 301 and UPF 302. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 301. The AMF 321 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 321 and an N17 reference point between the AMF 321 and a 5G-EIR (not shown by Figure 3).

[00080] The UE 301 may need to register with the AMF 321 in order to receive network services. RM is used to register or deregister the UE 301 with the network (e.g., AMF 321), and establish a UE context in the network (e.g., AMF 321). The UE 301 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 301 is not registered with the network, and the UE context in AMF 321 holds no valid location or routing information for the UE 301 so the UE 301 is not reachable by the AMF 321. In the RM-REGISTERED state, the UE 301 is registered with the network, and the UE context in AMF 321 may hold a valid location or routing information for the UE 301 so the UE 301 is reachable by the AMF 321. In the RM-REGISTERED state, the UE 301 may perform mobility Registration Update procedures, perform periodic Registration Update procedures triggered by expiration of the periodic update timer (e.g., to notify the network that the UE 301 is still active), and perform a Registration Update procedure to update UE capability information or to re-negotiate protocol parameters with the network, among others.

[00081] The AMF 321 may store one or more RM contexts for the UE 301, where each RM context is associated with a specific access to the network. The RM context may be a data structure, database object, etc. that indicates or stores, inter alia, a registration state per access type and the periodic update timer. The AMF 321 may also store a 5GC MM context that may be the same or similar to the (E)MM context discussed previously. In various implementations, the AMF 321 may

store a CE mode B Restriction parameter of the UE 301 in an associated MM context or RM context. The AMF 321 may also derive the value, when needed, from the UE's usage setting parameter already stored in the UE context (and/or MM/RM context).

[00082] CM may be used to establish and release a signaling connection between the UE 301 and the AMF 321 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 301 and the CN 320, and comprises both the signaling connection between the UE and the AN (e.g., RRC connection or UE-N3IWF connection for non-3GPP access) and the N2 connection for the UE 301 between the AN (e.g., RAN 310) and the AMF 321. The UE 301 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 301 is operating in the CM-IDLE state/mode, the UE 301 may have no NAS signaling connection established with the AMF 321 over the N1 interface, and there may be (R)AN 310 signaling connection (e.g., N2 and/or N3 connections) for the UE 301. When the UE 301 is operating in the CM-CONNECTED state/mode, the UE 301 may have an established NAS signaling connection with the AMF 321 over the N1 interface, and there may be a (R)AN 310 signaling connection (e.g., N2 and/or N3 connections) for the UE 301. Establishment of an N2 connection between the (R)AN 310 and the AMF 321 may cause the UE 301 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 301 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 310 and the AMF 321 is released.

[00083] The SMF 324 may be responsible for SM (e.g., session establishment, modify and release, including tunnel maintain between UPF and AN node); UE IP address allocation and management (including optional authorization); selection and control of UP function; configuring traffic steering at UPF to route traffic to proper destination; termination of interfaces toward policy control functions; controlling part of policy enforcement and QoS; lawful intercept (for SM events and interface to LI system); termination of SM parts of NAS messages; downlink data notification; initiating AN specific SM information, sent via AMF over N2 to AN; and determining SSC mode of a session. SM may refer to management of a PDU session, and a PDU session or "session" may refer to a PDU connectivity service that provides or enables the exchange of PDUs between a UE 301 and a data network (DN) 303 identified by a Data Network Name (DNN). PDU sessions may

be established upon UE 301 request, modified upon UE 301 and 5GC 320 request, and released upon UE 301 and 5GC 320 request using NAS SM signaling exchanged over the N1 reference point between the UE 301 and the SMF 324. Upon request from an application server, the 5GC 320 may trigger a specific application in the UE 301. In response to receipt of the trigger message, the UE 301 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 301. The identified application(s) in the UE 301 may establish a PDU session to a specific DNN. The SMF 324 may check whether the UE 301 requests are compliant with user subscription information associated with the UE 301. In this regard, the SMF 324 may retrieve and/or request to receive update notifications on SMF 324 level subscription data from the UDM 327.

[00084] The SMF 324 may include the following roaming functionality: handling local enforcement to apply QoS SLAs (VPLMN); charging data collection and charging interface (VPLMN); lawful intercept (in VPLMN for SM events and interface to LI system); and support for interaction with external DN for transport of signalling for PDU session authorization/authentication by external DN. An N16 reference point between two SMFs 324 may be included in the system 300, which may be between another SMF 324 in a visited network and the SMF 324 in the home network in roaming scenarios. Additionally, the SMF 324 may exhibit the Nsmf service-based interface.

[00085] The NEF 323 may provide means for securely exposing the services and capabilities provided by 3GPP network functions for third party, internal exposure/re-exposure, Application Functions (e.g., AF 328), edge computing or fog computing systems, etc. In such implementations, the NEF 323 may authenticate, authorize, and/or throttle the AFs. NEF 323 may also translate information exchanged with the AF 328 and information exchanged with internal network functions. For example, the NEF 323 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 323 may also receive information from other network functions (NFs) based on exposed capabilities of other network functions. This information may be stored at the NEF 323 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 323 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 323 may exhibit an Nnef service-based

interface.

[00086] The NRF 325 may support service discovery functions, receive NF discovery requests from NF instances, and provide the information of the discovered NF instances to the NF instances. NRF 325 also maintains information of available NF instances and their supported services. As used herein, the terms "instantiate," "instantiation," and the like may refer to the creation of an instance, and an "instance" may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. Additionally, the NRF 325 may exhibit the Nnrf service-based interface.

[00087] The PCF 326 may provide policy rules to control plane function(s) to enforce them, and may also support unified policy framework to govern network behaviour. The PCF 326 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 327. The PCF 326 may communicate with the AMF 321 via an N15 reference point between the PCF 326 and the AMF 321, which may include a PCF 326 in a visited network and the AMF 321 in case of roaming scenarios. The PCF 326 may communicate with the AF 328 via an N5 reference point between the PCF 326 and the AF 328; and with the SMF 324 via an N7 reference point between the PCF 326 and the SMF 324. The system 300 and/or CN 320 may also include an N24 reference point between the PCF 326 (in the home network) and a PCF 326 in a visited network. Additionally, the PCF 326 may exhibit an Npcf service-based interfa

[00088] The UDM 327 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 301. For example, subscription data may be communicated between the UDM 327 and the AMF 321 via an N8 reference point between the UDM 327 and the AMF. The UDM 327 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 3). The UDR may store subscription data and policy data for the UDM 327 and the PCF 326, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 301) for the NEF 323. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 327, PCF 326, and NEF 323 to access a particular set of the stored data, as well as to read, update (e.g., add, modify), delete, and subscribe to notification of relevant data changes in the UDR. The UDM may include a UDM-FE, which is in

charge of processing credentials, location management, subscription management and so on. Several different front ends may serve the same user in different transactions. The UDM-FE accesses subscription information stored in the UDR and performs authentication credential processing, user identification handling, access authorization, registration/mobility management, and subscription management. The UDR may interact with the SMF 324 via an N10 reference point between the UDM 327 and the SMF 324. UDM 327 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 327 may exhibit the Nudm service-based interface.

[00089] The AF 328 may provide application influence on traffic routing, provide access to the NCE, and interact with the policy framework for policy control. The NCE may be a mechanism that allows the 5GC 320 and AF 328 to provide information to each other via NEF 323, which may be used for edge computing implementations. In such implementations, the network operator and third party services may be hosted close to the UE 301 access point of attachment to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network. For edge computing implementations, the 5GC may select a UPF 302 close to the UE 301 and execute traffic steering from the UPF 302 to DN 303 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 328. In this way, the AF 328 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 328 is considered to be a trusted entity, the network operator may permit AF 328 to interact directly with relevant NFs. Additionally, the AF 328 may exhibit an Naf service-based interface.

[00090] The NSSF 329 may select a set of network slice instances serving the UE 301. The NSSF 329 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 329 may also determine the AMF set to be used to serve the UE 301, or a list of candidate AMF(s) 321 based on a suitable configuration and possibly by querying the NRF 325. The selection of a set of network slice instances for the UE 301 may be triggered by the AMF 321 with which the UE 301 is registered by interacting with the NSSF 329, which may lead to a change of AMF 321. The NSSF 329 may interact with the AMF 321 via an N22 reference point between AMF 321 and NSSF 329; and may communicate with another NSSF 329 in a visited network via

an N31 reference point (not shown by Figure 3). Additionally, the NSSF 329 may exhibit an Nnssf service-based interface.

[00091] As discussed previously, the CN 320 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 301 to/from other entities, such as an SMS-GMSC/IWMSC/SMS-router. The SMS may also interact with AMF 321 and UDM 327 for a notification procedure that the UE 301 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 327 when UE 301 is available for SMS).

[00092] The CN 120 may also include other elements that are not shown by Figure 3, such as a Data Storage system/architecture, a 5G-EIR, a SEPP, and the like. The Data Storage system may include a SDSF, an UDSF, and/or the like. Any NF may store and retrieve unstructured data into/from the UDSF (e.g., UE contexts), via N18 reference point between any NF and the UDSF (not shown by Figure 3). Individual NFs may share a UDSF for storing their respective unstructured data or individual NFs may each have their own UDSF located at or near the individual NFs. Additionally, the UDSF may exhibit an Nudsf service-based interface (not shown by Figure 3). The 5G-EIR may be an NF that checks the status of PEI for determining whether particular equipment/entities are blacklisted from the network; and the SEPP may be a non-transparent proxy that performs topology hiding, message filtering, and policing on inter-PLMN control plane interfaces.

[00093] Additionally, there may be many more reference points and/or service-based interfaces between the NF services in the NFs; however, these interfaces and reference points have been omitted from Figure 3 for clarity. In one example, the CN 320 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 221) and the AMF 321 in order to enable interworking between CN 320 and CN 220. Other example interfaces/reference points may include an N5g-EIR service-based interface exhibited by a 5G-EIR, an N27 reference point between the NRF in the visited network and the NRF in the home network; and an N31 reference point between the NSSF in the visited network and the NSSF in the home network.

[00094] Figure 4 illustrates an example of infrastructure equipment 400, according to some implementations of the present disclosure. The infrastructure equipment 400 (or "system 400") may be implemented as a base station, radio head, RAN node such as the RAN nodes 111 and/or AP 106 shown and described previously, application server(s) 130, and/or any other element/device discussed herein. In other examples, the system 400 could be implemented in or by a UE.

[00095] The system 400 includes application circuitry 405, baseband circuitry 410, one or more radio front end modules (RFEMs) 415, memory circuitry 420, power management integrated circuitry (PMIC) 425, power tee circuitry 430, network controller circuitry 435, network interface connector 440, satellite positioning circuitry 445, and user interface 450. In some implementations, the device 400 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other implementations, the components described below may be included in more than one device. For example, said circuitries may be separately included in more than one device for CRAN, vBBU, or other like implementations.

[00096] Application circuitry 405 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 405 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 400. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[00097] The processor(s) of application circuitry 405 may include, for example, one or more processor cores (CPUs), one or more application processors, one or more graphics processing units (GPUs), one or more reduced instruction set computing (RISC) processors, one or more Acorn RISC Machine (ARM) processors, one or more complex instruction set computing (CISC) processors, one or more digital signal processors (DSP), one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, or any suitable combination thereof. In some implementations, the application circuitry 405 may comprise, or may be, a special-purpose processor/controller to operate according to the various implementations herein. As examples, the processor(s) of application circuitry 405 may include one or more Apple A-series processors, Intel Pentium®, Core®, or Xeon® processor(s); Advanced Micro Devices (AMD) Ryzen® processor(s), Accelerated Processing Units (APUs), or Epyc® processors; ARM-based processor(s) licensed from ARM Holdings, Ltd. such as the ARM Cortex-A family of processors and the ThunderX2® provided by Cavium(TM), Inc.; a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior P-class processors; and/or the like. In some implementations, the system 400 may not utilize application circuitry 405, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[00098] In some implementations, the application circuitry 405 may include one or more hardware accelerators, which may be microprocessors, programmable processing devices, or the like. The one or more hardware accelerators may include, for example, computer vision (CV) and/or deep learning (DL) accelerators. As examples, the programmable processing devices may be one or more a field-programmable devices (FPDs) such as field-programmable gate arrays (FPGAs) and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such implementations, the circuitry of application circuitry 405 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various implementations discussed herein. In such implementations, the circuitry of application circuitry 405 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash

memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up-tables (LUTs) and the like.

[00099] The baseband circuitry 410 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 410 are discussed infra with regard to Figure 6.

[000100] User interface circuitry 450 may include one or more user interfaces designed to enable user interaction with the system 400 or peripheral component interfaces designed to enable peripheral component interaction with the system 400. User interfaces may include, but are not limited to, one or more physical or virtual buttons (e.g., a reset button), one or more indicators (e.g., light emitting diodes (LEDs)), a physical keyboard or keypad, a mouse, a touchpad, a touchscreen, speakers or other audio emitting devices, microphones, a printer, a scanner, a headset, a display screen or display device, etc. Peripheral component interfaces may include, but are not limited to, a nonvolatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, etc.

[000101] The radio front end modules (RFEMs) 415 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 611 of Figure6 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 415, which incorporates both mmWave antennas and sub-mmWave.

[000102] The memory circuitry 420 may include one or more of volatile memory including dynamic random access memory (DRAM) and/or synchronous dynamic random access memory (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM),

magnetoresistive random access memory (MRAM), etc., and may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®. Memory circuitry 420 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[000103] The PMIC 425 may include voltage regulators, surge protectors, power alarm detection circuitry, and one or more backup power sources such as a battery or capacitor. The power alarm detection circuitry may detect one or more of brown out (under-voltage) and surge (over-voltage) conditions. The power tee circuitry 430 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 400 using a single cable.

[000104] The network controller circuitry 435 may provide connectivity to a network using a standard network interface protocol such as Ethernet, Ethernet over GRE Tunnels, Ethernet over Multiprotocol Label Switching (MPLS), or some other suitable protocol. Network connectivity may be provided to/from the infrastructure equipment 400 via network interface connector 440 using a physical connection, which may be electrical (commonly referred to as a "copper interconnect"), optical, or wireless. The network controller circuitry 435 may include one or more dedicated processors and/or FPGAs to communicate using one or more of the aforementioned protocols. In some implementations, the network controller circuitry 435 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[000105] The positioning circuitry 445 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a global navigation satellite system (GNSS). Examples of navigation satellite constellations (or GNSS) include United States' Global Positioning System (GPS), Russia's Global Navigation System (GLONASS), the European Union's Galileo system, China's BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., Navigation with Indian Constellation (NAVIC), Japan's Quasi-Zenith Satellite System (QZSS), France's Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), etc.), or the like. The positioning circuitry 445 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with

components of a positioning network, such as navigation satellite constellation nodes. In some implementations, the positioning circuitry 445 may include a Micro-Technology for Positioning, Navigation, and Timing (Micro-PNT) IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 445 may also be part of, or interact with, the baseband circuitry 410 and/or RFEMs 415 to communicate with the nodes and components of the positioning network. The positioning circuitry 445 may also provide position data and/or time data to the application circuitry 405, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 111, etc.), or the like.

[000106] The components shown by Figure 4 may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[000107] Figure 5 illustrates an example of a platform 500, according to some implementations of the present disclosure. In implementations, the computer platform 500 may be suitable for use as UEs 101, 201, 301, application servers 130, and/or any other element/device discussed herein. The platform 500 may include any combinations of the components shown in the example. The components of platform 500 may be implemented as integrated circuits (ICs), portions thereof, discrete electronic devices, or other modules, logic, hardware, software, firmware, or a combination thereof adapted in the computer platform 500, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 5 is intended to show a high level view of components of the computer platform 500. However, some of the components shown may be omitted, additional components may be present, and different arrangement of the components shown may occur in other implementations.

[000108] Application circuitry 505 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, RTC, timer-

counters including interval and watchdog timers, general purpose I/O, memory card controllers such as SD MMC or similar, USB interfaces, MIPI interfaces, and JTAG test access ports. The processors (or cores) of the application circuitry 505 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 500. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[000109] The processor(s) of application circuitry 405 may include, for example, one or more processor cores, one or more application processors, one or more GPUs, one or more RISC processors, one or more ARM processors, one or more CISC processors, one or more DSP, one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, a multithreaded processor, an ultra-low voltage processor, an embedded processor, some other known processing element, or any suitable combination thereof. In some implementations, the application circuitry 405 may comprise, or may be, a special-purpose processor/controller to operate according to the various implementations herein.

[000110] As examples, the processor(s) of application circuitry 505 may include an Apple A-series processor. The processors of the application circuitry 505 may also be one or more of an Intel® Architecture Core™ based processor, such as a Quark™, an Atom™, an i3, an i5, an i7, or an MCU-class processor, or another such processor available from Intel® Corporation, Santa Clara, CA; Advanced Micro Devices (AMD) Ryzen® processor(s) or Accelerated Processing Units (APUs); Snapdragon™ processor(s) from Qualcomm® Technologies, Inc., Texas Instruments, Inc.® Open Multimedia Applications Platform (OMAP)™ processor(s); a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior M-class, Warrior I-class, and Warrior P-class processors; an ARM-based design licensed from ARM Holdings, Ltd., such as the ARM Cortex-A, Cortex-R, and Cortex-M family of processors; or the like. In some implementations, the application circuitry 505 may be a part of a system on a chip (SoC) in which the application circuitry 505 and other components are formed into a single integrated circuit, or a single package.

[000111] Additionally or alternatively, application circuitry 505 may include circuitry such as, but not limited to, one or more a field-programmable devices (FPDs) such as FPGAs and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such implementations, the circuitry of application circuitry 505 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various implementations discussed herein. In such implementations, the circuitry of application circuitry 505 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up tables (LUTs) and the like.

[000112] The baseband circuitry 510 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 510 are discussed infra with regard to Figure6.

[000113] The RFEMs 515 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 611 of Figure 6 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 515, which incorporates both mmWave antennas and sub-mmWave.

[000114] The memory circuitry 520 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 520 may include one or more of volatile memory including random access memory (RAM), dynamic RAM (DRAM) and/or synchronous dynamic RAM (SDRAM), and nonvolatile memory (NVM)

including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM), magnetoresistive random access memory (MRAM), etc. The memory circuitry 520 may be developed in accordance with a Joint Electron Devices Engineering Council (JEDEC) low power double data rate (LPDDR)-based design, such as LPDDR2, LPDDR3, LPDDR4, or the like. Memory circuitry 520 may be implemented as one or more of solder down packaged integrated circuits, single die package (SDP), dual die package (DDP) or quad die package (Q17P), socketed memory modules, dual inline memory modules (DIMMs) including microDIMMs or MiniDIMMs, and/or soldered onto a motherboard via a ball grid array (BGA). In low power implementations, the memory circuitry 520 may be on-die memory or registers associated with the application circuitry 505. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 520 may include one or more mass storage devices, which may include, inter alia, a solid state disk drive (SSDD), hard disk drive (HDD), a micro HDD, resistance change memories, phase change memories, holographic memories, or chemical memories, among others. For example, the computer platform 500 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[000115] Removable memory circuitry 523 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 500. These portable data storage devices may be used for mass storage purposes, and may include, for example, flash memory cards (e.g., Secure Digital (SD) cards, microSD cards, xD picture cards, and the like), and USB flash drives, optical discs, external HDDs, and the like.

