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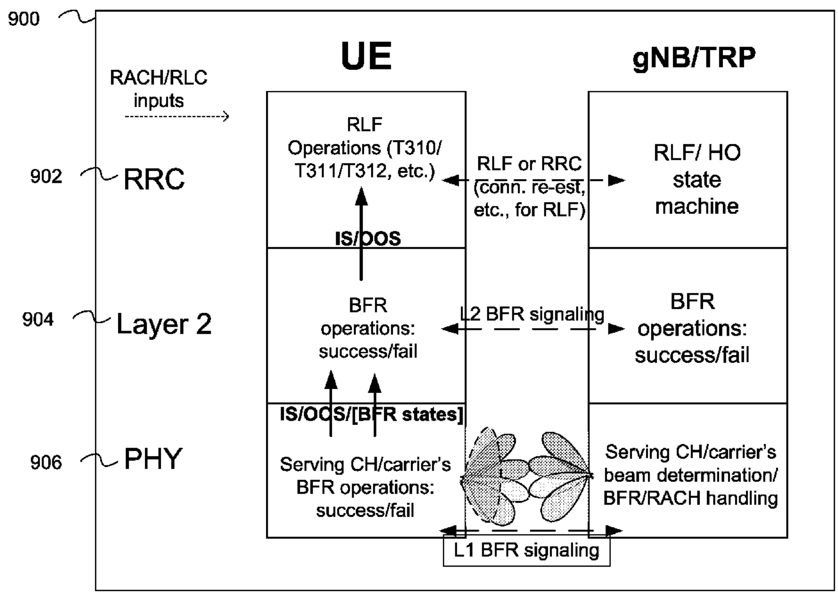

Figure 9

(57) Abstract: Disclosed is a system and method for detecting new radio (NR) link failures and executing RLM and link failure recovery in network equipment, e.g., a user-side UE device (or a network-side device such as TRP or base stations). The systems and methods unify the received indication for the detected radio link utilizing the multi-beam RLM and full-diversity or multipath link failure recovery indication(s) for performance optimization.

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UNIFIED RLF DETECTION, MULTI-BEAM RLM, AND FULL-DIVERSITY BFR MECHANISMS IN NR

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to US Provisional Patent Application Serial No. 62/524,362 filed on June 23, 2017 and entitled System and Method for a Unified RLF Detection and Full-Diversity BFR Mechanism in NR and US Provisional Patent Application Serial No. 62/557,052 filed on September 11, 2017 and entitled System and Method for a Unified RLF Detection and Full-Diversity BFR Mechanism in NR, the contents of which is incorporated by reference.

FIELD OF THE INVENTION

The present disclosure relates to the field of Communications Networks, and particular embodiments of radio links.

BACKGROUND

In Radio Access Networks (RAN), the criteria of beam failure and beam recovery failure (BFR) continues to be an area of research. Outstanding technical issues include, but are not limited to how the physical layer (PHY) layer can generate and provide (cell-specific) OOS, IS indication or other necessary new indications to RRC declared RLF, and how to define a single procedure of RLF, RLM, and BFR interaction for both multi-beam and single-beam operations.

This background information is intended to provide information that may be of possible relevance to the present disclosure. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY

It is an object of the present disclosure to obviate or mitigate at least one disadvantage of the prior art.

In one embodiment, a method for determining radio link recovery or beam failure recovery (BFR) indications in a user equipment (UE) is disclosed that includes receiving and processing downlink (DL) reference signals from multiple beams, determining a signal quality metric for each of the multiple beams, evaluating the determined signal quality metrics of multiple diversity of physical-layer transmission paths for executing link recovery operations of signaling, beam failure detection, new beam identification, and link failure recovery request and response, accomplishing the link recovery operations by fully exploiting the configured multiple paths at the physical layer for configured link recovery operations under configured or timer-based constraints, during the link recovery process, determining the link recovery operation status, generating link recovery indications according to the link recovery operation status, and sending the link recovery indication(s) from physical layer to an upper layer (e.g., RLM or RLF).

In another embodiment, a method for determining radio link recovery or beam failure recovery (BFR) indications in a user equipment (UE), is disclosed that includes receiving and processing downlink (DL) reference signals from multiple beams, determining a signal quality metric for each of the multiple beams, evaluating the determined signal quality metrics of multiple diversity of physical-layer transmission paths for executing link recovery operations of signaling, beam failure detection, new beam identification, and link failure recovery request and response, performing the link recovery operations by fully exploiting the configured multiple paths at the physical layer for configured link recovery operations under configured or timer-based constraints, determining the link recovery operation status during the link recovery process, generating link recovery indications according to the link recovery operation status, and sending the link recovery indication(s) from physical layer to an upper layer.

Embodiments have been described above in conjunctions with aspects of the present invention upon which they can be implemented. Those skilled in the art will appreciate that embodiments may be implemented in conjunction with the aspect with which they are described, but may also be implemented with other embodiments of that aspect. When embodiments are mutually exclusive, or are otherwise incompatible with each other, it will be apparent to those skilled in the art. Some embodiments may be described in relation to one aspect, but may also be applicable to other aspects, as will be apparent to those of skill in the art.

BRIEF DESCRIPTION OF THE FIGURES

Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

Figure 1 is a block diagram of an electronic device within a computing and communications environment that may be used for implementing devices and methods in accordance with representative embodiments of the present disclosure;

Figure 2 is a block diagram illustrating a service-based view of a system architecture of a 5G Core Network;

Figure 3 a block diagram illustrating the system architecture of a Fifth Generation (5G) Core Network as shown in Figure 2 from the perspective of reference point connectivity;

Figure 4 is a block diagram illustrating an architecture of a 5G Radio Access Network;

Figure 5 is a block diagram illustrating an architecture of a 5G Radio Access Network;

Figure 6 illustrates an embodiment of full-diversity Beam Failure Recovery (BRF) and unified Radio Link Failure (RLF) mechanisms.

Figure 7 illustrates the design of RLF state machine in Long Term Evolution (LTE), showing the necessary timers and counters for In-Sync (IS) indication or out-of-sync (OOS) indications coming from underlying RLM.

Figure 8 illustrates the design of RLF phases in LTE.

Figure 9 illustrates that the end-to-end and cross-layer framework of BFR-RLF interactions..

Figure 10 illustrates the end-to-end and cross-layer framework of BFR-RLF.

Figure 11 illustrates that detailed flow of RLF detection procedure based on underlying BFR state machine triggered IS, OOS, link or BFR IS, OOS status indications.

Figure 12 illustrates an embodiment of the BFR, RLM, and RLF interaction process.

Figure 13 illustrates an embodiment of the BFR, RLM, and RLF interaction process.

Figure 14 illustrates an embodiment of the BFR, RLM, and RLF interaction process.

Figure 15 illustrates a prior art of layered architecture for the interactions between RLF and BFR.

Figure 16 illustrates that detailed flow of optimizing BFR procedure.

DETAILED DESCRIPTION

For the purposes of this application, the following list of acronyms is provided to aid in the understanding of the disclosure. As is known to someone skilled in the art, various acronyms may have a plurality of meanings, therefore the meaning of any acronym should be interpreted in view of the appropriate context of the disclosure.

Figure 1 is a block diagram of an electronic device (ED) 52 illustrated within a computing and communications environment 50 that may be used for implementing the devices and methods disclosed herein. In some embodiments, the electronic device may be an element of communications network infrastructure, such as a base station (for example a NodeB, an evolved Node B (eNodeB, or eNB), a next generation NodeB (sometimes referred to as a gNodeB or gNB), a home subscriber server (HSS), Mobility Management Entity (MME), a gateway (GW) such as a packet gateway (PGW) or a serving gateway (SGW) or various other nodes or functions within a core network (CN) or a Public Land Mobility Network (PLMN). For clarity, a gNB may be a next generation (5G) of eNB (LTE base station), which may include one CU (Central Unit) and one or more DUs (Distributed Units). A CU may host L3 RRC, PDCP protocol layers. A DU may host RLC, and/or Medium Access Control (MAC), and/or PHY, etc.

In other embodiments, the electronic device may be a device that connects to the network infrastructure over a radio interface, such as a mobile phone, smart phone or other such device that may be classified as a User Equipment (UE). In some embodiments, ED 52 may be a Machine Type Communications (MTC) device (also referred to as a machine-to-machine (m2m) device), or another such device that may be categorized as a UE despite not providing a direct service to a user. In some references, an ED may also be referred to as a mobile device, a term intended to reflect devices that connect to mobile network, regardless of whether the device itself is designed for, or capable of, mobility. Specific devices may utilize all of the components shown or only a subset of the components, and levels of integration may vary from device to device. Furthermore, a device may contain multiple instances of a component, such as multiple processors, memories, transmitters, receivers, etc. The electronic device 52 typically includes a processor 54, such as a Central Processing Unit (CPU), and may further include specialized processors such as a Graphics Processing Unit (GPU) or other such processor, a memory 56, a network interface 58 and a bus 60 to connect the components of ED 52. ED 52 may optionally also include components such as a mass storage device 62, a video adapter 64, and an I/O interface 68 (shown in dashed lines).

The memory 56 may comprise any type of non-transitory system memory, readable by the processor 54, such as static random access memory (SRAM), dynamic random access memory (DRAM), synchronous DRAM (SDRAM), read-only memory (ROM), or a combination thereof. In an embodiment, the memory 56 may include more than one type of memory, such as ROM for use at boot-up, and DRAM for program and data storage for use while executing programs. The bus 60 may be one or more of any type of several bus architectures including a memory bus or memory controller, a peripheral bus, or a video bus.

The electronic device 52 may also include one or more network interfaces 58, which may include at least one of a wired network interface and a wireless network interface. As illustrated in Figure 1, network interface 58 may include a wired network interface to connect to a network 74, and also may include a radio access network interface 72 for connecting to other devices over a radio link. When ED 52 is a network infrastructure element, the radio access network interface 72 may be omitted for nodes or functions acting as elements of the PLMN other than those at the radio edge (e.g. an eNB). When ED 52 is infrastructure at the radio edge of a network, both wired and wireless network interfaces may be included. When ED 52 is a wirelessly connected device, such as a User Equipment, radio access network interface 72 may be present and it may be supplemented by other wireless interfaces such as WiFi network interfaces. The network interfaces 58 allow the electronic device 52 to communicate with remote entities such as those connected to network 74.

The mass storage 62 may comprise any type of non-transitory storage device configured to store data, programs, and other information and to make the data, programs, and other information accessible via the bus 60. The mass storage 62 may comprise, for example, one or more of a solid state drive, hard disk drive, a magnetic disk drive, or an optical disk drive. In some embodiments, mass storage 62 may be remote to the electronic device 52 and accessible through use of a network interface such as interface 58. In the illustrated embodiment, mass storage 62 is distinct from memory 56 where it is included, and may generally perform storage tasks compatible with higher latency, but may generally provide lesser or no volatility. In some embodiments, mass storage 62 may be integrated with a heterogeneous memory 56.

The optional video adapter 64 and the I/O interface 68 (shown in dashed lines) provide interfaces to couple the electronic device 52 to external input and output devices. Examples of input and output devices include a display 66 coupled to the video adapter 64 and an I/O device 70 such as a touch-screen coupled to the I/O interface 68. Other devices may be coupled to the electronic device 52, and additional or fewer interfaces may be utilized. For example, a serial interface such as Universal Serial Bus (USB) (not shown) may be used to provide an interface for an external device. Those skilled in the art will appreciate that in embodiments in which ED 52 is part of a data center, I/O interface 68 and Video Adapter 64 may be virtualized and provided through network interface 58. In some embodiments, electronic device 52 may be a standalone device, while in other embodiments electronic device 52 may be resident within a data center. A data center, as will be understood in the art, is a collection of computing resources (typically in the form of servers) that can be used as a collective computing and storage resource. Within a data center, a plurality of servers can be connected together to provide a computing resource pool upon which virtualized entities can be instantiated. Data centers can be interconnected with each other to form networks consisting of pools computing and storage resources connected to each by connectivity resources. The connectivity resources may take the form of physical connections such as Ethernet or optical communications links, and in some instances may include wireless communication channels as well. If two different data centers are connected by a plurality of different communication channels, the links can be combined together using any of a number of techniques including the formation of link aggregation groups (LAGs). It should be understood that any or all of the computing, storage and connectivity resources (along with other resources within the network) can be divided between different sub-networks, in some cases in the form of a resource slice. If the resources across a number of connected data centers or other collection of nodes are sliced, different network slices can be created.

