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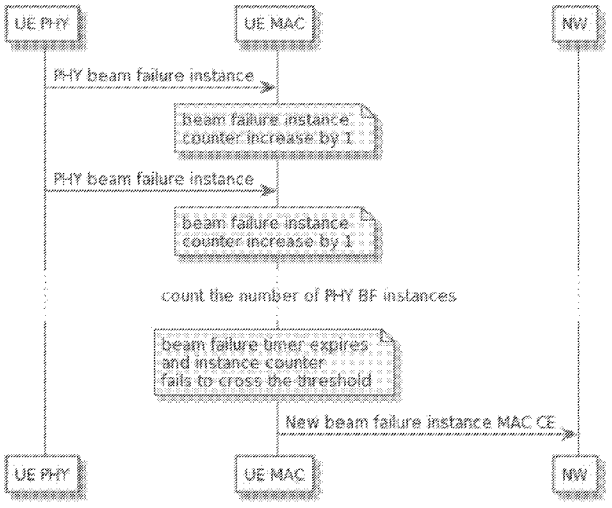

FIG. 6

(57) Abstract: A radio-access network (RAN) node configured for operation in a RAN, may be configured over an E2 interface by an intelligence controller (IC) of the RAN to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR). The RAN node configures one or more user equipments (UEs) for BFD and BFR reporting and receives physical layer (PHY) beam failure instance reports from the UEs based on the BFD and BFR reporting. The UEs are configured to report the PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the reporting UE.

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RAN NODE AND UE CONFIGURED FOR BEAM FAILURE DETECTION REPORTING TO SUPPORT TO AI AND ML BASED BEAM MANAGEMENT

PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 63/072,842, filed August 31, 2020 [reference number AD2186-Z] which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to fifth generation (5G) and sixth generation (6G) wireless communications. Some embodiments relate to an Open Radio Access Network (O-RAN). Some embodiments relate configuring user equipment (UE) to support artificial intelligence (AI) / machine learning (ML) based multi-input multiple output (MIMO) beam management optimization.

BACKGROUND

[0003] O-RAN has been striving to embrace artificial intelligence (AI) and machine learning (ML) based intelligence into wireless communication networks [1]. The purpose of introducing AI/ML spans not only to increase performance of existing networks and test up to their limit, but also to optimize/steer various network components to a certain key performance indicators (KPI) of interest in an efficient and elegant way.

[0004] Currently, there are many use cases being considered for such AI/ML based intelligence [2], and Massive MIMO (and their corresponding beam management) is one of the main subjects that operators are very keen to optimize:

- Beam Sweeping
- Beam Measurement
- Beam Reporting
- Beam Determination/Indication
- Beam Failure Detection
- Beam Failure Recovery

[0005] One issue with respect to beam management is that the network is not always aware of beam failure instances and beam recovery instances that occur at the UE.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1A illustrates an architecture of a network, in accordance with some embodiments.

[0007] FIG. 1B illustrates a non-roaming 5G system architecture, in accordance with some embodiments.

[0008] FIG. 1C illustrates a non-roaming 5G system architecture, in accordance with some embodiments.

[0009] FIG. 2 illustrates a block diagram of a communication device, in accordance with some embodiments.

[0010] FIG. 3 illustrates an Open RAN (O-RAN) system architecture, in accordance with some embodiments.

[0011] FIG. 4 illustrates a logical architecture of the O-RAN system of FIG. 3, in accordance with some embodiments.

[0012] FIG. 5 illustrates an overall beam management procedure, in accordance with some embodiments.

[0013] FIG. 6 illustrates a procedure to report PHY beam failure instances using MAC CE, in accordance with some embodiments.

[0014] FIG. 7 illustrates a MAC CE for PHY beam failure instance reporting, in accordance with some embodiments.

[0015] FIG. 8 illustrates an information element (IE) for detected beam failure measured during an E2 reporting period, in accordance with some embodiments.

DETAILED DESCRIPTION

[0016] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0017] Some embodiments are directed to a radio-access network (RAN) node configured for operation in a RAN, that may be configured over an E2 interface by an intelligence controller (IC) of the RAN to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR). The RAN node configures one or more user equipments (UEs) for BFD and BFR reporting and receives physical layer (PHY) beam failure instance reports from the UEs based on the BFD and BFR reporting. The UEs are configured to report the PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the reporting UE. These embodiments are described in more detail below.

[0018] In some embodiments, the RAN node may decode signalling received over an E2 interface from an intelligence controller (IC) of the RAN. The signalling may configure the RAN node to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR). In these embodiments, in response to the signalling received over the E2 interface, the RAN node may encode signalling for transmission to one or more user equipments (UEs) to configure the UEs for BFD and BFR reporting and may decode physical layer (PHY) beam failure instance reports received from the UEs based on the BFD and BFR reporting. In these embodiments, the signalling transmitted to the UEs is to configure each UE to report the PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the reporting UE.

[0019] In some embodiments, the RAN node may generate the statistics for the BFD and BFR based on the PHY beam failure instance reports received from the UEs and may encode signalling for transmission over the E2 interface to the intelligence controller to report the statistics for beam management by the intelligence controller. In these embodiments, the statistics may include at least a mean number of detected PHY beam failures during an E2 reporting period.

[0020] In some O-RAN embodiments, an RAN intelligence controller (RIC) of the O-RAN may command the RAN node to monitor/measure a new measurement type and report the measured values accordingly to RIC. In these embodiments, the new measurement type may require metric reporting that includes the mean number of detected beam failures per cell and/or per UE, although the scope of the embodiments is not limited in this respect. In these embodiments, the RIC may use the reported statistics for artificial intelligence (AI) / machine learning (ML) based optimized beam management, although the scope of the embodiments is not limited in this respect.

[0021] In some embodiments, the signalling transmitted over the E2 interface to the intelligence controller may comprise a Mean Number of Detected Beam Failures information element (IE) and the statistics may include at least a mean number of detected PHY beam failures for individual UEs or averaged for the UEs in a cell during the E2 reporting period.

[0022] In some embodiments, at least some of the PHY beam failure instance reports may be received from one or more of the UEs in a medium access control (MAC) control element (CE) configured for PHY beam failure instance reporting. In these embodiments, the MAC CE may have one or more fields for reporting the statistics for the BFD and BFR including one or more fields for reporting individual PHY beam failure instances. In these embodiments, each UE may be configured to report by the MAC CE a number of detected PHY beam failure instances that occur over a period of time configured. In these embodiments, each UE may be configured to report the number of detected PHY beam failure instances even when the number does not cross a threshold for triggering the beam failure recovery procedure.

[0023] In these embodiments, the RAN node may configure the UE with a configured period of time via the MAC CE for reporting detected PHY beam

failure instances. During that configured period of time, the UE may count the number of occurrences and report accordingly. The configured period of time may be a countdown timer or a predetermined period of time.

[0024] In some embodiments, the MAC CE may include a Serving Cell ID field, a Reference signal indicator (RSi) field, an Instance Counter field, an additional-differential (AD) indicator field, a Layer 1 Reference Signal Received Power (L1-RSRP) field, and up to one or more optional additional differential L1-RSRP fields when indicated by the AD indicator field.

[0025] In some embodiments, the Serving Cell ID field may indicate an identity of a serving cell for which a PHY beam failure instance is reported from a lower layer of the UE, the RSi field may indicate a presence of L1-RSRP reports in the MAC CE of reference signals (RS) defined by RadioLinkMonitoringConfig, the Instance Counter Field may indicate a number of PHY beam failure instances were reported from the lower layer before expiration of a timer, the AD field may indicate a presence of additional differential L1-RSRP reports in a next octet of the MAC CE, the L1-RSRP field may indicate a maximum measurement L1-RSRP value for a corresponding reference signal (RS) during a monitoring period; and the AD-RSRP field, when present, may indicate a differential L1-RSRP measurement value for the corresponding RS during the monitoring period.

[0026] In some embodiments, the signalling to configure the UEs for BFD and BFR reporting may comprise radio-resource control (RRC) signalling that configures the UE for the BFD and BFR reporting using the MAC CE. In these embodiments, the RRC signalling that configures the UEs for the BFD and BFR reporting using the MAC CE may comprise an RRC information element (IE). In these embodiments, the RRC signalling may configure the UEs to perform layer 1 (L1) and layer 2 (L2) measurements for the BFD and BFR reporting.

[0027] In some embodiments, the RRC IE that configures the UE for the BFD and BFR reporting using the MAC CE may be a new RRC IE, although the scope of the embodiments is not limited in this respect as one or more existing RRC IEs may be used. In some embodiments, the RRC IE that configures the UEs for the BFD and BFR reporting using the MAC CE may comprise one of an

RadioLinkMonitoringConfig IE, a *BeamFailureRecoveryConfig* IE, and a *BeamFailureRecoverySCellConfig* IE.

[0028] In some embodiments, the intelligence controller may be a RAN intelligence controller (RIC) of an open radio-access network (O-RAN). In these embodiments, the RAN node may comprises an E2 node configured for operation in the O-RAN. In these embodiments, the RAN intelligence controller may decode signalling received over the E2 interface from the intelligence controller to configure the RAN node for artificial intelligence (AI) / machine learning (ML) based multi-input multiple output (MIMO) beam management optimization.

[0029] In these O-RAN embodiments, the RAN node may be configured by the RAN intelligence controller in accordance with a subscription. In these embodiments, the RIC requests the RAN node to accept the subscription which is followed by the RAN node if the RAN node accepts the subscription. Such subscription request handling/procedures are defined in O-RAN E2AP (E2 Application Protocol) specification where they are used for various types of service subscriptions. The details of each service are defined in E2SM (Service Model). One service model, the Key Performance Monitor (E2SM-KPM), defines some services that a RAN node needs to monitor and measure certain measurement types and report periodically. The E2SM-KPM may support a measurement type for the mean number of detected beam failures described herein. Accordingly, an RIC can command a RAN node to monitor/measure this new measurement type and report the measured values accordingly to RIC.

[0030] In some embodiments, the RAN node may comprise a next generation node B (gNB) configured for operation in a fifth-generation new radio (5G NR) network.

[0031] Some embodiments are directed to a user equipment (UE) configured for operation in a radio-access network (RAN). In these embodiments, the UE may be configured to decode radio-resource control (RRC) signalling received from a RAN node. The RRC signalling may configure the UE for beam failure detection (BFD) and beam failure recovery (BFR) reporting. The UE may encode physical layer (PHY) beam failure instance reports for transmission to the RAN node. In these embodiments, the RRC signalling may configure the UE

to report PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the UE. These embodiments are described in more detail below.

[0032] In some embodiments, the UE may be configured by the RRC signalling to report the PHY beam failure instances in a medium access control (MAC) control element (CE) configured for PHY beam failure instance reporting. The MAC CE may have one or more fields for reporting the statistics for the BFD and BFR including one or more fields for reporting individual PHY beam failure instances.

[0033] In some embodiments, the UE may be configured by the RRC signalling to report by the MAC CE a number of detected PHY beam failure instances that occur over a time-period configured. In these embodiments, the UE may be configured to report the number of detected PHY beam failure instances even when the number does not cross a threshold for triggering the beam failure recovery procedure.

[0034] In some embodiments, the MAC CE may be encoded by the UE to include a Serving Cell ID field, Reference signal indicator (RSi) field, an Instance Counter field, an additional-differential (AD) indicator field, a Layer 1 Reference Signal Received Power (L1-RSRP) field, and up to one or more optional additional differential L1-RSRP fields when indicated by the AD indicator field.

[0035] In some embodiments, the UE may enter the beam failure recovery procedure in response to a beam failure declaration by a MAC layer of the UE based on a number of detected PHY beam failure instances reaching a beamFailureInstanceMaxCount threshold before a beam Failure Detection Timer expires. In these embodiments, in response to the beam failure declaration by the MAC layer, the UE may be configured to identify a new beam for recovery. In these embodiments, prior to entering the beam failure recovery procedure, the UE may be configured to report the number of detected PHY beam failure instances by the MAC CE.

[0036] In some embodiments, the RRC signalling that configures the UE for the BFD and BFR reporting using the MAC CE comprises an RRC information element (IE). In these embodiments, the RRC signalling is to configure the UEs

to perform layer 1 (L1) and layer 2 (L2) measurements for the BFD and BFR reporting. In some embodiments, the RRC IE that configures the UE for the BFD and BFR reporting using the MAC CE comprises one of an *RadioLinkMonitoringConfig* IE, a *BeamFailureRecoveryConfig* IE, and a *BeamFailureRecoverySCellConfig* IE.

[0037] Some embodiments are directed to intelligence controller (IC) for use in an radio-access network (RAN). In these embodiments, the intelligence controller may encode signalling for transmission over an E2 interface to a RAN node of the RAN. The signalling may configure the RAN node to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR). In these embodiments, the IC may decode signalling received over the E2 interface from the RAN node that includes the reported statistics for the BFD and BFR. In these embodiments, the IC may encode signalling for transmission over the E2 interface to configure the RAN node for artificial intelligence (AI) / machine learning (ML) based multi-input multiple output (MIMO) beam management optimization. In these embodiments, the statistics reported for the BFD and BFR include reports of physical layer (PHY) beam failure instances at user equipment (UEs) whether or not a beam failure recovery procedure is triggered by a reporting UE. These embodiments are described in more detail below.

[0038] In some embodiments, the statistics reported may include at least a mean number of detected PHY beam failures during an E2 reporting period. In some embodiments, the signalling received over the E2 interface from the RAN node may comprise a Mean Number of Detected Beam Failures information element (IE). In some embodiments, the statistics may include at least a mean number of detected PHY beam failures for individual UEs or averaged for the UEs in a cell during the E2 reporting period.

[0039] FIG. 1A illustrates an architecture of a network, in accordance with some embodiments. The network 140A includes 3GPP LTE/4G and NG network functions that may be extended to 6G functions. Accordingly, although 5G will be referred to, it is to be understood that this is to extend as able to 6G structures, systems, and functions. A network function can be implemented as a

discrete network element on a dedicated hardware, as a software instance running on dedicated hardware, and/or as a virtualized function instantiated on an appropriate platform, e.g., dedicated hardware or a cloud infrastructure.

[0040] The network 140A is shown to include user equipment (UE) 101 and UE 102. The UEs 101 and 102 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks) but may also include any mobile or non-mobile computing device, such as portable (laptop) or desktop computers, wireless handsets, drones, or any other computing device including a wired and/or wireless communications interface. The UEs 101 and 102 can be collectively referred to herein as UE 101, and UE 101 can be used to perform one or more of the techniques disclosed herein.