[000116] The platform 500 may also include interface circuitry (not shown) that is used to connect external devices with the platform 500. The external devices connected to the platform 500 via the interface circuitry include sensor circuitry 521 and electro-mechanical components (EMCs) 522, as well as removable memory devices coupled to removable memory circuitry 523.

[000117] The sensor circuitry 521 include devices, modules, or subsystems whose purpose is to detect events or changes in its environment and send the information (sensor data) about the detected events to some other a device, module, subsystem, etc. Examples of such sensors include, inter alia, inertia measurement units (IMUs) comprising accelerometers, gyroscopes, and/or

magnetometers; microelectromechanical systems (MEMS) or nanoelectromechanical systems (NEMS) comprising 3-axis accelerometers, 3-axis gyroscopes, and/or magnetometers; level sensors; flow sensors; temperature sensors (e.g., thermistors); pressure sensors; barometric pressure sensors; gravimeters; altimeters; image capture devices (e.g., cameras or lensless apertures); light detection and ranging (LiDAR) sensors; proximity sensors (e.g., infrared radiation detector and the like), depth sensors, ambient light sensors, ultrasonic transceivers; microphones or other like audio capture devices; etc.

[000118] EMCs 522 include devices, modules, or subsystems whose purpose is to enable platform 500 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 522 may be configured to generate and send messages/signalling to other components of the platform 500 to indicate a current state of the EMCs 522. Examples of the EMCs 522 include one or more power switches, relays including electromechanical relays (EMRs) and/or solid state relays (SSRs), actuators (e.g., valve actuators, etc.), an audible sound generator, a visual warning device, motors (e.g., DC motors, stepper motors, etc.), wheels, thrusters, propellers, claws, clamps, hooks, and/or other like electro-mechanical components. In implementations, platform 500 is configured to operate one or more EMCs 522 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[000119] In some implementations, the interface circuitry may connect the platform 500 with positioning circuitry 545. The positioning circuitry 545 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a GNSS. Examples of navigation satellite constellations (or GNSS) include United States' GPS, Russia's GLONASS, the European Union's Galileo system, China's BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., NAVIC), Japan's QZSS, France's DORIS, etc.), or the like. The positioning circuitry 545 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as navigation satellite constellation nodes. In some implementations, the positioning circuitry 545 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 545 may also be part of,

or interact with, the baseband circuitry 410 and/or RFEMs 515 to communicate with the nodes and components of the positioning network. The positioning circuitry 545 may also provide position data and/or time data to the application circuitry 505, which may use the data to synchronize operations with various infrastructure (e.g., radio base stations), for turn-by-turn navigation applications, or the like.

[000120] In some implementations, the interface circuitry may connect the platform 500 with Near-Field Communication (NFC) circuitry 540. NFC circuitry 540 is configured to provide contactless, short-range communications based on radio frequency identification (RFID) standards, wherein magnetic field induction is used to enable communication between NFC circuitry 540 and NFC-enabled devices external to the platform 500 (e.g., an "NFC touchpoint"). NFC circuitry 540 comprises an NFC controller coupled with an antenna element and a processor coupled with the NFC controller. The NFC controller may be a chip/IC providing NFC functionalities to the NFC circuitry 540 by executing NFC controller firmware and an NFC stack. The NFC stack may be executed by the processor to control the NFC controller, and the NFC controller firmware may be executed by the NFC controller to control the antenna element to emit short-range RF signals. The RF signals may power a passive NFC tag (e.g., a microchip embedded in a sticker or wristband) to transmit stored data to the NFC circuitry 540, or initiate data transfer between the NFC circuitry 540 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 500.

[000121] The driver circuitry 546 may include software and hardware elements that operate to control particular devices that are embedded in the platform 500, attached to the platform 500, or otherwise communicatively coupled with the platform 500. The driver circuitry 546 may include individual drivers allowing other components of the platform 500 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 500. For example, driver circuitry 546 may include a display driver to control and allow access to a display device, a touchscreen driver to control and allow access to a touchscreen interface of the platform 500, sensor drivers to obtain sensor readings of sensor circuitry 521 and control and allow access to sensor circuitry 521, EMC drivers to obtain actuator positions of the EMCs 522 and/or control and allow access to the EMCs 522, a camera driver to control and allow access to an

embedded image capture device, audio drivers to control and allow access to one or more audio devices.

[000122] The power management integrated circuitry (PMIC) 525 (also referred to as "power management circuitry 525") may manage power provided to various components of the platform 500. In particular, with respect to the baseband circuitry 510, the PMIC 525 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 525 may often be included when the platform 500 is capable of being powered by a battery 530, for example, when the device is included in a UE 101, 201, 301.

[000123] In some implementations, the PMIC 525 may control, or otherwise be part of, various power saving mechanisms of the platform 500. For example, if the platform 500 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the platform 500 may power down for brief intervals of time and thus save power. If there is no data traffic activity for an extended period of time, then the platform 500 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The platform 500 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The platform 500 may not receive data in this state; in order to receive data, it must transition back to RRC_Connected state. An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[000124] A battery 530 may power the platform 500, although in some examples the platform 500 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 530 may be a lithium ion battery, a metal-air battery, such as a zinc-air battery, an aluminum-air battery, a lithium-air battery, and the like. In some implementations, such as in V2X applications, the battery 530 may be a typical lead-acid automotive battery.

[000125] In some implementations, the battery 530 may be a "smart battery," which includes or is coupled with a Battery Management System (BMS) or battery monitoring integrated circuitry. The BMS may be included in the platform 500 to track the state of charge (SoCh) of the battery 530. The BMS may be used to monitor other parameters of the battery 530 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 530. The BMS may communicate the information of the battery 530 to the application circuitry 505 or other components of the platform 500. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 505 to directly monitor the voltage of the battery 530 or the current flow from the battery 530. The battery parameters may be used to determine actions that the platform 500 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[000126] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 530. In some examples, the power block XS30 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 500. In these examples, a wireless battery charging circuit may be included in the BMS. The specific charging circuits chosen may depend on the size of the battery 530, and thus, the current required. The charging may be performed using the Airfuel standard promulgated by the Airfuel Alliance, the Qi wireless charging standard promulgated by the Wireless Power Consortium, or the Rezence charging standard promulgated by the Alliance for Wireless Power, among others.

[000127] User interface circuitry 550 includes various input/output (I/O) devices present within, or connected to, the platform 500, and includes one or more user interfaces designed to enable user interaction with the platform 500 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 500. The user interface circuitry 550 includes input device circuitry and output device circuitry. Input device circuitry includes any physical or virtual means for accepting an input including, inter alia, one or more physical or virtual buttons (e.g., a reset button), a physical keyboard, keypad, mouse, touchpad, touchscreen, microphones, scanner, headset, and/or the like. The output device circuitry includes any physical or virtual means for showing information or otherwise conveying information, such as sensor readings, actuator position(s), or other like information. Output device circuitry may include any number and/or

combinations of audio or visual display, including, inter alia, one or more simple visual outputs/indicators (e.g., binary status indicators (e.g., light emitting diodes (LEDs)) and multi-character visual outputs, or more complex outputs such as display devices or touchscreens (e.g., Liquid Chrystal Displays (LCD), LED displays, quantum dot displays, projectors, etc.), with the output of characters, graphics, multimedia objects, and the like being generated or produced from the operation of the platform 500. The output device circuitry may also include speakers or other audio emitting devices, printer(s), and/or the like. In some implementations, the sensor circuitry 521 may be used as the input device circuitry (e.g., an image capture device, motion capture device, or the like) and one or more EMCs may be used as the output device circuitry (e.g., an actuator to provide haptic feedback or the like). In another example, NFC circuitry comprising an NFC controller coupled with an antenna element and a processing device may be included to read electronic tags and/or connect with another NFC-enabled device. Peripheral component interfaces may include, but are not limited to, a non-volatile memory port, a USB port, an audio jack, a power supply interface, etc.

[000128] Although not shown, the components of platform 500 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIx, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[000129] Figure 6 illustrates example components of baseband circuitry 610 and radio front end modules (RFEM) 615, according to some implementations of the present disclosure. The baseband circuitry 610 corresponds to the baseband circuitry 410 and 510 of Figures 4 and 5, respectively. The RFEM 615 corresponds to the RFEM 415 and 515 of Figures 4 and 5, respectively. As shown, the RFEMs 615 may include Radio Frequency (RF) circuitry 606, front-end module (FEM) circuitry 608, antenna array 611 coupled together at least as shown.

[000130] The baseband circuitry 610 includes circuitry and/or control logic configured to carry out various radio/network protocol and radio control functions that enable communication with one or more radio networks via the RF circuitry 606. The radio control functions may include, but

are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some implementations, modulation/demodulation circuitry of the baseband circuitry 610 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some implementations, encoding/decoding circuitry of the baseband circuitry 610 may include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Implementations of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other implementations. The baseband circuitry 610 is configured to process baseband signals received from a receive signal path of the RF circuitry 606 and to generate baseband signals for a transmit signal path of the RF circuitry 606. The baseband circuitry 610 is configured to interface with application circuitry 405/505 (see Figures 4 and 5) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 606. The baseband circuitry 610 may handle various radio control functions.

[000131] The aforementioned circuitry and/or control logic of the baseband circuitry 610 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 604A, a 4G/LTE baseband processor 604B, a 5G/NR baseband processor 604C, or some other baseband processor(s) 604D for other existing generations, generations in development or to be developed in the future (e.g., sixth generation (6G), etc.). In other implementations, some or all of the functionality of baseband processors 604A-D may be included in modules stored in the memory 604G and executed via a Central Processing Unit (CPU) 604E. In other implementations, some or all of the functionality of baseband processors 604A-D may be provided as hardware accelerators (e.g., FPGAs, ASICs, etc.) loaded with the appropriate bit streams or logic blocks stored in respective memory cells. In various implementations, the memory 604G may store program code of a real-time OS (RTOS), which when executed by the CPU 604E (or other baseband processor), is to cause the CPU 604E (or other baseband processor) to manage resources of the baseband circuitry 610, schedule tasks, etc. Examples of the RTOS may include Operating System Embedded (OSE)™ provided by Enea®, Nucleus RTOS™ provided by Mentor Graphics®, Versatile Real-Time Executive (VRTX) provided by Mentor Graphics®, ThreadX™ provided by Express Logic®, FreeRTOS, REX OS provided by Qualcomm®, OKL4 provided by Open Kernel (OK) Labs®, or any other suitable RTOS, such as

those discussed herein. In addition, the baseband circuitry 610 includes one or more audio digital signal processor(s) (DSP) 604F. The audio DSP(s) 604F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other implementations.

[000132] In some implementations, each of the processors 604A-XT104E include respective memory interfaces to send/receive data to/from the memory 604G. The baseband circuitry 610 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as an interface to send/receive data to/from memory external to the baseband circuitry 610; an application circuitry interface to send/receive data to/from the application circuitry 405/505 of FIGS. 4-XT); an RF circuitry interface to send/receive data to/from RF circuitry 606 of Figure 6; a wireless hardware connectivity interface to send/receive data to/from one or more wireless hardware elements (e.g., Near Field Communication (NFC) components, Bluetooth®/ Bluetooth® Low Energy components, Wi-Fi® components, and/or the like); and a power management interface to send/receive power or control signals to/from the PMIC 525.

[000133] In alternate implementations (which may be combined with the above described implementations), baseband circuitry 610 comprises one or more digital baseband systems, which are coupled with one another via an interconnect subsystem and to a CPU subsystem, an audio subsystem, and an interface subsystem. The digital baseband subsystems may also be coupled to a digital baseband interface and a mixed-signal baseband subsystem via another interconnect subsystem. Each of the interconnect subsystems may include a bus system, point-to-point connections, network-on-chip (NOC) structures, and/or some other suitable bus or interconnect technology, such as those discussed herein. The audio subsystem may include DSP circuitry, buffer memory, program memory, speech processing accelerator circuitry, data converter circuitry such as analog-to-digital and digital-to-analog converter circuitry, analog circuitry including one or more of amplifiers and filters, and/or other like components. In an aspect of the present disclosure, baseband circuitry 610 may include protocol processing circuitry with one or more instances of control circuitry (not shown) to provide control functions for the digital baseband circuitry and/or radio frequency circuitry (e.g., the radio front end modules 615).

[000134] Although not shown by Figure 6, in some implementations, the baseband circuitry 610 includes individual processing device(s) to operate one or more wireless communication protocols (e.g., a "multi-protocol baseband processor" or "protocol processing circuitry") and individual processing device(s) to implement PHY layer functions. In these implementations, the PHY layer functions include the aforementioned radio control functions. In these implementations, the protocol processing circuitry operates or implements various protocol layers/entities of one or more wireless communication protocols. In a first example, the protocol processing circuitry may operate LTE protocol entities and/or 5G/NR protocol entities when the baseband circuitry 610 and/or RF circuitry 606 are part of mmWave communication circuitry or some other suitable cellular communication circuitry. In the first example, the protocol processing circuitry would operate MAC, RLC, PDCP, SDAP, RRC, and NAS functions. In a second example, the protocol processing circuitry may operate one or more IEEE-based protocols when the baseband circuitry 610 and/or RF circuitry 606 are part of a Wi-Fi communication system. In the second example, the protocol processing circuitry would operate Wi-Fi MAC and logical link control (LLC) functions. The protocol processing circuitry may include one or more memory structures (e.g., 604G) to store program code and data for operating the protocol functions, as well as one or more processing cores to execute the program code and perform various operations using the data. The baseband circuitry 610 may also support radio communications for more than one wireless protocol.

[000135] The various hardware elements of the baseband circuitry 610 discussed herein may be implemented, for example, as a solder-down substrate including one or more integrated circuits (ICs), a single packaged IC soldered to a main circuit board or a multi-chip module containing two or more ICs. In one example, the components of the baseband circuitry 610 may be suitably combined in a single chip or chipset, or disposed on a same circuit board. In another example, some or all of the constituent components of the baseband circuitry 610 and RF circuitry 606 may be implemented together such as, for example, a system on a chip (SoC) or System-in-Package (SiP). In another example, some or all of the constituent components of the baseband circuitry 610 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 606 (or multiple instances of RF circuitry 606). In yet another example, some or all of the constituent components of the baseband circuitry 610 and the application circuitry 405/505 may be

implemented together as individual SoCs mounted to a same circuit board (e.g., a "multi-chip package").

[000136] In some implementations, the baseband circuitry 610 may provide for communication compatible with one or more radio technologies. For example, in some implementations, the baseband circuitry 610 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Implementations in which the baseband circuitry 610 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[000137] RF circuitry 606 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various implementations, the RF circuitry 606 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 606 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 608 and provide baseband signals to the baseband circuitry 610. RF circuitry 606 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 610 and provide RF output signals to the FEM circuitry 608 for transmission.

[000138] In some implementations, the receive signal path of the RF circuitry 606 may include mixer circuitry 606a, amplifier circuitry 606b and filter circuitry 606c. In some implementations, the transmit signal path of the RF circuitry 606 may include filter circuitry 606c and mixer circuitry 606a. RF circuitry 606 may also include synthesizer circuitry 606d for synthesizing a frequency for use by the mixer circuitry 606a of the receive signal path and the transmit signal path. In some implementations, the mixer circuitry 606a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 608 based on the synthesized frequency provided by synthesizer circuitry 606d. The amplifier circuitry 606b may be configured to amplify the down-converted signals and the filter circuitry 606c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 610 for further processing. In some implementations, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some implementations,

mixer circuitry 606a of the receive signal path may comprise passive mixers, although the scope of the implementations is not limited in this respect.

[000139] In some implementations, the mixer circuitry 606a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 606d to generate RF output signals for the FEM circuitry 608. The baseband signals may be provided by the baseband circuitry 610 and may be filtered by filter circuitry 606c.

[000140] In some implementations, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some implementations, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some implementations, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some implementations, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may be configured for super-heterodyne operation.

[000141] In some implementations, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the implementations is not limited in this respect. In some alternate implementations, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate implementations, the RF circuitry 606 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 610 may include a digital baseband interface to communicate with the RF circuitry 606.

[000142] In some dual-mode implementations, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the implementations is not limited in this respect.

[000143] In some implementations, the synthesizer circuitry 606d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the implementations is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 606d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[000144] Synthesizer circuitry 606d may be configured to synthesize an output frequency for use by the mixer circuitry 606a of the RF circuitry 606 based on a frequency input and a divider control input. In some implementations, the synthesizer circuitry 606d may be a fractional N/N+1 synthesizer.

[000145] In some implementations, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 610 or the application circuitry 405/505 depending on the desired output frequency. In some implementations, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the application circuitry 405/XS205.

[000146] Synthesizer circuitry 606d of the RF circuitry 606 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some implementations, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some implementations, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example implementations, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these implementations, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[000147] In some implementations, synthesizer circuitry 606d may be configured to generate a carrier frequency as the output frequency, while in other implementations, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate

multiple signals at the carrier frequency with multiple different phases with respect to each other. In some implementations, the output frequency may be a LO frequency (fLO). In some implementations, the RF circuitry 606 may include an IQ/polar converter.

[000148] FEM circuitry 608 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 611, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 606 for further processing. FEM circuitry 608 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 606 for transmission by one or more of antenna elements of antenna array 611. In various implementations, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 606, solely in the FEM circuitry 608, or in both the RF circuitry 606 and the FEM circuitry 608.

[000149] In some implementations, the FEM circuitry 608 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 608 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 608 may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 606). The transmit signal path of the FEM circuitry 608 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 606), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 611.

[000150] The antenna array 611 comprises one or more antenna elements, each of which is configured convert electrical signals into radio waves to travel through the air and to convert received radio waves into electrical signals. For example, digital baseband signals provided by the baseband circuitry 610 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 611 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arranges as are known and/or discussed herein. The antenna array 611 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 611 may be formed in as a patch of metal foil (e.g., a patch antenna) in a variety of

shapes, and may be coupled with the RF circuitry 606 and/or FEM circuitry 608 using metal transmission lines or the like.

[000151] Processors of the application circuitry 405/XS205 and processors of the baseband circuitry 610 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 610, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 405/XS205 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., TCP and UDP layers). As referred to herein, Layer 3 may comprise a RRC layer, described in further detail below. As referred to herein, Layer 2 may comprise a MAC layer, an RLC layer, and a PDCP layer, described in further detail below. As referred to herein, Layer 1 may comprise a PHY layer of a UE/RAN node, described in further detail below.

[000152] Figure 7 illustrates various protocol functions that may be implemented in a wireless communication device, according to some implementations of the present disclosure. In particular, Figure 7 includes an arrangement 700 showing interconnections between various protocol layers/entities. The following description of Figure 7 is provided for various protocol layers/entities that operate in conjunction with the 5G/NR system standards and LTE system standards, but some or all of the aspects of Figure 7 may be applicable to other wireless communication network systems as well.