Figure 2 illustrates service-base architecture 80 for a 5G or Next Generation Core (NGC) Network (5GCN / NGCN/ NCN). This illustration depicts logical connections between nodes and functions, and its illustrated connections should not be interpreted as direct physical connection. ED 50 forms a radio access network connection with a (Radio) Access Network node (R)AN 84, which is connected to a User Plane (UP) Function (UPF) 86 such as a UP Gateway over a network interface such as an N3 interface. UPF 86 connects to a Data Network (DN) 88 over a network interface such as an N6 interface. DN 88 may be a data network used to provide an operator service, or it may be outside the scope of the standardization of the Third Generation Partnership Project (3GPP).

3GPP is a collaboration between groups of telecommunications associations, known as the Organizational Partners. The initial scope of 3GPP was to make a globally applicable third-generation (3G) mobile phone system specification based on evolved Global System for Mobile Communications (GSM) specifications within the scope of the International Mobile Telecommunications-2000 project of the International Telecommunication Union (ITU). The scope was later enlarged to include the development and maintenance of many telecommunications standards and systems.

In some embodiments DN 88 may represent an Edge Computing network or resource, such as a Mobile Edge Computing (MEC) network. ED 52 also connects to the Access and Mobility Management Function (AMF) 90. The AMF 90 is responsible for authentication and authorization of access requests, as well as Mobility management functions.

Mobility Management, referring to switching of serving nodes due to UE's mobility, and often incurring L2 (Layer 2) or L3 (Layer 3) signaling and even data transfer/split between the nodes and with the UE for the switch.

The AMF 90 may perform other roles and functions as defined by the 3GPP Technical Specification (TS) 23.501. In a service based view, AMF 90 can communicate with other functions through a service based interface denoted as Namf. The Session Management Function (SMF) 92 is a network function that is responsible for the allocation and management of IP addresses that are assigned to a UE as well as the selection of a UPF 86 (or a particular instance of a UPF 86) for traffic associated with a particular session of ED 52. The SMF 92 can communicate with other functions, in a service based view, through a service based interface denoted as Nsmf. The Authentication Server Function (AUSF) 94, provides authentication services to other network functions over a service based Nausf interface. A Network Exposure Function (NEF) 96 can be deployed in the network to allow servers, functions and other entities such as those outside a trusted domain to have exposure to services and capabilities within the network. In one such example, an NEF 96 can act much like a proxy between an application server outside the illustrated network and network functions such as the Policy Control Function (PCF) 100, the SMF 92 and the AMF 90, so that the external application server can provide information that may be of use in the setup of the parameters associated with a data session. The NEF 96 can communicate with other network functions through a service based Nnef network interface. The NEF 96 may also have an interface to non-3GPP functions. A Network Repository Function (NRF) 98, provides network service discovery functionality. The NRF 98 may be specific to the Public Land Mobility Network (PLMN) or network operator, with which it is associated. The service discovery functionality can allow network functions and UEs connected to the network to determine where and how to access existing network functions, and may present the service based interface Nnrf. PCF 100 communicates with other network functions over a service based Npcf interface, and can be used to provide policy and rules to other network functions, including those within the control plane. Enforcement and application of the policies and rules is not necessarily the responsibility of the PCF 100, and is instead typically the responsibility of the functions to which the PCF 100 transmits the policy. In one such example the PCF 100 may transmit policy associated with session management to the SMF 92. This may be used to allow for a unified policy framework with which network behavior can be governed. A Unified Data Management Function (UDM) 102 can present a service based Nudm interface to communicate with other network functions, and can provide data storage facilities to other network functions. Unified data storage can allow for a consolidated view of network information that can be used to ensure that the most relevant information can be made available to different network functions from a single resource. This can make implementation of other network functions easier, as they do not need to determine where a particular type of data is stored in the network. The UDM 102 may be implemented as a UDM Front End (UDM-FE) and a User Data Repository (UDR). The PCF 100 may be associated with the UDM 102 because it may be involved with requesting and providing subscription policy information to the UDR, but it should be understood that typically the PCF 100 and the UDM 102 are independent functions. The PCF may have a direct interface to the UDR. The UDM-FE receives requests for content stored in the UDR, or requests for storage of content in the UDR, and is typically responsible for functionality such as the processing of credentials, location management and subscription management. The UDR-FE may also support any or all of Authentication Credential Processing, User Identification handling, Access Authorization, Registration / Mobility management, subscription management, and Short Message Service (SMS) management. The UDR is typically responsible for storing data provided by the UDM-FE. The stored data is typically associated with policy profile information (which may be provided by PCF 100) that governs the access rights to the stored data. In some embodiments, the UDR may store policy data, as well as user subscription data which may include any or all of subscription identifiers, security credentials, access and mobility related subscription data and session related data. Application Function (AF) 104 represents the non-data plane (also referred to as the non-user plane) functionality of an application deployed within a network operator domain and within a 3GPP compliant network. The AF 104 interacts with other core network functions through a service based Naf interface, and may access network capability exposure information, as well as provide application information for use in decisions such as traffic routing. The AF 104 can also interact with functions such as the PCF 100 to provide application specific input into policy and policy enforcement decisions. It should be understood that in many situations the AF 104 does not provide network services to other NFs, and instead is often viewed as a consumer or user of services provided by other NFs. An application outside the 3GPP network, can perform many of the same functions as AF 104 through the use of NEF 96.

ED 52 communicates with network functions that are in the User Plane (UP) 106, and the Control Plane (CP) 108. The UPF 86 is a part of the CN UP 106 (DN 88 being outside the 5GCN). (R)AN 84 may be considered as a part of a User Plane, but because it is not strictly a part of the CN, it is not considered to be a part of the CN UP 106. AMF 90, SMF 92, AUSF 94, NEF 96, NRF 98, PCF 100, and UDM 102 are functions that reside within the CN CP 108, and are often referred to as Control Plane Functions. AF 104 may communicate with other functions within CN CP 108 (either directly or indirectly through the NEF 96), but is typically not considered to be a part of the CN CP 108.

Those skilled in the art will appreciate that there may be a plurality of UPFs connected in series between the (R)AN 84 and the DN 88, and as will be discussed with respect to Figure 5GSA2-B, multiple data sessions to different DNs can be accommodated through the use of multiple UPFs in parallel.

Figure 3 illustrates a reference point representation of a 5G Core Network architecture 82. For the sale of clarity, some of the network functions illustrated in Figure 2 are omitted from this figure, but it should be understood that the omitted functions (and those not illustrated in either Figure 1 or Figure 2 can interact with the illustrated functions.

ED 52 connects to both (R)AN 84 (in the user plane 106) and AMF 90 (in the control plane 108). The ED-to-AMF connection is an N1 connection. (R)AN 84 also connects to the AMF 90, and does so over an N2 connection. The (R)AN 84 connects to a UPF function 86 over and N3 connection. The UPF 86 is associated with a PDU session, and connects to the SMF 92 over an N4 interface to receive session control information. If the ED has multiple PDU sessions active, they can be supported by multiple different UPFs, each of which is connected to an SMF over an N4 interface. It should be understood that from the perspective of reference point representation, multiple instances of either an SMF 92 or an UPF 86 are considered as distinct entities. The UPFs 86 each connect to a

DN 88 outside the 5GCN over an N6 interface. SMF 92 connects to the PCF 100 over an N7 interface, while the PCF 100 connects to an AF 104 over an N5 interface. The AMF 90 connects to the UDM 102 over an N8 interface. If two UPFs in UP 106 connect to each other, they can do so over an N9 interface. The UDM 102 can connect to an SMF 92 over an N10 interface. The AMF 90 and AMF 92 connect to each other over an N11 interface. The N12 interface connects the AUSF 94 to the AMF 90. The AUSF can connect to the UDM 102 over the N13 interface. In networks in which there is a plurality of AMFs, they can connect to each other over an N14 interface. The PCF 100 can connect to an AMF 90 over the N15 interface. If there is a plurality of SMFs in the network, they can communicate with each other over an N16 interface.

It should also be understood that any or all of the functions and nodes, discussed above with respect to the architectures 80 and 82 of the 5G Core Network, may be virtualized within a network, and the network itself may be provided as a network slice of a larger resource pool, as will be discussed below.

Figure 4 illustrates an proposed architecture 110 for the implementation of a Next Generation Radio Access Network (NG-RAN) 112, also referred to as a 5G RAN, where one ED may communicate with multiple gNB's or multiple DUs for each gNB (simultaneously) over the same or different frequency carrier, or using some resource multiplexing approach. Not shown here, each ED-DU radio link may consists of multiple beams or beam pairs. NG-RAN 112 is the radio access network that connects an ED 52 to a core network 114. Those skilled in the art will appreciate that core network 114 may be the 5GCN (as illustrated in Figure 5GSA2-A and Figure 5GSA2-B). In other embodiments, the core network 114 may be a 4g Evolved Packet Core (EPC) network. Nodes with NG-RAN 112 connect to the 5G Core Network 114 over an NG interface. This NG interface can comprise both the N2 interface to a control plane and an N3 interface to a user plane as illustrated in Figure 5GSA2-A and Figure 5GSA2-B. The N3 interface can provide a connection to a CN UPF. NG-RAN 112 includes a plurality of radio access nodes which can be referred to as a next generation NodeB (gNB). In the NG-RAN 112, gNB 116A and gNB 116B are able to communicate with each other over an Xn interface. Within a single gNB 116A, the functionality of the gNB may be decomposed into a Centralized Unit (gNB-CU) 118A and a set of distributed units (gNB-DU 120A-1 and gNB-DU 120A-2, collectively referred to as 120A). gNB-CU 118A is connected to a gNB-DU 120A over an F1 interface. Similarly gNB 116B has a gNB-CU 118B connecting to a set of distributed units gNB-DU 120B-1 and gNB-DU 120B. Each gNB DU may be responsible for one or more cells providing radio coverage within the PLMN.

The division of responsibilities between the gNB-CU and the gNB-DU are being defined by 3GPP. Different functions, such as the radio resource management or radio resource monitoring (RLM) functionality may be placed in one of the CU and the DU, and also on ED too to monitor one or multiple radio links or one or multiple beams per link between the ED and DU(s). As with all functional placements, there may be advantages and disadvantages to placement of a particular function in one or the other location. It should also be understood that any or all of the functions discussed above with respect to the NG-RAN 112 may be virtualized within a network, and the network itself may be provided as a network slice of a larger resource pool, as will be discussed below.

Figure 5 illustrates an architecture 122 of a Radio Access Network for a 5G network that may support interworked New Radio (NR) and LTE radio interface by the same ED, i.e., one interface (with LTE ng-eNB) may be omni-directional radio link on a carrier, while another interface (with NR gNB) may be omni-directional links on another carrier coupled with multi-beam radio links on yet another carrier. The RLM function and BFR functions embedded in the UE will have to monitor the downlink radio links (e.g, RSRP, RSRQ, etc), interacting with RLF within the same UE through in-device indications (beam-, channel- or cell-specific radio link quality metrics, or IS, OOS, or yet-to-be-defined RLF or BFR indications) for deriving link- or cell-level RLF status, and reporting the measured single or multi-beam link quality metrics and RLF status to the network. It is critical at this moment for NR to define such mechanisms for multi-beam related RLM, BFR, and RLM, and for their interactions. The Next Generation RAN (NG-RAN) includes a plurality of NG-RAN nodes such as NG-RAN Node 124A, NG-RAN Node 124B, and NG-RAN Node 124C, collectively referred to as NG-RAN Node 124. A NG-RAN Node 124 is typically the radio edge node through which an ED 52 connects to the NG-RAN. Each NG-RAN node 124 can be split into a CU and DU as discussed in Figure 5G RAN3-1. The type of connection provided to ED 52 can vary depending on the capabilities of the ED 52 and the capabilities of the particular NG-RAN Node 124. NG-RAN Node 124A includes, as part of its DU, a next generation evolved NodeB (ng-eNB) 126A which can provide an LTE connection to ED 52. NG-RAN Node 124C includes as part of its DU a gNB 128B which can provide a Next generation Radio access (NR) connection to ED 52. It should be noted that much as NG-RAN Node 124A cannot provide an NR connection to ED 52 because of its lack of gNB, NG-RAN Node 124C cannot provide an LTE connection to ED 52 because of its lack of ng-eNB. It should be further noted that with reference to this figure discussion of a gNB as part of a DU is meant to encompass a DU that is able to provide a Next Generation RAT connection to an ED, while an ng-eNB is meant to encompass a DU that is able to provide an LTE RAT connection to an ED. NG-RAN Node 124B includes within its DU, both ng-eNB 126B and gNB 128A. This allows NG-RAN Node 124B to provide both LTE and NR connections to ED 52.