[0041] Any of the radio links described herein (e.g., as used in the network 140A or any other illustrated network) may operate according to any exemplary radio communication technology and/or standard. Any spectrum management scheme including, for example, dedicated licensed spectrum, unlicensed spectrum, (licensed) shared spectrum (such as Licensed Shared Access (LSA) in 2.3-2.4 GHz, 3.4-3.6 GHz, 3.6-3.8 GHz, and other frequencies and Spectrum Access System (SAS) in 3.55-3.7 GHz and other frequencies). Different Single Carrier or Orthogonal Frequency Domain Multiplexing (OFDM) modes (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.), and in particular 3GPP NR, may be used by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

[0042] In some embodiments, any of the UEs 101 and 102 can comprise an Internet-of-Things (IoT) UE or a Cellular IoT (CIoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. In some embodiments, any of the UEs 101 and 102 can include a narrowband (NB) IoT UE (e.g., such as an enhanced NB-IoT (eNB-IoT) UE and Further Enhanced (FeNB-IoT) UE). An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (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 includes 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. In some embodiments, any of the UEs 101 and 102 can include enhanced MTC (eMTC) UEs or further enhanced MTC (FeMTC) UEs.

[0043] The UEs 101 and 102 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 110. The RAN 110 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN.

[0044] The UEs 101 and 102 utilize connections 103 and 104, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); 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 Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a 5G protocol, a 6G protocol, and the like.

[0045] In an aspect, the UEs 101 and 102 may further directly exchange communication data via a ProSe interface 105. The ProSe interface 105 may alternatively be referred to as a sidelink (SL) interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), a Physical Sidelink Broadcast Channel (PSBCH), and a Physical Sidelink Feedback Channel (PSFCH).

[0046] The UE 102 is shown to be configured to access an access point (AP) 106 via connection 107. The connection 107 can comprise a local wireless connection, such as, for example, a connection consistent with any IEEE 802.11

protocol, according to which the AP 106 can comprise a wireless fidelity (WiFi®) 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).

[0047] The RAN 110 can include one or more access nodes that enable the connections 103 and 104. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), Next Generation NodeBs (gNBs), RAN nodes, and the like, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). In some embodiments, the communication nodes 111 and 112 can be transmission/reception points (TRPs). In instances when the communication nodes 111 and 112 are NodeBs (e.g., eNBs or gNBs), one or more TRPs can function within the communication cell of the NodeBs. The RAN 110 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 111, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 112.

[0048] Any of the RAN nodes 111 and 112 can terminate the air interface protocol and can be the first point of contact for the UEs 101 and 102. In some embodiments, any of the RAN nodes 111 and 112 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. In an example, any of the nodes 111 and/or 112 can be a gNB, an eNB, or another type of RAN node.

[0049] The RAN 110 is shown to be communicatively coupled to a core network (CN) 120 via an S1 interface 113. In aspects, the CN 120 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN (e.g., as illustrated in reference to FIGS. 1B-1C). In this aspect, the S1 interface 113 is split into two parts: the S1-U interface 114, which carries traffic data between the RAN nodes 111 and 112 and the serving gateway (S-GW) 122, and the S1-mobility management entity (MME) interface 115,

which is a signaling interface between the RAN nodes 111 and 112 and MMEs 121.

[0050] In this aspect, the CN 120 comprises the MMEs 121, the S-GW 122, the Packet Data Network (PDN) Gateway (P-GW) 123, and a home subscriber server (HSS) 124. The MMEs 121 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 121 may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS 124 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN 120 may comprise one or several HSSs 124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 124 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[0051] The S-GW 122 may terminate the S1 interface 113 towards the RAN 110, and routes data packets between the RAN 110 and the CN 120. In addition, the S-GW 122 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities of the S-GW 122 may include a lawful intercept, charging, and some policy enforcement.

[0052] The P-GW 123 may terminate an SGi interface toward a PDN. The P-GW 123 may route data packets between the EPC network 120 and external networks such as a network including the application server 184 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 125. The P-GW 123 can also communicate data to other external networks 131A, which can include the Internet, IP multimedia subsystem (IPS) network, and other networks. Generally, the application server 184 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this aspect, the P-GW 123 is shown to be communicatively coupled to an application server 184 via an IP interface 125. The application server 184 can also be configured to support one or more communication services (e.g., Voice-over-Internet

Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101 and 102 via the CN 120.

[0053] The P-GW 123 may further be a node for policy enforcement and charging data collection. Policy and Charging Rules Function (PCRF) 126 is the policy and charging control element of the CN 120. In a non-roaming scenario, in some embodiments, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with a local breakout of traffic, there may be two PCRFs associated with a UE'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 126 may be communicatively coupled to the application server 184 via the P-GW 123.

[0054] In some embodiments, the communication network 140A can be an IoT network or a 5G or 6G network, including 5G new radio network using communications in the licensed (5G NR) and the unlicensed (5G NR-U) spectrum. One of the current enablers of IoT is the narrowband-IoT (NB-IoT). Operation in the unlicensed spectrum may include dual connectivity (DC) operation and the standalone LTE system in the unlicensed spectrum, according to which LTE-based technology solely operates in unlicensed spectrum without the use of an "anchor" in the licensed spectrum, called MulteFire. Further enhanced operation of LTE systems in the licensed as well as unlicensed spectrum is expected in future releases and 5G systems. Such enhanced operations can include techniques for sidelink resource allocation and UE processing behaviors for NR sidelink V2X communications.

[0055] An NG system architecture (or 6G system architecture) can include the RAN 110 and a 5G network core (5GC) 120. The NG-RAN 110 can include a plurality of nodes, such as gNBs and NG-eNBs. The core network 120 (e.g., a 5G core network/5GC) can include an access and mobility function (AMF) and/or a user plane function (UPF). The AMF and the UPF can be communicatively coupled to the gNBs and the NG-eNBs via NG interfaces. More specifically, in some embodiments, the gNBs and the NG-eNBs can be

connected to the AMF by NG-C interfaces, and to the UPF by NG-U interfaces. The gNBs and the NG-eNBs can be coupled to each other via Xn interfaces.

[0056] In some embodiments, the NG system architecture can use reference points between various nodes. In some embodiments, each of the gNBs and the NG-eNBs can be implemented as a base station, a mobile edge server, a small cell, a home eNB, and so forth. In some embodiments, a gNB can be a master node (MN) and NG-eNB can be a secondary node (SN) in a 5G architecture.

[0057] FIG. 1B illustrates a non-roaming 5G system architecture, in accordance with some embodiments. In particular, FIG. 1B illustrates a 5G system architecture 140B in a reference point representation, which may be extended to a 6G system architecture. More specifically, UE 102 can be in communication with RAN 110 as well as one or more other 5GC network entities. The 5G system architecture 140B includes a plurality of network functions (NFs), such as an AMF 132, session management function (SMF) 136, policy control function (PCF) 148, application function (AF) 150, UPF 134, network slice selection function (NSSF) 142, authentication server function (AUSF) 144, and unified data management (UDM)/home subscriber server (HSS) 146.

[0058] The UPF 134 can provide a connection to a data network (DN) 152, which can include, for example, operator services, Internet access, or third-party services. The AMF 132 can be used to manage access control and mobility and can also include network slice selection functionality. The AMF 132 may provide UE-based authentication, authorization, mobility management, etc., and may be independent of the access technologies. The SMF 136 can be configured to set up and manage various sessions according to network policy. The SMF 136 may thus be responsible for session management and allocation of IP addresses to UEs. The SMF 136 may also select and control the UPF 134 for data transfer. The SMF 136 may be associated with a single session of a UE 101 or multiple sessions of the UE 101. This is to say that the UE 101 may have multiple 5G sessions. Different SMFs may be allocated to each session. The use of different SMFs may permit each session to be individually managed. As a consequence, the functionalities of each session may be independent of each other.

[0059] The UPF 134 can be deployed in one or more configurations according to the desired service type and may be connected with a data network. The PCF 148 can be configured to provide a policy framework using network slicing, mobility management, and roaming (similar to PCRF in a 4G communication system). The UDM can be configured to store subscriber profiles and data (similar to an HSS in a 4G communication system).

[0060] The AF 150 may provide information on the packet flow to the PCF 148 responsible for policy control to support a desired QoS. The PCF 148 may set mobility and session management policies for the UE 101. To this end, the PCF 148 may use the packet flow information to determine the appropriate policies for proper operation of the AMF 132 and SMF 136. The AUSF 144 may store data for UE authentication.

[0061] In some embodiments, the 5G system architecture 140B includes an IP multimedia subsystem (IMS) 168B as well as a plurality of IP multimedia core network subsystem entities, such as call session control functions (CSCFs). More specifically, the IMS 168B includes a CSCF, which can act as a proxy CSCF (P-CSCF) 162BE, a serving CSCF (S-CSCF) 164B, an emergency CSCF (E-CSCF) (not illustrated in FIG. 1B), or interrogating CSCF (I-CSCF) 166B. The P-CSCF 162B can be configured to be the first contact point for the UE 102 within the IM subsystem (IMS) 168B. The S-CSCF 164B can be configured to handle the session states in the network, and the E-CSCF can be configured to handle certain aspects of emergency sessions such as routing an emergency request to the correct emergency center or PSAP. The I-CSCF 166B can be configured to function as the contact point within an operator's network for all IMS connections destined to a subscriber of that network operator, or a roaming subscriber currently located within that network operator's service area. In some embodiments, the I-CSCF 166B can be connected to another IP multimedia network 170E, e.g. an IMS operated by a different network operator.

[0062] In some embodiments, the UDM/HSS 146 can be coupled to an application server 160E, which can include a telephony application server (TAS) or another application server (AS). The AS 160B can be coupled to the IMS 168B via the S-CSCF 164B or the I-CSCF 166B.

[0063] A reference point representation shows that interaction can exist between corresponding NF services. For example, FIG. 1B illustrates the following reference points: N1 (between the UE 102 and the AMF 132), N2 (between the RAN 110 and the AMF 132), N3 (between the RAN 110 and the UPF 134), N4 (between the SMF 136 and the UPF 134), N5 (between the PCF 148 and the AF 150, not shown), N6 (between the UPF 134 and the DN 152), N7 (between the SMF 136 and the PCF 148, not shown), N8 (between the UDM 146 and the AMF 132, not shown), N9 (between two UPFs 134, not shown), N10 (between the UDM 146 and the SMF 136, not shown), N11 (between the AMF 132 and the SMF 136, not shown), N12 (between the AUSF 144 and the AMF 132, not shown), N13 (between the AUSF 144 and the UDM 146, not shown), N14 (between two AMFs 132, not shown), N15 (between the PCF 148 and the AMF 132 in case of a non-roaming scenario, or between the PCF 148 and a visited network and AMF 132 in case of a roaming scenario, not shown), N16 (between two SMFs, not shown), and N22 (between AMF 132 and NSSF 142, not shown). Other reference point representations not shown in FIG. 1B can also be used.

[0064] FIG. 1C illustrates a 5G system architecture 140C and a service-based representation. In addition to the network entities illustrated in FIG. 1B, system architecture 140C can also include a network exposure function (NEF) 154 and a network repository function (NRF) 156. In some embodiments, 5G system architectures can be service-based and interaction between network functions can be represented by corresponding point-to-point reference points Ni or as service-based interfaces.

[0065] In some embodiments, as illustrated in FIG. 1C, service-based representations can be used to represent network functions within the control plane that enable other authorized network functions to access their services. In this regard, 5G system architecture 140C can include the following service-based interfaces: Namf 158H (a service-based interface exhibited by the AMF 132), Nsmf 158I (a service-based interface exhibited by the SMF 136), Nnef 158B (a service-based interface exhibited by the NEF 154), Npcf 158D (a service-based interface exhibited by the PCF 148), a Nudm 158E (a service-based interface exhibited by the UDM 146), Naf 158F (a service-based interface exhibited by

the AF 150), Nnrf 158C (a service-based interface exhibited by the NRF 156), Nnssf 158A (a service-based interface exhibited by the NSSF 142), Nausf 158G (a service-based interface exhibited by the AUSF 144). Other service-based interfaces (e.g., Nudr, N5g-eir, and Nudsf) not shown in FIG. 1C can also be used.

[0066] NR-V2X architectures may support high-reliability low latency sidelink communications with a variety of traffic patterns, including periodic and aperiodic communications with random packet arrival time and size. Techniques disclosed herein can be used for supporting high reliability in distributed communication systems with dynamic topologies, including sidelink NR V2X communication systems.

[0067] FIG. 2 illustrates a block diagram of a communication device, in accordance with some embodiments. The communication device 200 may be a UE such as a specialized computer, a personal or laptop computer (PC), a tablet PC, or a smart phone, dedicated network equipment such as an eNB, a server running software to configure the server to operate as a network device, a virtual device, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. For example, the communication device 200 may be implemented as one or more of the devices shown in FIGS. 1A-1C. Note that communications described herein may be encoded before transmission by the transmitting entity (e.g., UE, gNB) for reception by the receiving entity (e.g., gNB, UE) and decoded after reception by the receiving entity.

[0068] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules and components are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may

reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0069] Accordingly, the term "module" (and "component") is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0070] The communication device 200 may include a hardware processor (or equivalently processing circuitry) 202 (e.g., a central processing unit (CPU), a GPU, a hardware processor core, or any combination thereof), a main memory 204 and a static memory 206, some or all of which may communicate with each other via an interlink (e.g., bus) 208. The main memory 204 may contain any or all of removable storage and non-removable storage, volatile memory or non-volatile memory. The communication device 200 may further include a display unit 210 such as a video display, an alphanumeric input device 212 (e.g., a keyboard), and a user interface (UI) navigation device 214 (e.g., a mouse). In an example, the display unit 210, input device 212 and UI navigation device 214 may be a touch screen display. The communication device 200 may additionally include a storage device (e.g., drive unit) 216, a signal generation device 218 (e.g., a speaker), a network interface device 220, and one or more sensors, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 200 may further include an output controller, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to

communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0071] The storage device 216 may include a non-transitory machine readable medium 222 (hereinafter simply referred to as machine readable medium) on which is stored one or more sets of data structures or instructions 224 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 224 may also reside, completely or at least partially, within the main memory 204, within static memory 206, and/or within the hardware processor 202 during execution thereof by the communication device 200. While the machine readable medium 222 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 224.