[000153] The protocol layers of arrangement 700 may include one or more of PHY 710, MAC 720, RLC 730, PDCP 740, SDAP 747, RRC 755, and NAS layer 757, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 759, 756, 750, 749, 745, 735, 725, and 715 in Figure 7) that may provide communication between two or more protocol layers.

[000154] The PHY 710 may transmit and receive physical layer signals 705 that may be received from or transmitted to one or more other communication devices. The physical layer signals 705 may comprise one or more physical channels, such as those discussed herein. The PHY 710 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by

higher layers, such as the RRC 755. The PHY 710 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and MIMO antenna processing. In implementations, an instance of PHY 710 may process requests from and provide indications to an instance of MAC 720 via one or more PHY-SAP 715. According to some implementations, requests and indications communicated via PHY-SAP 715 may comprise one or more transport channels.

[000155] Instance(s) of MAC 720 may process requests from, and provide indications to, an instance of RLC 730 via one or more MAC-SAPs 725. These requests and indications communicated via the MAC-SAP 725 may comprise one or more logical channels. The MAC 720 may perform mapping between the logical channels and transport channels, multiplexing of MAC SDUs from one or more logical channels onto TBs to be delivered to PHY 710 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 710 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[000156] Instance(s) of RLC 730 may process requests from and provide indications to an instance of PDCP 740 via one or more radio link control service access points (RLC-SAP) 735. These requests and indications communicated via RLC-SAP 735 may comprise one or more RLC channels. The RLC 730 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 730 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC 730 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[000157] Instance(s) of PDCP 740 may process requests from and provide indications to instance(s) of RRC 755 and/or instance(s) of SDAP 747 via one or more packet data convergence protocol service access points (PDCP-SAP) 745. These requests and indications communicated

via PDCP-SAP 745 may comprise one or more radio bearers. The PDCP 740 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[000158] Instance(s) of SDAP 747 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 749. These requests and indications communicated via SDAP-SAP 749 may comprise one or more QoS flows. The SDAP 747 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 747 may be configured for an individual PDU session. In the UL direction, the NG-RAN 110 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 747 of a UE 101 may monitor the QFIs of the DL packets for each DRB, and may apply the same mapping for packets flowing in the UL direction. For a DRB, the SDAP 747 of the UE 101 may map the UL packets belonging to the QoS flows(s) corresponding to the QoS flow ID(s) and PDU session observed in the DL packets for that DRB. To enable reflective mapping, the NG-RAN 310 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 755 configuring the SDAP 747 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 747. In implementations, the SDAP 747 may only be used in NR implementations and may not be used in LTE implementations.

[000159] The RRC 755 may configure, via one or more management service access points (M-SAP), aspects of one or more protocol layers, which may include one or more instances of PHY 710, MAC 720, RLC 730, PDCP 740 and SDAP 747. In implementations, an instance of RRC 755 may process requests from and provide indications to one or more NAS entities 757 via one or more RRC-SAPs 756. The main services and functions of the RRC 755 may include broadcast of system information (e.g., included in MIBs or SIBs related to the NAS), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of

an RRC connection between the UE 101 and RAN 110 (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter-RAT mobility, and measurement configuration for UE measurement reporting. The MIBs and SIBs may comprise one or more IEs, which may each comprise individual data fields or data structures.

[000160] The NAS 757 may form the highest stratum of the control plane between the UE 101 and the AMF 321. The NAS 757 may support the mobility of the UEs 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and a P-GW in LTE systems.

[000161] According to various implementations, one or more protocol entities of arrangement 700 may be implemented in UEs 101, RAN nodes 111, AMF 321 in NR implementations or MME 221 in LTE implementations, UPF 302 in NR implementations or S-GW 222 and P-GW 223 in LTE implementations, or the like to be used for control plane or user plane communications protocol stack between the aforementioned devices. In such implementations, one or more protocol entities that may be implemented in one or more of UE 101, gNB 111, AMF 321, etc. may communicate with a respective peer protocol entity that may be implemented in or on another device using the services of respective lower layer protocol entities to perform such communication. In some implementations, a gNB-CU of the gNB 111 may host the RRC 755, SDAP 747, and PDCP 740 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 111 may each host the RLC 730, MAC 720, and PHY 710 of the gNB 111.

[000162] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 757, RRC 755, PDCP 740, RLC 730, MAC 720, and PHY 710. In this example, upper layers 760 may be built on top of the NAS 757, which includes an IP layer 761, an SCTP 762, and an application layer signaling protocol (AP) 763.

[000163] In NR implementations, the AP 763 may be an NG application protocol layer (NGAP or NG-AP) 763 for the NG interface 113 defined between the NG-RAN node 111 and the AMF

321, or the AP 763 may be an Xn application protocol layer (XnAP or Xn-AP) 763 for the Xn interface 112 that is defined between two or more RAN nodes 111.

[000164] The NG-AP 763 may support the functions of the NG interface 113 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 111 and the AMF 321. The NG-AP 763 services may comprise two groups: UE-associated services (e.g., services related to a UE 101) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 111 and AMF 321). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 111 involved in a particular paging area; a UE context management function for allowing the AMF 321 to establish, modify, and/or release a UE context in the AMF 321 and the NG-RAN node 111; a mobility function for UEs 101 in ECM-CONNECTED mode for intra-system HOs to support mobility within NG-RAN and inter-system HOs to support mobility from/to EPS systems; a NAS Signaling Transport function for transporting or rerouting NAS messages between UE 101 and AMF 321; a NAS node selection function for determining an association between the AMF 321 and the UE 101; NG interface management function(s) for setting up the NG interface and monitoring for errors over the NG interface; a warning message transmission function for providing means to transfer warning messages via NG interface or cancel ongoing broadcast of warning messages; a Configuration Transfer function for requesting and transferring of RAN configuration information (e.g., SON information, performance measurement (PM) data, etc.) between two RAN nodes 111 via CN 120; and/or other like functions.

[000165] The XnAP 763 may support the functions of the Xn interface 112 and may comprise XnAP basic mobility procedures and XnAP global procedures. The XnAP basic mobility procedures may comprise procedures used to handle UE mobility within the NG RAN 111 (or E-UTRAN 210), such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The XnAP global procedures may comprise procedures that are not related to a specific UE 101, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[000166] In LTE implementations, the AP 763 may be an S1 Application Protocol layer (S1-AP) 763 for the S1 interface 113 defined between an E-UTRAN node 111 and an MME, or the AP 763 may be an X2 application protocol layer (X2AP or X2-AP) 763 for the X2 interface 112 that is defined between two or more E-UTRAN nodes 111.

[000167] The S1 Application Protocol layer (S1-AP) 763 may support the functions of the S1 interface, and similar to the NG-AP discussed previously, the S1-AP may comprise S1-AP EPs. An S1-AP EP may be a unit of interaction between the E-UTRAN node 111 and an MME 221within an LTE CN 120. The S1-AP 763 services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[000168] The X2AP 763 may support the functions of the X2 interface 112 and may comprise X2AP basic mobility procedures and X2AP global procedures. The X2AP basic mobility procedures may comprise procedures used to handle UE mobility within the E-UTRAN 120, such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The X2AP global procedures may comprise procedures that are not related to a specific UE 101, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[000169] The SCTP layer (alternatively referred to as the SCTP/IP layer) 762 may provide guaranteed delivery of application layer messages (e.g., NGAP or XnAP messages in NR implementations, or S1-AP or X2AP messages in LTE implementations). The SCTP 762 may ensure reliable delivery of signaling messages between the RAN node 111 and the AMF 321/MME 221 based, in part, on the IP protocol, supported by the IP 761. The Internet Protocol layer (IP) 761 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 761 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 111 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[000170] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 747, PDCP 740, RLC 730, MAC 720, and PHY 710. The user plane protocol stack may be used for communication between the UE 101, the RAN node 111, and UPF 302 in NR implementations or an S-GW 222 and P-GW 223 in LTE implementations. In this example, upper layers 751 may be built on top of the SDAP 747, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 752, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 753, and a User Plane PDU layer (UP PDU) 763.

[000171] The transport network layer 754 (also referred to as a "transport layer") may be built on IP transport, and the GTP-U 753 may be used on top of the UDP/IP layer 752 (comprising a UDP layer and IP layer) to carry user plane PDUs (UP-PDUs). The IP layer (also referred to as the "Internet layer") may be used to perform packet addressing and routing functionality. The IP layer may assign IP addresses to user data packets in any of IPv4, IPv6, or PPP formats, for example.

[000172] The GTP-U 753 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP/IP 752 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 111 and the S-GW 222 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 710), an L2 layer (e.g., MAC 720, RLC 730, PDCP 740, and/or SDAP 747), the UDP/IP layer 752, and the GTP-U 753. The S-GW 222 and the P-GW 223 may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising an L1 layer, an L2 layer, the UDP/IP layer 752, and the GTP-U 753. As discussed previously, NAS protocols may support the mobility of the UE 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and the P-GW 223.

[000173] Moreover, although not shown by Figure 7, an application layer may be present above the AP 763 and/or the transport network layer 754. The application layer may be a layer in which

a user of the UE 101, RAN node 111, or other network element interacts with software applications being executed, for example, by application circuitry 405 or application circuitry 505, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 101 or RAN node 111, such as the baseband circuitry 610. In some implementations the IP layer and/or the application layer may provide the same or similar functionality as layers 5-7, or portions thereof, of the Open Systems Interconnection (OSI) model (e.g., OSI Layer 7 – the application layer, OSI Layer 6 – the presentation layer, and OSI Layer 5 – the session layer).

[000174] Figure 8 illustrates components of a core network, according to some implementations of the present disclosure. The components of the CN 220 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In implementations, the components of CN 320 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 220. In some implementations, NFV is utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums (described in further detail below). A logical instantiation of the CN 220 may be referred to as a network slice 801, and individual logical instantiations of the CN 220 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 220 may be referred to as a network sub-slice 802 (e.g., the network sub-slice 802 is shown to include the P-GW 223 and the PCRF 226).

[000175] As used herein, the terms “instantiate,” “instantiation,” and the like may refer to the creation of an instance, and an “instance” may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. A network instance may refer to information identifying a domain, which may be used for traffic detection and routing in case of different IP domains or overlapping IP addresses. A network slice instance may refer to a set of network functions (NFs) instances and the resources (e.g., compute, storage, and networking resources) required to deploy the network slice.

[000176] With respect to 5G systems (see, e.g., Figure 3), a network slice always comprises a RAN part and a CN part. The support of network slicing relies on the principle that traffic for different slices is handled by different PDU sessions. The network can realize the different network slices by scheduling and also by providing different L1/L2 configurations. The UE 301 provides assistance information for network slice selection in an appropriate RRC message, if it has been provided by NAS. While the network can support large number of slices, the UE need not support more than 8 slices simultaneously.

[000177] A network slice may include the CN 320 control plane and user plane NFs, NG-RANs 310 in a serving PLMN, and a N3IWF functions in the serving PLMN. Individual network slices may have different S-NSSAI and/or may have different SSTs. NSSAI includes one or more S-NSSAIs, and each network slice is uniquely identified by an S-NSSAI. Network slices may differ for supported features and network functions optimizations, and/or multiple network slice instances may deliver the same service/features but for different groups of UEs 301 (e.g., enterprise users). For example, individual network slices may deliver different committed service(s) and/or may be dedicated to a particular customer or enterprise. In this example, each network slice may have different S-NSSAIs with the same SST but with different slice differentiators. Additionally, a single UE may be served with one or more network slice instances simultaneously via a 5G AN and associated with eight different S-NSSAIs. Moreover, an AMF 321 instance serving an individual UE 301 may belong to each of the network slice instances serving that UE.

[000178] Network Slicing in the NG-RAN 310 involves RAN slice awareness. RAN slice awareness includes differentiated handling of traffic for different network slices, which have been pre-configured. Slice awareness in the NG-RAN 310 is introduced at the PDU session level by indicating the S-NSSAI corresponding to a PDU session in all signaling that includes PDU session resource information. How the NG-RAN 310 supports the slice enabling in terms of NG-RAN functions (e.g., the set of network functions that comprise each slice) is implementation dependent. The NG-RAN 310 selects the RAN part of the network slice using assistance information provided by the UE 301 or the 5GC 320, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 310 also supports resource management and policy enforcement between slices as per SLAs. A single NG-RAN node may support multiple slices,

and the NG-RAN 310 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 310 may also support QoS differentiation within a slice.

[000179] The NG-RAN 310 may also use the UE assistance information for the selection of an AMF 321 during an initial attach, if available. The NG-RAN 310 uses the assistance information for routing the initial NAS to an AMF 321. If the NG-RAN 310 is unable to select an AMF 321 using the assistance information, or the UE 301 does not provide any such information, the NG-RAN 310 sends the NAS signaling to a default AMF 321, which may be among a pool of AMFs 321. For subsequent accesses, the UE 301 provides a temp ID, which is assigned to the UE 301 by the 5GC 320, to enable the NG-RAN 310 to route the NAS message to the appropriate AMF 321 as long as the temp ID is valid. The NG-RAN 310 is aware of, and can reach, the AMF 321 that is associated with the temp ID. Otherwise, the method for initial attach applies.

[000180] The NG-RAN 310 supports resource isolation between slices. NG-RAN 310 resource isolation may be achieved by means of RRM policies and protection mechanisms that should avoid that shortage of shared resources if one slice breaks the service level agreement for another slice. In some implementations, it is possible to fully dedicate NG-RAN 310 resources to a certain slice. How NG-RAN 310 supports resource isolation is implementation dependent.

[000181] Some slices may be available only in part of the network. Awareness in the NG-RAN 310 of the slices supported in the cells of its neighbors may be beneficial for inter-frequency mobility in connected mode. The slice availability may not change within the UE's registration area. The NG-RAN 310 and the 5GC 320 are responsible to handle a service request for a slice that may or may not be available in a given area. Admission or rejection of access to a slice may depend on factors such as support for the slice, availability of resources, support of the requested service by NG-RAN 310.

[000182] The UE 301 may be associated with multiple network slices simultaneously. In case the UE 301 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 301 tries to camp on the best cell. For inter-frequency cell reselection, dedicated priorities can be used to control the frequency on which the UE 301 camps. The 5GC 320 is to validate that the UE 301 has the rights to access a network

slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 310 may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 301 is requesting to access. During the initial context setup, the NG-RAN 310 is informed of the slice for which resources are being requested.

[000183] NFV architectures and infrastructures may be used to virtualize one or more NFs, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[000184] Figure 9 is a block diagram illustrating components, according to some implementations of the present disclosure, of a system 900 to support NFV. The system 900 is illustrated as including a VIM 902, an NFVI 904, an VNFM 906, VNFs 908, an EM 910, an NFVO 912, and a NM 914.

[000185] The VIM 902 manages the resources of the NFVI 904. The NFVI 904 can include physical or virtual resources and applications (including hypervisors) used to execute the system 900. The VIM 902 may manage the life cycle of virtual resources with the NFVI 904 (e.g., creation, maintenance, and tear down of VMs associated with one or more physical resources), track VM instances, track performance, fault and security of VM instances and associated physical resources, and expose VM instances and associated physical resources to other management systems.

[000186] The VNFM 906 may manage the VNFs 908. The VNFs 908 may be used to execute EPC components/functions. The VNFM 906 may manage the life cycle of the VNFs 908 and track performance, fault and security of the virtual aspects of VNFs 908. The EM 910 may track the performance, fault and security of the functional aspects of VNFs 908. The tracking data from the VNFM 906 and the EM 910 may comprise, for example, PM data used by the VIM 902 or the NFVI 904. Both the VNFM 906 and the EM 910 can scale up/down the quantity of VNFs of the system 900.

[000187] The NFVO 912 may coordinate, authorize, release and engage resources of the NFVI 904 in order to provide the requested service (e.g., to execute an EPC function, component, or

slice). The NM 914 may provide a package of end-user functions with the responsibility for the management of a network, which may include network elements with VNFs, non-virtualized network functions, or both (management of the VNFs may occur via the EM 910).

[000188] Figure 10 is a block diagram illustrating components able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein, according to some implementations of the present disclosure. Specifically, Figure 10 shows a diagrammatic representation of hardware resources 1000 including one or more processors (or processor cores) 1010, one or more memory/storage devices 1020, and one or more communication resources 1030, each of which may be communicatively coupled via a bus 1040. For implementations where node virtualization (e.g., NFV) is utilized, a hypervisor 1002 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 1000.

[000189] The processors 1010 may include, for example, a processor 1012 and a processor 1014. The processor(s) 1010 may be, for example, a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.

[000190] The memory/storage devices 1020 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1020 may include, but are not limited to, any type of volatile or nonvolatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

[000191] The communication resources 1030 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 1004 or one or more databases 1006 via a network 1008. For example, the communication resources 1030 may include wired communication components (e.g., for coupling via USB), cellular

communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components.

[000192] Instructions 1050 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1010 to perform any one or more of the methodologies discussed herein. The instructions 1050 may reside, completely or partially, within at least one of the processors 1010 (e.g., within the processor's cache memory), the memory/storage devices 1020, or any suitable combination thereof. Furthermore, any portion of the instructions 1050 may be transferred to the hardware resources 1000 from any combination of the peripheral devices 1004 or the databases 1006. Accordingly, the memory of processors 1010, the memory/storage devices 1020, the peripheral devices 1004, and the databases 1006 are examples of computer-readable and machine-readable media.

[000193] For one or more implementations, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section.

[000194] **PWS Notification**

[000195] In IDLE mode, UE can monitor PDCCH scrambled with P-RNTI to receive the ETWS/CMAS notification. However, in a connected mode such as RRC_CONNECTED mode, multiple different implementations can be considered. These options described in this invention are also applicable to provide any system information change notification and/or system information contents in connected mode.

[000196] Dedicated Signalling for PWS Notification

[000197] In some implementations, dedicated signalling for ETWS/CMAS notifications can be achieved using unicast MPDCCH. The unicast MPDCCH can include a novel DCI format that either (i) directly indicates the PWS notification by defining new DCI bit-fields or reinterpreting existing DCI bit-fields or (ii) schedules a PDSCH to carry the PWS notification, which is described in more detail below. Examples of a novel DCI formats are set forth below with reference to DCI format 6-1A and DCI format 6-1B, respectively.

[000198] In some implementations, dedicated signalling for ETWS/CMAS notifications can be achieved using unicast physical downlink shared channel (PDSCH). The unicast PDSCH can include new or updated RRC messages that can be used for PWS notification. Alternatively, or in addition, the PDSCH can include new or updated MAC CE PDUs that can be used for the PWS notification. In some implementations, the PWS notification can be implicit. An implicit notification can include an RRC msg or an MAC CE PDU that already carries the PWS notification information. Alternatively, the PWS notification can be explicit. An explicit notification can convey an indication for UE to acquire SIB10/11/12 or convey the scheduling information of SIB10/11/12 for the UE to acquire them.