An NG-RAN Node 124 can communicate with another NG-RAN Node 124 over an Xn interface. Although not shown, NG-RAN Node 124A could have an Xn interface connection to NG-RAN Node 124C. NG-RAN Node 124 can connect to the Core Network 114 over a connection through an NG interface such as an N2 or N3 interface, while an ED 52 may connect to the Core Network 114 over an NG Network Access Stratum (NG NAS) interface such as an N1 interface.

In one embodiment, the proposed unified 5G NR RLF detection mechanism effectively interacts with the proposed underlying full-diversity beam failure recovery (BFR) mechanism. The "full diversity" BFR refers to the BFR process that has exhaustively or selectively but sufficiently timely considered multi-dimensional diversified factors or choices (e.g., feasible communication and signaling paths) at any or all of the exemplary sequential BFR steps below, and have reached a conclusion about BFR status (success or failure) before sending any to-be-defined BFR indications about its status to upper layer (RLM or RLF):

1) BPL failure detection (step 1), measuring the serving beam pair links constituting the configured serving (e.g., control) Channel (CH) and reference signals (e.g., xSS, xRS) in any or all of UE-specific serving cells (e.g., Primary Cell (Pcell), Primary Secondary Cell (Pscell), or Secondary Cell (Scell)).

2) New beam identification (step 2), exploring a full diversity of one or more feasible beam pairs, based on configuration, of the source or target serving CH's. The CH's may be downlink (DL), uplink (UL), for Control or Data in any or all of PCell/SCell/PScell, or based on any or all reference signals, etc.

3) Beam recovery request (step 3), exploring a full diversity of feasible UL paths along with control or data channel (RACH, PUCCH, PUSCH, etc.), through

L1 to L3 signaling (UCI, MAC Control Element (CE), Scheduling Request (SR), Sounding Reference Signal (SRS), etc.), in any or all UE-specific serving cells (PCell/SCell/PScell, etc.), e.g., with same or mixed carriers of low frequency (LF) or high frequency (HF).

4) monitoring of BFR recovery response (step 4), exploring a full diversity of feasible DL paths for control or data channel (Physical Downlink Control Channel (PDCCH), PDSCH, etc.), reference signals (SS-block/PSS/SSS, xRS, etc.), through L1~L3 signaling (DCI, RRC, MAC CE, etc.), or in one or across multiple serving cells (PCell/SCell/Pscell), or over specific serving carrier or multiple carriers in each cell, etc.,

In the above design, each exemplary step of BFR may attempt to exhaustively or selectively but timely (based on network configured timer-constraint) and sufficiently (i.e., with retries of request-response under network configured maximum retry limit) resolve beam failure at L1/L2 without triggering the RLF behavior in upper layers, but failure of any of the above steps may sufficiently causally trigger timer-based (e.g., as periodically in LTE) or a periodic, aperiodic, or event-based (OOS, IS, link or BFR status) indication to upper-layer RLF or RLM. The timely accomplishment of all the (4) steps (1 to 4, shown above) may be claimed as BFR success with (IS or success) indication(s) sent to RLF or RLM. Conversely the RLF status, timers, and knowledge in the upper layers may indicate to the lower-layer to optimize (e.g., reset, postpone, early terminate, or accelerate upon events of RLF declaration or link recovery) the BFR state machine.

In addition, a proposed interaction unification module (IUM) helps BFR to unify indications from the above BFR steps and RLM to generate unique *event- or* timer-driven indications (e.g., IS, OOS) to upper layer (L2 or L3) RLF module. Reversely the IUM may consider RLF state machines and other upper layer info to assist lower layer BFR operations as well. The IUM may be implemented as hardware or software, or a combination thereof, and may be located at a single or multiple protocol layers, or in a single or multiple modules (BFR, Beam Management (BM), RLM, or RLF).

For clarity, BM may refer to any beam-specific operations, particularly beam alignment, beam refinement, beam tracking, and beam switching with respect to the same serving node, node family (Transmission And Reception Point (TRP) and its parent cell/gNB), or strictly synchronized nodes (multiple TRPs that literally can not be distinguished by UE from beam operations' perspective.)

For purposes of clarity, the TRP is intended to refer to the unit of serving node inside yet at the edge of a network, talking to the UE over the air radio, typically referring to RRH w. or w/o PHY or MAC.

The presently disclosed innovations provide a much-needed, modular and single/multi-beam unified procedure of RLF and RLF-BFR interaction method to enable low-cost, scalable, and reliable RLF detection in NR. Lower-layer BFR and upper-layer RLF state machines can be properly decoupled with simple interactions, because RLF may not need to know nor care what caused OOS, IS, as long as the BFR masks lower-layer beam-specific dynamics (beam failure) from RLF though the IUM module.

In NR systems in 3GPP RAN1, the criteria of beam failure and beam recovery failure are not decided yet, and no "full-diversity" indications considered yet in each step of BFR, particularly for step-wise IS/OSS generation and (cell-level) indication unification before sending the indications to RLF; On the other hand, the 3GPP RAN2 for NR systems RAN2 has reached certain agreements, but left the following problems open:

2) how can UE generate and send BFR and RLM (OOS, IS) indication for RRC declared (cell-specific) RLF for a multiple-beam link, and

3) what is the uniform procedure of BFR-RLF interactions regardless of multi-beam and single-beam RLM operations?

RLF may be is based on 3 options: PHY indication of OOS, IS, RLC (ARQ retry) failure, or RACH (after SR retry) failure. In other words, for connected mode, UE declares RLF upon (T310 or T312) timer expiry due to DL OOS detection, random access procedure failure detection, and RLC (ARQ retransmission) failure detection. It is for future study whether maximum ARQ retransmission number is the only criterion for RLC failure detection. In NR RLM procedure, physical layer performs out-of-sync (OOS) / in-sync (IS) indication and RRC declares RLF, but NR RLM for a multi-beam link is yet to be defined.

For RLF, RAN2 preference is that the in sync / out of sync indication should be a per cell indication, and this invention aims to design a single procedure of RLF/RLM-BFR interaction regardless of multi-beam or single-beam radio link operations in a single or across multiple serving cells.

Currently a new RLF detection mechanism is needed, that is different from LTE, because of the newly introduced PHY features in NR, such as the beamformed directional reference signals noted by xSS/xRS (instead of omni-directional cell specific RS (CRS) in LTE) that are yet to be defined for NR RLF and beam failure detection, the unclear (link-level, cell-level, multi-cell) RLF definition for a UE due to multi-beam composition of each serving channel or link, spatially uncorrelated or non-quasi-co-located (QCL) channels between control and data, non-ideal UL and DL beam correspondence, multiple serving cells (Pcell/Scell/Pscell) at the same time, different carriers or reference signals, and unclear interactions between L1 (or L2 or both layer) BFR state machine and upper layer (L2 or L3) RLF state machine, including unclear indications exchange in-between.

Currently the LTE's RLM/RLF (with channel metric threshold Q_out/Q_in) is generally based on SINR from omni-directional CRS measurement and table-lookup based hypothetical PDCCH channel Block Error Rate (BLER), but there is no cell-specific CRS in NR any more, where SS Block, PBCH DM-RS, CSI-RS, or other reference signals may be used instead, which are not formally defined yet in 3GPP standards. In addition, the LTE RLF with DC/ Carrier Aggregation (CA) is based only on PCell at MeNB or PScell at SeNB, but actually UL/DL data transmission can also be performed in available PUCCH SCell group even if PCell fails. Also, within each cell of CA, one carrier may fail but another carrier may still be alive. The existing NR proposals for NR RLF either failed to explore the full diversity of BFR before generating indications to the upper layer, and hence triggering arbitrary or unable indications based on transient BFR status, or tangling the cell-level RLF and beam-level BFR state machine all together regardless of their vastly different time scales, and hence causing unstable or non-optimized RLF behavior. The lack of a formal definition of multi-beam RLM and BFR in NR also makes the design very challenging. For purposes of clarity, CSI-RS/DM-RS/SS Block/PSS/SSS: are acronyms for reference signal (RS) or Primary/Secondary Synchronization Signals (PSS/SSS), normally called collectively xSS/xRS.

Figure 6 illustrates an embodiment of full-diversity Beam Failure Recovery (BRF) and unified Radio Link Failure (RLF) mechanisms and their interactions at UE, where the logical module of Integration and Unification Module (IUM) may be located anywhere, say, as part of RLM or RLF solely, or across different layers, or as part of RLF, BFR, or RLM modules, and BFR exploits the “full-diversity” of options to accomplish its due missions at much as possible and as quickly as possible (with time constraints) before sending any trigger to the upper layer.

As disclosed in Figure 6, an embodiment of the proposed full-diversity BRF is disclosed The proposed (multi-cell, per-cell, or per-link) unified RLF mechanisms, the proposed unifications of multi-source indications in-between for and their interactions at UE: the sidelined layer-specific signaling (implicitly a remote network device) provides over-the-air inputs for each layer of operations within the UE. In short, this plot illustrates an embodiment of the mechanisms that keep RLF state machine at Layer 3 as intact (vs. LTE’s) as possible, handle multi-beam BRF at L1 (or L2) as comprehensively and timely as possible. The proposed RLF considers only network configured or per-determined level of IS, OOS that are unified from full-diversity BRF indication of its status, its aperiodic or event-driven IS, OOS and implicitly any other (e.g., multi-beam RLM generated periodic) IS, OOS; Eventually a uniform procedure of RLF detection works regardless of single or multiple underlying serving beams, reference signals, cells, CHs, and carriers, etc. An IUM module, located *at L2 (as plotted just for illustration purpose) or distributively across multiple layers or inside RLF, RLM, and/or BRF*, derives and reports unified indications in-between RLF and BRF.

Upwards from lower layer to upper layer, the proposed IUM derives unified IS, OOS in a time sequence, or multiple sequences of them in parallel, each at a configured level for the target radio link across one or multiple serving cells or carriers (PSCell, Scell, Pcell, etc.), corresponding to one or multiple reference signals (xSS/xRS), in a single or multiple cell groups (secondary cell group (SCG), master cell group (MCG), etc), for a single or multiple CHs (in each cell or over each carrier, etc.), based on a single or multiple serving beams (per CH), etc..

Downwards from upper layer to lower layer, the proposed IUM also derives unified BFR assistance indication in a time sequence, or multiple sequences of them in parallel, from upper layers helpful information, including Dual Connectivity (DC)/ Multi-connectivity (MC)/CA/Handover (HO)/RLF/RLM/ Radio Resource Management (RRM)/RRC etc. status, to assist or optimize of the BFR operations.

Figure 7 illustrates the RLM and RLF procedure, including the RLM channel metrics (RSRP/RSRQ) measurement, first and periodic IN/OOS indication(s) from RLM sent to RLF, counting of the consecutive indications for timer-based RLF operations in the existing LTE systems. In some embodiments, the UE monitors downlink radio link quality (based on CRS) and compare it to the out-of-sync and in-sync thresholds, Qout (-8dB) and Qin (-6 dB), as in TS 36.133, based on measurement of CRS SINR (CIR) for PCell or PSCell. Same threshold levels are applicable with and without DRX. Note that with DRX ON, the periodic IS, OOS are generated based on the DRX cycle if configured.