[0072] The term “machine readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the communication device 200 and that cause the communication device 200 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks.

[0073] The instructions 224 may further be transmitted or received over a communications network using a transmission medium 226 via the network interface device 220 utilizing any one of a number of wireless local area network (WLAN) transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include

a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks. Communications over the networks may include one or more different protocols, such as Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi, IEEE 802.16 family of standards known as WiMax, IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, a next generation (NG)/5th generation (5G) standards among others. In an example, the network interface device 220 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the transmission medium 226.

[0074] Note that the term "circuitry" as used herein refers to, is part of, or includes hardware components such as an electronic circuit, a logic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group), an Application Specific Integrated Circuit (ASIC), a field-programmable device (FPD) (e.g., a field-programmable gate array (FPGA), a programmable logic device (PLD), a complex PLD (CPLD), a high-capacity PLD (HCPLD), a structured ASIC, or a programmable SoC), digital signal processors (DSPs), etc., that are configured to provide the described functionality. In some embodiments, the circuitry may execute one or more software or firmware programs to provide at least some of the described functionality. The term "circuitry" may also refer to a combination of one or more hardware elements (or a combination of circuits used in an electrical or electronic system) with the program code used to carry out the functionality of that program code. In these embodiments, the combination of hardware elements and program code may be referred to as a particular type of circuitry.

[0075] The term "processor circuitry" or "processor" as used herein thus refers to, is part of, or includes circuitry capable of sequentially and automatically carrying out a sequence of arithmetic or logical operations, or recording, storing, and/or transferring digital data. The term "processor circuitry" or "processor" may refer to one or more application processors, one or more baseband processors, a physical central processing unit (CPU), a single- or

multi-core processor, and/or any other device capable of executing or otherwise operating computer-executable instructions, such as program code, software modules, and/or functional processes.

[0076] Any of the radio links described herein may operate according to any one or more of the following radio communication technologies and/or standards including but not limited to: a Global System for Mobile Communications (GSM) radio communication technology, a General Packet Radio Service (GPRS) radio communication technology, an Enhanced Data Rates for GSM Evolution (EDGE) radio communication technology, and/or a Third Generation Partnership Project (3GPP) radio communication technology, for example Universal Mobile Telecommunications System (UMTS), Freedom of Multimedia Access (FOMA), 3GPP Long Term Evolution (LTE), 3GPP Long Term Evolution Advanced (LTE Advanced), Code division multiple access 2000 (CDMA2000), Cellular Digital Packet Data (CDPD), Mobitex, Third Generation (3G), Circuit Switched Data (CSD), High-Speed Circuit-Switched Data (HSCSD), Universal Mobile Telecommunications System (Third Generation) (UMTS (3G)), Wideband Code Division Multiple Access (Universal Mobile Telecommunications System) (W-CDMA (UMTS)), High Speed Packet Access (HSPA), High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA), High Speed Packet Access Plus (HSPA+), Universal Mobile Telecommunications System-Time-Division Duplex (UMTS-TDD), Time Division-Code Division Multiple Access (TD-CDMA), Time Division-Synchronous Code Division Multiple Access (TD-CDMA), 3rd Generation Partnership Project Release 8 (Pre-4th Generation) (3GPP Rel. 8 (Pre-4G)), 3GPP Rel. 9 (3rd Generation Partnership Project Release 9), 3GPP Rel. 10 (3rd Generation Partnership Project Release 10) , 3GPP Rel. 11 (3rd Generation Partnership Project Release 11), 3GPP Rel. 12 (3rd Generation Partnership Project Release 12), 3GPP Rel. 13 (3rd Generation Partnership Project Release 13), 3GPP Rel. 14 (3rd Generation Partnership Project Release 14), 3GPP Rel. 15 (3rd Generation Partnership Project Release 15), 3GPP Rel. 16 (3rd Generation Partnership Project Release 16), 3GPP Rel. 17 (3rd Generation Partnership Project Release 17) and subsequent Releases (such as Rel. 18, Rel. 19, etc.), 3GPP 5G, 5G, 5G New Radio (5G NR), 3GPP 5G New Radio, 3GPP

LTE Extra, LTE-Advanced Pro, LTE Licensed-Assisted Access (LAA), MuLTEfire, UMTS Terrestrial Radio Access (UTRA), Evolved UMTS Terrestrial Radio Access (E-UTRA), Long Term Evolution Advanced (4th Generation) (LTE Advanced (4G)), cdmaOne (2G), Code division multiple access 2000 (Third generation) (CDMA2000 (3G)), Evolution-Data Optimized or Evolution-Data Only (EV-DO), Advanced Mobile Phone System (1st Generation) (AMPS (1G)), Total Access Communication System/Extended Total Access Communication System (TACS/ETACS), Digital AMPS (2nd Generation) (D-AMPS (2G)), Push-to-talk (PTT), Mobile Telephone System (MTS), Improved Mobile Telephone System (IMTS), Advanced Mobile Telephone System (AMTS), OLT (Norwegian for Offentlig Landmobil Telefoni, Public Land Mobile Telephony), MTD (Swedish abbreviation for Mobiltelefonisystem D, or Mobile telephony system D), Public Automated Land Mobile (Autotel/PALM), ARP (Finnish for Autoradiopuhelin, "car radio phone"), NMT (Nordic Mobile Telephony), High capacity version of NTT (Nippon Telegraph and Telephone) (Hicap), Cellular Digital Packet Data (CDPD), Mobitex, DataTAC, Integrated Digital Enhanced Network (iDEN), Personal Digital Cellular (PDC), Circuit Switched Data (CSD), Personal Handy-phone System (PHS), Wideband Integrated Digital Enhanced Network (WiDEN), iBurst, Unlicensed Mobile Access (UMA), also referred to as also referred to as 3GPP Generic Access Network, or GAN standard), Zigbee, Bluetooth(r), Wireless Gigabit Alliance (WiGig) standard, mmWave standards in general (wireless systems operating at 10-300 GHz and above such as WiGig, IEEE 802.11ad, IEEE 802.11ay, etc.), technologies operating above 300 GHz and THz bands, (3GPP/LTE based or IEEE 802.11p or IEEE 802.11bd and other) Vehicle-to-Vehicle (V2V) and Vehicle-to-X (V2X) and Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Vehicle (I2V) communication technologies, 3GPP cellular V2X, DSRC (Dedicated Short Range Communications) communication systems such as Intelligent-Transport-Systems and others (typically operating in 5850 MHz to 5925 MHz or above (typically up to 5935 MHz following change proposals in CEPT Report 71)), the European ITS-G5 system (i.e. the European flavor of IEEE 802.11p based DSRC, including ITS-G5A (i.e., Operation of ITS-G5 in European ITS frequency bands

dedicated to ITS for safety re-lated applications in the frequency range 5,875 GHz to 5,905 GHz), ITS-G5B (i.e., Operation in European ITS frequency bands dedicated to ITS non- safety applications in the frequency range 5,855 GHz to 5,875 GHz), ITS-G5C (i.e., Operation of ITS applications in the frequency range 5,470 GHz to 5,725 GHz)), DSRC in Japan in the 700MHz band (including 715 MHz to 725 MHz), IEEE 802.11bd based systems, etc.

[0077] Aspects described herein can be used in the context of any spectrum management scheme including dedicated licensed spectrum, unlicensed spectrum, license exempt spectrum, (licensed) shared spectrum (such as LSA = Licensed Shared Access in 2.3-2.4 GHz, 3.4-3.6 GHz, 3.6-3.8 GHz and further frequencies and SAS = Spectrum Access System / CBRS = Citizen Broadband Radio System in 3.55-3.7 GHz and further frequencies). Applicable spectrum bands include IMT (International Mobile Telecommunications) spectrum as well as other types of spectrum/bands, such as bands with national allocation (including 450 - 470 MHz, 902-928 MHz (note: allocated for example in US (FCC Part 15)), 863-868.6 MHz (note: allocated for example in European Union (ETSI EN 300 220)), 915.9-929.7 MHz (note: allocated for example in Japan), 917-923.5 MHz (note: allocated for example in South Korea), 755-779 MHz and 779-787 MHz (note: allocated for example in China), 790 - 960 MHz, 1710 - 2025 MHz, 2110 - 2200 MHz, 2300 - 2400 MHz, 2.4-2.4835 GHz (note: it is an ISM band with global availability and it is used by Wi-Fi technology family (11b/g/n/ax) and also by Bluetooth), 2500 - 2690 MHz, 698-790 MHz, 610 - 790 MHz, 3400 - 3600 MHz, 3400 – 3800 MHz, 3800 – 4200 MHz, 3.55-3.7 GHz (note: allocated for example in the US for Citizen Broadband Radio Service), 5.15-5.25 GHz and 5.25-5.35 GHz and 5.47-5.725 GHz and 5.725-5.85 GHz bands (note: allocated for example in the US (FCC part 15), consists four U-NII bands in total 500 MHz spectrum), 5.725-5.875 GHz (note: allocated for example in EU (ETSI EN 301 893)), 5.47-5.65 GHz (note: allocated for example in South Korea, 5925-7125 MHz and 5925-6425MHz band (note: under consideration in US and EU, respectively. Next generation Wi-Fi system is expected to include the 6 GHz spectrum as operating band but it is noted that, as of December 2017, Wi-Fi system is not yet allowed in this band. Regulation is expected to be finished in 2019-2020 time frame), IMT-advanced spectrum,

IMT-2020 spectrum (expected to include 3600-3800 MHz, 3800 – 4200 MHz, 3.5 GHz bands, 700 MHz bands, bands within the 24.25-86 GHz range, etc.), spectrum made available under FCC's "Spectrum Frontier" 5G initiative (including 27.5 - 28.35 GHz, 29.1 - 29.25 GHz, 31 - 31.3 GHz, 37 - 38.6 GHz, 38.6 - 40 GHz, 42 - 42.5 GHz, 57 - 64 GHz, 71 - 76 GHz, 81 - 86 GHz and 92 - 94 GHz, etc), the ITS (Intelligent Transport Systems) band of 5.9 GHz (typically 5.85-5.925 GHz) and 63-64 GHz, bands currently allocated to WiGig such as WiGig Band 1 (57.24-59.40 GHz), WiGig Band 2 (59.40-61.56 GHz) and WiGig Band 3 (61.56-63.72 GHz) and WiGig Band 4 (63.72-65.88 GHz), 57-64/66 GHz (note: this band has near-global designation for Multi-Gigabit Wireless Systems (MGWS)/WiGig . In US (FCC part 15) allocates total 14 GHz spectrum, while EU (ETSI EN 302 567 and ETSI EN 301 217-2 for fixed P2P) allocates total 9 GHz spectrum), the 70.2 GHz - 71 GHz band, any band between 65.88 GHz and 71 GHz, bands currently allocated to automotive radar applications such as 76-81 GHz, and future bands including 94-300 GHz and above. Furthermore, the scheme can be used on a secondary basis on bands such as the TV White Space bands (typically below 790 MHz) where in particular the 400 MHz and 700 MHz bands are promising candidates. Besides cellular applications, specific applications for vertical markets may be addressed such as PMSE (Program Making and Special Events), medical, health, surgery, automotive, low-latency, drones, etc. applications.

[0078] Aspects described herein can also implement a hierarchical application of the scheme is possible, e.g., by introducing a hierarchical prioritization of usage for different types of users (e.g., low/medium/high priority, etc.), based on a prioritized access to the spectrum e.g. with highest priority to tier-1 users, followed by tier-2, then tier-3, etc. users, etc.

[0079] Aspects described herein can also be applied to different Single Carrier or OFDM flavors (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.) and in particular 3GPP NR (New Radio) by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

[0080] Some of the features in this document are defined for the network side, such as APs, eNBs, NR or gNBs – note that this term is typically used in

the context of 3GPP fifth generation (5G) communication systems, etc. Still, a UE may take this role as well and act as an AP, eNB, or gNB; that is some or all features defined for network equipment may be implemented by a UE.

[0081] FIG. 3 illustrates an O-RAN system architecture, in accordance with some embodiments. FIG. 3 provides a high-level view of an O-RAN architecture 300. The O-RAN architecture 300 includes four O-RAN defined interfaces – namely, the A1 interface, the O1 interface, the O2 interface, and the Open Fronthaul Management (M)-plane interface – which connect the Service Management and Orchestration (SMO) framework 302 to O-RAN network functions (NFs) 304 and the O-Cloud 306. The SMO 302 also connects with an external system 310, which provides additional configuration data to the SMO 302. FIG. 3 also illustrates that the A1 interface connects the O-RAN Non-Real Time (RT) RAN Intelligent Controller (RIC) 312 in or at the SMO 302 and the O-RAN Near-RT RIC 314 in or at the O-RAN NFs 304. The O-RAN NFs 304 can be virtualized network functions (VNFs) such as virtual machines (VMs) or containers, sitting above the O-Cloud 306 and/or Physical Network Functions (PNFs) utilizing customized hardware. All O-RAN NFs 304 are expected to support the O1 interface when interfacing with the SMO framework 302. The O-RAN NFs 304 connect to the NG-Core 308 via the NG interface (which is a 3GPP defined interface). The Open Fronthaul M-plane interface between the SMO 302 and the O-RAN Radio Unit (O-RU) 316 supports the O-RU 316 management in the O-RAN hybrid model. The Open Fronthaul M-plane interface is an optional interface to the SMO 302 that is included for backward compatibility purposes and is intended for management of the O-RU 316 in hybrid mode only. The O-RU 316 termination of the O1 interface towards the SMO 302.

[0082] FIG. 4 illustrates a logical architecture of the O-RAN system of FIG. 3, in accordance with some embodiments. FIG. 4 shows an O-RAN logical architecture 400 corresponding to the O-RAN architecture 300 of FIG. 3. In FIG. 4, the SMO 402 corresponds to the SMO 302, O-Cloud 406 corresponds to the O-Cloud 306, the non-RT RIC 412 corresponds to the non-RT RIC 312, the near-RT RIC 414 corresponds to the near-RT RIC 314, and the O-RU 416

corresponds to the O-RU 316 of FIG. 3, respectively. The O-RAN logical architecture 400 includes a radio portion and a management portion.