[000199] In some implementations, when using dedicated signalling for PWS notification, the network does not need to wait for paging occasion to send the notification. This can results in faster notification to the UE. In this implementations, legacy UE behaviour is not impacted, a UE is not required to receive broadcast signal when in connected mode. The network sends the same PWS notification to each UE operating in CE mode A and CE mode B, as a dedicated mechanism is used.

[000200] Broadcast Signalling For PWS Notification

[000201] In some implementations, broadcast signalling for PWS notifications can be achieved using a broadcast MPDCCH. The broadcast MPDCCH can cse P-RNTI or other cell-specific RNTI with possible impact to DCI format. In some implementations, a novel DCI format could be used to indicate the scheduling information of particular SI messages to be acquired by the UE. Alternatively, in other implementations, as described below, the UE may be configured by higher layers to monitor for DCI formats 6-1A or 6-1B with CRC scrambled with P-RNTI for MPDCCH

candidates starting at subframes and in narrow bands (NBs) corresponding to the paging occasions (POs) and paging NBs (PNBs) respectively. Such configuration could be defined as monitoring of MPDCCH candidates as per Type-1 CSS for MPDCCH, or alternatively as described in more detail below, be defined as extension of currently defined Type-0 CSS for MPDCCH.

[000202] In some implementations, when using broadcast signalling for PWS notification, a group of UEs can be notified at the same time. A novel DCI format could be used to indicate the scheduling information of SI. In such implementations, non-BL UE in CE may need to perform additional blind decoding (BD) trials of MPDCCH scrambled, for example, with P-RNTI because UE has to also monitor CSS in a connected mode such as RRC-Connected mode. However, for non-BL UEs, performance of a few additional BD trials, e.g., for type-2 CSS in CE mode is not a significant drawback. Indeed, in some implementations, optimizations can be employed to reduce or entirely avoid the additional BD trials. Such optimizations can be achieved, for example, by monitoring only MPDCCH scrambled with P-RNTI at a certain POs.

[000203] In some implementations using broadcast signalling for PWS, paging can be monitored in all POs. Alternatively, in other implementations, paging can be monitoring in one PO per paging discontinuous reception (DRX) cycle. Alternatively, in other implementations, paging can be monitored in at least one PO in a paging DRX cycle. Alternatively, in other implementations, paging can be monitoring in at least one PO in a given period. In some implementations, a new DCI format or update of existing DCI format for type-0 CSS can also be defined.

[000204] **PWS Information Acquisition**

[000205] For non-BL UE operating in CE mode and connected mode, one or more of the following implementations can be considered to send and acquire the PWS information. In some implementations, if SIB10/11/12 needs to be acquired by a UE, the UE may not have up to date SI scheduling information as a UE in CE is not required to have up to date MIB/SIB(s).

[000206] Acquire broadcast SIB10/11/12

[000207] In some implementations, a UE can acquire latest scheduling of SIB 10/11/12 and acquire the information. The PWS notification can be conveyed via any of the mechanisms described herein.

[000208] In some implementations, a UE has to acquire the master information block (MIB) and system information block (SIB) 1-BR because the UE may not be aware of the change in system information and have the updated schedule of SIB10/11/12. This could take a long time which is not desirable when in connected mode.

[000209] In some implementations, a UE can use scheduling information of SIB1-BR or SIB10/11/12 provided by the unicast physical downlink shared channel (PDSCH) or a broadcast MPDCCH. In such implementations, PWS notification itself provides the scheduling information of SIB10/11/12 (e.g., narrowband, periodicity and TBS size) or SIB1-BR. In such implementations, the UE can save power by avoiding the acquisition of MIB and SIB1-BR or MIB only.

[000210] Acquire copy of SIB10/11/12

[000211] In some implementations, a copy of SIB10/11/12 can be acquired using unicast. For example, an RRC message or new or update MAC CE PDU can provide the PWS information, for example, including SIB10/11/12. In such implementations, there is no need to have explicit PWS notification. Instead, for example, implicit PWS notifications can be used.

[000212] In some implementations, a copy of SIB10/11/12 can be acquired using broadcast. For example, a new or updated broadcast message such as a paging-like message class extension or an SI-like message can be used. It can be advantageous to define a copy of SIB10/11/12. For example, such a copy of that information could potentially be sent in any narrowband which could help for parallel unicast transmissions. The PWS notification can be conveyed via any of the mechanisms herein.

[000213] When the network provides a separate copy of SIB 10/11/12 in unicast or broadcast, the PDSCH scheduled by either broadcast signalling or dedicated signalling with legacy gap between physical downlink control channel (PDCCH) and PDSCH. In such implementations, the

broadcast PDSCH with P-RNTI or other RNTI can be scheduled at the beginning of a notification period. However, if the PDCCH monitoring and PDSCH broadcast are in different narrowband, UE does not monitor the PDCCH at the beginning of the notification period even no broadcast PDSCH is scheduled.

[000214] In some implementations, the UE acquires the PWS information directly and receives the scheduled PDSCH reducing the acquisition delay. In such implementations, the network has to send a separate copy of information to UEs in IDLE mode and non-BL UEs in CE in connected mode.

[000215] **Acquiring Broadcast PDSCH**

[000216] In some implementations, the copy of SIB 10/11/12 in PDSCH with the encoded bits scrambled with P-RNTI or other RNTI are scheduled at the beginning of ETWS/CMAS notification period. A new period for monitoring the broadcast PDSCH can be defined or existing modification period or SI periodicity can also be used. At the subframe starting the period, UEs try to decode the PDSCH with the encoded bits scrambled with P-RNTI or other RNTI with a high priority, for example, higher priority than unicast transport block transmission, even unicast transmission is scheduled at the subframe 1110 as shown in 1100 of Figure 11.

[000217] In other implementations, a UE can monitor and receive the PDCCH with the CRC scrambled with P-RNTI or a new broadcast RNTI and the scheduled PDSCH in the same or different narrowband simultaneously at this subframe 1110. Likewise, in some other implementations, the UE can also receive unicast TB and broadcast TB at same or different narrowband simultaneously at this subframe 1110. Note that receiving DL physical channels over different NBs simultaneously may be feasible for non-BL UEs in CE mode due to their inherent RF and baseband capability to operate in systems with up to 20 MHz system bandwidth (BW). The resource configuration for such PDSCH (e.g., narrowband, periodicity, TB size, repetitions) can be configured by dedicated RRC signalling or broadcast in SI.

[000218] In other implementations, the copy of SIB 10/11/12 in PDSCH can be scheduled in a broadcast way after receiving notification at a PO as shown in Figure 12. The UE can monitor

PDCCH in all POs or one PO per paging DRX cycle or at least one PO in a paging DRX cycle or at least one PO in a given period for the notification.

[000219] In some implementations, a plurality of options are available to schedule broadcast PDSCH. For example, in some implementations, broadcast PDSCH can be sent in a fixed NB X. In some implementations, the broadcast PDSCH can be sent in a NB configured by RRC or broadcast in SI. In some implementations, PDCCH can indicate which NB is to be used for broadcast PDSCH. In some implementations, a broadcast PDSCH cab be scheduled in each narrowband so UE is required to decode it in the same NB. In some implementations, periodicity (or new notification period), TBS size, or repetitions can be predefined or configured via RRC or broadcast in system information. In some implementations, SIB10, SIB11, or SIB12 are used. For purposes of this specification and given components A, B "or" means, for example, "A," "B," "A or B," or "A AND B."

[000220] In some implementations, a plurality of options are available to notify a UE regarding the presence of broadcast PDSCH. For example, in some implementations, a new PHY signal (similar to WUS) is defined to indicate presence of broadcast PDSCH. In some implementations, DCI in a paging occasion can indicate presence of broadcast PDSCH. In some implementations, dedicated signalling such as PDCCH in UESS, RRC message, or MAC CE PDUs can indicate the presence of broadcast PDSCH. In some implementations, DCI, a new paging message, an RRC message, or a MAC CE PDU can provide scheduling information of SIB1-BR or SIB10/11/12 as indication of broadcast PDSCH. In some implementation, broadcast PDSCH is dynamically scheduled with SI-RNTI or P-RNTI or other cell specific RNTI. Such indications of broadcast PDSCH may be used, for particular UE types, as certain particular UE types may not be configured to monitor for broadcast PDSCH and thus can be alerted to the presence of broadcast PDSCH using the notifications described herein.

[000221] In some implementations, a plurality of options are available to decode the broadcast PDSCH. For example, in some implementations, broadcast PDSCH can be prioritized over unicast transmission. An example of this is depicted in Fig. 11. In some implementations, a UE receives both TBs in unicast and broadcast PDSCH from the same NB. In some implementations, a NB switching gap can be defined for parallel reception of unicast PDSCH and broadcast PDSCH.

[000222] **DCI Design For PWS Notification/Acquisition**

[000223] In some implementations, the one or more DCI design options are available for consideration. In some implementations, existing DCI formats (6-1A, 6-1B) scrambled with C-RNTI for unicast DCI based notification. In some implementations, new DCI format scrambled with C-RNTI. For example, new unicast DCI based notification can be used to provide at least 5 bits information for SIB1-BR scheduling or scheduling of SIB10/11/12.

[000224] In some implementations, existing DCI format 6-2 scrambled with P-RNTI/ or new RNTI for broadcast DCI based notification with both flag 0 and flag 1. In some implementations, new DCI scrambled with P-RNTI/ or new RNTI can be used for new broadcast DCI based notification to provide at least additional 5 bits for SIB1-BR scheduling. This DCI format can be based on DCI format 6-2 with the direct information flag bit-field assumed enabled and the remaining bits in the DCI format used for direct indication including any information on SIB1-BR scheduling or SIB10/11/12 scheduling. For example, the DCI format 6-2 when flag = 0 for direct indication has reserved bits available which can be used to provide the SIB1-BR scheduling information or SIB10/11/12 scheduling information as shown below.

[000225] A first DCI format is presented below. In some implementations, the following format for DCI shown in Table 1 below can be used, for example, to schedule SIB1-BR:

Field	Number of bits	Description
Flag for paging/direct indication differentiation	1	0 - direct indication, 1 - paging
Direct Indication Information	8	Value 2: etws-Indication Value 3: cmas-Indication If UE supports, check scheduling information of SIB1-BR
schedulingInfoSIB1-BR	5	Scheduling information for SIB1-BR
Remaining bits reserved		

-Table 1 reserved bit in DCI format 6-2 when flag = 0 for paging direct indication-

[000226] A second DCI format is presented below. In some implementations, the following format for DCI shown in Table 2 below can be used, for example, to schedule SIB1-BR. In the example DCI of Table 2, a flag can be used to indicate whether the following bits are used for scheduling information of SIB1-BR. In some implementations, if this flag = 1, it can also mean that there is some change in the scheduling information of SIB1-BR.

Field	Number of bits	Description
Flag for paging/direct indication differentiation	1	0 – direct indication, 1 – paging
Direct Indication Information	8	Value 2: etws-Indication Value 3: cmas-Indication If UE supports, checks flag for SIB1-BR
Flag for SIB1-BR	1	0 – No SIB1-BR scheduling, 1 – next bits for SIB1-BR scheduling
schedulingInfoSIB1-BR	5	Scheduling information for SIB1-BR
Remaining bits reserved		

-Table 2 reserved bit in DCI format 6-2 when flag = 0 for paging direct indication.-

[000227] In some implementations, a DCI format can be used that provides an indication of whether SIB1-BR scheduling has changed or not at least over the SI validity time.

[000228] For example, if UE is synchronized (e.g., in connected mode), it does not require to re-synchronize, therefore, it just needs the scheduling information of SIB1-BR if it has changed. If the indication is true, it indicates that no change has occurred in the scheduling information of SIB1-BR message at least over the SI validity time so UE can assume the stored scheduling information of SIB-BR as valid and use it to acquire the SIB1-BR. If UE does not have stored scheduling information, then it can acquire the MIB.

[000229] Examples of these other DCI formats that can be used to provide an indication of whether SIB1-BR scheduling has changed or not are set forth below in Tables 3 and 4.

Field	Number of bits	Description
Flag for paging/direct indication differentiation	1	0 – direct indication, 1 – paging

Direct Indication Information	8	Value 2: etws-Indication Value 3: cmas-Indication If UE supports, checks flag for schedulingInfoUnchanged-SIB1-BR
schedulingInfoUnchanged-SIB1-BR	1	1 – no change has occurred in the scheduling information of SIB1-BR at least over the SI validity time.
Remaining bits reserved		

-Table 3 reserved bit in DCI format 6-2 when flag = 0 for paging direct indication-

Field	Number of bits	Description
Flag for paging/direct indication differentiation	1	0 – direct indication, 1 – paging
Direct Indication Information	8	Value 2: etws-Indication Value 3: cmas-Indication If UE supports, checks flag for mibInfoUnchanged
mibInfoUnchanged	1	1 – no change has occurred in the contents of MIB (Dl bandwidth, and scheduling information of SIB1-BR) at least over the SI validity time.
Remaining bits reserved		

-Table 4 reserved bit in DCI format 6-2 when flag = 0 for paging direct indication-

[000230] Minimizing Blind Decoding (BD) Efforts At The UE

[000231] In some implementations, the following options can be considered to minimize the impact on complexity and power consumption from additional BD efforts for the UEs to additionally monitor for MPDCCH in connected mode.

[000232] In some implementations, the UE is not expected to monitor for MPDCCH with CRC scrambled with C-RNTI during subframes starting from a PO in which the UE is expected to monitor DCI w/ P-RNTI. However, this can be too restrictive and, especially when using larger #s of repetitions, adversely impact scheduling ability for the UE in connected mode.

[000233] In some implementations, it is possible to limit the additional # of BDs for monitoring MPDCCH carrying DCI format 6-2 with CRC scrambled with P-RNTI. Following this approach, the existing number of BD candidates in a Type-1 MPDCCH CSS for paging of four candidates with different numbers of repetitions could be reduced by allowing the UE to monitor a subset of the possible set of candidates (based on Rmax for paging CSS) based on one or more of: the configured CE mode, Rmax of MPDCCH UESS, Rmax of Type 1 MPDCCH CSS for paging, etc.).

[000234] In some implementations, a new variant of DCI formats 6-1A/6-1B can be defined that, when the CRC is scrambled with P-RNTI (instead of C-RNTI) carries PWS (and possibly SI update) related information. This implies no increase in the BD efforts for the non-BL UEs (and this mechanism could even be supported for BL UEs). However, the down-side is that the NW now needs to transmit both DCI formats 6-2 and the 6-1A/6-1B considering mix of Idle and different Connected mode UEs in the cell/tracking area for each PO. For DCI format 6-2, for the use case of only PWS notification, as one option, the header bit field could be removed or fixed to always indicate “direct indication”.

[000235] Design of RRC Message Based implementation

[000236] In some implementations, an RRC reconfiguration message can be used to provide SIB1-BR and additionally can provide that the signalling schedule for SIB10 or SIB11 or SIB12 is also provided and UE shall acquire the ETWS and/or CMS information. An example of this type of RCC configuration message is shown below in Structure 1 or Structure 2:

```
RRCConnectionReconfiguration-v1510-IEs ::= SEQUENCE {
    nr-Config-r15                   CHOICE {
        release                         NULL,
        setup                           SEQUENCE {
            endc-ReleaseAndAdd-r15  BOOLEAN,
            nr-SecondaryCellGroupConfig-r15 OCTET STRING                OPTIONAL,   -
- Need ON
            p-MaxEUTRA-r15                  P-Max                       OPTIONAL    --
Need ON
        }
    }                                                                   OPTIONAL,   -- Need
ON
```

```
    sk-Counter-r15                  INTEGER (0.. 65535)                 OPTIONAL,   --
Need ON
    nr-RadioBearerConfig1-r15       OCTET STRING                        OPTIONAL,   --
Need ON
    nr-RadioBearerConfig2-r15       OCTET STRING                        OPTIONAL,   --
Need ON
    tdm-PatternConfig-r15           CHOICE {
        release                         NULL,
        setup                           SEQUENCE {
            subframeAssignment-r15              SubframeAssignment-r15,
            harq-Offset-r15                 INTEGER (0.. 9)
        }
    }                                                                   OPTIONAL,   -- Cond
FDD-PCell
    nonCriticalExtension            RRCConnectionReconfiguration-v16xy-IEs
        OPTIONAL
}
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
    notificationETWS-CMAS-r16       ENUMERATED{true}    OPTIONAL,   -- Cond
SIB1-BR
    nonCriticalExtension            SEQUENCE {}         OPTIONAL
}
```

-Structure #1-

```
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
    notificationETWS-CMAS-r16       ENUMERATED{ETWS, CMAS}      OPTIONAL,   -
- Cond SIB1-BR
    nonCriticalExtension            SEQUENCE {}         OPTIONAL
}
```

-Structure #2-

[000237] Fields of Structure #1 and Structure #2 are described in more detail below with respect to Tables 5 and 6:

Conditional presence	Explanation
EARFCN-max	The field is mandatory present if *dl-CarrierFreq-r10* is included and set to *maxEARFCN*. Otherwise the field is not present.
FDD-PCell	This field is optionally present, need ON, for a FDD PCell if there is no SCell with configured uplink. Otherwise, the field is not present.
fullConfig	This field is mandatory present for handover within E-UTRA when the *fullConfig* is included; otherwise it is optionally present, Need OP.
HO	The field is mandatory present in case of handover within E-UTRA or to E-UTRA; otherwise the field is not present.
HO-Reestab	This field is optionally present, need ON, in case of handover within E-UTRA or upon the first reconfiguration after RRC connection re-establishment; otherwise the field is not present.
HO-toEUTRA	The field is mandatory present in case of handover to E-UTRA or for reconfigurations when *fullConfig* is included; otherwise the field is optionally present, need ON.
nonFullConfig	The field is not present when the *fullConfig* is included or in case of handover to E-UTRA; otherwise it is optional present, need ON.
nonHO	The field is not present in case of handover within E-UTRA or to E-UTRA; otherwise it is optional present, need ON.
SCellAdd	The field is mandatory present upon SCell addition; otherwise it is not present.
SCellAdd2	The field is mandatory present upon SCell addition; otherwise it is optionally present, need ON.
SIB1-BR	This field is optionally present, need OR if *systemInformationBlockType1Dedicated-r11* is included. Otherwise, the field is not present.

-Table 5-

RRCConnectionReconfiguration field descriptions
dedicatedInfoNASList ***This field is used to transfer UE specific NAS layer information between the network and the UE. The RRC layer is transparent for each PDU in the list.***
nextHopChainingCount Parameter NCC: See TS 33.401 [32]
notificationETWS-CMAS This field is used indicating whether non-BL UE operating in CE mode A or B in RRC_CONNECTED is required acquire SIB10 or SIB11 or SIB12.
nr-Config Includes the NR related configurations. This filed is used to configure EN-DC configuration, possibly in conjunction with fields *sk-Counter* and *nr-RadioBearerConfig1/ 2*. NOTE.