In LTE, the threshold Qout is defined as the level at which the downlink radio link cannot be reliably received and shall correspond to 10% BLER (Qin corresponds to a 2% BLER) of a hypothetical PDCCH transmission from the serving cell, taking into account the PCFICH errors with transmission parameters specified in Table 7.6.1-1 in TS 36.133. In LTE, when CRS SINR of the PCell or PSCell estimated becomes worse than Qout, Layer 1 of the UE shall send out-of-sync (OOS) indications (periodically) to the higher layers and upper layer shall start a timer (T310). When CRS SINR is above Qin, L1 shall send an In-Sync (IS) indications (periodically) to the upper layers

When a timer of T310 expires, i.e., no IS indicator over the last (200 ms) period of T310, RLF is declared, RRC connection reestablishment and T311 are triggered. When consecutive N310 OOS indications are observed, T310 will be started, and T310 is stopped if N311 IS indications are received.

Physical layer problems are detected by an existing RLM module monitoring the metrics of cell-specific and non-beamformed (or omni-directional) the LTE CRS (e.g., RSS/CIR, or RSRP/RSRQ):

4) L1 filtering/sampling of (RSS/CIR) (10ms sampling over 200ms or 100ms sliding windows) of CRS pilot-based measurement are mapped to PDCCH BLER >10% or <2% by comparing filtered CIRs <Qout (-8dB) or >Qin(-6dB) thresholds

5) L3 filtering of Out-sync/In-sync indication refers to comparing the number of OOS >=N310 (to trigger T310) or IS >=N311 (to trigger T310 reset) of consecutive out-of-sync or in-sync indications, while

T310 can be set as 500~1000ms, or 50ms for smallcell as the RLF detection period

At L3/RRC layer, there are the following RLF timers

6) T310 starts upon detecting physical layer problems for the Pcell/Pscell, i.e. upon receiving N310 consecutive OOSs from lower layers; It stops when UE receives N311 consecutive ISs from lower layers Pcell/Pscell before T310 expires, upon triggering the HANDOVER procedure, and upon initiating the CONNECTION reestablishment procedure; T310 expiry triggers T311 and RLF and hence initiates the connection re-establishment procedure

7) T311 starts upon initiating the RRC connection re-establishment procedure, stops upon selection of a suitable E-UTRA cell or a cell using another RAT. T311 expiry will trigger UE to enter RRC_IDLE.

8) T312 starts upon triggering a measurement report for a measurement identity for which T312 has been configured while T310 is running; It stops upon receiving N311 consecutive in-sync indications from lower layers, upon triggering the handover procedure, upon initiating the connection re-establishment procedure, and upon the expiry of T310; T312 expiry will trigger RLF and initiate the connection re-establishment procedure, if context/security prepared, otherwise go to RRC_IDLE

For LTE there are two phases of RLF---first is RLF detection (upon T310 expiry), second is RRC recovery (ends by T311 or T312 expiry). Figure 8 illustrates the two phases of RLF which may be used in LTE.

9) In LTE CA and DC, LTE RLF/RLM is based only on PCell at MeNB or PScell at SeNB:

10) For CA, RRC connection re-establishment is triggered when PCell experiences RLF. The UE does not monitor the RLF of SCells, which are monitored by the eNB.

11) For DC, the first phase of the radio link failure procedure is supported for PCell and PSCell. Re-establishment is triggered when PCell experiences RLF. However, upon detecting RLF on the PSCell, the re-establishment procedure is not triggered at the end of the first phase. Instead, the UE informs the radio link failure of PSCell to the MeNB.

12) The two phases (RLF detection and RRC recovery) for DC/CA:

13) For single carrier and CA, re-establishment is triggered when PCell experiences RLF. The UE does not monitor the RLF of SCells, which are monitored by the eNB.

14) For DC, the first phase of the radio link failure procedure is supported for PCell and PSCell. Re-establishment is triggered when PCell experiences RLF. However, upon detecting RLF on the PSCell, the re-establishment procedure is not triggered at the end of the first phase. Instead, the UE informs the radio link failure of PSCell to the MeNB.

15) In LTE, a UE should declare radio link failure (RLF) in the higher layer (L3) when one of the following situations is satisfied (NOT just based on PHY layer detections):

16) An indication from RLC that the maximum number of (ARQ) re-transmission has been reached;

17) An indication from MAC that random access (RACH) problem occurs while neither T300, T301, T304 nor T311 is running;

18) The failure of receiving handover command during T312 when T310 is running, e.g., upon T312 expiry

19) Physical layer problem detection based on radio link monitoring (RLM) (i.e., consecutive OOSs for N310 numbers but no consecutive ISs for N311 numbers before T310 expiry), e.g., upon T310 expiry and T311 starts

Per 3GPP TR 38.802, in NR, beam failure event occurs when the quality of beam pair link(s) of an associated control channel falls low enough (e.g. comparison with a threshold, time-out of an associated timer).

RAN1 is designing UE triggered beam recovery procedure, targeting to overcome a sudden beam quality drop.

In one embodiment of the present disclosure, Full-Diversity BFR for Deriving IS, OOS. In our proposed full-diversity BFR, any step of BFR (taking a specific UE device for example):

20) may use a multi-beam RLM mechanism, if needed,

   i. to select/consolidate multiple feasible beams, similar or as an extension to multi-beam RRM [2,6] in NR,

   ii. *to derive CH- or cell-level RLM metrics* from measuring multiple beams based on configuration as in [2, 6]

21) upon failure or timeout may trigger (per-CH or per-cell) RLF OOS, IS, (e.g., w/ or w/o IUM functions) , as long as

   i. the following *OOS, IS generation condition is met* , and/or

   ii. *layer-specific indication frequency control or periodic timers are triggered* for the measured cell or CH per carrier

22) Checks CH-specific OOS, IS generation condition: Assuming that each specific beam carries specific xSS/xRS of serving carrier/CH/cell, and the UE's PHY layer adopts revised or similar RLM mechanisms as in LTE (w. L1 sampling and filtering, and IN/OOS generation intervals) ; Also assuming each of the 4 BFR steps may have its concrete (signaling or decision) mechanisms regardless of the number of serving beams/CHs/cells for this UE.

A multi-beam CH-specific OOS generation condition is met for various reasons. For example, in some examples, for when its filtered/sampled RLM metrics < Qout, or equivalently the hypothetical BLER of the CH (e.g., PDCCH) > threshold_OOS based on UE or channel-specific xRS (CSI-RS and/or DMRS), AND if a timer to control OOS generation frequency is triggered. In another example, the condition may be met when its filtered/sampled RLM metrics < Qout, or equivalently the hypothetical BLER of the CH (e.g., PDCCH) > threshold_OOS based on UE or channel-specific xRS (CSI-RS and/or DMRS). An IS generation condition can be likewise based on Qin and threshold_IS for all of scenarios here after OOS triggered. In addition, CH-specific indications may reduce to beam-specific if there is only beam per channel.

A common OOS generation condition is upon UE's reception and decoding failure of cell-specific common signals, e.g., PSS or SS-blocks or PBCH (with its DMRS), for a few numbers (e.g., w. combination) or over a certain time period (by a timer), e.g., in one or multiple cycles of beam sweeping where each cycle may be equivalent to one SS-block-burst set period.

Each step of the proposed full diversity BFR exploits a selection or all available choices in the steps for quick and solid determination of BFR success or failure with time constraints; For example, the beam recovery request of a failing control CH (beam) in cell1 in step 1 may resort to MAC CE piggy back along an Step 2 identified UL data CH (beam) or RACH in cell2, as long as time allows (based on certain timer); Success or failure of early steps or exploitation of some diversity may skip later steps /other diversity to provide indications to RLF. Each step may provide indications directly or indirectly to RLF through the unification function.

In another embodiment, the Interaction Unification Module (IUM) Functions between BFR and Unified RLF is disclosed. The IUM module can be embodied as below to filter or unify L1/L2 multi-dimensional OOS, IS, link, or BFR status indications into unified per-cell OOS, IS indications (or forwarded as is w. new indication, but preferably OOS, IS only), taking a specific UE for example,

The link recovery indications refer to an aperiodic indication (e.g., same IS as defined for RLM) corresponding to a link recovery success, or an aperiodic indication (e.g., same OOS as defined for RLM) corresponding to a link recovery failure, or a periodic or event-based link recovery status. The link recovery status refers to failure detection instance, identified new beams, measured reference signal strength or control or data channel quality, feasibility of the identified beam path according to a configured criteria, and stepwise success or failure under a configured, timer or counter based constraint, and final success or failure of the whole link recovery process. A per-cell RLF OOS indication is generated by IUM functions upon below and periodically afterwards, if in this cell,

23) a CH-specific OOS generation condition of common DL control CH (e.g., common PDCCH) is met, OR

24) a CH-specific OOS generation condition of UE-specific DL control CH (e.g., UE-specific PDCCH) is met, OR

25) the common OOS generation condition is met, OR

26) a link or BFR status indicating either eventual link or BFR failure or stepwise (out of the 4 steps) failure, or criteria-based channel quality drop as described in the above paragraph, OR

27) A link or BFR or BM event or a control timer for reporting or generation frequency, is triggered.

In different embodiments of the IUM's unification functions,

28) The above A~E may be combined differently, by logical AND instead, or mixed OR and AND, etc., or by other math. Combinations like weighted sum (Note: when weight is equal or 1/0, then it is like average or like priority-based, say, only consider PSCell/Pcell, or specific xRS, or others. This also may be configurable.)

29) One or multiple of the above A~E can be combined, not necessarily all of them, by OR or AND with other orthogonal conditions to define IUM functions

30) per-cell RLF IS: The above is applicable to IS too (w. BFR success replacing link recovery or BFR failure);

31) The above A~E is also applicable to per-channel or per-carrier or per signal, if link or BFR status is channel, carrier, or signal-specific

Multi-cell OOS, IS can be unified by IUM likewise

32) by mixing A~E steps of IUMs applied to multiple serving cells (PSCell, PCell, Scell) or cell groups all together, or

33) By only combining the cell-level RLF OOS or IS results as outputs from the per-cell IUM.

IUM unification functions can be per-CH, *per signal*, per-carrier, per-cell, multi-cell, per-cell group, or their combination, based on scenarios or *configurations*, for generation or reporting of indications.

IUM unification functions can be centralized or distributed at any or all specific layers (L1 ~ L3), i.e., as an independent module or integrated into RLF or BRF.

IUM unification functions can start from lower BRF to upper layers RLF (to generate unified IS, OOS) or the reverse (to generate unified BFR assistance) at a single UE or network devices, or end-to-end (involving UE-side and network-side signaling). Unification functions can be based on other numerical formats of NR_CH_quality, for example, rather than AND and OR combinations of per-beam or per-CH IS, OOS, etc.

In another embodiment, proposed end-to-end interaction model between RLF and BFR mechanisms (state machines) is disclosed.

Figure 9 illustrates that the end-to-end and cross-layer framework of BFR-RLF interactions in 900, where end-to-end and layer-by-layer signaling between a user-side device, e.g., a UE (or any other user devices capable of wireless communication including tablet, PC, etc.), and a network device (e.g., a gNB or TRP) happens at 902 (Layer 3), 904 (Layer 2), 906 (Physical layer). Note that the layering displayed is demonstrative in nature, and may change in different embodiments. For example, functions in L2 in block 904 could be considered part of a RLM (which may span multiple protocol layers) for performing the proposed unification, etc. Additionally, in different embodiments, L2 904 in UE could be simply skipped, and then the BFR operations in lower layer directly provides causal (with sufficiency) foundation to trigger IN/OUT-of-SYNC (IS, OOS) or other BFR indications to upper layer RLF state machine. Also the existence of (L2) BFR operations 904 is just for example purposes, and likewise in Figure 10, in case L2 BFR signaling (e.g., MAC CE) is introduced into the standards.

In the PHY layer 906, the UE has L1 BFR signaling with the gNB/TRP, and UE also monitors the (DL) beamformed reference signals from the gNB/TRP as part of multi-beam RLM and/or the full diversity BFR process described elsewhere. Note that the full diversity BFR operations in the previously discussed steps derives BFT (success or failure) status, IS, or OOS indications by considering the multi-dimensional beams, signals, cells, and channels, etc., over the air at this layer 906 at least. In the Layer 2 904, the UE and/or gNB/TRP may jointly determine if the BFR operation is successful or failure through L2 BFR related signaling (e.g., MAC CE). In Layer 3 or RRC 902, the RLF operations with a plurality of timers and counters are setup and work based on the IS, OOS (and possible BFR state) indications from the lower layer, in conjunction with other orthogonal inputs from RLF or RACH or RLC state machines and over-the-air RRC signaling exchange between gNB/TRP's RLF/HO states and UE-side states, to derive RLF machine in the gNB/TRP.