[0083] The management portion/side of the architectures 400 includes the SMO Framework 402 containing the non-RT RIC 412 and may include the O-Cloud 406. The O-Cloud 406 is a cloud computing platform including a collection of physical infrastructure nodes to host the relevant O-RAN functions (e.g., the near-RT RIC 414, O-RAN Central Unit - Control Plane (O-CU-CP) 421, O-RAN Central Unit - User Plane (O-CU-UP) 422, and the O-RAN Distributed Unit (O-DU) 415), supporting software components (e.g., OSs, VMMs, container runtime engines, ML engines, etc.), and appropriate management and orchestration functions.

[0084] The radio portion/side of the logical architecture 400 includes the near-RT RIC 414, the O-RAN Distributed Unit (O-DU) 415, the O-RU 416, the O-RAN Central Unit – Control Plane (O-CU-CP) 421, and the O-RAN Central Unit – User Plane (O-CU-UP) 422 functions. The radio portion/side of the logical architecture 400 may also include the O-e/gNB 410.

[0085] The O-DU 415 is a logical node hosting radio link control (RLC), medium access control (MAC), and higher physical (PHY) layer entities/ elements (High-PHY layers) based on a lower layer functional split. The O-RU 416 is a logical node hosting lower PHY layer entities/elements (Low-PHY layer) (e.g., Fast Fourier Transform/Inverse Fast Fourier Transform (FFT/iFFT), Physical Random Access Channel (PRACH) extraction, etc.) and RF processing elements based on a lower layer functional split. The O-CU-CP 421 is a logical node hosting the Radio Resource Control (RRC) and the control plane (CP) part of the PDCP protocol. The O O-CU-UP 422 is a logical node hosting the user-plane part of the PDCP protocol and the Service Data Adaptation Protocol (SDAP) protocol.

[0086] An E2 interface terminates at a plurality of E2 nodes. The E2 nodes are logical nodes/entities that terminate the E2 interface. For NR/5G access, the E2 nodes include the O-CU-CP 421, O-CU-UP 422, O-DU 415, or any combination of elements. For E-UTRA access the E2 nodes include the O-e/gNB 410. As shown in FIG. 4, the E2 interface also connects the O-e/gNB 410 to the Near-RT RIC 414. The protocols over the E2 interface are based

exclusively on CP protocols. The E2 functions are grouped into the following categories: (a) near-RT RIC 414 services (REPORT, INSERT, CONTROL, and POLICY; and (b) near-RT RIC 414 support functions, which include E2 Interface Management (E2 Setup, E2 Reset, Reporting of General Error Situations, etc.) and Near-RT RIC Service Update (e.g., capability exchange related to the list of E2 Node functions exposed over E2).

[0087] FIG. 4 shows the Uu interface between a UE 401 and O-e/gNB 410 as well as between the UE 401 and O-RAN components. The Uu interface is a 3GPP defined interface, which includes a complete protocol stack from L1 to L3 and terminates in the NG-RAN or E-UTRAN. The O-e/gNB 410 is an LTE eNB, a 5G gNB, or ng-eNB that supports the E2 interface. The O-e/gNB 410 may be the same or similar as other RAN nodes discussed previously. The UE 401 may correspond to UEs discussed previously and/or the like. There may be multiple UEs 401 and/or multiple O-e/gNB 410, each of which may be connected to one another via respective Uu interfaces. Although not shown in FIG. 4, the O-e/gNB 410 supports O-DU 415 and O-RU 416 functions with an Open Fronthaul (OF) interface between them.

[0088] The OF interface(s) is/are between O-DU 415 and O-RU 416 functions. The OF interface(s) includes the Control User Synchronization (CUS) Plane and Management (M) Plane. FIG. 3 and FIG. 4 also show that the O-RU 416 terminates the OF M-Plane interface towards the O-DU 415 and optionally towards the SMO 402. The O-RU 416 terminates the OF CUS-Plane interface towards the O-DU 415 and the SMO 402.

[0089] The F1-c interface connects the O-CU-CP 421 with the O-DU 415. As defined by 3GPP, the F1-c interface is between the gNB-CU-CP and gNB-DU nodes. However, for purposes of O-RAN, the F1-c interface is adopted between the O-CU-CP 421 with the O-DU 415 functions while reusing the principles and protocol stack defined by 3GPP and the definition of interoperability profile specifications.

[0090] The F1-u interface connects the O-CU-UP 422 with the O-DU 415. As defined by 3GPP, the F1-u interface is between the gNB-CU-UP and gNB-DU nodes. However, for purposes of O-RAN, the F1-u interface is adopted between the O-CU-UP 422 with the O-DU 415 functions while reusing the

principles and protocol stack defined by 3GPP and the definition of interoperability profile specifications.

[0091] The NG-c interface is defined by 3GPP as an interface between the gNB-CU-CP and the AMF in the 3GC. The NG-c is also referred to as the N2 interface. The NG-u interface is defined by 3GPP, as an interface between the gNB-CU-UP and the UPF in the 3GC. The NG-u interface is referred to as the N3 interface. In O-RAN, NG-c and NG-u protocol stacks defined by 3GPP are reused and may be adapted for O-RAN purposes.

[0092] The X2-c interface is defined in 3GPP for transmitting control plane information between eNBs or between eNB and en-gNB in EN-DC. The X2-u interface is defined in 3GPP for transmitting user plane information between eNBs or between eNB and en-gNB in EN-DC. In O-RAN, X2-c and X2-u protocol stacks defined by 3GPP are reused and may be adapted for O-RAN purposes.

[0093] The Xn-c interface is defined in 3GPP for transmitting control plane information between gNBs, ng-eNBs, or between an ng-eNB and gNB. The Xn-u interface is defined in 3GPP for transmitting user plane information between gNBs, ng-eNBs, or between ng-eNB and gNB. In O-RAN, Xn-c and Xn-u protocol stacks defined by 3GPP are reused and may be adapted for O-RAN purposes.

[0094] The E1 interface is defined by 3GPP as being an interface between the gNB-CU-CP and gNB-CU-UP. In O-RAN, E1 protocol stacks defined by 3GPP are reused and adapted as being an interface between the O-CU-CP 421 and the O-CU-UP 422 functions.

[0095] The O-RAN Non-Real Time (RT) RAN Intelligent Controller (RIC) 412 is a logical function within the SMO framework 302, 402 that enables non-real-time control and optimization of RAN elements and resources; AI/machine learning (ML) workflow(s) including model training, inferences, and updates; and policy-based guidance of applications/features in the Near-RT RIC 414.

[0096] In some embodiments, the Non-RT RIC 412 is a function that sits within the SMO platform (or SMO framework) 402 in the O-RAN architecture. The primary goal of non-RT RIC is to support intelligent radio resource management for a non-real-time interval (i.e., greater than 300 ms), policy

optimization in RAN, and insertion of AI/ML models to near-RT RIC and other RAN functions. The non-RT RIC terminates the A1 interface to the near-RT RIC. It will also collect OAM data over the O1 interface from the O-RAN nodes.

[0097] The O-RAN near-RT RIC 414 is a logical function that enables near-real-time control and optimization of RAN elements and resources via fine-grained data collection and actions over the E2 interface. The near-RT RIC 414 may include one or more AI/ML workflows including model training, inferences, and updates.

[0098] The non-RT RIC 412 can be an ML training host to host the training of one or more ML models. ML training can be performed offline using data collected from the RIC, O-DU 415, and O-RU 416. For supervised learning, non-RT RIC 412 is part of the SMO 402, and the ML training host and/or ML model host/actor can be part of the non-RT RIC 412 and/or the near-RT RIC 414. For unsupervised learning, the ML training host and ML model host/actor can be part of the non-RT RIC 412 and/or the near-RT RIC 414. For reinforcement learning, the ML training host and ML model host/actor may be co-located as part of the non-RT RIC 412 and/or the near-RT RIC 414. In some implementations, the non-RT RIC 412 may request or trigger ML model training in the training hosts regardless of where the model is deployed and executed. ML models may be trained and not currently deployed.

[0099] In some implementations, the non-RT RIC 412 provides a query-able catalog for an ML designer/developer to publish/install trained ML models (e.g., executable software components). In these implementations, the non-RT RIC 412 may provide a discovery mechanism if a particular ML model can be executed in a target ML inference host (MF), and what number and type of ML models can be executed in the MF. For example, there may be three types of ML catalogs made discoverable by the non-RT RIC 412: a design-time catalog (e.g., residing outside the non-RT RIC 412 and hosted by some other ML platform(s)), a training/deployment-time catalog (e.g., residing inside the non-RT RIC 412), and a run-time catalog (e.g., residing inside the non-RT RIC 412). The non-RT RIC 412 supports necessary capabilities for ML model inference in support of ML assisted solutions running in the non-RT RIC 412 or some other

ML inference host. These capabilities enable executable software to be installed such as VMs, containers, etc. The non-RT RIC 412 may also include and/or operate one or more ML engines, which are packaged software executable libraries that provide methods, routines, data types, etc., used to run ML models. The non-RT RIC 412 may also implement policies to switch and activate ML model instances under different operating conditions.

[00100] The non-RT RIC 412 can access feedback data (e.g., FM and PM statistics) over the O1 interface on ML model performance and perform necessary evaluations. If the ML model fails during runtime, an alarm can be generated as feedback to the non-RT RIC 412. How well the ML model is performing in terms of prediction accuracy or other operating statistics it produces can also be sent to the non-RT RIC 412 over O1. The non-RT RIC 412 can also scale ML model instances running in a target MF over the O1 interface by observing resource utilization in MF. The environment where the ML model instance is running (e.g., the MF) monitors resource utilization of the running ML model. This can be done, for example, using an ORAN-SC component called ResourceMonitor in the near-RT RIC 414 and/or in the non-RT RIC 412, which continuously monitors resource utilization. If resources are low or fall below a certain threshold, the runtime environment in the near-RT RIC 414 and/or the non-RT RIC 412 provides a scaling mechanism to add more ML instances. The scaling mechanism may include a scaling factor such as a number, percentage, and/or other like data used to scale up/down the number of ML instances. ML model instances running in the target ML inference hosts may be automatically scaled by observing resource utilization in the MF. For example, the Kubernetes® (K8s) runtime environment typically provides an auto-scaling feature.

[00101] The A1 interface is between the non-RT RIC 412 (within or outside the SMO 402) and the near-RT RIC 414. The A1 interface supports three types of services, including a Policy Management Service, an Enrichment Information Service, and ML Model Management Service. A1 policies have the following characteristics compared to persistent configuration: A1 policies are not critical to traffic; A1 policies have temporary validity; A1 policies may handle individual UE or dynamically defined groups of UEs; A1 policies act

within and take precedence over the configuration, and A1 policies are non-persistent, i.e., do not survive a restart of the near-RT RIC.

[00102] O-RAN has been striving to embrace AI and ML based intelligence into wireless communication networks. Introducing AI/ML not only increases performance of existing networks, but also optimizes/steers various network components to a certain key performance indicator (KPI) of interest. Currently, feeding accurate and timely measurement information in a RAN to the intelligence controller is a first step to succeed in those optimizations. E2 Service Model KPM (E2SM-KPM) supports open centralized unit control plane (O-CU-CP), open centralized unit user plane (O-CU-UP), and open centralized unit distributed unit (O-DU) as part of NG-RAN connected to 5GC or as part of E-UTRAN connected to EPC.

[00103] FIG. 5 illustrates an overall beam management procedure, in accordance with some embodiments. Such an optimized "beam management" indeed requires a tight interaction between UEs, RAN nodes (NW nodes), and an intelligence controller, from accurate measurement information (fed from the UE and NW nodes) to the AI/ML based control coming down from the intelligence controller that affects NW behaviors and UEs, which spans across the territories of 3GPP and ORAN.

[00104] In the present disclosure, we investigate the current status quo and propose several embodiments that we believe are essential for such an AI/ML based beam management optimization, for example related to beam failure detection (BFD) and beam failure recovery (BFR).

[00105] The present disclosure describes various embodiments. The embodiments may be used individually and/or in combination.

[00106] 1. Introduce BFD/BFR reporting of individual PHY beam failure instances from the UE to NW: The current status quo in 3GPP limits NW to collect only limited statistics related to BFD/BFR, such as number or rate of beam failures, or counts of failed/recovered beams, etc. Specifically, currently the UE does not report individual PHY beam failure instances and thus NW is oblivious of which instances (among configured) triggered beam failure events.

[00107] 2. Introduce new L2 measurement or new performance measurement for BFD/BFR related statistics (per UE or per cell): there has been no L2 measurement or performance measurement (sub)counters specified in 3GPP for the collection of measurements related to BFD/BFR.

[00108] 3. L1/L2 measurements on BFD/BFR (per UE or per cell) are collected to intelligence controller via E2 interface: L1/L2 measurements related to BFD/BFR are essential feedbacks for intelligent controller to produce AI/ML based optimized beam management control over NW nodes, which is currently missing over E2 interface.

[00109] The embodiments of the present disclosure provide several mechanisms in 3GPP and ORAN that are essential for AI/ML based beam management optimization, especially related to beam failure detection (BFD) and beam failure recovery (BFR).