-Table 5-

[000238] In some implementations, the RRC reconfiguration message can also be used to provide a container which includes the contents of SIB10 or SIB11 or SIB12 as shown below in Structures 3 or 4:

```
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
    systemInformationBlockType10or11or12Dedicated-r11OCTET STRING (CONTAINING
SystemInformationBlockType10 or SystemInformationBlockType11 or
SystemInformationBlockType12) OPTIONAL, -- Need ON
    nonCriticalExtension            SEQUENCE {}          OPTIONAL
}
```

-Structure 3-

```
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
    systemInformationBlockType10or11or12Dedicated-r11OCTET STRING (CONTAINING
SystemInformationBlockType10 or SystemInformationBlockType11 or
SystemInformationBlockType12) OPTIONAL, -- Need ON
    nonCriticalExtension            SEQUENCE {}          OPTIONAL
}
```

-Structure 4-

[000239] Fields of Structure #3 and Structure #4 are described in more detail below in Table 6:

RRCConnectionReconfiguration field descriptions
dedicatedInfoNASList ***This field is used to transfer UE specific NAS layer information between the network and the UE. The RRC layer is transparent for each PDU in the list.***
systemInformationBlockType1Dedicated This field is used to transfer *SystemInformationBlockType1* or *SystemInformationBlockType1-BR* to the UE.
systemInformationBlockType10or11or12Dedicated This field is used to transfer *SystemInformationBlockType10* or *SystemInformationBlockType11 and/or SystemInformationBlockType12* to the non-BL UE.
systemInformationBlockType2Dedicated This field is used to transfer BR version of *SystemInformationBlockType2* to BL UEs or UEs in CE or *SystemInformationBlockType2* to non-BL UEs.

-Table 6-

[000240] Another example of an RRC reconfiguration message that be used to provide a container which includes the contents of SIB10 or SIB11 or SIB12 is shown below in Structure 5:

```
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
systemInformationBlockType10or11or12Dedicated      SEQUENCE {
        systemInformationBlockType10Dedicated-r11  OCTET STRING (CONTAINING
        SystemInformationBlockType10) OPTIONAL, -- Need ON
        systemInformationBlockType11Dedicated-r11  OCTET STRING (CONTAINING
        SystemInformationBlockType11) OPTIONAL, -- Need ON
        systemInformationBlockType12Dedicated-r11  OCTET STRING (CONTAINING
        SystemInformationBlockType12) OPTIONAL, -- Need ON
} OPTIONAL,  -- Need ON
    nonCriticalExtension            SEQUENCE {}        OPTIONAL
```

-Structure 5-

[000241] Fields of Structure #5 are described in more detail below in Table 7:

RRCConnectionReconfiguration field descriptions
dedicatedInfoNASList ***This field is used to transfer UE specific NAS layer information between the network and the UE. The RRC layer is transparent for each PDU in the list.***
systemInformationBlockType1Dedicated This field is used to transfer *SystemInformationBlockType1* or *SystemInformationBlockType1-BR* to the UE.
systemInformationBlockType10Dedicated This field is used to transfer *SystemInformationBlockType10* to the non-BL UE.
systemInformationBlockType11Dedicated This field is used to transfer *SystemInformationBlockType10* to the non-BL UE.
systemInformationBlockType12Dedicated This field is used to transfer *SystemInformationBlockType10* to the non-BL UE.
systemInformationBlockType2Dedicated This field is used to transfer BR version of *SystemInformationBlockType2* to BL UEs or UEs in CE or *SystemInformationBlockType2* to non-BL UEs.

-Table 7-

[000242] In some implementations, the scheduling information of SIB10 or SIB11 and or SIB12 can be provided in an RCC reconfiguration message as shown in Structure 6:

```
RRCConnectionReconfiguration-v16xy-IEs ::= SEQUENCE {
```

```
shedulingInfoList-BR-r16   SchedulingInfoList-BR-r16 OPTIONAL,    -- Need ON
    nonCriticalExtension            SEQUENCE {}          OPTIONAL
}

SchedulingInfoList-BR-r16 ::= SEQUENCE (SIZE (1..3)) OF SchedulingInfo-BR-r16

SchedulingInfo-BR-r16 ::= SEQUENCE {
    si-Periodicity-r16                  ENUMERATED {
                                        rf8, rf16, rf32, rf64, rf128, rf256, rf512},
    sib-MappingInfo-r16                     SIB-MappingInfo-r16,
    si-Narrowband-r16               INTEGER (1..maxAvailNarrowBands-r13),
    si-TBS-r16                      ENUMERATED {b152, b208, b256, b328, b408, b504,
                                    b600, b712, b808, b936}
}

SIB-MappingInfo-r16 ::= SEQUENCE (SIZE (0..3)) OF SIB-Type-r16

SIB-Type-r16 ::=                    ENUMERATED {sibType10, sibType11, sibType12-
v920}
```

-Structure 6-

[000243] **Design of MAC CE PDU Based Implementation**

[000244] In some implementations, a new MAC CE PDU 1300A can be used to provide scheduling information of SIB1-BR as shown in FIG. 13A. In some implementations, this MAC CE PDU 1300A can include LCID information of the scheduling information SIB1-BR in one or more fields such as field 1310A. Examples of LCID information are shown in Table 8 below.

[000245] In some implementations, the MAC CE PDU 1300A can also provide the scheduling information of SI containing SIB10/11/12. An example of this is shown as MAC CE PDU 1300A as indicated by the bitmap "SIB11/12/12" in FIG. 13B. The UE can acquire the ETWS and/or CMS information using the MAC CE PDU.

[000246] In some implementations, the MAC CE PDU 1300A can also provide scheduling information of SIB10, SIB11, and SIB12 as indicated by bitmap "SIB11/12/12." Note that this

can be achieved in a fixed size of 6 octets without bitmap "SIB11/12/12" containing SIB 10 of SIB 11 or SIB 12 is shown in FIG. 13C.

[000247] For this purpose, a new LCID can be used as shown in Table 8 below. In other implementations, eLCID can be used as shown in Table 9 below.

Codepoint/Index	LCID values
00000	CCCH
00001-01010	Identity of the logical channel
01011-01111	Reserved
10000	Extended logical channel ID field
10001	~~Reserved~~ ETWS/CMAS notification
10010	Activation/Deactivation of PDCP Duplication
10011	Hibernation (1 octet)
10100	Hibernation (4 octets)
10101	Activation/Deactivation of CSI-RS
10110	Recommended bit rate
10111	SC-PTM Stop Indication
11000	Activation/Deactivation (4 octets)
11001	SC-MCCH, SC-MTCH (see note)
11010	Long DRX Command
11011	Activation/Deactivation (1 octet)
11100	UE Contention Resolution Identity
11101	Timing Advance Command
11110	DRX Command
11111	Padding
NOTE: Both SC-MCCH and SC-MTCH cannot be multiplexed with other logical channels in the same MAC PDU except for Padding and SC-PTM Stop Indication	

Table 8 Values of LCID for DL-SCH

Codepoint	Index	LCID values
000000-000110	32-38	Identity of the logical channel
000111-111110~~1~~	39-94~~5~~	Reserved
111111	95	ETWS/CMAS notification

Table 9 Values of eLCID for DL-SCH

[000248] **Completion of Obtaining The ETWS/CMAS Information**

[000249] In some implementations, when UE receives the notification of ETWS/CMAS in connected mode, UE may be performing unicast transmission/reception or scheduled for the unicast transmission/reception. However, network would not know exactly when the UE would be able to finish receiving the ETWS/CMAS information and resume unicast. In one option, UE can signal the network that it finished obtaining the ETWS/CMAS information and ready for unicast transmission/reception. If there is any ongoing or scheduled unicast transmission/reception, UE can resume the unicast with or without indicating UE finished receiving ETWS/CMAS information.

[000250] In some implementations, the indication can be sent using dedicated RRC message or a MAC CE or UE can just send a scheduling request (SR) or any CQI or SRS report or HARQ feedback or any new signal on PUCCH as indication. While receiving the ETWS/CMAS, UE can also indicate to the network to pause any ongoing or to be schedules transmission.

[000251] In some implementations, UE can prioritize receiving of system information of ETWS/CMAS over unicast. In another option, an expected window (e.g., SI modification window) can be defined. If there is no activity from the time UE receives the notification of ETWS/CMAS and the expected window expires, UE may go to IDLE mode or network can release the UE to IDLE mode.

[000252] In some implementations, if UE receives RRC connection release message while acquiring the ETWS/CMAS information, UE can follow but UE also completes the acquisition of ETWS/CMAS.

[000253] In some implementations, receiving the ETWS/CMAS does not impact the connected mode DRX procedure.

[000254] Figure 14 is a flowchart of an example of a process 1400 for warning system information notification and acquisition... In some implementations, the process 1400 can generally include receiving, by user equipment (UE) and from an access node, data indicating the presence of a PDSCH broadcast (1410), configuring, by the UE and based on the received data, a narrowband (NB) to receive transport blocks in PDSCH (1420), and receiving, by the UE, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information (1430). The process 1400 will be described in more detail below as being performed by a user device such as a UE 101.

[000255] A UE 101 can begin execution of the process 1400 by receiving, from an access node, data indicating the presence of a PDSCH broadcast (1410). In some implementations, the received data used can include dedicated RRC messages, data broadcast in system information, or data indicated by PDCCH that schedules the PDSCH. In some implementations, the received data indicating presence of PDSCH broadcast is indicated by a new PHY signal, a PDCCH scrambled with P-RNTI or SI-RNTI, a unicast PDSCH, RRC signaling, a MAC CE PDU, or unicast PDCCH in UESS.

[000256] In some implementations, the UE can include a UE that is in coverage enhanced (CE) mode A or CE mode B. In some implementations, the UE can be a UE that is not configured to monitoring PDSCH broadcasts. Accordingly, the received data that indicates the presence of the PDSCH broadcast can alert the UE to the occurrence of the PDSCH broadcast.

[000257] **The UE 101 can continue execution of the process 1400 by configuring** the narrowband (NB) to receive transport blocks in PDSCH (1420). In some implementations, the UE can configure the narrowband (NB) using dedicated RRC signaling, data broadcast in system

information, or data indicated by PDCCH that schedules the PDSCH that was received in the received data at stage 14010 from the access node.

[000258] The UE 101 can continue execution of the process 1400 by receiving one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information (1430). In some implementations, one or more transport blocks broadcast in PDSCH can be prioritized over unicast transmission, as shown by example in Figure 11. In some implementations, the UE is not required to receive unicast transmission for a predetermined amount of time. In yet other the UE can receive one or more second transport blocks in unicast while also receiving the one or more transport blocks broadcast PDSCH using an NB switching gap that is defined for parallel reception of unicast transport blocks and broadcast transport blocks.

OTHER IMPLEMENTATIONS

[000259] A number of implementations have been described. Nevertheless, it will be understood that various modifications can be made without departing from the spirit and scope of the invention. In addition, the logic flows depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other steps can be provided, or steps can be eliminated, from the described flows, and other components can be added to, or removed from, the described systems. Accordingly, other implementations are within the scope of the following claims.

CLAIMS

1. A method for acquiring warning system information, the method comprising:

receiving, by user equipment (UE) and from an access node, data indicating the presence of a PDSCH broadcast;

configuring, by the UE and based on the received data, a narrowband (NB) to receive transport blocks in PDSCH; and

receiving, by the UE and from the access node, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information.

2. The method of claim 1, wherein the UE is in coverage enhanced (CE) mode A or CE mode B.

3. The method of claim 1, wherein the warning system information includes earthquake and tsunami warning system (ETWS) / commercial mobile alert system (CMAS) information.

4. The method of claim 1, wherein the received data used to configure the narrowband (NB) includes dedicated RRC signaling, data broadcast in system information, or data indicated by PDCCH that schedules the PDSCH.

5. The method of claim 1, where PDSCH is broadcast in each narrowband.

6. The method of claim 1, wherein periodicity, TBS size, or repetitions parameters are predefined.

7. The method of claim 1, wherein periodicity, TBS size, or repetitions parameters are configured via RRC or broadcast in system information.

8. The method of claim 1,

wherein the received data indicating presence of PDSCH broadcast is indicated by a PHY signal, a PDCCH scrambled with P-RNTI or SI-RNTI, a unicast PDSCH, RRC signaling, a MAC CE PDU, or unicast PDCCH in UESS.

9. The method of claim 1, wherein the one or more transport blocks broadcast in PDSCH are prioritized over unicast transmissions.

10. The method of claim 1, wherein the UE is not required to receive unicast transmission for a predetermined amount of time.

11. The method of claim 1, the method further comprising:

receiving, by the UE, one or more second transport blocks in unicast while also receiving the one or more transport blocks broadcast PDSCH using an NB switching gap that is defined for parallel reception of unicast transport blocks and broadcast transport blocks.

12. The method of claim 1, wherein received data indicating the presence of a PDSCH broadcast includes scheduling information of SIB1-BR or SIB10, SIB11, or SIB12.

13. The method of claim 1, wherein the UE is configured to monitor PDCCH for waring system information.

14. The method of claim 1, wherein the UE is not required to monitor PDCCH for warning system information.

15. The method of claim 1, the method further comprising:

receiving or transmitting DCI having DCI format 6-2 with a flag to indicate paging or direct indication differentiation.

16. The method of claim 15, the wherein a first flag = 0 to indicate direct indication or the first flag = 1 to indicate paging.

17. The method of claim 15, wherein the DCI includes direct indication information to provide an indication of warning system information.

18. The method of claim 15, wherein the DCI includes scheduling information for SIB1-BR or SIB10/11/12.

19. The method of claim 1, the method further comprising:

after receiving the warning system information:

transmitting, to the access node, an indication that the UE has finished receiving the warning system information and is ready for unicast transmission/reception.

20. The method of claim 19, wherein the indication is transmitted in an RRC message, a MAC CE PDU, a scheduling request, a CQI or SRS report, or HARQ feedback.

21. The method of claim 1, the method further comprising:

receiving an RRC connection release message during reception of warning system information; and

completing reception of warning system information before completing release of connection.

22. A device comprising:

one or more processors and one or more storage devices storing instructions that are operable, when executed by the one or more processors, to cause the one or more processors to perform operations comprising:

receiving, from an access node, data indicating the presence of a PDSCH broadcast;

configuring, based on the received data, a narrowband (NB) to receive transport blocks in PDSCH; and

receiving, from the access node, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information.

23. The device of claim 22, wherein the UE is in coverage enhanced (CE) mode A or CE mode B.

24. The device of claim 22, wherein the warning system information includes earthquake and tsunami warning system (ETWS) / commercial mobile alert system (CMAS) information.

25. The device of claim 22, wherein the received data used to configure the narrowband (NB) includes dedicated RRC signaling, data broadcast in system information, or data indicated by PDCCH that schedules the PDSCH.

26. The device of claim 22, where PDSCH is broadcast in each narrowband.

27. The device of claim 22, wherein periodicity, TBS size, or repetitions parameters are predefined.

28. The device of claim 22, wherein periodicity, TBS size, or repetitions parameters are configured via RRC or broadcast in system information.

29. The device of claim 22,

wherein the received data indicating presence of PDSCH broadcast is indicated by a PHY signal, a PDCCH scrambled with P-RNTI or SI-RNTI, a unicast PDSCH, RRC signaling, a MAC CE PDU, or unicast PDCCH in UESS.

30. The device of claim 22, wherein the one or more transport blocks broadcast in PDSCH are prioritized over unicast transmissions.

31. The device of claim 22, wherein the UE is not required to receive unicast transmission for a predetermined amount of time.

32. The device of claim 22, the operations further comprising:

receiving, by the UE, one or more second transport blocks in unicast while also receiving the one or more transport blocks broadcast PDSCH using an NB switching gap that is defined for parallel reception of unicast transport blocks and broadcast transport blocks.

33. The device of claim 22, wherein received data indicating the presence of a PDSCH broadcast includes scheduling information of SIB1-BR or SIB10, SIB11, or SIB12.

34. The device of claim 22, wherein the UE is configured to monitor PDCCH for waring system information.

35. The device of claim 22, wherein the UE is not required to monitor PDCCH for warning system information.

36. The device of claim 22, the operations further comprising:

receiving or transmitting DCI having DCI format 6-2 with a flag to indicate paging or direct indication differentiation.

37. The device of claim 36, the wherein a first flag = 0 to indicate direct indication or the first flag = 1 to indicate paging.

38. The device of claim 36, wherein the DCI includes direct indication information to provide an indication of warning system information.

39. The device of claim 36, wherein the DCI includes scheduling information for SIB1-BR or SIB10/11/12.

40. The device of claim 22, the operations further comprising:

after receiving the warning system information:

transmitting, to the access node, an indication that the UE has finished receiving the warning system information and is ready for unicast transmission/reception.

41. The device of claim 40, wherein the indication is transmitted in an RRC message, a MAC CE PDU, a scheduling request, a CQI or SRS report, or HARQ feedback.

42. The device of claim 22, the operations further comprising:

receiving an RRC connection release message during reception of warning system information; and

completing reception of warning system information before completing release of connection.

43. A non-transitory computer-readable medium storing software comprising instructions executable by one or more processors which, upon such execution, cause the one or more processors to perform operations comprising:

receiving, by user equipment (UE) and from an access node, data indicating the presence of a PDSCH broadcast;

configuring, by the UE and based on the received data, a narrowband (NB) to receive transport blocks in PDSCH; and

receiving, by the UE and from the access node, one or more transport blocks broadcast in PDSCH using the NB, the one or more transport blocks including the warning system information.

44. The computer-readable medium of claim 43, wherein the UE is in coverage enhanced (CE) mode A or CE mode B.

45. The computer-readable medium of claim 43, wherein the warning system information includes earthquake and tsunami warning system (ETWS) / commercial mobile alert system (CMAS) information.

46. The computer-readable medium of claim 43, wherein the received data used to configure the narrowband (NB) includes dedicated RRC signaling, data broadcast in system information, or data indicated by PDCCH that schedules the PDSCH.

47. The computer-readable medium of claim 43, where PDSCH is broadcast in each narrowband.

48. The computer-readable medium of claim 43, wherein periodicity, TBS size, or repetitions parameters are predefined.

49. The computer-readable medium of claim 43, wherein periodicity, TBS size, or repetitions parameters are configured via RRC or broadcast in system information.

50. The computer-readable medium of claim 43,

wherein the received data indicating presence of PDSCH broadcast is indicated by a PHY signal, a PDCCH scrambled with P-RNTI or SI-RNTI, a unicast PDSCH, RRC signaling, a MAC CE PDU, or unicast PDCCH in UESS.

51. The computer-readable medium of claim 43, wherein the one or more transport blocks broadcast in PDSCH are prioritized over unicast transmissions.

52. The computer-readable medium of claim 43, wherein the UE is not required to receive unicast transmission for a predetermined amount of time.

53. The computer-readable medium of claim 43, the operations further comprising:

receiving, by the UE, one or more second transport blocks in unicast while also receiving the one or more transport blocks broadcast PDSCH using an NB switching gap that is defined for parallel reception of unicast transport blocks and broadcast transport blocks.

54. The computer-readable medium of claim 43, wherein received data indicating the presence of a PDSCH broadcast includes scheduling information of SIB1-BR or SIB10, SIB11, or SIB12.