Figure 10 illustrates the end-to-end and cross-layer framework of BFR-RLF interactions in 1000, but with a reversed direction of top-down or downward indications (rather than the bottom-up or upwards indications in Figure 9). In Figure 10, the end-to-end and layer-by-layer signaling between a user-side device, e.g., a UE (or any other user devices including tablet, PC, etc.), and a network device (e.g., a gNB or TRP) happens at 1002 (Layer 3), 1004 (Layer 2), 1006 (Physical layer). Note that the layering here is more for illustration purposes and may change in different embodiments. Figure 10 shows that an upper layer (e.g., RLF, etc.) or layer 3 1002 can assist to optimize a lower layer (e.g., Layer 2 1004 or Physical Layer 1006 for BFR) operations, in contrast to Figure 9 where a lower layer (e.g., Physical Layer 906 or Layer 2 904 for BFR) assists an upper layer (e.g., Layer 3 902 RLF) operations. For example, functions in L2 in block 1004 could be considered part of a RLM (which may span multiple protocol layers) for performing the proposed unification, etc. In different embodiments, L2 1004 in UE could be simply skipped, and then the BFR operations in lower layer directly takes L3 1002 inputs (BFR assistance information or indications) as causal or sufficient foundation to optimize BFR indications. Also the existence of (L2) BFR operations 1004 are just for example, in case L2 BFR signaling (e.g., MAC CE) is introduced into the standards.

In Figure 10 1002, the upper layer RLF state machine, together with relevant BFR assistance information may enable early termination or speedup of BFR success/recovery or failure/reset, where such assistance information at 1002 may be based on RLF or RRC over-the-air signaling (e.g., HO command, RRC Connection Re-establishment, DC/MC/CA signaling related to carrier or cell addition or removal), or positioning-based beam discovery or recovery information, or any alternative communication path over another carrier or cell in PCell, PScell or SCell in DC/CA/MC enabled systems. In the example shown in Figure 10, the PHY layer 1006 the UE communicates with the gNB/TRP using L1 BFR signaling. In Layer 2 1004, the UE communicates with the gNB/TRP using L2 BFR signaling. In the RRC layer 1002 the UE communicates with the gNB/TRP using RLF or RRC signaling or data paths, same as in Figure 9 902, etc.

In the Layer 2 1004, the UE and/or gNB/TRP may jointly determine if the BFR operation can be optimized through L2 BFR related signaling (e.g., MAC CE). In the PHY layer 1006, the UE has L1 BFR signaling with the gNB/TRP, and UE also monitors the (DL) beamformed reference signals from the gNB/TRP as part of multi-beam RLM and/or the full diversity BFR process described elsewhere. Note that the full diversity BFR operations in the previously discussed steps derives BFT (success or failure) status, IS, or OOS indications by considering the multi-dimensional beams, signals, cells, and channels, etc., over the air at this layer 1006, but also the upper-layer provided BFT reset or speedup indications or BFT assistance information directly. In Physical Layer 1006, the BFR operations with a plurality of timers and counters and over-the-air signaling (BFR request and response) setup and work based on the beamformed reference signals, new beam identification, in conjunction with other orthogonal inputs from upper layer, to optimize its operation by speeding it up or making it more efficient.

Note that in different embodiments for both Figure 10 and Figure 9 the UE-side BFR and RLF may be mirrored to those at the gNB/TRP side for UL based RLM. For example, gNB/TRP could be from Pcell, PScell, or Scell, communicating with UE over different carriers simultaneously beyond the monitored carrier only. Similarly the monitored link or CH could be control, data, or their combination in deciding the target link (BFR or RLF) status; The IUM functions for unification of IS, OOS or BFT reset/speedup indications could be at anywhere between L1 (PHY) ~ L3 (RRC) interactions between RLF and BFR on UE or network device (gNB/TRP) involves the newly introduced IUM functions at L2 (as shown), or integrated into L1 or L3, or distributed in any layers; RLF and IS, OOS, link and/or BFR states can be multi-cell, per-cell, per-CH, per-signal, or per-carrier, per-link, or as a combination of them accordingly.

Figure 10 illustrates upper layer RLF state machine, together with relevant BFR assistance information (say, positioning-based beam discovery or recovery info in PCell, PScell or SCell in DC/CA/MC), enables early termination or speedup of BFR success/recovery or failure/reset. In the example shown in Figure 10, in the PHY layer 1006 the UE communicates with the gNB/TRP using L1 BFR signaling. In Layer 2 1004, the UE communicates with the gNB/TRP using L2 BFR signaling. In the RRC layer 1002 the UE communicates with the gNB/TRP using RFL or RRC signaling.

In different embodiments: UE-side BFR and RLF may be mirrored to those at the gNB/TRP side for UL based RLM, etc.; gNB/TRP could be from Pcell, Pscell, or Scell, different carriers, and the serving CH could be control, data, or their combination; IUM functions for unification of IS, OOS or BFT reset/speedup indications could be at anywhere between L1 (PHY) ~ L3 (RRC) interactions between RLF and BFR on UE or network device (gNB/TRP) involves the newly introduced IUM functions at L2 (as shown), or integrated into L1 or L3, or distributed in any layers; RLF and IS, OOS and/or BFR states can be multi-cell, per-cell, per-CH, per-signal, or per-carrier, or as a combination of them accordingly.

In a third embodiment, illustrated by Figure 11, a unified flow procedure of RLF detection is disclosed, wherein our proposed multi-beam RLM for NR is implicitly embedded as part of IUM (or the other way with IUM being part of RLM) to derive the serving CH's quality, NR_CH_quality, and compared it with normally network-configured channel threshold Qin / Qout as shown in flowchart 1100, using similar beam consolidation/selection criteria as for multi-beam RRM [2, 3, 4, 6, …]. The IS/OSS indications in the proposed multi-beam IUM/RLM module can be derived similar to LTE, i.e., Step v below) based on either hypothetical PDCCH that is mapped from NR_CH_quality (e.g., RSRQ in dB) based on table lookup, or can be based on direct comparison of the NR_CH_quality (e.g., RSRQ in dB, RSRP in dBm, or unit power in Watt) with certain threshold (e.g., Qin and Qout). The RLM-derived timer or event-driven IS, OOS can be unified with the IS, OOS, link or BFR failure/success indications (as in Step vi below, and in the Figure 11 by IUM unification functions) for a unified stream of IS, OOS indications to L3 RLF.

34) NR_CH_quality = average_of_(feasible beams' quality, i.e., beam_quality_above_a_threshold) + offset (N),

   i. where N is the number of feasible beams that are above the threshold; if none-of them is above the threshold, the best beam could be considered; offset(N) can be any non-decreasing discrete or continuous function of N, e.g., offset increases with N to reflect that more feasible (N) beams the better of the multi-beam channel quality. Note that N, average function, and the threshold comparison methods proposed here for multi-beam RLM, are very similar to prior art of multi-beam RRM, but the concrete parameters could be differently determined or configured by network (e.g., RRC configuration) than RRM.

ii. Per-beam quality metrics are measured in Watt, dBm, or in dB

iii. Initialization (reset) of the flow can be like a beam success status

iv. average could be any weighted sum, be it linear or non-linear functions, including linear sum, of per-beam quality, and averaged by N; N could be per-CH, per-carrier, per-cell, or across multiple of them.

v. Hypothetical BLER of PDCCH in NR BFR, say, can be similar to LTE's

vi. The IS, OOS indications inputs to IUM functions could be consistently for multi-cell, per cell, per multi-beam CH, or per-beam, one or multiple xSS/xRS per beam, but not necessarily used in mixture

vii. The measurement of per-beam quality metrics is based on multiple signals, e.g., RLM/RLF xSS/xRS (combined or separately)

viii. Figure 11 illustrates the detailed flowchart 1100 of RLF detection procedure on the UE side, corresponding to Fig. 9 based on the lower-layer or underlying BFR state machine (1102, 1104, 1106, 1108) that triggered IS, OOS, link or BFR status indications. In the middle, the IUM (1110, 1112, 1114, 1116, 1118) that works possibly independently or as a part of proposed multi-beam RLM or RLF is a logical function to unify (aperoidic or event-driven) BFR indications with (first and periodic) multi-beam RLM NR_CH_quality based indications.

The purpose is to speed up or optimize the upper layer RLF state machines 1120, e.g., by impacting the IS, OOS counters or timers and RLF declaration, etc..

In the embodiment shown in Figure 11, the exemplary (4) steps of the proposed full diversity BFR is executed sequentially in block 1102, 1104, 1106, and 1109 in the method 1100. It is disclosed where there is beam failure detection in block 1102 based on monitoring of the serving beams for the target CH or link, which leads to block 1104. If there is a (serving) beam failure detected but a “full diversity” new beam identified in 1104, the flowchart moves to block 1106, otherwise the method moves to block 1114. If, in block 1106, the full-diversity BFR request (TX) is successful, the method moves to block 1108, otherwise the method moves to block 1114. If in block 1108 the full-diversity BFR response (RX) is received with recover, the method moves to block 1110, otherwise the method moves to block 1114. If in block 1110 if the BFR is eventually successful (i.e., all steps succeeded), and also per the proposed multi-beam RLM we have multi-beam NR_CH_quality > Qin (or BLER< a threshold) upon periodic check, the method moves to block 1112, otherwise the method moves to block 1114. In block 112 there is an indicator (regardless periodic or timer-based, or aperiodic, or event-based) sent to upper layer and the method moves to block 1118. In block 1114, if the BFR failed, or per the proposed multi-beam RLM we have multi-beam NR_CH_quality < Qout (or BLER > a threshold) upon a periodic check the method moves to block 1116, otherwise the method returns to block 1102. Similarly to the IS in block 1112, in block 1116 there is a timer (Timer or event-driven OOS) indicator to upper layers, and the method moves to block 1118. In block 1118 the IUM unification functions perform, i.e., by logically AND|OR (or other) unification operations across a single or multiple beam/CH/carrier/cell’s IS, OOS’s, with indication frequency check (e.g., periodicity check) and the RLF state machine is updated accordingly (e.g., its timers and counters and states influenced by the IS, OOS possibly same or similarly as in LTE) in block 1120. Note the keeping a single stream of IS, OOS (periodic or not) to RLF can simply the RLF state machine, or keep it the same in NR as in LTE.

In different embodiments, the above can be revised likewise to generate cell-level IS, OOS, which could be based on a control CH (e.g., hypothetical PDCCH BLER as in LTE) be it multi- or single-beam; Or on derived “cell” quality metrics by selecting/consolidating multi-beams multiple (control, data, UL, DL, same or different cell, or combined) CH's metrics in a similar way.

In different embodiments, the above can be on serving or candidate beams/CHs/cells and IUM can be distributed or centralized at different layers;

In other embodiments, concrete steps in flow chart can vary. For example, BFR steps involved could be different; Each BFR step's success (Y) or states may directly trigger some IS or other BFR state indication to IUM;

RSRP can be directly used as NR_CH_quality to compare with old or newly defined thresholds (Q_in or Q_out) with or without mapping to BLER.

In another embodiment, A unified flow procedure of RLF with its or other upper-layer assistance to BFR is disclosed and illustrated by Figure 11.

In this embodiment, assuming assistance info can be obtained for helping the BFR process:

across all available beam links, and/or

Across or based on one or multiple xSS/xRS, and/or

across different freq. carriers, as in intra-cell CA, and/or

multiple cells (Pcell, Pscell, Scell), as in DC/CA or LF assisted HF, and/or

across UL or DL or both, and/or,

upper layer timeout event (RLF T310/T321 expiry), and/or

In-device or over-the-air (RLF) HO trigger, etc., that can be used to terminate BFR or reset its parameters

In different embodiments, the above can be based only on the control CH of the Pcell or Pscell (e.g., hypothetical PDCCH BLER as in LTE), or may be using any available data CH (granted resources by SPS in PUSCH/PDSCH, PUCCH, or RACH/SR, or MAC CE piggyback, etc), or any detectable signals (xSS/xRS, including DL SS-block, CSI-RS, DMRS, UL SRS/DMRS, etc.) to derive, speed-up, reset, or generally help BFR.