[00110] Current status quo

[00111] RRC configuration for beam failure detection and recovery: NW can configure the UE via RRC (TS 38.331), the following parameters for the purpose of beam failure detection and recovery:

- *RadioLinkMonitoringConfig*

```
RadioLinkMonitoringConfig ::=      SEQUENCE {
  failureDetectionResourcesToAddModList  SEQUENCE
(SIZE(1..maxNrofFailureDetectionResources)) OF RadioLinkMonitoringRS
                                                          OPTIONAL, -- Need N
  failureDetectionResourcesToReleaseList  SEQUENCE
(SIZE(1..maxNrofFailureDetectionResources)) OF RadioLinkMonitoringRS-Id
                                                          OPTIONAL, -- Need N
  beamFailureInstanceMaxCount          ENUMERATED {n1, n2, n3, n4, n5, n6, n8, n10}
OPTIONAL, -- Need R
  beamFailureDetectionTimer          ENUMERATED {pbfd1, pbfd2, pbfd3, pbfd4, pbfd5,
pbfd6, pbfd8, pbfd10}  OPTIONAL, -- Need R
  ...
}

RadioLinkMonitoringRS ::=          SEQUENCE {
  radioLinkMonitoringRS-Id          RadioLinkMonitoringRS-Id,
  purpose                    ENUMERATED {beamFailure, rlf, both},
  detectionResource              CHOICE {
    ssb-Index                  SSB-Index,
    csi-RS-Index                NZP-CSI-RS-ResourceId
  },
```

```
    ...
}
```

- *BeamFailureRecoveryConfig*

```
BeamFailureRecoveryConfig ::=      SEQUENCE {
  rootSequenceIndex-BFR            INTEGER (0..137)
OPTIONAL, -- Need M
  rach-ConfigBFR                   RACH-ConfigGeneric
OPTIONAL, -- Need M
  rsrp-ThresholdSSB                RSRP-Range
OPTIONAL, -- Need M
  candidateBeamRSList              SEQUENCE (SIZE(1..maxNrofCandidateBeams)) OF
PRACH-ResourceDedicatedBFR  OPTIONAL, -- Need M
  ssb-perRACH-Occasion             ENUMERATED {oneEighth, oneFourth, oneHalf, one, two,
                                   four, eight, sixteen}                    OPTIONAL, --
Need M
  ra-ssb-OccasionMaskIndex         INTEGER (0..15)
OPTIONAL, -- Need M
  recoverySearchSpaceId            SearchSpaceId
OPTIONAL, -- Need R
  ra-Prioritization                RA-Prioritization                        OPTIONAL,
-- Need R
  beamFailureRecoveryTimer         ENUMERATED {ms10, ms20, ms40, ms60, ms80,
ms100, ms150, ms200}          OPTIONAL, -- Need M
  ...,
  [[
  msg1-SubcarrierSpacing           SubcarrierSpacing
OPTIONAL  -- Need M
  ]],
  [[
  ra-PrioritizationTwoStep-r16     RA-Prioritization
OPTIONAL, -- Need R
  candidateBeamRSListExt-v1610     SetupRelease{ CandidateBeamRSListExt-r16 }
OPTIONAL -- Need M
  ]]
}
```

- *BeamFailureRecoverySCellConfig*

```
BeamFailureRecoverySCellConfig-r16 ::= SEQUENCE {
  rsrp-ThresholdBFR-r16            RSRP-Range
OPTIONAL, -- Need M
  candidateBeamRSSCellList-r16     SEQUENCE (SIZE(1..maxNrofCandidateBeams-r16))
OF CandidateBeamRS-r16  OPTIONAL, -- Need M
  ...
}

CandidateBeamRS-r16 ::=            SEQUENCE {
  candidateBeamConfig-r16            CHOICE {
    ssb-r16                        SSB-Index,
    csi-RS-r16                     NZP-CSI-RS-ResourceId
  },
  servingCellId                    ServCellIndex                            OPTIONAL -
- Need R
```

}

[00112] Beam failure detection and recovery procedure at UE: based on the configured parameters via RRC, the UE detects beam failure based on the following beam failure detection procedure:

[00113] PHY provides an indication to its MAC, when the radio link quality for all SSB/CSI-RS the UE uses to assess the radio link quality is worse than the threshold;

[00114] The threshold is derived based on the block error rate of hypothetical PDCCH transmission;

[00115] MAC declares failure, when # of beam failure instance indications from PHY reaches a configured threshold (*beamFailureInstanceMaxCount*) before a configured timer (*beamFailureDetectionTimer*) expires.

[00116] Upon detection of beam failure, the UE is specified to do the following beam failure recovery procedure:

[00117] For PCell, MAC triggers random access procedure;

[00118] For SCell, MAC prepares SCell BFR MAC CE or truncated SCell BFR MAC CE;

[00119] PHY finds new beam for recovery if L1-RSRP (of corresponding SSB/CSI-RS) is higher than or equal to the configured threshold;

[00120] Beam failure detection and recovery information at NW: based on the specified UE behaviors, NW is able to detect beam failure events:

[00121] For PCell, NW detects beam failure upon the reception on the configured CFRA transmission from UE, which happens except (1) if *beamFailureRecoveryTimer* expires, UE does not use CFRA for BFR; (2) if UE cannot find proper SSB/CSI-RS in candidate RS list with L1-RSRP higher than or equal to the threshold;

[00122] For SCell, a field in (truncated) SCell BFR MAC CE indicates beam failure detection.

[00123] In case of a beam failure event, NW is able to infer failed beams and recovered beams based on the following:

[00124] All beams in *RadioLinkMonitoringRS* for beam failure detection are failed;

[00125] For PCell, recovered beams can be known based on the received CFRA and mapping to SSB/CSI-RS;

[00126] For SCell, fields in (truncated) SCell BFR MAC CE are used to indicate the candidate SSB/CSI-RS (beam).

[00127] As a result, NW is possible to collect some BFR statistics, such as number or rate of beam failures, or counts of failed/recovered beams, etc. However, currently the UE does not report PHY beam failure instances, which limits the use of collected statistics for beam management optimization. NW is oblivious of which instances (among configured) triggered beam failure.

[00128] And last but not least, there has been no L2 measurement or performance measurement counters specified in 3GPP for the collection of those measurement information mentioned above.

[00129] Embodiment 1: Introduce BFD/BFR reporting of PHY beam failure instances from the UE to NW.

[00130] FIG. 6 illustrates a procedure to report PHY beam failure instances using MAC CE, in accordance with some embodiments. As explained above, a UE goes into beam failure recovery procedure, if the number of PHY beam failure instance indications reaches a configured threshold before a configured timer expires. In one embodiment, a new MAC CE is proposed to inform NW the occurrence of PHY beam failure instances, even if the beam failure recovery procedure is not triggered, e.g., the instance counter does not cross the threshold before the timer expires. The general procedure is illustrated in FIG. 6.

[00131] The proposed MAC CE for PHY beam instance reporting includes the cell identity, e.g., *ServCellIndex*, and PHY beam failure instance

information. It reports the number of PHY beam instances for given serving cell during the monitoring time, e.g., between the first PHY BF instance and timer expiration. A UE can use it to report the L1-RSRP measurement value of RSs, which are configured for beam failure detection. The maximum value of L1-RSRP measured during the monitoring period is reported, and optionally two more differential L1-RSRP measurement values can be reported, e.g., the second best and third best L1-RSRP measurement, if available.

[00132] FIG. 7 illustrates a MAC CE for PHY beam failure instance reporting, in accordance with some embodiments.

[00133] For 3GPP TS 38.321

[00134] The fields in the new proposed MAC CEs can be defined as follows:

[00135] Serving Cell ID: This field indicates the identity of the Serving Cell, e.g., *ServCellIndex*, for which the PHY beam failure instance is reported from the lower layer. The length of the field is 5 bits. Note that *ServCellIndex* = 0 for the PCell;

[00136] RSi : This fields indicates the presence of L1-RSRP reports of RS i defined by *RadioLinkMonitoringConfig*. The length of the field is 10 bits, corresponding to maximum number of RSs used for beam failure detection (e.g., *maxNrofFailureDetectionResources* = 10). If the RSi sets to 1, the octet(s) containing the L1-RSRP field is present in this MAC CE. If the RSi sets to 0, this RS is not configured or the L1-RSRP of the RS is not reported in this MAC CE;

[00137] Instance counter: This fields indicates how many PHY beam failure instances were reported from lower layer before timer expires. The length of the field is 4 bits. The maximum possible value of instance counter is 9;

[00138] AD: This field indicates the presence of additional differential L1-RSRP reports in a next octet. The length of this field is 1 bit. If this field set to 0, then only the L1-RSRP in the current octet is reported for the RS, and there is no additional differential L1-RSRP reports, i.e., R bits for the following octet;

[00139] L1-RSRP: This field indicates the maximum measurement L1-RSRP value for the corresponding RS during the monitoring period. The length of this field is 7 bits. The reported L1-RSRP value is quantized to a 7-bit value in the range [-140, -44] dBm with 1dB step size;

[00140] AD-RSRP: This field indicated the differential L1-RSRP measurement value for the corresponding RS during the monitoring period, compared to the maximum L1-RSRP value. The length of this field is 4 bits. The reported differential L1-RSRP value is quantized to a 4-bit value with 2dB step size;

[00141] R: Reserved bit, set to 0.

[00142] Embodiment 2: Introduce new L2 measurement or new performance measurement for BFD/BFR related statistics (per UE or per cell)

[00143] Some example implementation for 3GPP TS 28.552 is as follows.

[00144] For TS 28.552

[00145] 5.1.1.4.X Mean number of detected beam failure for UEs in a NR cell averaged over a certain time period

[00146] a) This measurement provides the mean number of detected beam failure for UEs in a NR cell averaged during each granularity period.

[00147] b) SI.

[00148] c) This measurement is obtained by counting number of beam failures reported from UEs for each NR cell where the unit of measured value is per second in the granularity period, and then taking the arithmetic mean.

[00149] d) A single integer value.

[00150] e) BFD.MeanPerCell

[00151] f) NRCellDU

[00152] g) Valid for packet switched traffic

[00153] h) 5GS

[00154] i) One usage of this measurement is to support beam management optimization.

[00155] Embodiment 3: L1/L2 measurements on BFD/BFR (per UE or per cell) are collected to intelligence controller via E2 interface

[00156] FIG. 8 illustrates an information element (IE) for detected beam failure measured during an E2 reporting period, in accordance with some embodiments. Some example implementation for ORAN-WG3.E2SM-KPM is as follows.

[00157] For ORAN-WG3.E2SM-KPM

[00158] 8.3.XX Mean number of detected beam failure

[00159] This IE defines mean number of detected beam failure measured during E2 reporting period (see FIG. 8)

[00160] [1] O-RAN WG1, "O-RAN Architecture Description"

[00161] [2] O-RAN WG1, "Use Case Detailed Specification"

[00162] [3] Li, Yu-Ngok Ruyue, et al. "Beam Management in Millimeter-Wave Communications for 5G and Beyond." IEEE Access 8 (2020): 13282-13293.

[00163] EXAMPLES:

[00164] Example 1 may include a Beam Failure Detection (BFD) or Beam Failure Recovery (BFR) related L2 measurement or new performance measurement to enable RAN nodes to measure and collect statistics related to BFD/BFR, e.g. Mean number of detected beam failure for UEs in a NR cell averaged over a certain time.

[00165] Example 2 may include a new reporting procedure or a new MAC CE to enable the UE to report BFD/BFR related statistics (e.g. individual PHY beam failure instances) that helps NW utilize for beam management optimization.

[00166] Example 3 may include a new reporting procedure over E2 interface to enable RAN nodes to report the collected BFD/BFR related statistics to the intelligence controller for AI/ML based beam management optimization.

[00167] Example 4 may include a method comprising: receiving, from one of more UEs, statistics associated with beam failure detection (BFD) and/or beam failure recovery (BFR); and generate one or more performance measurements for a cell based on the statistics.

[00168] Example 5 may include the method of example 4 or some other example herein, wherein the statistics include a number of individual beam failure instances.

[00169] Example 6 may include the method of example 4-5 or some other example herein, wherein one or more performance measurements includes a mean number of detected beam failures of UEs in the cell over a time period.

[00170] Example 7 may include the method of example 4-6 or some other example herein, further comprising reporting the statistics and/or performance measurements to an intelligence controller for AI/ML based beam management optimization.

[00171] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An apparatus for a radio-access network (RAN) node configured for operation in a RAN, the apparatus comprising: processing circuitry; and memory, wherein the processing circuitry is configured to:

decode signalling received over an E2 interface from an intelligence controller (IC) of the RAN, the signalling to configure the RAN node to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR); and

in response to the signalling received over the E2 interface:

encode signalling for transmission to one or more user equipments (UEs) to configure the UEs for BFD and BFR reporting; and

decode physical layer (PHY) beam failure instance reports received from the UEs based on the BFD and BFR reporting,

wherein the signalling transmitted to the UEs is to configure each UE to report the PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the reporting UE.

2. The apparatus of claim 1, wherein the processing circuitry is further configured to:

generate the statistics for the BFD and BFR based on the PHY beam failure instance reports received from the UEs; and

encode signalling for transmission over the E2 interface to the intelligence controller to report the statistics for beam management by the intelligence controller,

wherein the statistics include at least a mean number of detected PHY beam failures during an E2 reporting period.

3. The apparatus of claim 2, wherein the signalling transmitted over the E2 interface to the intelligence controller comprises a Mean Number of Detected Beam Failures information element (IE), and

wherein the statistics include at least a mean number of detected PHY beam failures for individual UEs or averaged for the UEs in a cell during the E2 reporting period.

4. The apparatus of claim 2, wherein at least some of the PHY beam failure instance reports are received from one or more of the UEs in a medium access control (MAC) control element (CE) configured for PHY beam failure instance reporting, the MAC CE having one or more fields for reporting the statistics for the BFD and BFR including one or more fields for reporting individual PHY beam failure instances,

wherein each UE is configured to report by the MAC CE a number of detected PHY beam failure instances that occur over a period of time configured, and

wherein each UE is configured to report the number of detected PHY beam failure instances even when the number does not cross a threshold for triggering the beam failure recovery procedure.

5. The apparatus of claim 4, wherein the MAC CE includes a Serving Cell ID field, Reference signal indicator (RSi) field, an Instance Counter field, an additional-differential (AD) indicator field, a Layer 1 Reference Signal Received Power (L1-RSRP) field, and up to one or more additional differential L1-RSRP fields when indicated by the AD indicator field.

6. The apparatus of claim 5, wherein:

the Serving Cell ID field indicates an identity of a serving cell for which a PHY beam failure instance is reported from a lower layer of the UE;

the RSi field indicates a presence of L1-RSRP reports in the MAC CE of reference signals (RS) defined by RadioLinkMonitoringConfig;

the Instance Counter Field indicates a number of PHY beam failure instances were reported from the lower layer;

the AD field indicates a presence of additional differential L1-RSRP reports in the MAC CE;

the L1-RSRP field indicates a maximum measurement L1-RSRP value for a corresponding reference signal (RS) during a monitoring period; and

the AD-RSRP field, when present, indicates a differential L1-RSRP measurement value for the corresponding RS during the monitoring period.

7. The apparatus of claim 4, wherein the signalling to configure the UEs for BFD and BFR reporting comprises radio-resource control (RRC) signalling that configures the UE for the BFD and BFR reporting using the MAC CE,

wherein the RRC signalling that configures the UEs for the BFD and BFR reporting using the MAC CE comprises an RRC information element (IE), and

wherein the RRC signalling is to configure the UEs to perform layer 1 (L1) and layer 2 (L2) measurements for the BFD and BFR reporting.

8. The apparatus of claim 7, wherein the RRC IE comprises one of an *RadioLinkMonitoringConfig* IE, a *BeamFailureRecoveryConfig* IE, and a *BeamFailureRecoverySCellConfig* IE.