55. The computer-readable medium of claim 43, wherein the UE is configured to monitor PDCCH for waring system information.

56. The computer-readable medium of claim 43, wherein the UE is not required to monitor PDCCH for warning system information.

57. The computer-readable medium of claim 43, the operations further comprising:

receiving or transmitting DCI having DCI format 6-2 with a flag to indicate paging or direct indication differentiation.

58. The computer-readable medium of claim 57, the wherein a first flag = 0 to indicate direct indication or the first flag = 1 to indicate paging.

59. The computer-readable medium of claim 57, wherein the DCI includes direct indication information to provide an indication of warning system information.

60. The computer-readable medium of claim 57, wherein the DCI includes scheduling information for SIB1-BR or SIB10/11/12.

61. The computer-readable medium of claim 43, the operations further comprising:

after receiving the warning system information:

transmitting, to the access node, an indication that the UE has finished receiving the warning system information and is ready for unicast transmission/reception.

62. The computer-readable medium of claim 61, wherein the indication is transmitted in an RRC message, a MAC CE PDU, a scheduling request, a CQI or SRS report, or HARQ feedback.

63. The computer-readable medium of claim 43, the operations further comprising:

receiving an RRC connection release message during reception of warning system information; and

completing reception of warning system information before completing release of connection.

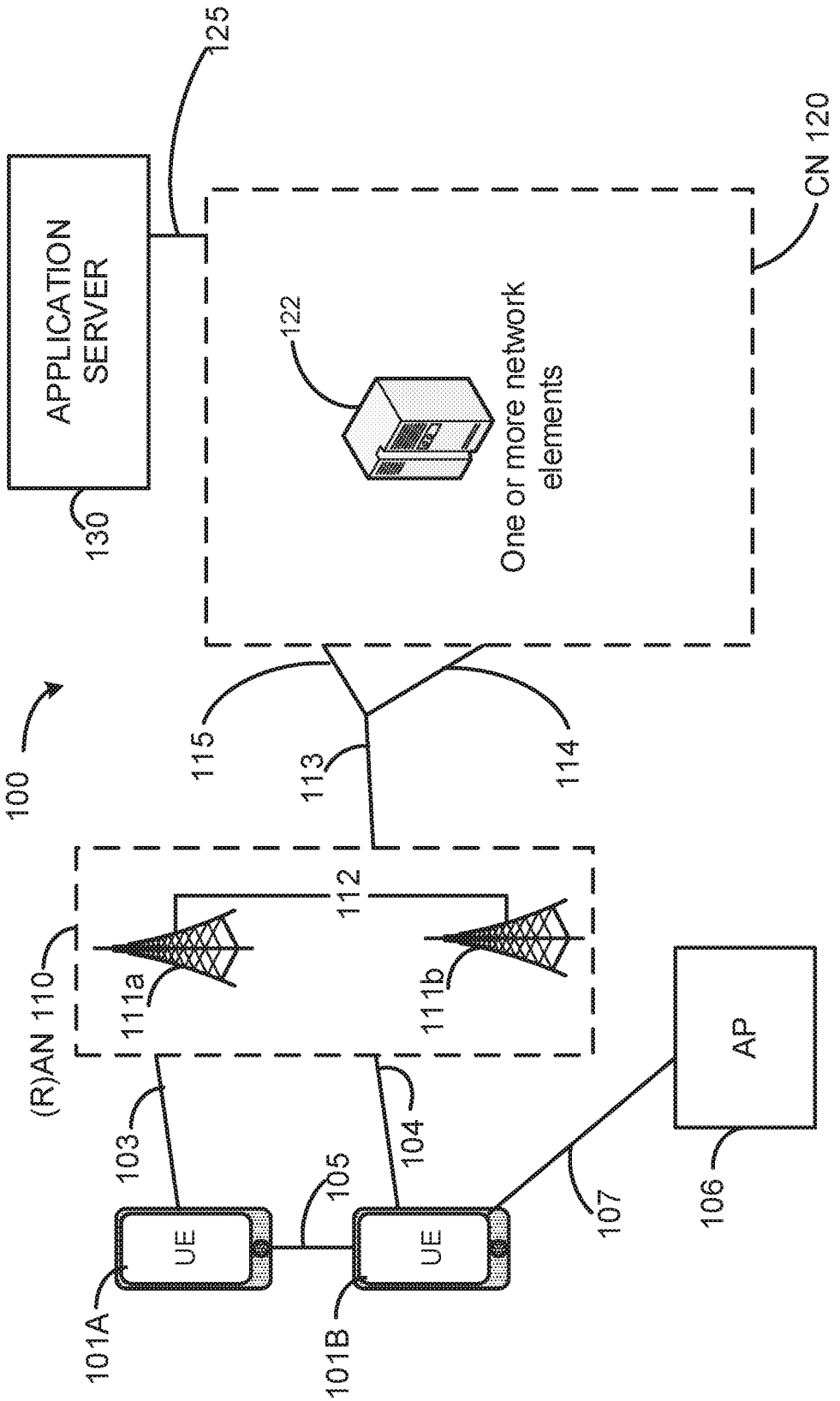

APPLICATION SERVER
130
125
CN 120
122
One or more network elements
100
115
113
114
(R)AN 110
112
111a
111b
AP
103
104
105
107
106
UE
UE
101A
101B

FIG. 1

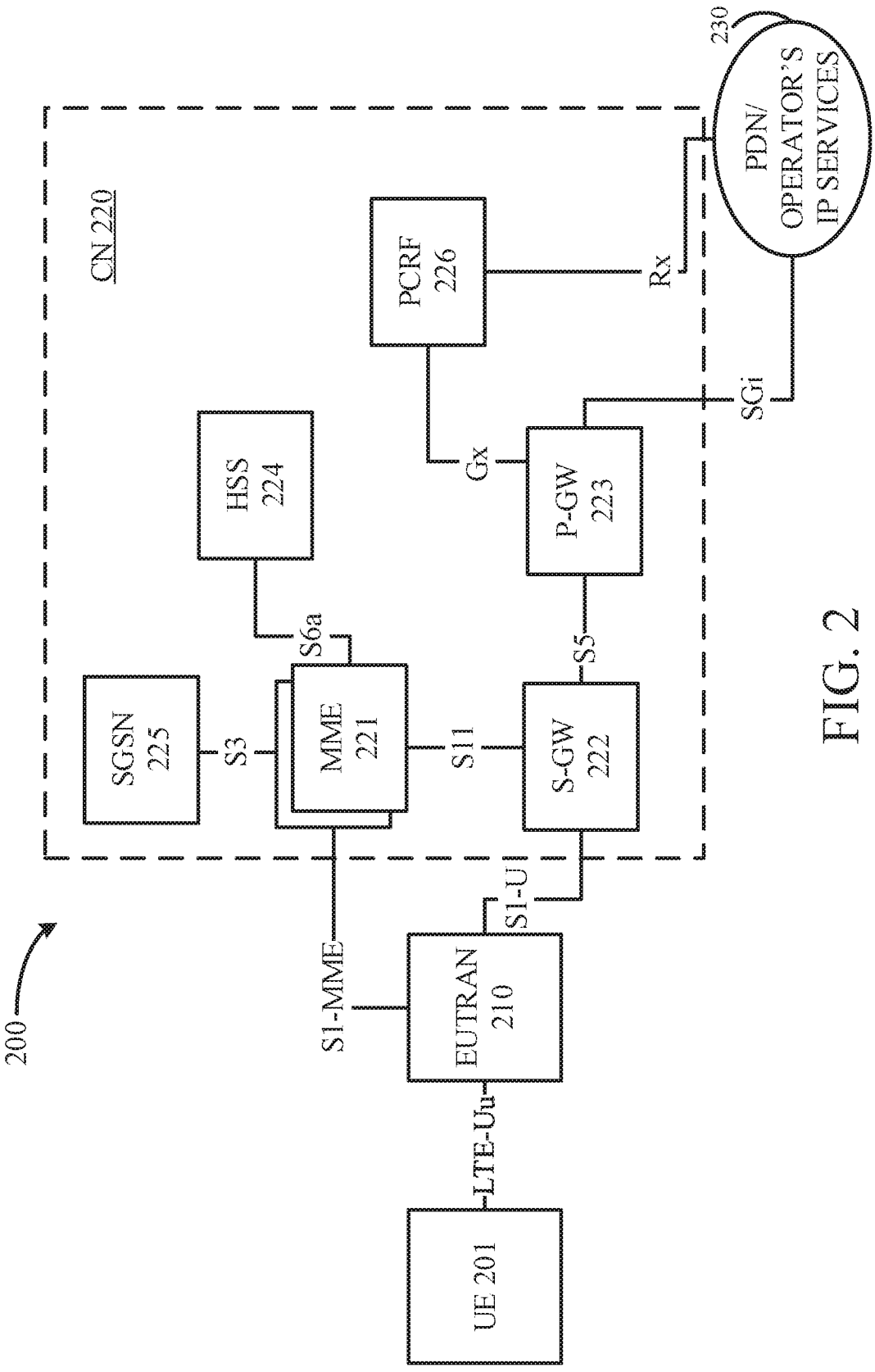

200
CN 220
UE 201
EUTRAN 210
MME 221
S-GW 222
P-GW 223
HSS 224
SGSN 225
PCRF 226
PDN/ OPERATOR'S IP SERVICES
230
LTE-Uu
S1-MME
S1-U
S11
S5
S6a
S3
Gx
Rx
SGi

FIG. 2

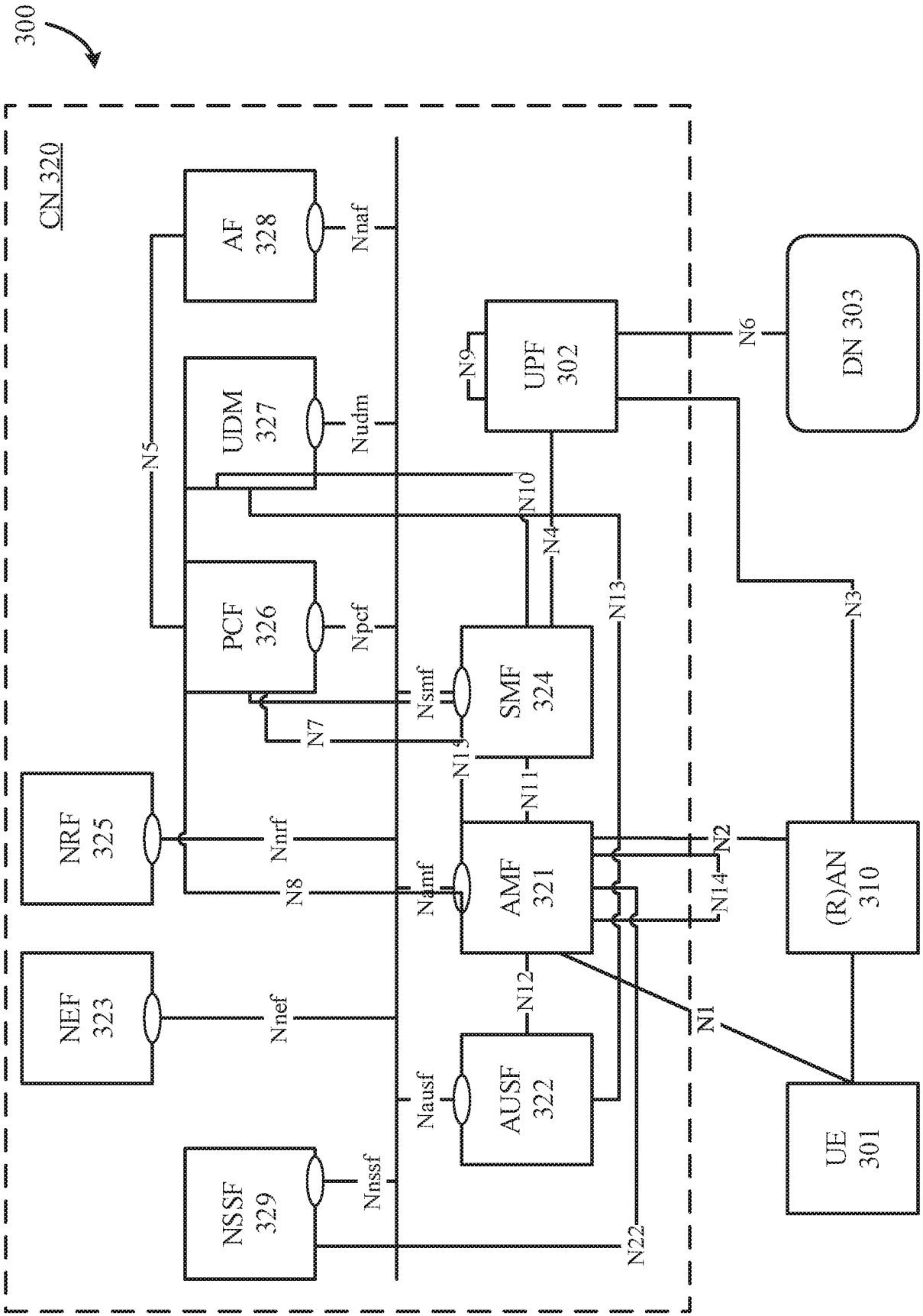

300
CN 320
AF 328
Naf
UDM 327
Nudm
PCF 326
Npcf
SMF 324
Nsmf
NRF 325
Nnrf
AMF 321
Namf
NEF 323
Nnef
AUSF 322
Nausf
NSSF 329
Nnssf
UPF 302
DN 303
(R)AN 310
UE 301
N1
N2
N3
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N14
N15
N22

FIG. 3

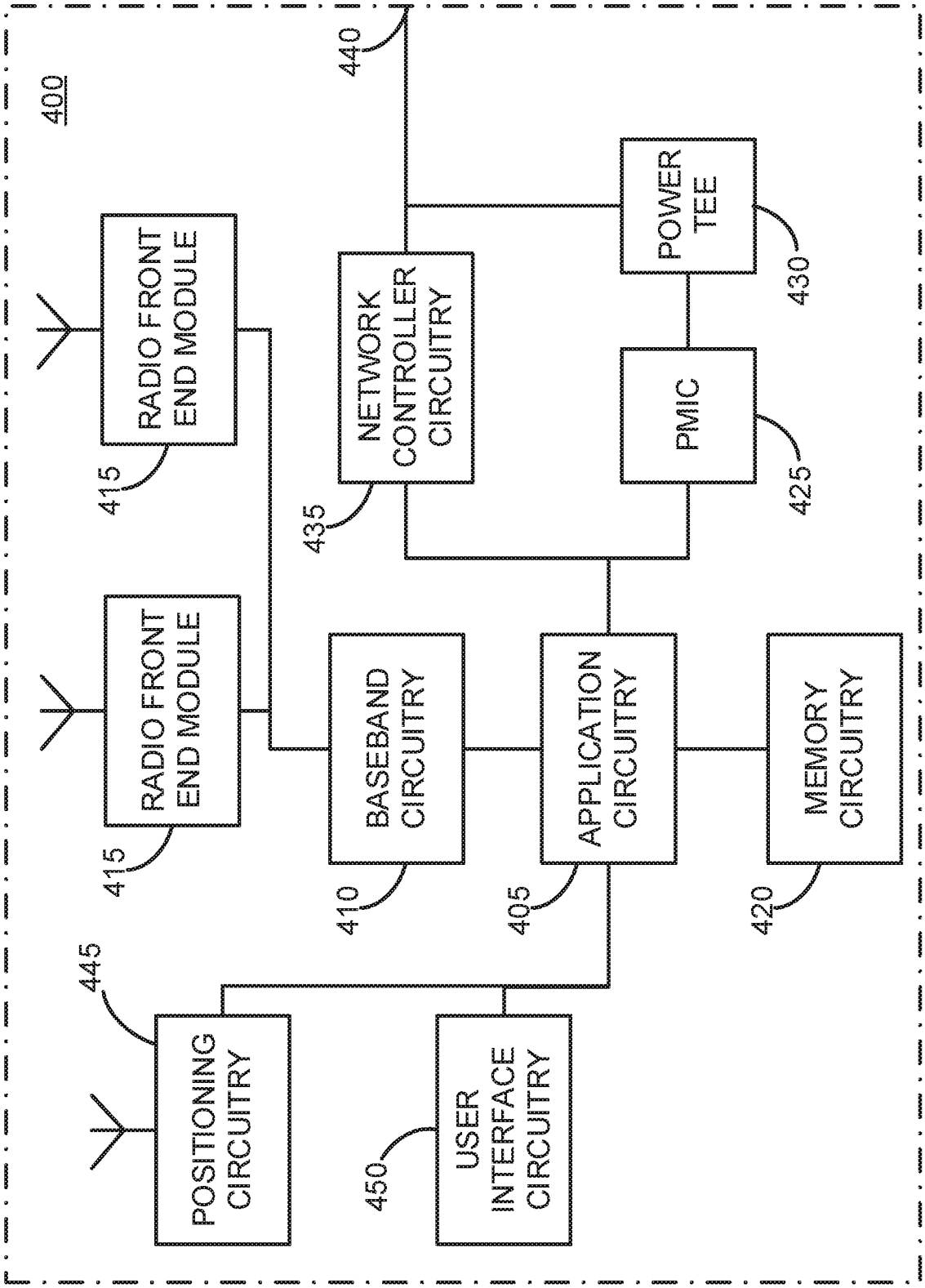

400
440
RADIO FRONT END MODULE
415
RADIO FRONT END MODULE
415
NETWORK CONTROLLER CIRCUITRY
435
POWER TEE
430
PMIC
425
BASEBAND CIRCUITRY
410
APPLICATION CIRCUITRY
405
MEMORY CIRCUITRY
420
POSITIONING CIRCUITRY
445
USER INTERFACE CIRCUITRY
450