In different embodiments, the above can be applied to serving or candidate beams/carriers/CHs/cells; IUM can be distributed or centralized at different layers; Concrete steps in flow chart can vary.

In other embodiments, concrete steps in flow chart can vary. For example, BFR steps involved could be different; Upper layer's indications can be used to indicate to a specific step of BFR, to help optimize BFR operations.

It is expressly understood that a number of different embodiments are contemplated by this disclosure. UIM and RLF/RLM/BFR mechanisms on UE-side can be embodied and applied to different scenarios with the following details:

Similar to LTE's RLM, the metrics used here, e.g., RSRP (RSSI) or RSRQ (CINR) per beam in dBm/watts or dB, can be measured from the beam specific xSS/xRS's.

The metrics can be extended to single or multi-beam metrics for each CH, Cell, or Carrier.

Multi-beam RLM/RLF with combination of multiple measured beam metrics to derive a single RLM metrics is described herein.

The beam or CH-specific RLM metrics can be used to derive beam, CH, or cell-specific IS, OOS indicators, using the base IS, OOS generation condition and IUM functions.

UE-side design of IUM, etc., can be mirrored to network device (TRP, gNB, CU, or DU, etc.) side with UL signal/beam/CH based RLF and RLM, etc., corresponding to DL signal/beam/CH based RLF and RLM, etc., (similar to [5] with UL mobility and BM vs. the legacy DL mobility and BM)

In different embodiments, the details in the embodiment plots (Figure 2~6) can be applied to serving or candidate beams/carriers/CHs/cells; The IUM functions can be distributed or centralized at different layers; Concrete details in the framework design, NR_CH_quality, or steps in the flow charts can vary.

One example of the implementation of the present disclosure is illustrated in Figure 12, which shows the BFR, RLM, and RLF interaction process, wherein the IUM module as part of RLM unifies or converts RLM-generated IS, OOS and BFR-generated status (success or failure) indications into a single stream of IS, OOS before sending them to L3 RLF. Suppose RLM and BFR on UE side are considering the same xRS or SS as shown in flow chart 1200:

> If beam failure has been detected in block 1202, in the following process, BFR module should not indicate anything to upper layer until any final BFR success/failure is declared.
>
> If BFR success in block 1204, then UE sends a positive indication (e.g., aperiodic BFR success or aperiodic IS) to RLM as illustrated in block 1206.
>
> If BFR failure in block 1204, then UE send a negative indication (e.g., aperiodic BFR failure or aperiodic OOS) to RLM as illustrated in block 1208.
>
> RLM module (as an embodiment of IUM in 1210) can derive IS, OOS from BFR success/failure indication, which can be decoupled from RLM's normal process, to derive a merged IS, OOS stream based solely on the multi-beam monitored (serving) channel quality. This uses the input from blocks 1206 and 1208, and transmits the IS, OOS. Note that aperiodic BFR indication from 1206 or 1208 may trigger or convert to or influence successive or periodic (IS, OOS) indications in 1210 by following the previously defined unification criteria.
>
> RLM module in 1210 then sends the unified stream of IS, OOS to L3 RLF in block 1212.
>
> Note that based on this embodiment yet in another embodiment, 1210 can be implemented as part of BFR, i.e., integrated into BFR or 1206 and 1208, and hence influencing or generating periodic IS, OOS with or without aperiodic IS, OOS, link or BFR IS, OOS indications directly to L3.

In another embodiment, illustrated by Figure 13 for the BFR, RLM, and RLF interaction process or flowchart 1300, RLM indications (first and periodic IS, OOS) and BFR indications (aperiodic IS, OOS) are send in parallel to L3 RLF for further processing, i.e., the unification function is literally part of RLF state machine. The "IUM module" is literally passing whatever it received from BFR module (1306/1308/1310/1312) directly to L3 RLF module 1302, as shown by flow chart 1300. Suppose RLM 1304 and BFR on UE side are considering the same or different xRS or SS.

After beam failure is detected in block 1312, BFR module should not indicate anything to upper layer until any BFR success/failure declared.

If BFR successful in block 1310, then UE send an aperiodic IS to RLF directly in block 1306.

If BFR failure, then UE send an aperiodic OOS indication to RLF directly in block 1308.

The blocks 1306 and 1308 forward IS, OOS indications directly to L3 RLF block 1302.

In parallel, the proposed multi-beam RLM module in block 1304 as an independent or decoupled module derives first and periodic IS, OOS indication(s) based on the multi-beam monitored (serving) channel quality (as described earlier).

RLF module in block 1302 (with the implicitly embedded unification functions therein) can combine the IS, OOS indications from different sources (including, but not limited to, blocks 1304, 1306, and 1308) but treat them the same or similar as in LTE (in terms of consecutive counter N310, N311, T310, T311, T312, etc.).

E.g., an aperiodic OOS arriving in the middle of periodic ISs may reset the count of N311 (and hence delay of stop of T310)

E.g., an aperiodic IS arriving in the middle of periodic OOSs may reset the count of N310 (and hence delay the starting of T310)

Note that the treatment of any of the elements illustrated in Figure 13 may follow different logic or mathematical operations in different embodiments.

In another embodiment illustrated by Figure 14, another example of a UE embodiment BFR, RLM, and RLF interaction process is shown in flowchart 1400. Here the RLM indications (first and periodic IS, OOS) and BFR indications (aperiodic IS, OOS or success/failure indication) are sent to L3 RLF 1402 only after IUM unification in block 1404, where the IUM could be part of RLM 1406 or RLF 1402 or independent function, but regardless it unifies the indications in a weighted manner based on the type of indications, source of indications, or the reference signals on which the indications are based. Suppose RLM 1406 and BFR (1408, 1410, 1412, 1414) on UE side are considering the same or different xRS or SS, then IUM 1404 filters or unifies the indications from RLM 1405 and from BFR submodule 1408 and 1410, either as part of RLF 1402 or as inputs to RLF 1402.

1 After beam failure detected in block 1414, BFR module should not indicate anything to upper layer until any BFR success/failure declared, based on the configured xRS/SS.

If BFR success in block 1412, then UE send an aperiodic IS to RLF directly in block 1408.

If BFR failure in block 1412, then UE send an aperiodic OOS indication to RLF directly in block 1410.

RLM module 1406 as an independent or decoupled module from BFR derives periodic IS, OOS based on the multi-beam monitored (serving) channel quality, like what is defined in multi-beam RLM, based on the configured xRS/SS in block 1406.

RLF module in block 1402 combine the IS, OOS indications from different sources (including, but not limited to, blocks 1406, 1408, and 1410), but treat them the same or similar as in LTE (in terms of consecutive counter N310, N311, T310, T311, T312, etc.):

E.g., for different xRS/SS, IUM 1404 or RLF 1402 treats the indications differently by weights (or priority), possibly given higher weight or absoluate priority to aperiodic indications from

1408 and 1410 from BFR than RLM-generated periodic indications from 1406.

E.g., for the indications from different sources (RLM 1406 vs. BFR 1408 or 1410), IUM 1404 or RLF 1402 treats the indications differently by weights (or priority).

Note: equal weights means they may be treated the same. IUM if as part of RLF can be directly operating on N311, N310 (as shown) or the relevant timers.

Note that above treatment can follow the concrete weighting methods as defined elsewhere in the unification method. Note that in different embodiments, RLM 1402 and RLF 1406 (and IUM 1404) may be considered as a single module.

Figure 15 illustrates a chart with time on the X axis and various signals plotted against the Y Axis. The RRC, MAC, and PHY layer are each separated on the Y axis. This is intended to show the flow when the RLF occurs. Figure 15 also illustrates some of the timers disclosed herein as well as the beam recover disclosed herein.

Figure 16 is a flowchart 1600 illustrating an embodiment on the UE-side, corresponding to Fig. 10, illustrating that detailed flow of optimizing BFR procedure 1006 and (1610, 1612, 1614, 16161, 1618, 1620) based on the upper layer (RLF, RLC, HO state, or RRC signaling) provided assistance information, wherein the BFR state machine 1006, 1004, and (1610~1620) can be speed up or early terminated based on upper layer information (1002 or 1002 and 1004, corresponding to 1602, 1604, 1606, 1608, etc.).

Figure 16 is a flowchart 1600 relates to situations where upper-layer assistance can be obtained across multiple cells (Pcell, Pscell, Scell) of multiple or feasible or serving carriers, available or alternative communication paths, RLC ARQ retransmission status, RACH status, RRC or L2 signaling information, or upper layer RLF timeout event (T310/T312) or HO (command) trigger. Note that upper layer RLF timeout event (T310/T312) or HO (command) trigger can be used to early terminate lower-layer BFR as it is not necessary any more, while other events may help speed up BFR process. In this flowchart, the UE in L3 (or L2) learns

RLF/RLC/RACH state, or RRC or L2 signals for BFR assistance info in block 1602. The logical IUM in-between upper layer and lower layer BFR performs a variety of functions, including those illustrated in blocks 1604, 1606, and 1608. Note that those functions can be considered logically as part of RLF, RLM, or BFR too.

In block 1604, the available diversity path info, e.g., defined by alternative beams/CHs/carriers/cells to the same UE is queried, and utilized to speed up BFR. In block 1606 the T310/T312 (where the T310 and T312 being timers substantially similar to those timers defined in LTE) expiry, or upper-layer events such as newly received HO command, or connection reestablishment, or idle mode starts with a new beam, channel, carrier, or cell, are shown in block 1606. In block 1608, events such as timers T310 and T312 resets or stops occurred. Both 1606 and 1608 can be used to early terminate an ongoing BFR (ongoing or not is judged in block 1612). It is expressly contemplated that the events monitored by the IUM functions contemplated by 1604, 1606, and 1608 may or may NOT be simultaneous in nature. If there is a diversity UL path available as determined in block 1610, then in block 1614 a speed up of full-diversity BFR request (TX) is made to initiate RACH or SR / PUSCH through the upper-layer notified alternative communication path (e.g., another cell, channel, carrier, beam or other signals) rather than being blocked or delayed in the existing ones in lower layer. If a diversity UL path is not available in block 1610, then speed up of full-diversity BFR DL monitoring or response (RX) can be provided by initiating beam switching/identification with new DL beam, carrier, channels, cell, or other signals in block 1618, because the UL is already known as problematic by upper layer. If a BFR is still ongoing as determined in block 1612, then there is a BFR reset which causes a BFR parameters, timers, states (e.g., early terminated and re-initiated of BFT state machine), in block 1616. The UE after blocks 1612, 1616, 1618, and 1614 may continue to perform new beam failure detection in block 1620, possibly exploiting the upper-layer assistance information or upper-layer optimized BFT states.

For purposes of clarity the T310 timer may be used to determine how long a PHY related problem has occurred. One example operation is discussed below:

Starts when UE detects PHY layer related problems (when it receives N310 consecutive out-of-sync indications from lower layers)

Stops when:

When UE receives N311 consecutive in-sync INDs from lower layers

Upon triggering the HANDOVER procedure

Upon initiating the CONNECTION RE-ESTABLISHMENT procedure

At expiry, if security is not activated it goes to RRC IDLE else it initiates the CONNECTION RE-ESTABLISHMENT Procedure.

For purposes of clarity the T312 may be used to determine how long the UE waits for an N312 "in-sync" indication from layer 1 when establishing a dedicated channel in connected status.

Figure 16 demonstrates that assistance info can be obtained for helping the BFR process

across all available beam links, and/or

across or based on one or multiple xSS/xRS, and/or

across different freq. carriers, as in intra-cell CA, and/or

multiple cells (Pcell, Pscell, Scell), as in DC/CA or LF assisted HF, and/or

across UL or DL or both, and/or,

upper layer timeout event (RLF T310/T321 expiry), and/or

In-device or over-the-air (RLF) HO trigger, etc., that can be used to terminate BFR or reset its parameters

In different embodiments, the above can be based only on the control CH of the Pcell or Pscell (e.g., hypothetical PDCCH BLER as in LTE), or may be using any available data CH (granted resources by SPS in PUSCH/PDSCH, PUCCH, or RACH/SR, or MAC CE piggyback, etc), or any detectable signals (xSS/xRS, including DL SS-block, CSI-RS, DMRS, UL SRS/DMRS, etc.) to derive, speed-up, reset, or generally help BFR .