9. The apparatus of claim 1, wherein the intelligence controller is a RAN intelligence controller (RIC) of an open radio-access network (O-RAN), wherein the RAN node comprises an E2 node configured for operation in the O-RAN, and

wherein the processing circuitry is further configured to decode signalling received over the E2 interface from the intelligence controller to configure the RAN node for artificial intelligence (AI) / machine learning (ML) based multi-input multiple output (MIMO) beam management optimization.

10. The apparatus of claim 1, wherein the RAN node comprises a generation node B (gNB) configured for operation in a fifth-generation new radio (5G NR) network, and

wherein the memory is configured to store the PHY beam failure instance reports received from the UEs.

11. An apparatus of a user equipment (UE) configured for operation in a radio-access network (RAN), the UE comprising: processing circuitry; and memory,

wherein the processing circuitry is configured to:

decode radio-resource control (RRC) signalling received from a RAN node, the RRC signalling to configure the UE for beam failure detection (BFD) and beam failure recovery (BFR) reporting; and

encode physical layer (PHY) beam failure instance reports for transmission to the RAN node,

wherein the RRC signalling configures the UE to report PHY beam failure instances whether or not a beam failure recovery procedure is triggered by the UE.

12. The apparatus of claim 11, wherein the UE is configured by the RRC signalling to report the PHY beam failure instances in a medium access control (MAC) control element (CE) configured for PHY beam failure instance reporting, the MAC CE having one or more fields for reporting the statistics for the BFD and BFR including one or more fields for reporting individual PHY beam failure instances.

13. The apparatus of claim 12, wherein the UE is configured by the RRC signalling to report by the MAC CE a number of detected PHY beam failure instances that occur over a time-period configured, and

wherein the UE is configured to report the number of detected PHY beam failure instances even when the number does not cross a threshold for triggering the beam failure recovery procedure.

14. The apparatus of claim 13, wherein the MAC CE is encoded by the processing circuitry to include a Serving Cell ID field, Reference signal indicator (RSi) field, an Instance Counter field, an additional-differential (AD) indicator field, a Layer 1 Reference Signal Received Power (L1-RSRP) field, and up to one or more additional differential L1-RSRP fields when indicated by the AD indicator field.

15. The apparatus of claim 14, wherein the processing circuitry is to enter the beam failure recovery procedure in response to a beam failure declaration by a MAC layer of the UE based on a number of detected PHY beam failure instances reaching a beamFailureInstanceMaxCount threshold before a beam Failure Detection Timer expires, and

wherein in response to the beam failure declaration by the MAC layer, the UE is configured to identify a new beam for recovery,

wherein prior to entering the beam failure recovery procedure, the UE is configured to report the number of detected PHY beam failure instances by the MAC CE.

16. The apparatus of claim 14, wherein the RRC signalling that configures the UE for the BFD and BFR reporting using the MAC CE comprises an RRC information element (IE), and

wherein the RRC signalling is to configure the UEs to perform layer 1 (L1) and layer 2 (L2) measurements for the BFD and BFR reporting.

17. The apparatus of claim 16, wherein the RRC IE comprises one of an *RadioLinkMonitoringConfig* IE, a *BeamFailureRecoveryConfig* IE, and a *BeamFailureRecoverySCellConfig* IE.

18. An intelligence controller (IC) for use in an radio-access network (RAN), the intelligence controller comprising: processing circuitry; and memory,

encode signalling for transmission over an E2 interface to a RAN node of the RAN, the signalling to configure the RAN node to monitor and report statistics for beam failure detection (BFD) and beam failure recovery (BFR);

decode signalling received over the E2 interface from the RAN node that includes the reported statistics for the BFD and BFR; and

encode signalling for transmission over the E2 interface to configure the RAN node for artificial intelligence (AI) / machine learning (ML) based multi-input multiple output (MIMO) beam management optimization,

wherein the statistics reported for the BFD and BFR include reports of physical layer (PHY) beam failure instances at user equipment (UEs) whether or not a beam failure recovery procedure is triggered by a reporting UE.

19. The intelligence controller of claim 18, wherein the statistics reported include at least a mean number of detected PHY beam failures during an E2 reporting period.

20. The intelligence controller of claim 19, wherein the signalling received over the E2 interface from the RAN node comprises a Mean Number of Detected Beam Failures information element (IE), and

wherein the statistics include at least a mean number of detected PHY beam failures for individual UEs or averaged for the UEs in a cell during the E2 reporting period.

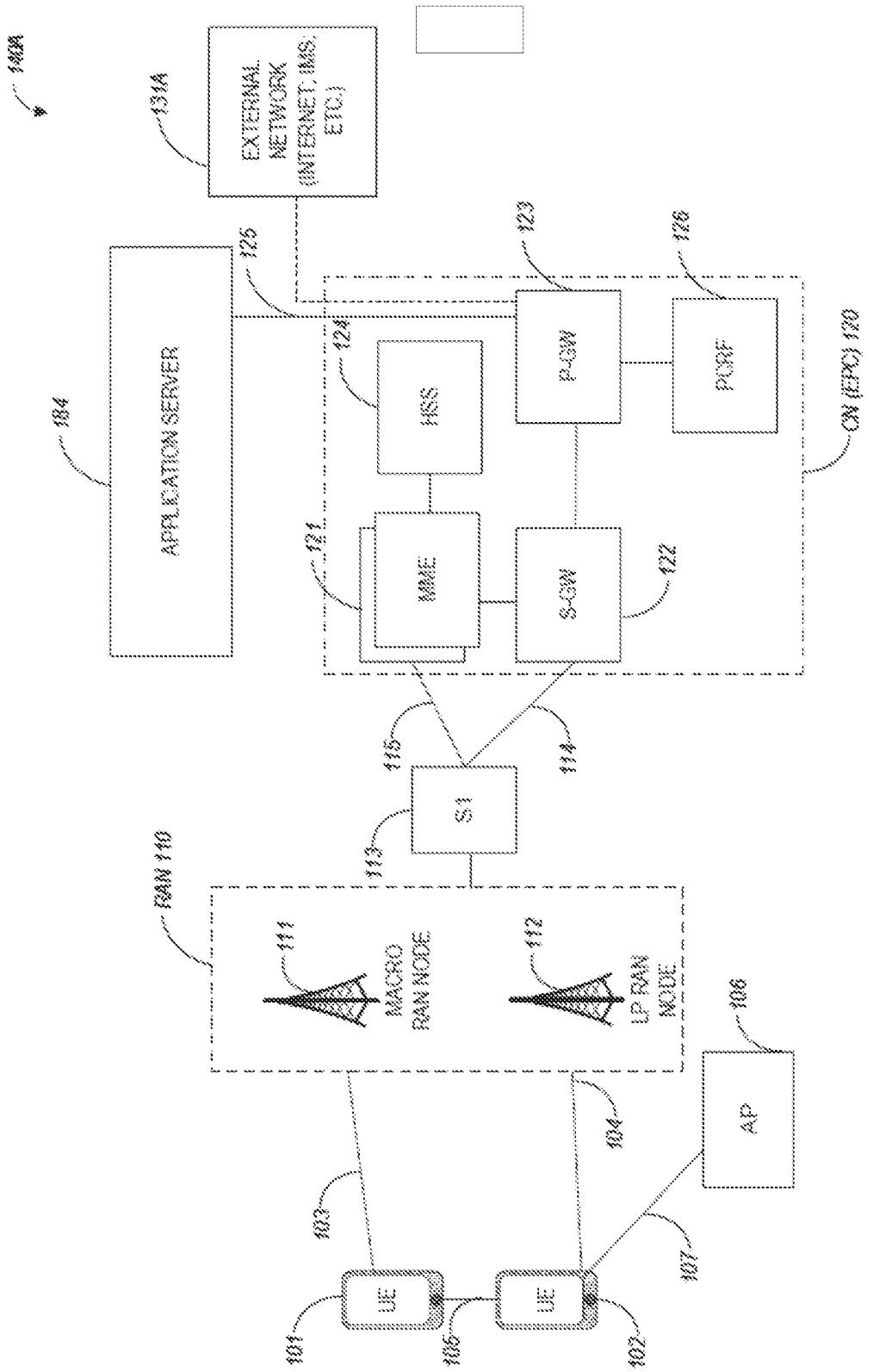

140A
131A
EXTERNAL NETWORK (INTERNET, IMS, ETC.)
126
123
126
184
APPLICATION SERVER
124
HSS
P-GW
PCRF
CN (EPC) 120
121
MME
S-GW
122
115
114
S1
113
RAN 110
111
MACRO RAN NODE
112
LP RAN NODE
106
AP
104
103
107
UE
UE
101
105
102

FIG. 1A

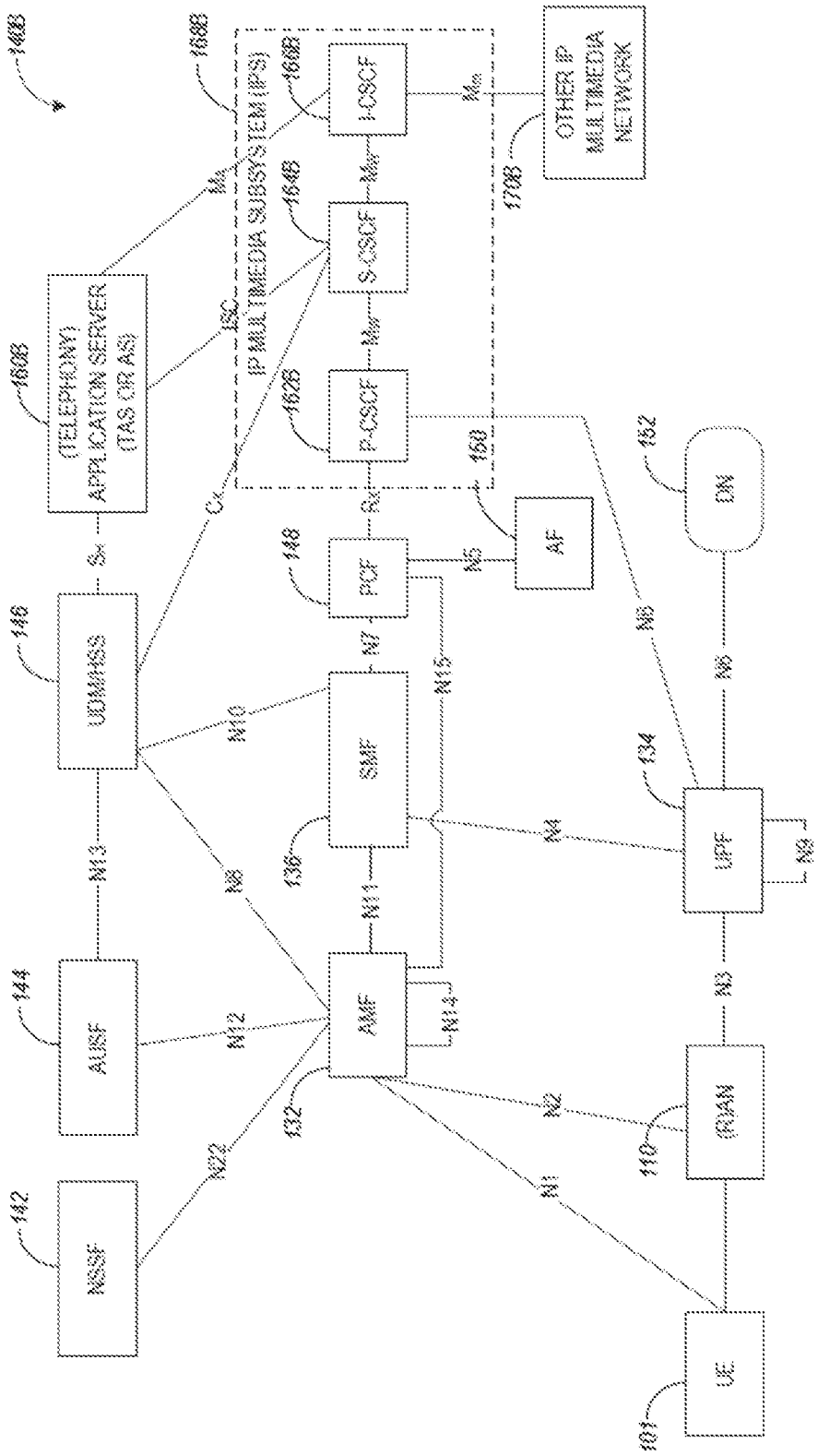
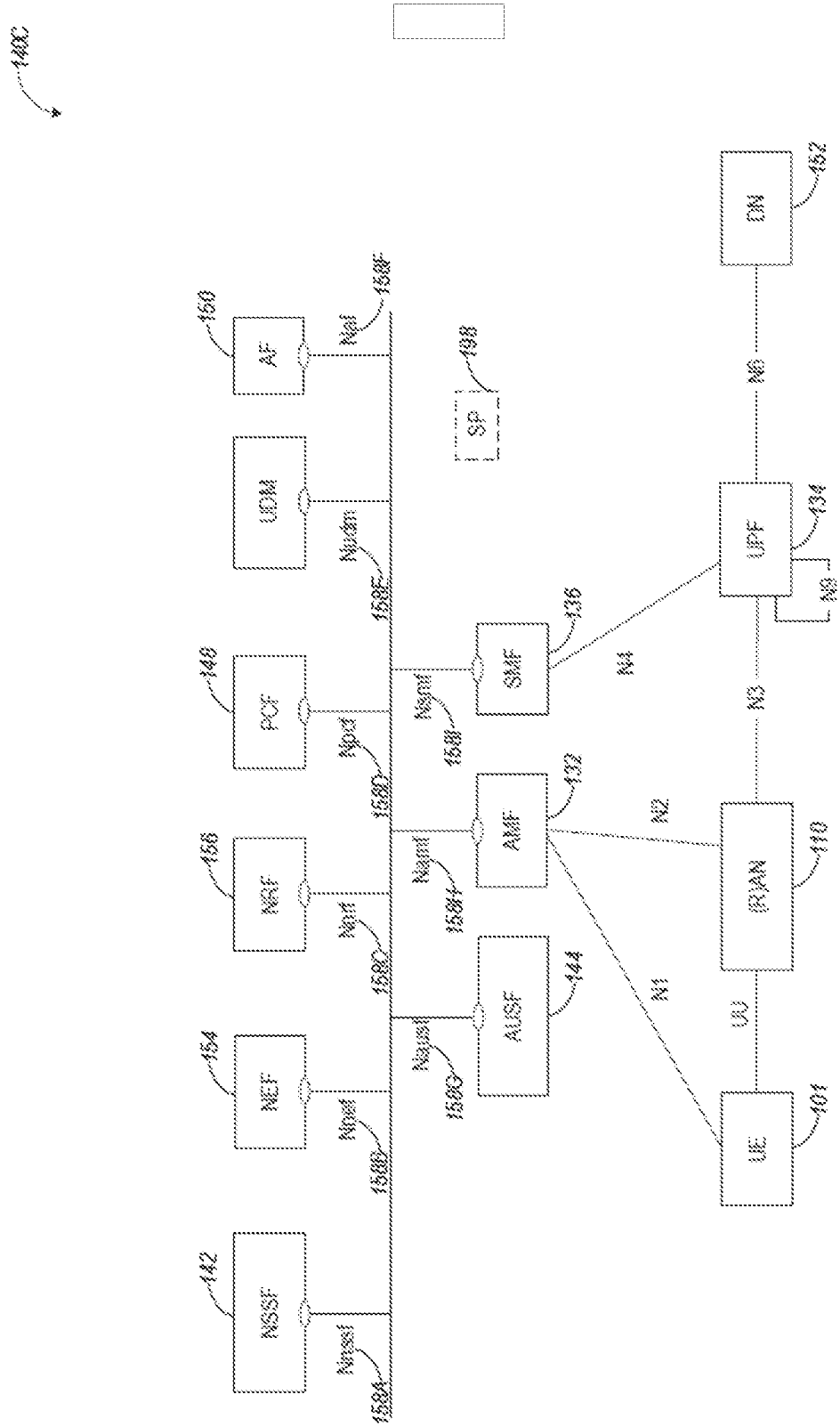