FIG. 4

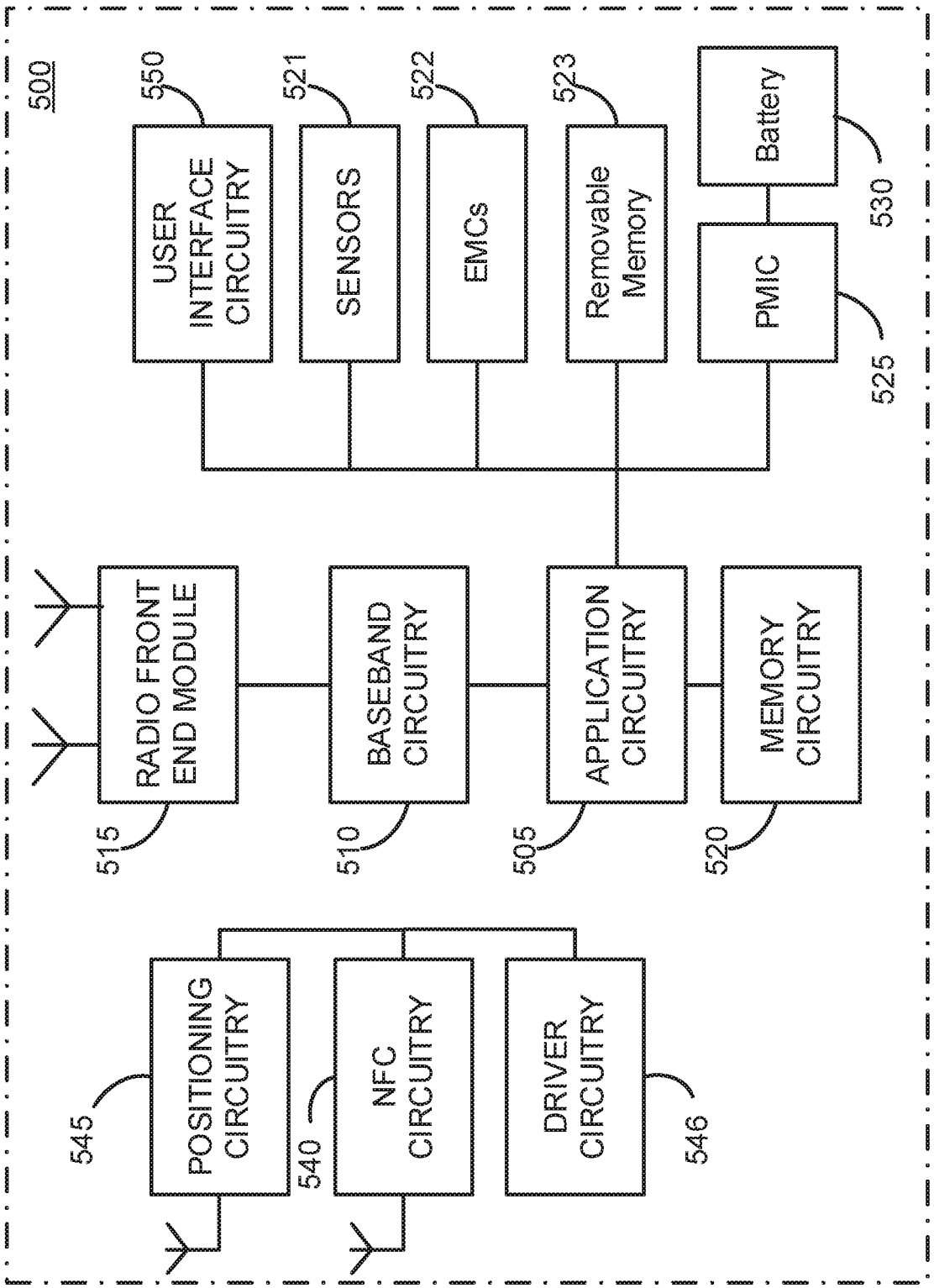

500
USER INTERFACE CIRCUITRY
550
SENSORS
521
EMCs
522
Removable Memory
523
Battery
530
PMIC
525
RADIO FRONT END MODULE
515
BASEBAND CIRCUITRY
510
APPLICATION CIRCUITRY
505
MEMORY CIRCUITRY
520
POSITIONING CIRCUITRY
545
NFC CIRCUITRY
540
DRIVER CIRCUITRY
546

FIG. 5

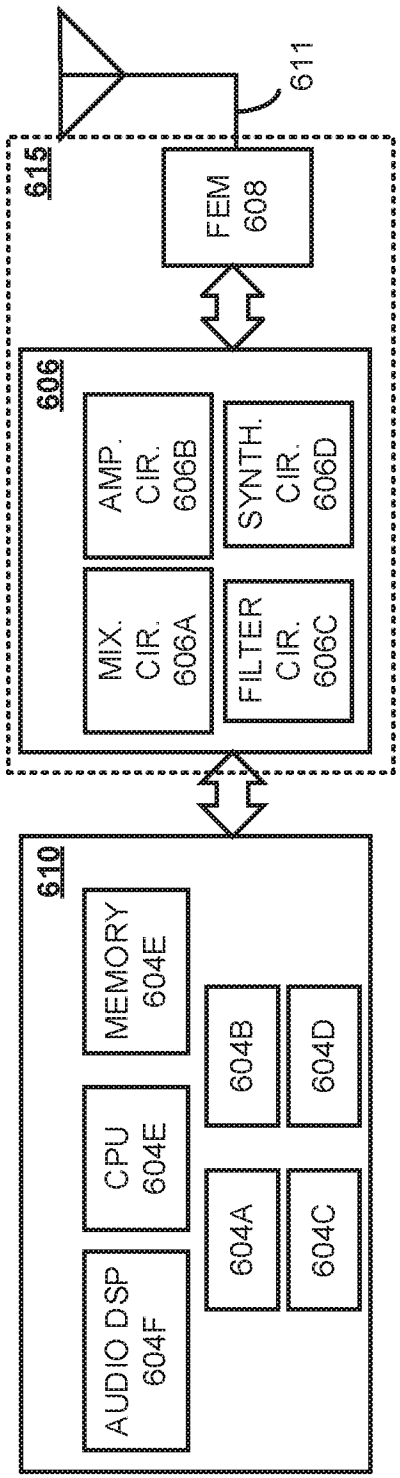

611
615
FEM
608
606
AMP.
CIR.
606B
SYNTH.
CIR.
606D
MIX.
CIR.
606A
FILTER
CIR.
606C
610
MEMORY
604E
604B
604D
CPU
604E
604A
604C
AUDIO DSP
604F

FIG. 6

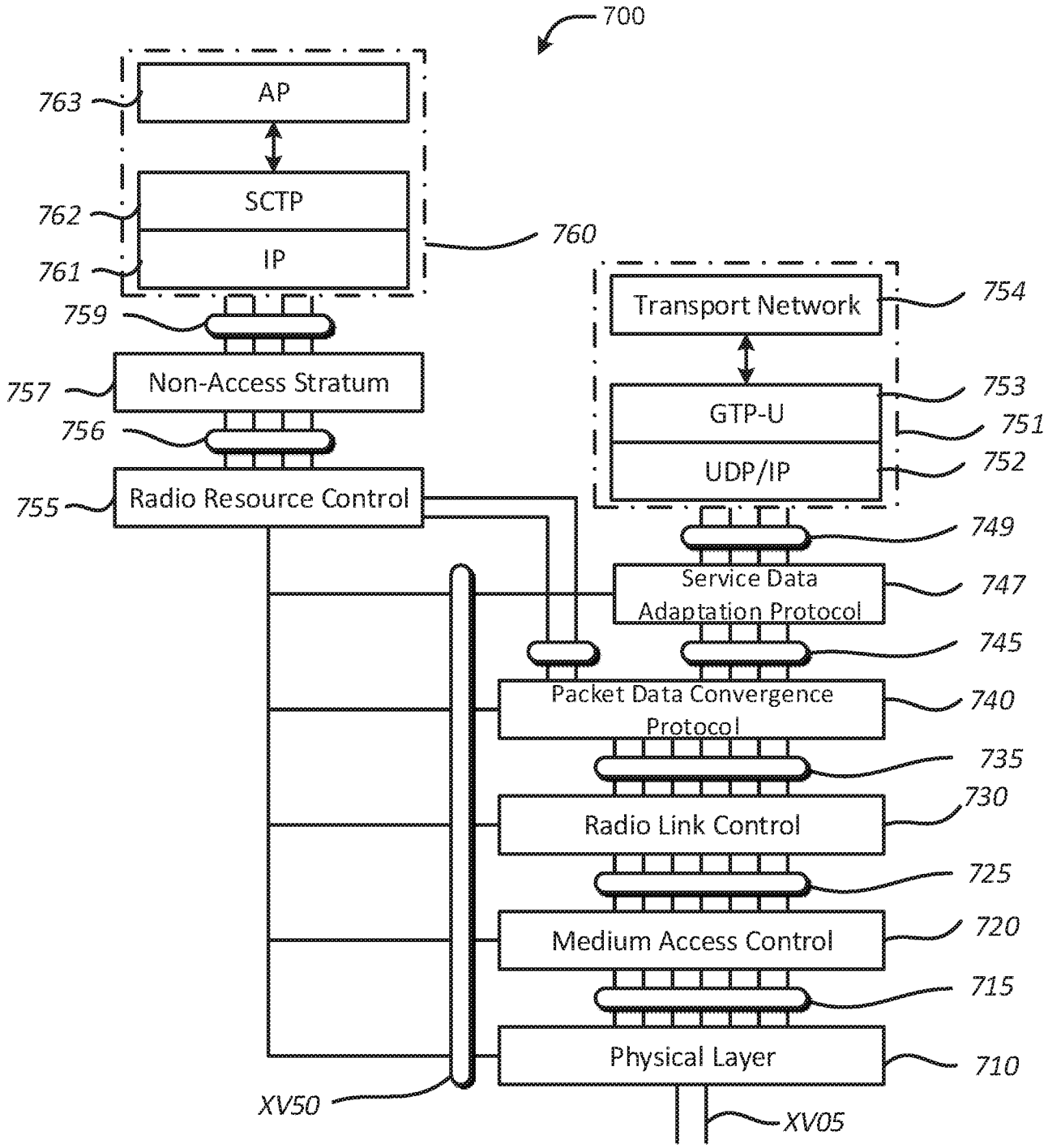

700
AP
763
SCTP
762
IP
761
760
759
Non-Access Stratum
757
756
Radio Resource Control
755
Transport Network
754
GTP-U
753
751
UDP/IP
752
749
Service Data Adaptation Protocol
747
745
Packet Data Convergence Protocol
740
735
Radio Link Control
730
725
Medium Access Control
720
715
Physical Layer
710
XV50
XV05

FIG. 7

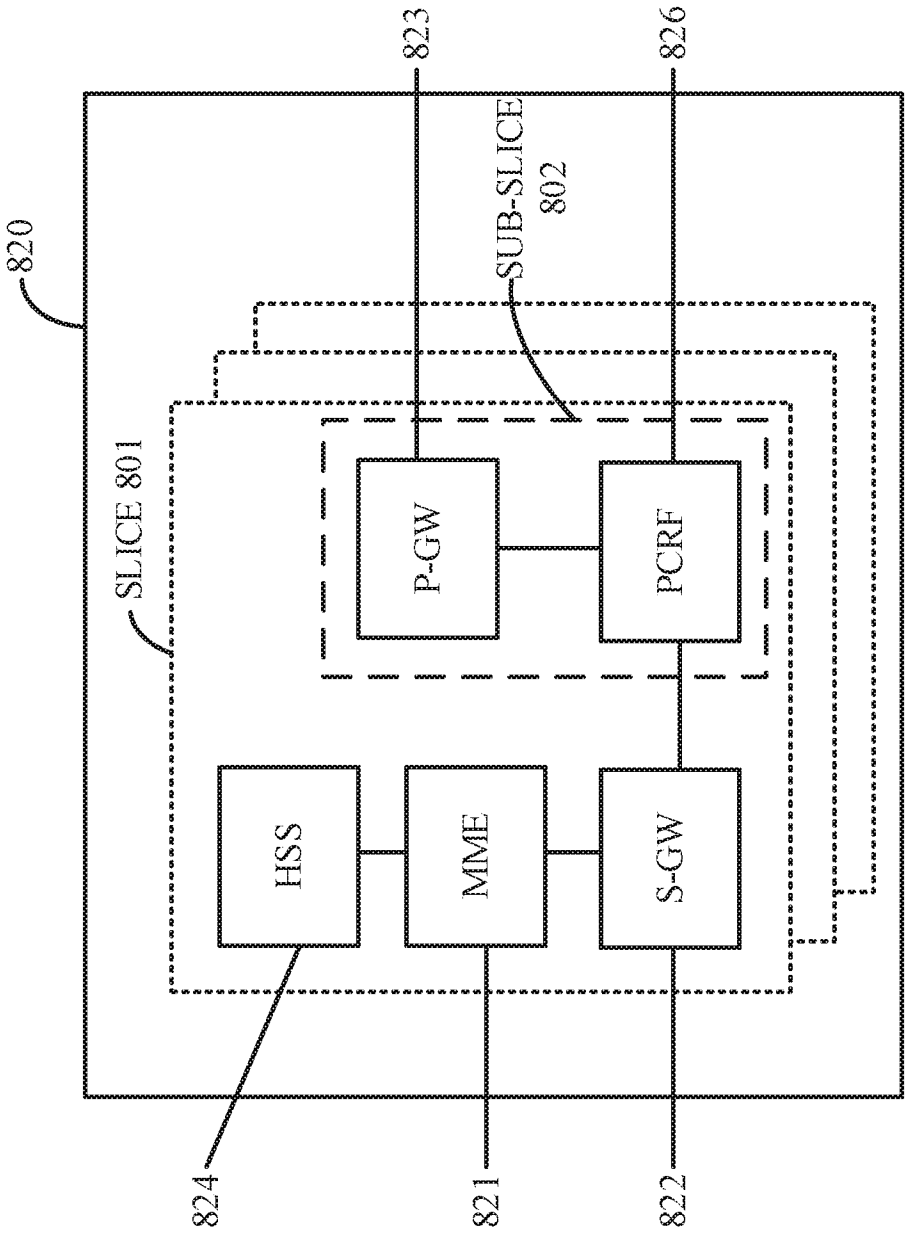

820
823
826
SUB-SLICE
802
SLICE 801
P-GW
PCRF
HSS
MME
S-GW
824
821
822

FIG. 8

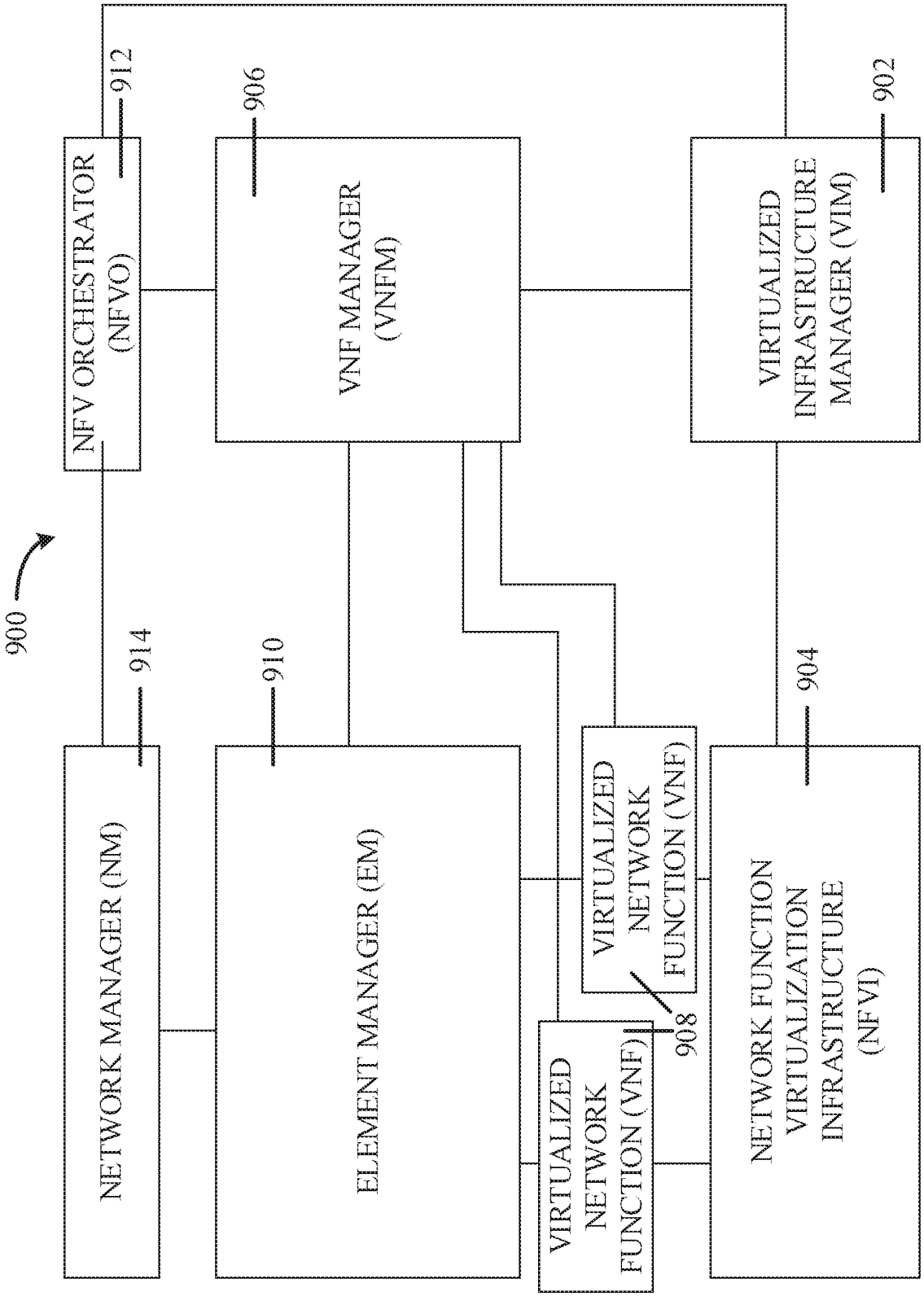

900
NFV ORCHESTRATOR (NFVO)
912
VNF MANAGER (VNFM)
906
VIRTUALIZED INFRASTRUCTURE MANAGER (VIM)
902
NETWORK MANAGER (NM)
914
ELEMENT MANAGER (EM)
910
VIRTUALIZED NETWORK FUNCTION (VNF)
908
VIRTUALIZED NETWORK FUNCTION (VNF)
NETWORK FUNCTION VIRTUALIZATION INFRASTRUCTURE (NFVI)
904