In different embodiments, the above can be applied to serving or candidate beams/carriers/CHs/cells; IUM can be distributed or centralized at different layers; Concrete steps in flow chart can vary.

In other embodiments, concrete steps in flow chart can vary. For example, BFR steps involved could be different; Upper layer's indications can be used to indicate to a specific step of BFR, to help optimize BFR operations.

The disclosed UIM and RLF/RLM/BFR mechanisms on UE-side can be embodied and applied to different scenarios with the following details:

Similar to LTE's RLM, the metrics used here, e.g., RSRP (RSSI) or RSRQ (CINR) per beam in dBm/watts or dB, can be measured from the beam specific xSS/xRS's.

The metrics can be extended to single or multi-beam metrics for each CH, Cell, or Carrier.

Multi-beam RLM/RLF with combination of multiple measured beam metrics to derive a single RLM metrics is described in page 20.

The beam or CH-specific RLM metrics can be used to derive beam, CH, or cell-specific IS, OOS indicators, using the base IS, OOS generation condition, and IUM functions disclosed herein.

UE-side design of IUM, etc., can be mirrored to network device (TRP, gNB, CU, or DU, etc.) side with UL signal/beam/CH based RLF and RLM, etc., corresponding to DL signal/beam/CH based RLF and RLM, etc., (similar with UL mobility and BM vs. the legacy DL mobility and BM disclosed herein).

In different embodiments, the details in the various figures disclosed herein can be applied to serving or candidate beams/carriers/CHs/cells; The IUM functions can be distributed or centralized at different layers; Concrete details in the framework design, NR_CH_quality, or steps in the flowchart disclosed herein.

In some embodiments, a method for determining beam failure recovery (BFR) indications in a user equipment (UE) means, comprising receiving and processing downlink (DL) reference signals from multiple beams at a physical layer, determining a beam quality metric for each of the multiple beams, evaluating the determined beam quality metrics of multiple diversity of physical-layer transmission paths (in terms of a separate beam, reference or synchronization signal, direction, carrier, data or control channel, cell) for executing BFR operations of signaling, beam identification, and beam failure recovery. In addition, the method further includes accomplishing the BFR operations by fully exploiting the diversities at the physical layer, e.g., under network configuration and timer-based constraints, during the BFR process, determining the finalized BFR operation status (success, failure), generating explicit BFR indications (an aperiodic IS corresponding to a BFR success, or an aperiodic OOS corresponding to a BFR failure, or an explicit BFR success or failure status) only when BFR operation status is final and sending the BFR indication(s) to the other module(s) (e.g., RLM or RLF).

In one embodiment, a method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), that includes receiving an indication (where the indication may be the BFR generated (aperiodic) IS, OOS, or explicit BFR success/failure status indication, receiving the RLM generated (periodic) IS, OOS indication, receiving both indications in parallel), and unifying one or multiple of the received indication(s) for the detected radio link for a specific reference signal or beam or channel or carrier or cell, or across multiple of them. This method also includes sending the unified indication(s) to a RLF and utilizing the unified indication(s) to influence (e.g., speed up, delay, or optimize) the RLF state machine (N310, T310, N311, T311, T312, etc.) for fast and reliable RLF declaration.

In another embodiment, a method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE) is disclosed that includes receiving an indication, wherein the indication is at least one of a BFR generated IS, OOS, explicit BFR success/failure status indication; or a RLM generated (periodic) IS, OOS indication, unifying the received indication for the detected radio link, sending the unified indication(s) to a RLF; and utilizing the unified indication(s) to alter the RLF state machine. This method may be located at one of RLF, RLM, or BFR modules, or across them or different protocol layers, and wherein the BFR and RLM indications may be input into the method in parallel, or only through RLM after RLM-based procedural unification.

In yet another embodiment, a method for determining beam failure recovery (BFR) indications in a user equipment (UE) is disclosed that includes receiving and processing downlink (DL) reference signals from multiple beams at a physical layer, determining a beam quality metric for each of the multiple beams, evaluating the determined beam quality metrics of multiple diversity of physical-layer transmission paths (in terms of a separate beam, reference signal, synchronization signal, direction, carrier, data or control channel, cell, or any combination of them) for executing BFR operations of signaling, beam identification, and beam failure recovery, accomplishing the BFR operations by fully exploiting the diversities at the physical layer, e.g., under network configuration and timer-based constraints; during the BFR process, determining the finalized BFR operation status (success, failure), generating explicit BFR indications (an aperiodic IS corresponding to a BFR success, or an aperiodic OOS corresponding to a BFR failure, or an explicit BFR success or failure status) only when BFR operation status is final, and sending the BFR indication(s) to the other module(s) (e.g., RLM or RLF).

In yet another embodiment, a network device is disclosed that includes a receiver means for receiving an indication from at least one network device, wherein the indication is at least one of a BFR generated IS, OOS, explicit BFR success/failure status indication; a RLM generated IS, or an OOS indication; and a processor means that unifies the received indication for the detected radio link, sends the unified indication to a RLF, and to alter the RLF state machine based upon the indication.

Disclosed is a system and method for detecting new radio (NR) link failures and executing RLM and link failure recovery in network equipment, e.g., a user-side UE device (or a network-side device such as TRP or base stations). These systems and methods may include means for measuring over-the-air signals and considering over-the-air signaling and configuration messages to generating and receiving an in-device indication that can be at least one of a link failure recovery (e.g., BFR) generated periodic, event-driven or aperiodic status or indication; or a multi-beam RLM generated (first and periodic) IS, OOS indication. The systems and methods unify the received indication for the detected radio link utilizing the multi-beam RLM and full-diversity or multipath link failure recovery indication(s) for performance optimization.

Disclosed is a system and method for detecting network radio (NR) radio link failures (RLF) and its interactions with RLM and link failure recovery in network equipment, e.g., a user-side UE device (or a network-side device such as TRP or base stations). These systems and methods may include means for measuring over-the-air signals and considering over-the-air signaling and configuration messages to generating and receiving an in-device indication that can be at least one of a link failure recovery (e.g., BFR) generated (periodic, event-driven, or aperiodic) indications such as IS, OOS, or link recovery status(such as success, failure, newly identified beam, detected quality metrics) indication; or a multi-beam RLM generated (first and periodic) IS, OOS indication, or channel quality metrics; or converted indications of BFR to RLM-defined indications; or upper-layer RLF, RRC, RLC, or RACH generated downward indication(s) to optimize the lower-layer link recovery related operations. The systems and methods unify the received indication for the detected radio link utilizing the unified upwards indication(s) to alter the RLF state machine to improve its performance, or the unified downwards indication(s) to alter the BFR state machine for performance optimization.

Although the present invention has been described with reference to specific features and embodiments thereof, it is evident that various modifications and combinations can be made thereto without departing from the invention. The specification and drawings are, accordingly, to be regarded simply as an illustration of the invention as defined by the appended claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present invention.

We claim:

1. A method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), comprising:

receiving at least one of the BFR generated (aperiodic) IS, OOS, or explicit BFR success/failure status indication, the RLM generated (periodic) IS, OOS indication, or both indications in parallel; and

unifying one or multiple of the received indication(s) for the detected radio link for a specific reference signal or beam or channel or carrier or cell, or across multiple of them;

sending the unified indication(s) to a RLF; and

utilizing the unified indication(s) to influence the RLF state machine (N310, T310, N311, T311, T312, etc.) for fast and reliable RLF declaration.

2. The method of claim 1, wherein the method is located at one of RLF, RLM, or BFR modules, or distributed across them or different protocol layers, and wherein the BFR and RLM indications may be input into the method in parallel, or only through RLM after RLM-based procedural unification

3. The method of claim 1, wherein a unified indication sent to RLF is solely based on the indication of whether BFR operations were a success or failure, or on BFR generated aperiodic IS or OOS indication, or on RLM generated periodic IS or OOS indication, or all of them.

4. The method of claim 1, further comprising:

producing a BFR operations command or a RLF status indication to the physical layer to influence the BFR operations.

5. The method according to claim 1, wherein the multiple beams comprises at least one of: multiple beams with a network device of the same or different reference signals, multiple beams on same or different frequency carriers, multiple beams of same or different directions, multiple beams of the same or different reference signals, multiple

beams on same or different channels, multiple beams from different network devices in a same or different cells.

6. The method according to claim 1, wherein the BFR indication includes at least one of beam-formed radio link, an indication of a serving channel of one or multiple beams, a reference signal of the beam, an indication of a component carrier, and identification of an associated cell.

7. The method of claim 6, further comprising:

producing a BFR operations command or a RLF status indication to the physical layer to influence the BFR operations.

8. The method according to claim 1, further comprising deriving carrier-level, channel-level, or cell-level channel quality based on the beam quality metric for each beam and of a specific reference signal.

9. The method according to claim 8, further comprising the mathematical criteria to derive multi-beam channel quality metrics (filtered RSRP or SINR), a number of best beams selection policy to select the beams of quality above configurable thresholds, beam-specific filtering policy, and the criteria to compare with metrics thresholds or hypothetical BLER or their combination to derive and generate RLM In-Sync (IS) indication or out-of-sync (OOS) indications.

10. The method according to claim 1, wherein the individual BFR indication is In-Sync (IS) indication, or out-of-sync (OOS) indication, or BFR status indications.

11. The method according to claim 10, before the receiving from a physical layer, the individual beam failure recovery (BFR) indication for each of the multiple beam signals, the physical layer determines a BFR success/failure status.

12. The method according to claim 11, further comprising:

sending, by the physical layer, an aperiodic individual indication for a specific beam signal after the physical layer determines the BFR for the specific beam signal is success status, wherein the aperiodic individual indication is the IS or the BFR success indication.

13. The method according to claim 11, further comprising:

sending, by the physical layer, an aperiodic individual indication for a specific beam signal after the physical layer determines the BFR for the specific beam signal is success status, wherein the aperiodic individual indication is the OSS indication or the BFR failure indication.

14. The method according to claim 1, further comprising:

deriving, based on RLM indications and the unified BFR indications, a radio link (at beam-level, carrier-level, UL or DL directions, control or data channel-level, or cell-level) indications for a specific reference signal or for combination of multiple reference signals, wherein the radio link is at least one of at beam-level, at carrier-level, in UL direction or in DL directions, at control channel level or at data channel-level, or cell-level.

15. The method according to claim 14, further comprising:

combining the IS indication or the OOS indication or BFR indications by OR, AND, weighted sum, or any combination for the radio link corresponding to one or multiple beams, reference signals, carriers, directions, control or data channels, cells.

16. The method according to claim 15, wherein the weight is defined for per-reference signal, for per-beam, for per-channel, for per-direction, for per-carrier, for per-cell, and the weight is a digital number or a linear scalar, the weight sum is linear or non-linear functions.

17. The method according to claim 14, wherein the unifying the individual BFR indications comprises at least one of:

determining a common out-of-sync (OOS) which indicates the common or cell-specific DL control channel that meets the OOS indication generation condition;

determining a UE-specific OOS indication which indicates the UE-specific DL control channel that meets the OOS indication generation condition;

determining a BFR failure status indicating either eventual BFR failure or stepwise failure, wherein the stepwise failure is out of the BFR process;

determining a timer or event triggered OOS indication following a configured periodicity or aperiodic event trigger condition; and

combining the above indications, and generating a unified OOS indication indicating a common link status.

18. The method according to claim 14, wherein the unifying the individual BFR indications comprises at least one of:

determining a common in-sync (IS) indication which indicates the common or cell-specific DL control channel that meets the IS generation condition; and

determining a UE-specific IS indication which indicates the UE-specific DL control channel that meets the IS generation condition; and

determining a BFR success status indicating BFR success; and

determining a timer or event triggered IS indication following a configured periodicity or aperiodic event trigger condition

combining the above indications, and generating a unified IS indication indicating a common link status.

19. The method according to any one of claims 1 to 18, wherein the unified BFR indications comprising at least one of:

only the unified (periodic or aperiodic) IS or OOS; or

only the (aperiodic) BFR status indication; or

only the eventual BFR success status indication; or

both the eventual and the stepwise (out of the BFR process) BFR success indication; or

only the eventual BFR failure status indication; or

both the eventual and the stepwise (out of the BFR process) BFR failure indication; or

both the unified IS and OOS, and the eventual BFR success or failure status indication.