140B
168B
IP MULTIMEDIA SUBSYSTEM (IPS)
160B
(TELEPHONY) APPLICATION SERVER (TAS OR AS)
166B
I-CSCF
164B
S-CSCF
162B
P-CSCF
170B
OTHER IP MULTIMEDIA NETWORK
150
AF
148
PCF
146
UDM/HSS
136
SMF
144
AUSF
132
AMF
142
NSSF
152
DN
134
UPF
110
(R)AN
101
UE
N1
N2
N3
N4
N5
N6
N7
N8
N9
N10
N11
N12
N13
N14
N15
N22
Sx
Cx
Mw
Mg
Mm
Mn
ISC

FIG. 1B


140C
AF
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Naf
158F
SP
198
UDM
Nudm
158E
PCF
140
Npcf
158D
Nsmf
158B
SMF
136
N4
UPF
134
N6
DN
152
N9
N3
AMF
132
N2
Namf
158A
NRF
156
Nnrf
158C
RAN
110
N1
AUSF
144
Nausf
158G
NEF
154
Nnef
158H
UU
UE
101
NSSF
142
Nnssf
158J

FIG. 1C

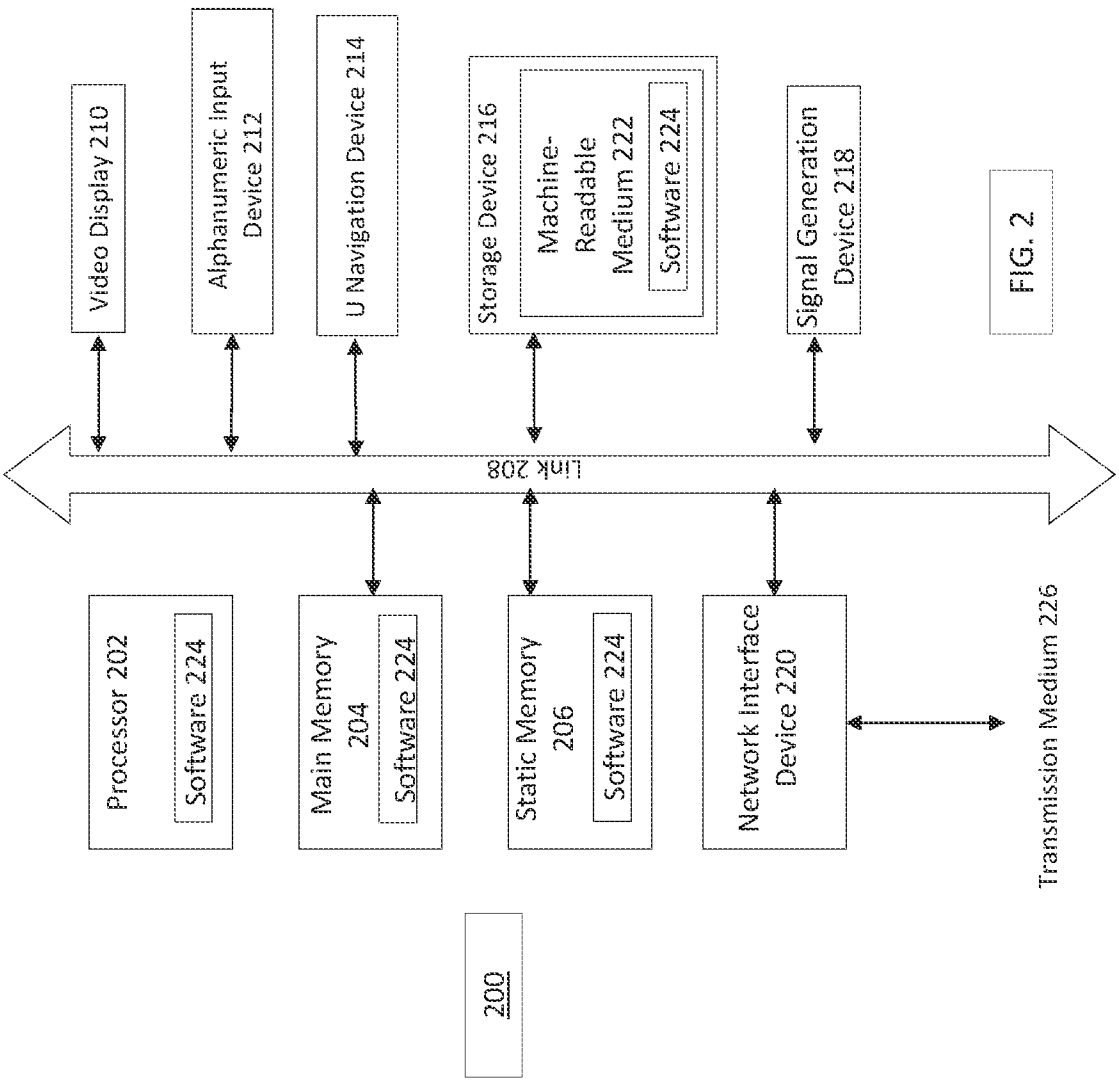
Video Display 210
Alphanumeric input Device 212
U Navigation Device 214
Storage Device 216
Machine-Readable Medium 222
Software 224
Signal Generation Device 218
Link 208
Processor 202
Software 224
Main Memory 204
Software 224
Static Memory 206
Software 224
Network Interface Device 220
Transmission Medium 226
200

FIG. 2

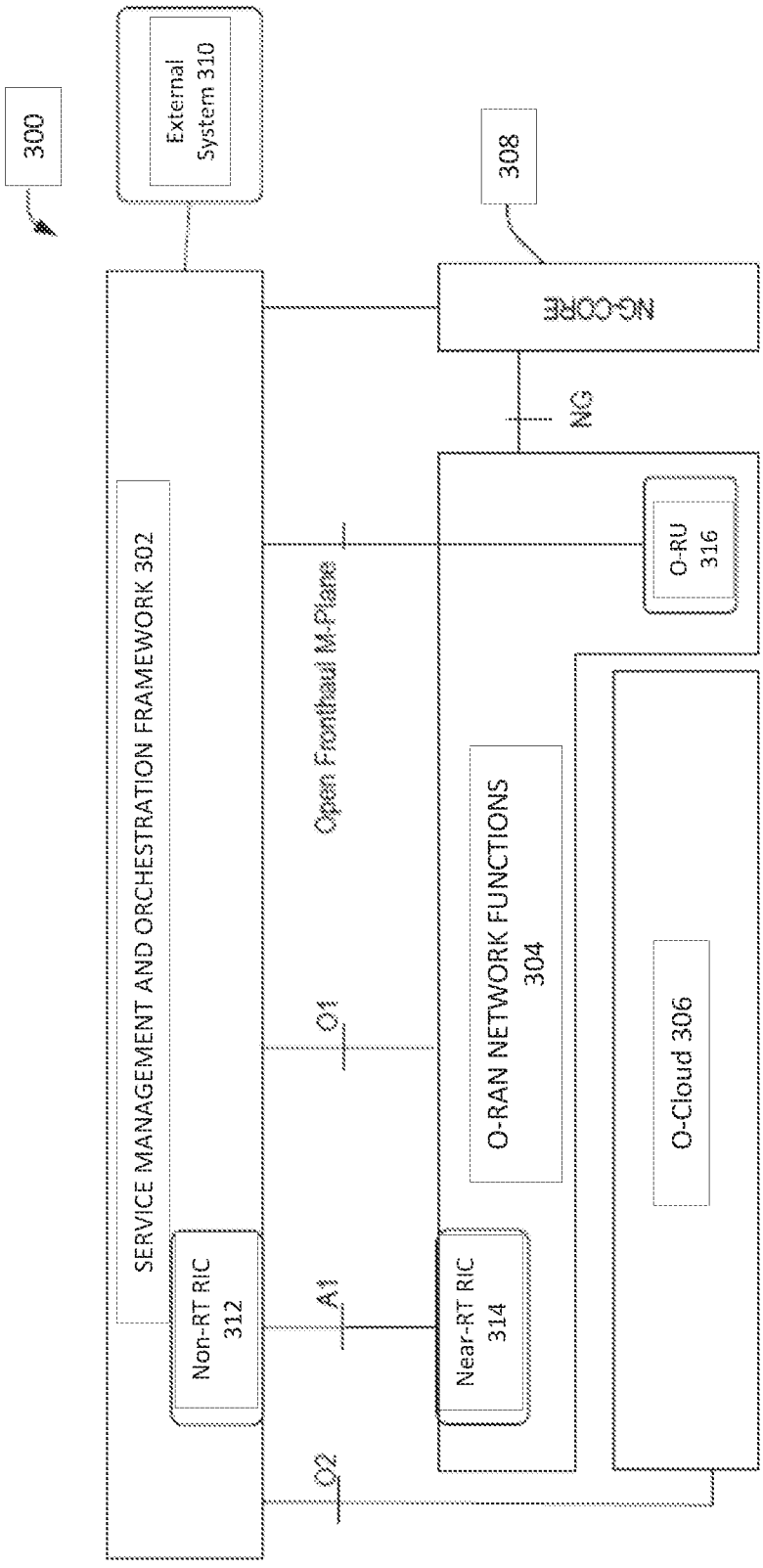
300
External System 310
308
NG-CORE
NG
SERVICE MANAGEMENT AND ORCHESTRATION FRAMEWORK 302
Open Fronthaul M-Plane
O-RU 316
O1
O-RAN NETWORK FUNCTIONS 304
O-Cloud 306
Non-RT RIC 312
A1
Near-RT RIC 314
O2

FIG. 3

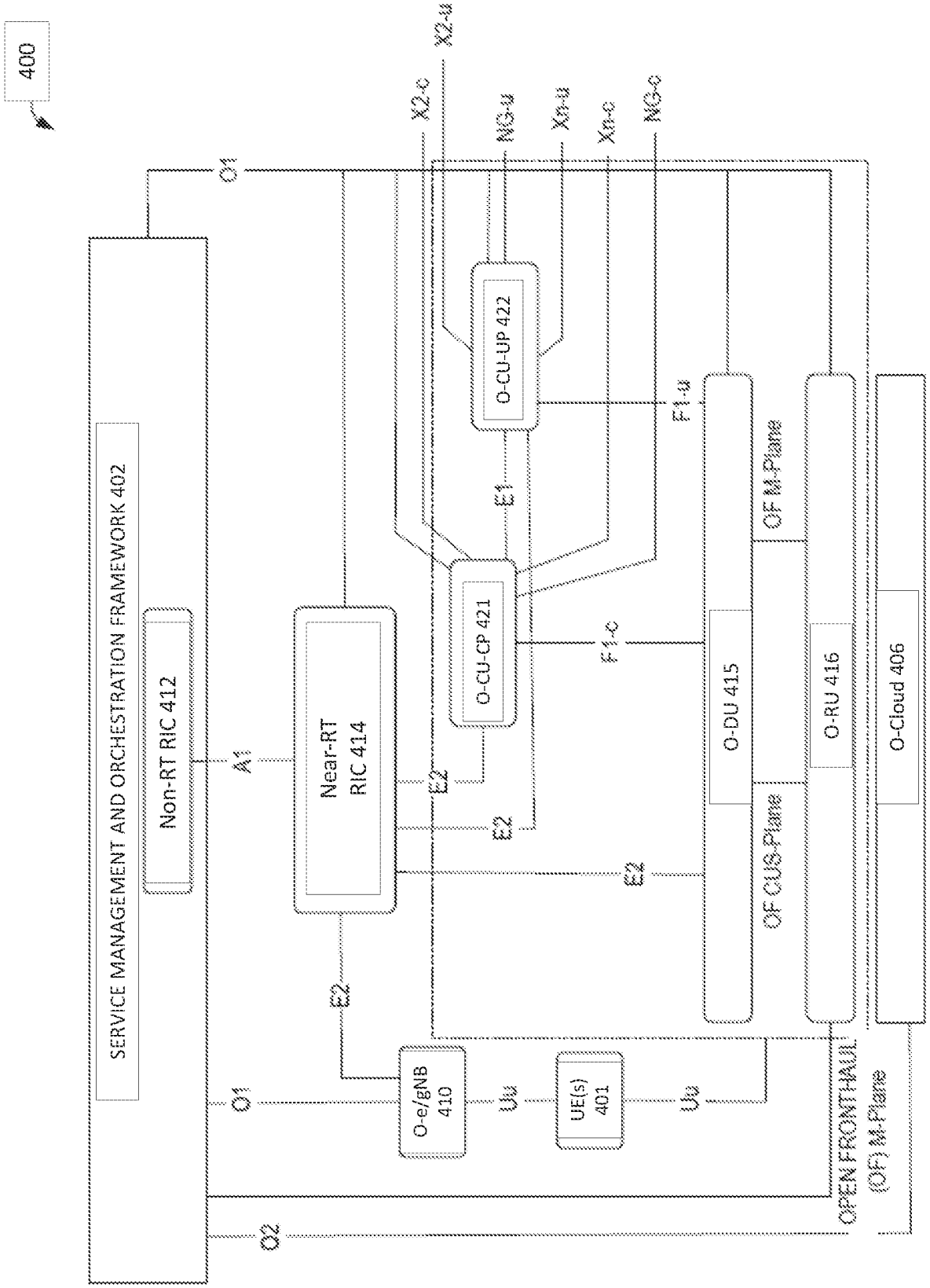
400
SERVICE MANAGEMENT AND ORCHESTRATION FRAMEWORK 402
Non-RT RIC 412
Near-RT RIC 414
O-CU-CP 421
O-CU-UP 422
O-DU 415
O-RU 416
O-Cloud 406
O-e/gNB 410
UE(s) 401
O1
O2
A1
E1
E2
F1-c
F1-u
X2-c
X2-u
NG-u
Xn-u
Xn-c
NG-c
Uu
OF C/U-Plane
OF M-Plane
OPEN FRONTHAUL (OF) M-Plane