FIG. 9

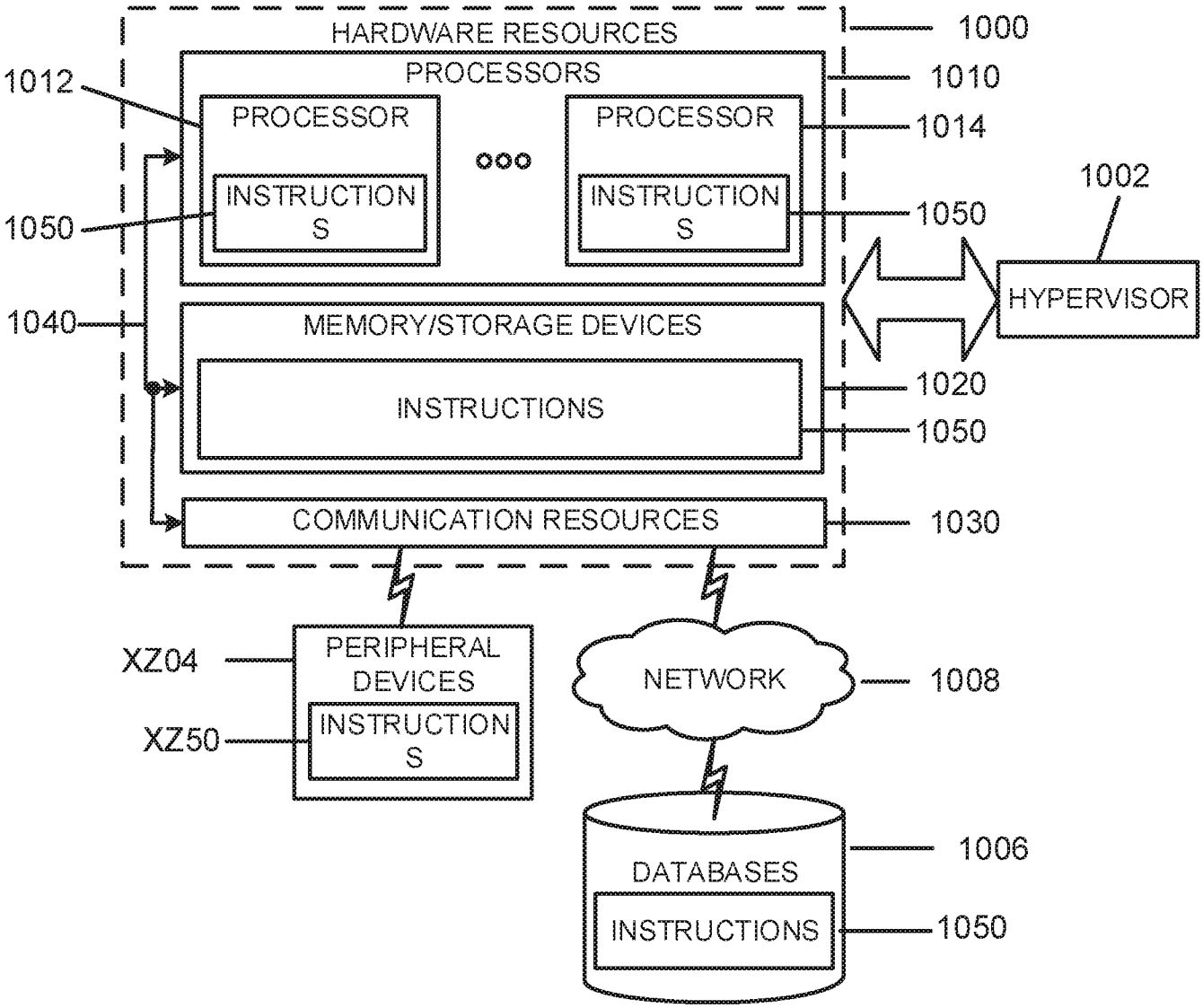

HARDWARE RESOURCES
1000
PROCESSORS
1010
1012
PROCESSOR
PROCESSOR
1014
INSTRUCTION S
INSTRUCTION S
1050
1002
HYPERVISOR
1040
MEMORY/STORAGE DEVICES
INSTRUCTIONS
1020
1050
COMMUNICATION RESOURCES
1030
XZ04
PERIPHERAL DEVICES
XZ50
INSTRUCTION S
NETWORK
1008
1006
DATABASES
INSTRUCTIONS
1050

FIG. 10

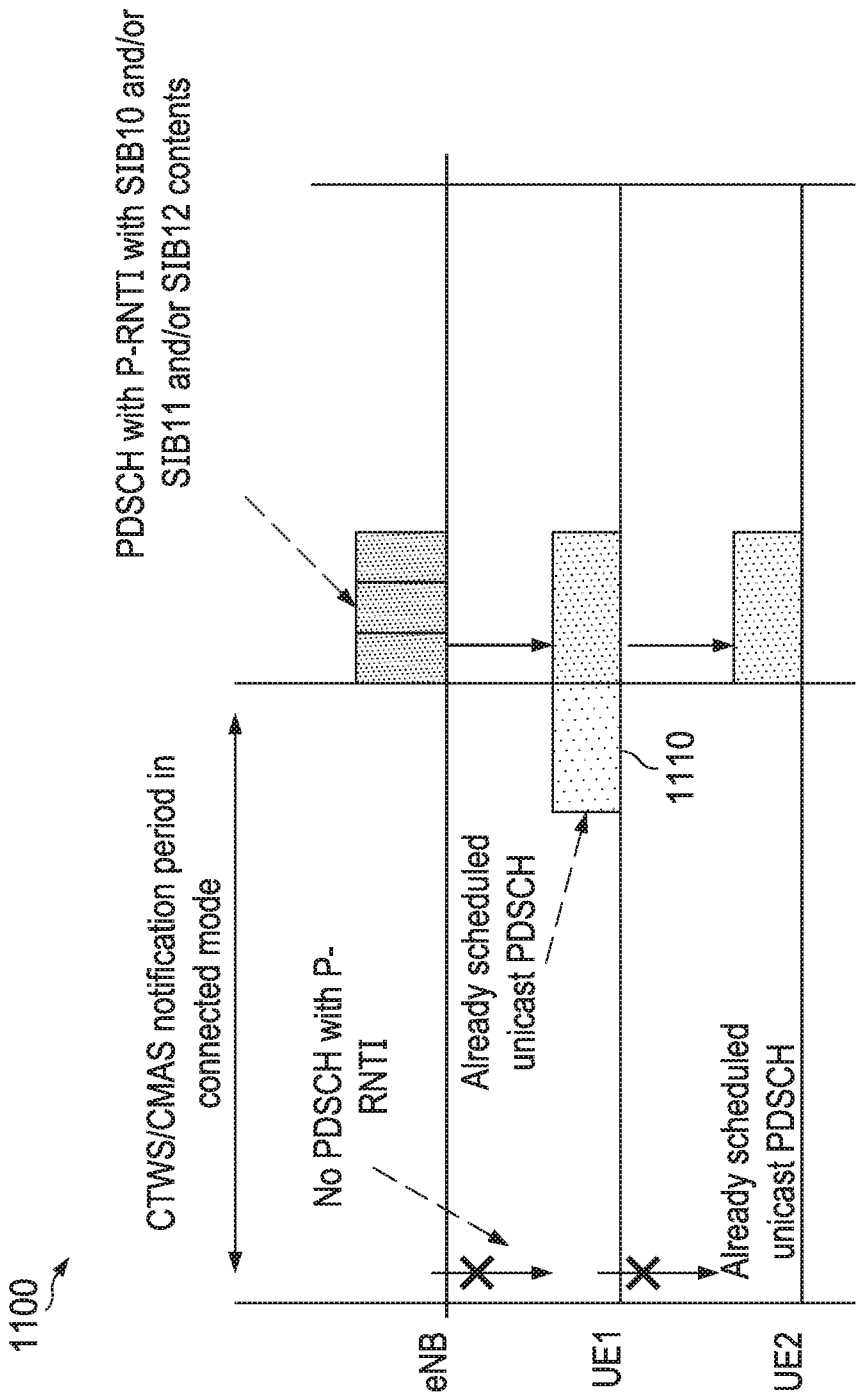

1100
PDSCH with P-RNTI with SIB10 and/or SIB11 and/or SIB12 contents
CTWS/CMAS notification period in connected mode
No PDSCH with P-RNTI
Already scheduled unicast PDSCH
1110
Already scheduled unicast PDSCH
eNB
UE1
UE2

FIG. 11

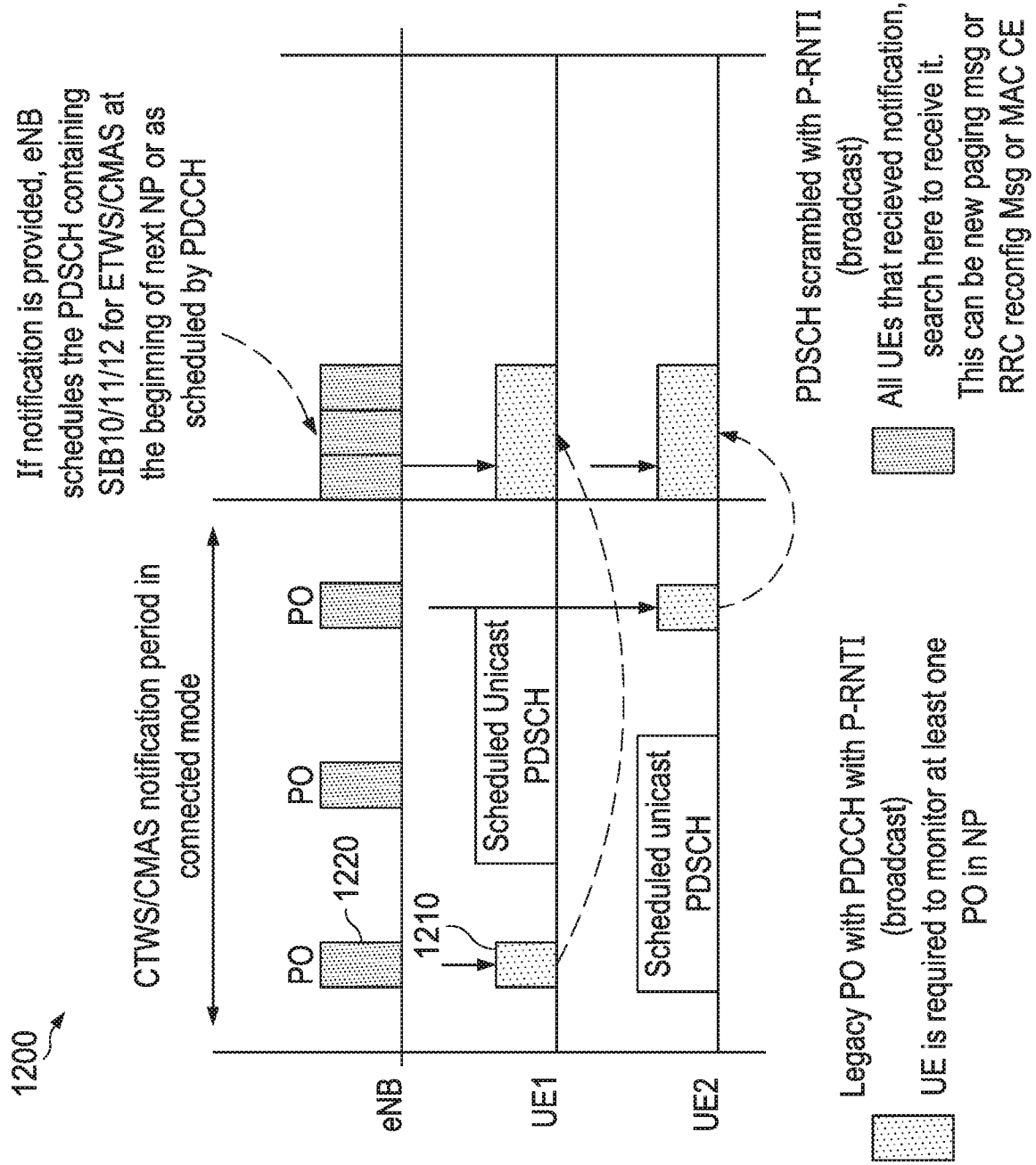

1200
If notification is provided, eNB schedules the PDSCH containing SIB10/11/12 for ETWS/CMAS at the beginning of next NP or as scheduled by PDCCH
CTWS/CMAS notification period in connected mode
PO
PO
PO
1220
1210
Scheduled Unicast PDSCH
Scheduled unicast PDSCH
eNB
UE1
UE2
PDSCH scrambled with P-RNTI (broadcast)
All UEs that recieved notification, search here to receive it.
This can be new paging msg or RRC reconfig Msg or MAC CE
Legacy PO with PDCCH with P-RNTI (broadcast)
UE is required to monitor at least one PO in NP

FIG. 12

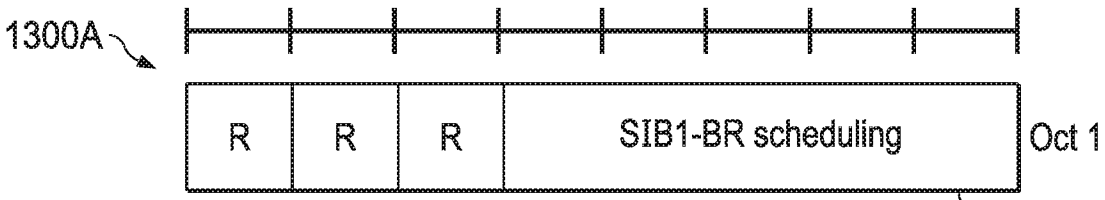


FIG. 13A

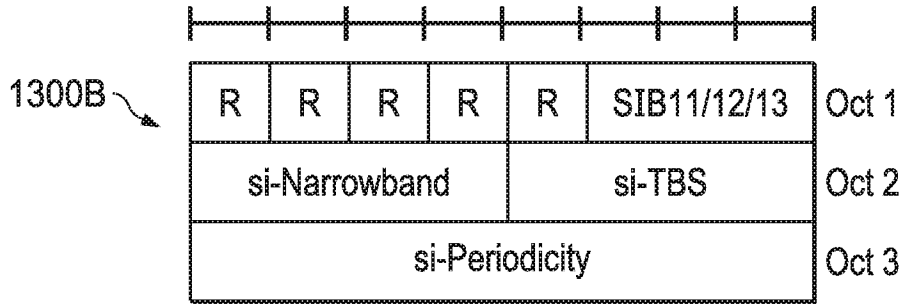


FIG. 13B

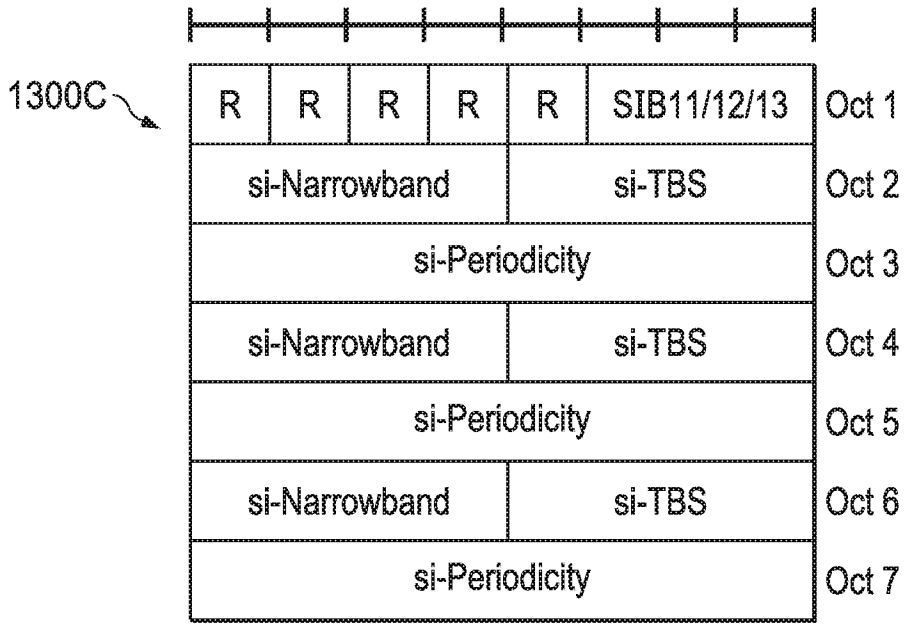


FIG. 13C

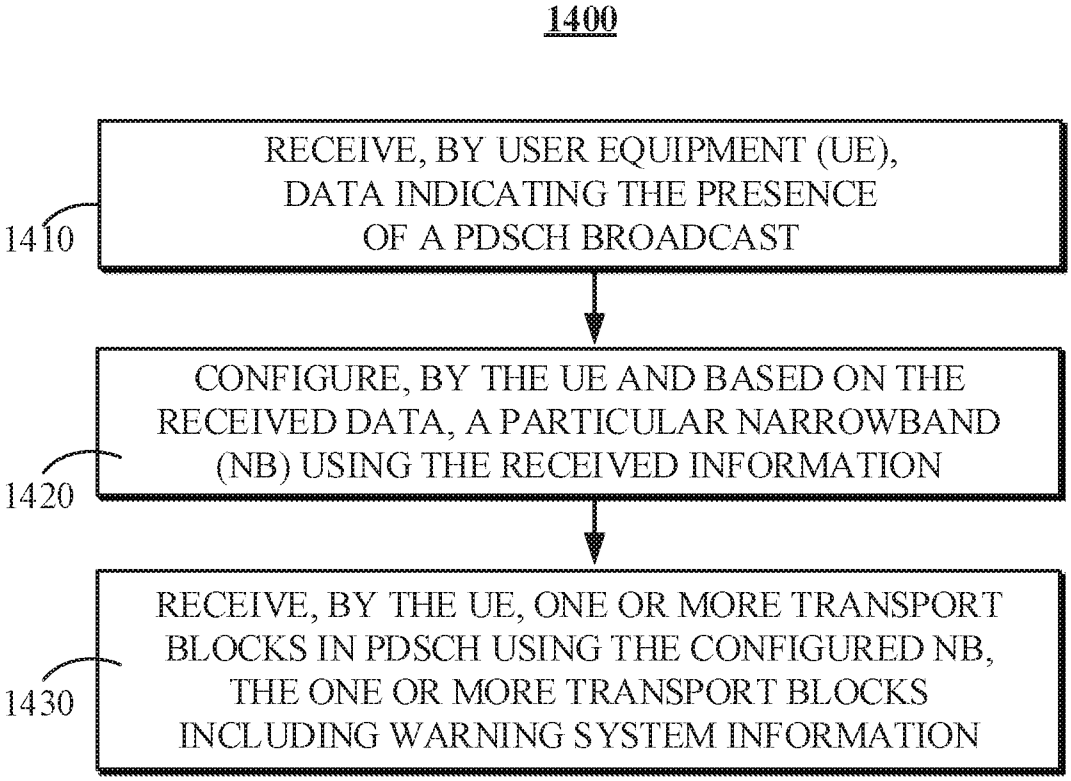

1400
RECEIVE, BY USER EQUIPMENT (UE), DATA INDICATING THE PRESENCE OF A PDSCH BROADCAST
1410
CONFIGURE, BY THE UE AND BASED ON THE RECEIVED DATA, A PARTICULAR NARROWBAND (NB) USING THE RECEIVED INFORMATION
1420
RECEIVE, BY THE UE, ONE OR MORE TRANSPORT BLOCKS IN PDSCH USING THE CONFIGURED NB, THE ONE OR MORE TRANSPORT BLOCKS INCLUDING WARNING SYSTEM INFORMATION
1430

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/025038

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W4/90
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)
H04W

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	INTEL CORPORATION: "ETWS/CMAS in connected mode for non-BL UE in CE", 3GPP DRAFT; R2-1814062 ETWSCMAS IN CONNECTED MODE, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG2, no. Chengdu, China; 20181008 - 20181012 28 September 2018 (2018-09-28), XP051523523, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg%5Fran/WG2%5FRL2/TSGR2%5F103bis/Docs/R2%2D1814062%2Ezip [retrieved on 2018-09-28] page 1 pages 2-3 -/--	1-63

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

[X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"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	Date of mailing of the international search report
15 May 2020	25/05/2020

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

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/025038

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	page 4 -----	
A	EP 2 427 030 A1 (MITSUBISHI ELECTRIC CORP [JP]) 7 March 2012 (2012-03-07) abstract paragraphs [0064] - [0079] figures 19-21	1-63

1

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Information on patent family members

International application No
PCT/US2020/025038

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