FIG. 4

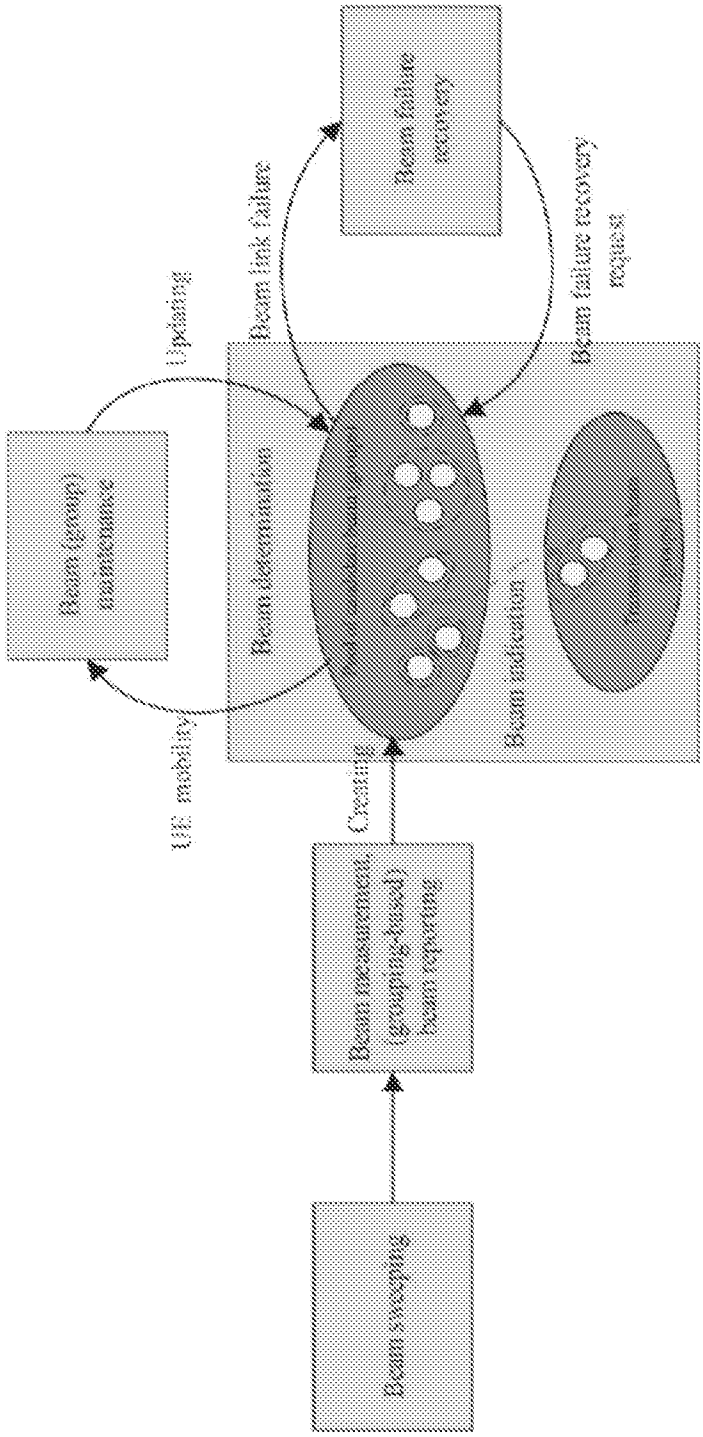
Beam sweeping
Beam measurement (grouping-based) beam reporting
Creating
Beam indication
Beam identification
UE mobility
Beam (group) maintenance
Updating
Beam link failure
Beam failure recovery
Beam failure recovery request

FIG. 5

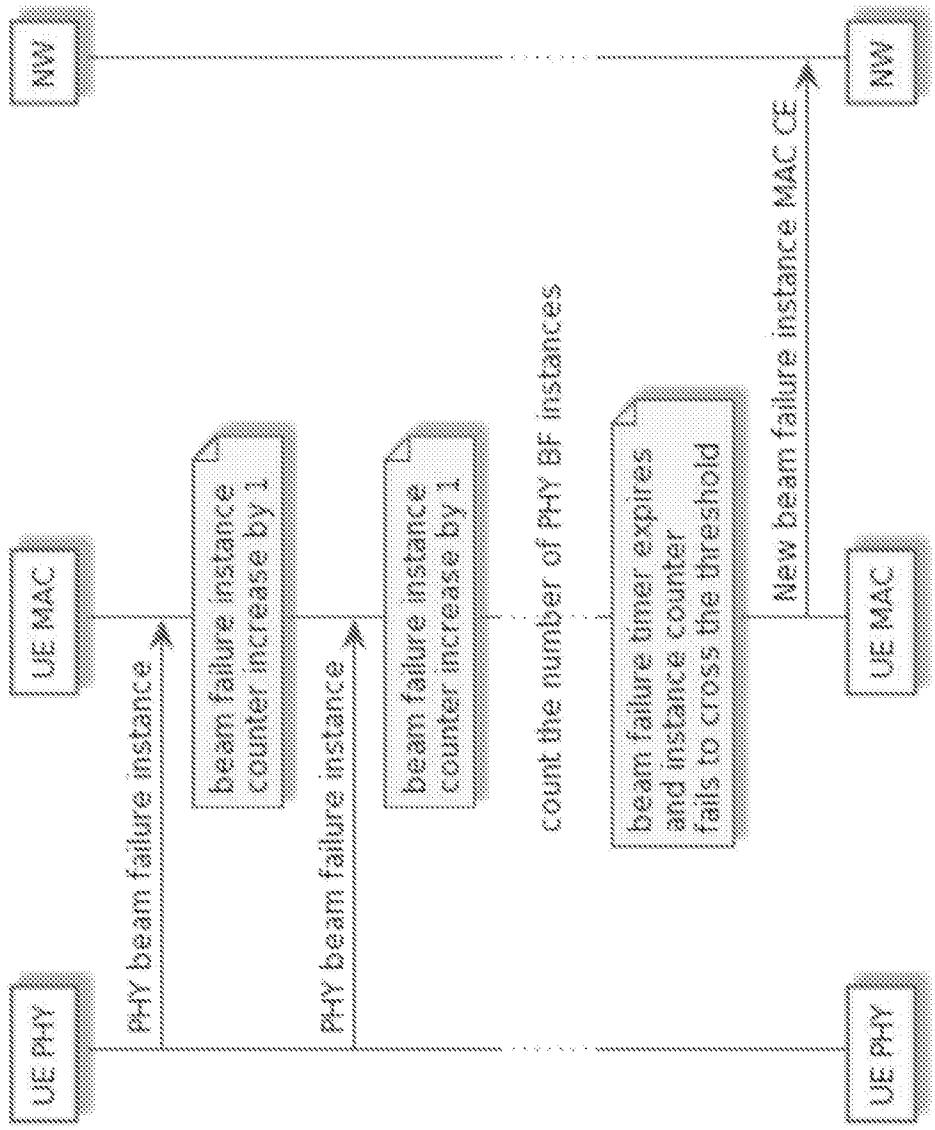
UE PHY
UE MAC
NW
PHY beam failure instance
beam failure instance counter increase by 1
PHY beam failure instance
beam failure instance counter increase by 1
count the number of PHY BF instances
beam failure timer expires and instance counter fails to cross the threshold
New beam failure instance MAC CE
UE PHY
UE MAC
NW

FIG. 6

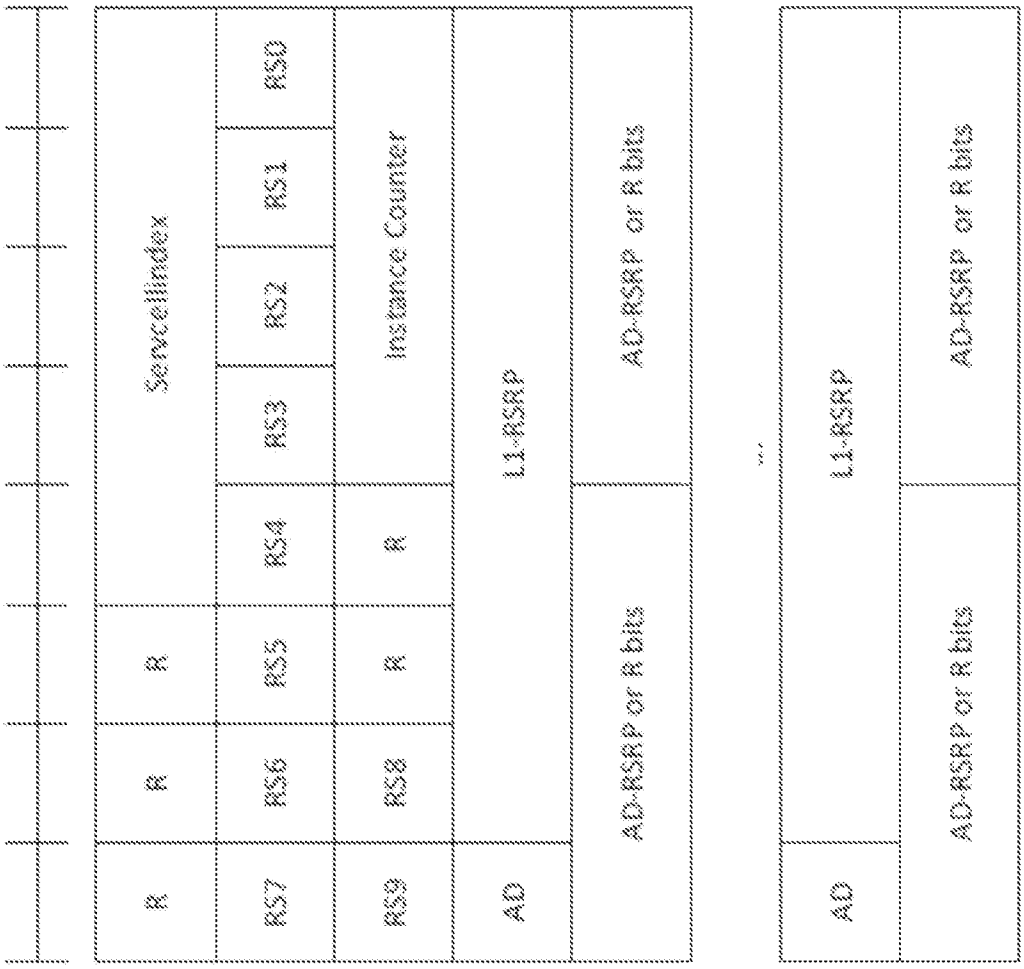
R
R
R
ServeCellIndex
RS0
RS1
RS2
RS3
RS4
RS5
RS6
RS7
RS8
RS9
Instance Counter
R
R
R
AD
L1-RSRP
AD-RSRP or R bits
AD-RSRP or R bits
...
AD
L1-RSRP
AD-RSRP or R bits
AD-RSRP or R bits

FIG. 7

IE/Group Name	Presence	Range	IE type and reference	Semantics description
Mean Number Of Detected Beam Failures	O		INTEGER	

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/048265

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/0408(2017.01)i; **H04B 7/06**(2006.01)i; **H04B 17/318**(2014.01)i; **H04B 7/0413**(2017.01)i; **G06N 3/02**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B 7/0408(2017.01); H04B 7/06(2006.01); H04L 5/00(2006.01); H04W 72/04(2009.01); H04W 72/08(2009.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: intelligence controller (IC), beam failure detection, recovery, reporting, instances

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020-0274606 A1 (LG ELECTRONICS INC.) 27 August 2020 (2020-08-27) Paragraphs [0344], [0428], [0697]-[0698]; claim 1; and figures 12, 15, 18	1-20
A	YU-NGOK RUYUE LI et al. Beam Management in Millimeter-Wave Communications for 5G and Beyond. Millimeter-Wave Communications: New Research Trends and Challenges. IEEE Access, 01 January 2020, Vol. 8, pages 13282-13293. Sections III-IV; and figure 6	1-20
A	US 2019-0116605 A1 (QUALCOMM INCORPORATED) 18 April 2019 (2019-04-18) Paragraphs [0056]-[0073]; claim 1; and figure 1	1-20
A	WO 2017-024516 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 16 February 2017 (2017-02-16) Paragraphs [0058]-[0067]; claim 1; and figure 3	1-20
A	UGUR BARAN ELMALI et al. Analysis and Performance of Beam Management in 5G Networks. 201 9 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC). IEEE, 11 September 2019, pages 1-7. Section IV; and figure 1	1-20

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 December 2021	**15 December 2021**

Name and mailing address of the ISA/KR	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2021/048265

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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		EP 3713340 A1	23 September 2020
		EP 3713340 A4	18 August 2021
		JP 2021-503261 A	04 February 2021
		SG 11202003186 PA	28 May 2020
		WO 2019-098798 A1	23 May 2019
US 2019-0116605 A1	18 April 2019	CN 111201721 A	26 May 2020
		EP 3695521 A1	19 August 2020
		US 10986644 B2	20 April 2021
		WO 2019-074761 A1	18 April 2019
WO 2017-024516 A1	16 February 2017	CN 107079459 A	18 August 2017
		EP 3335494 A1	20 June 2018
		EP 3335494 A4	01 August 2018
		US 10848230 B2	24 November 2020
		US 2018-0219604 A1	02 August 2018