20. The method according to claim 10, further comprising:

receiving a radio resource control (RRC) signal;

determining indications of BFR or RLM by following the radio link configuration by the RRC signal; and

influencing the RLF state machine (counters, timers) based on the indications at configured (beam, reference signal, channel, carrier, direction, or cell) level; and;

determining a RLF status at the configured cell or link level of a single or multiple beams.

21. The method according to claim 1, wherein the method further comprising:

receiving a radio resource control (RRC) signal;

determining an available (UL or DL) path at RLF or RRC layer; and

indicating to BFR the availability of the path; and

influencing the BFR state machine with optimization by redirecting or speeding up a BFR requesting through the path as an alternative.

22. The method according to claim 1, further comprising:

learning RLC or RACH or HO command status at upper layer;

indicating to BFR the status; and

influencing the BFR state machine by optimizing BFR process with speedup or early termination.

23. The method according to claim 1, wherein the receiving from a physical layer, unifying the individual BFR indication and sending the unified BFR indication, is performed by a functional module in the physical layer, or a module in the second layer or a module in the third layer or them jointly.

24. A method for determining beam failure recovery (BFR) indications in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams;

at a physical layer, determining a beam quality metric for each of the multiple beams;

evaluating the determined beam quality metrics of multiple diversity of physical-layer transmission paths in terms of a separate beam, reference or synchronization signal, direction, carrier, data or control channel, cell or any combination thereof for executing BFR operations of signaling, beam identification, and beam failure recovery

accomplishing the BFR operations by fully exploiting the diversities at the physical layer under network configuration and timer-based constraints;

during the BFR process, determining the finalized BFR operation status (success, failure);

generating explicit BFR indications (an aperiodic IS corresponding to a BFR success, or an aperiodic OOS corresponding to a BFR failure, or an explicit BFR success or failure status) only when BFR operation status is final;

sending the BFR indication(s) to the other module(s).

25. A method for determining Radio Link Monitoring (RLM) indications in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams;

at a physical layer, determining a beam quality metric for each of the multiple beams;

evaluating the determined beam quality metrics based on network configured multi-beam RLM criteria, including beam-specific metrics filtering, X best beam(s) selection based on filtered metrics versus configured thresholds, derive a unique serving link metrics from multiple selected beams according to the configured method and specific reference signal, carrier, channel, or cell;

evaluating the derived serving radio link metrics by following configured RLM criteria (RSRP or RSRQ or control channel BLER versus thresholds) to generate periodic (IS, OOS) indication(s),

sending the RLM indication(s) to the other module(s).

26. The method of claim 25, wherein the unification may convert a BFR success status indication into one or multiple IS(s) and failure status into OOS(s), before providing them into RLF.

27. The method of claim 25, wherein the influence of RLF state machine is based on utilizing the indications across different sources by logic or mathematical summarization of them.

28. A method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), comprising:
receiving an indication, wherein the indication is at least one of a BFR generated IS, OOS, explicit BFR success/failure status indication; or a RLM generated (periodic) IS, OOS indication;
unifying the received indication for the detected radio link;
sending the unified indication(s) to a RLF; and
utilizing the unified indication(s) to alter the RLF state machine.

29. The method of claim 28 wherein the method may be located at one of RLF, RLM, or BFR modules, or across them or different protocol layers, and wherein the BFR and RLM indications may be input into the method in parallel, or only through RLM after RLM-based procedural unification

30. The method of claim 28 wherein a unified indication sent to RLF is solely based on the indication of whether BFR operations were a success or failure, or on BFR generated aperiodic IS or OOS indication, or on RLM generated periodic IS or OOS indication, or all of them.

31. The method of claim 28, further comprising:
producing a BFR operations command or a RLF status indication to the physical layer to influence the BFR operations.

32. A network device comprising:
a receiver means for receiving an indication from at least one network device, wherein the indication is at least one of a BFR generated IS, OOS, explicit BFR success/failure status indication; a RLM generated IS, or an OOS indication; and
a processor means that unifies the received indication for the detected radio link, sends the unified indication to a RLF, and to alter the RLF state machine based upon the indication.

33. The device of claim 32 wherein the method may be located at one of RLF, RLM, or BFR modules, or across them or different protocol layers, and wherein the

BFR and RLM indications may be input into the method in parallel, or only through RLM after RLM-based procedural unification

34. The method of claim 33 wherein a unified indication sent to RLF is solely based on the indication of whether BFR operations were a success or failure, or on BFR generated aperiodic IS or OOS indication, or on RLM generated periodic IS or OOS indication, or all of them.

35. The method of claim 32, further comprising:

producing a BFR operations command or a RLF status indication to the physical layer to influence the BFR operations.

36. A method for determining beam failure recovery (BFR) indications in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams;

determining a beam quality metric for each of the multiple beams;

evaluating the determined beam quality metrics of multiple diversity of physical-layer transmission paths (in terms of a separate beam, direction, carrier, data or control channel, cell) for executing BFR operations of signaling, beam identification, and beam failure recovery;

accomplishing the BFR operations by fully exploiting the diversities at the physical layer under network configuration and timer-based constraints;

during the BFR process, determining the final BFR operation status (success, failure);

generating explicit BFR indications (an aperiodic IS corresponding to a BFR success, or an aperiodic OOS corresponding to a BFR failure, or an explicit BFR success or failure status) only when BFR operation status is final; and

sending the BFR indication(s) to the other module(s).

37. The method of claim 36 wherein BFR sends nothing in the middle of its process, but only the final indication after it is determined.

38. A method for determining Radio Link Monitoring (RLM) indications in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams; and

determining a beam quality metric for each of the multiple beams; and

evaluating the determined beam quality metrics based on network configured multi-beam RLM criteria, including beam-specific metrics filtering, X best beam(s) selection based on filtered metrics versus configured thresholds, derive a unique serving link metrics from multiple selected beams according to the configured method and specific reference signal, carrier, channel, or cell; and

evaluating the derived serving radio link metrics by following configured RLM criteria (RSRP or RSRQ or control channel BLER versus thresholds) to generate the first or periodic (IS, OOS) indication(s); and

sending the RLM indication(s) to the other module(s).

39. A method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), comprising:

receiving the BFR generated (aperiodic) IS, OOS, or explicit BFR success/failure status indication; or

receiving the RLM generated (periodic) IS, OOS indication; or

receiving both indications in parallel; or

receiving only from RLM indications that may be generated by BFR but processed by RLM; and

unifying one or multiple of the received indication(s) for the detected radio link for a specific reference signal or beam or channel or carrier or cell, or across multiple of them; and

sending the unified indication(s) to a RLF; and

utilizing the (unified) indication(s) to influence the RLF state machine for fast and reliable RLF declaration.

40. The method of claim 39 wherein multi-beam RLM operations and RLM indication generations are part of RLF, or vice versa.

41. The method of claim 39 wherein the method may be located at one of RLF, RLM, or BFR modules, or distributively across them or different protocol layers, and wherein

the BFR and RLM indications may be input into the method in parallel, or only through RLM after RLM-based processing or procedural unification

42. The method of claim 39 wherein a unified indication sent to RLF is solely based on the indication of whether BFR operations were a success or failure, or on BFR generated aperiodic IS or OOS indication, or on RLM generated periodic IS or OOS indication, or multiple of them.

43. The method of claim 39, further comprising:

producing a BFR operations command or a RLF or RLC or RRC or RLM status indication from upper layers to the physical layer to influence the BFR operations.

44. The method according to claim 39, wherein the multiple beams comprise at least one of: multiple beams with a network device of the same or different reference signals, multiple beams on same or different frequency carriers, multiple beams of same or different (DL/UL) directions, multiple beams of the same or different reference signals, multiple beams on same or different channels, multiple beams from same or different network devices in a same or different cells.

45. The method according to claim 39, wherein the BFR indication refers to at least one beam-formed radio link, a serving link or channel of one or multiple beams, a reference signal of the beam, a component carrier, and identification of an associated base station or cell.

46. The method according to claim 39, further comprising detecting link quality by deriving carrier-level, channel-level, or cell-level link quality metric based on the beam quality metric of a single or multiple beam(s) and of a specific reference signal.

47. The method according to claim 46, further comprising multi-beam RLM (IS, OOS) indications operations.

48. The method according to claim 39, wherein the individual BFR indication refers to In-Sync (IS) indication, or out-of-sync (OOS) indication, or BFR success or failure status indication.

49. The method according to claim 48, the individual BFR indication for each of the multiple beamformed signals is generated only after the physical layer determines a final BFR success/failure status.

50. The method according to claim 39, wherein the BFR indications are aperiodic or event-driven based on BFR or Beam Management events.

51. The method of claim 40, further comprising converting a BFR success status indication into one or multiple (RLM) IS(s), converting the failure status into one or multiple (RLM) OOS(s), or use BFR IS, OOS to replace or be counted as one or multiple RLM's IS or OOS, or treat a BFR aperiodic IS or OOS indication as a RLM indication but with special weights (an aperiodic IS / OOS may be given higher weight than RLM generated periodic IS, OOS), or use BFR aperiodic indications (IS, OOS or success and failure) to influence the periodic RLM IS, OOS indications, or use the BFR success or failure status to influence RLM state machine (IS, OOS generation) to influence RLM's IS or OOS periodicity, their starting point, etc..

52. The method according to claim 39, further comprising:

combine the (converted or not) IS indications from same source (RLM or BFR) and corresponding to the same reference signal and radio link by logic (OR, AND) operations or mathematical summarization such as weighted sum (count) across one or multiple beams, carriers, directions, control or data channels, cells. Same to the combination of (converted or not) OOS indications.

53. The method of claim 39, wherein the unification method combines the (converted or not) indications from different sources by logic (AND/OR) operation or mathematical operations such as weighted summarization counting periodic IS from RLM plus aperiodic IS from BFR in a weighted manner but following the same RLF timer and counter, etc., and similarly to OOS.

54. The method according to claim 53 or 52, wherein the weight is defined for per-reference signal, for per-beam, for per-channel, for per-direction, for per-carrier, OR for

per-cell, and the weight is a digital number or a linear scalar, the weight sum is linear or non-linear functions.

55. The method according to claim 53 or 52, wherein the unifying the individual BFR indications comprises at least one of, for a configured or a targeted (multi-beam) radio link:

determining a common out-of-sync (OOS) which indicates the common or cell-specific DL control channel that meets the OOS indication generation condition;

determining a UE-specific OOS indication which indicates the UE-specific DL control channel that meets the OOS indication generation condition;

determining a BFR failure status indicating either eventual BFR failure or stepwise failure, wherein the stepwise failure is out of the BFR process;

determining a timer or event triggered OOS indication following a configured periodicity or aperiodic event trigger condition; and

combining the above indications, and generating a unified OOS indication indicating a common link status for the radio link.

56. The method according to any of claim 53 or 52, wherein the unifying the individual BFR indications comprises at least one of, for a configured or a targeted (multi-beam) radio link:

determining a common in-sync (IS) indication which indicates the common or cell-specific DL control channel that meets the IS generation condition;

determining a UE-specific IS indication which indicates the UE-specific DL control channel that meets the IS generation condition;

determining a BFR success status indicating BFR success;

determining a timer or event triggered IS indication following a configured periodicity or aperiodic event trigger condition; and

combining the above indications, and generating a unified IS indication indicating a common link status for the radio link.

57. The method according to any one of claims 1 to 57, wherein the unified BFR indications comprising at least one of:

only the unified (periodic or aperiodic) IS or OOS;

only the (aperiodic) BFR status indication;

only the eventual BFR success status indication;

both the eventual and the stepwise (out of the BFR process) BFR success indication;

only the eventual BFR failure status indication;

both the eventual and the stepwise (out of the BFR process) BFR failure indication; or

both the unified IS and OOS, and the eventual BFR success or failure status indication.

58. The method according to any of claims 1 to 58, further comprising configuration methods of at least one of below:

receiving a radio resource control (RRC) configuration signal;

determining what or how indications of BFR or RLM are generated, used, or unified by following the radio link configuration by the RRC signal;

deciding the unification method and parameters according to the configuration;

deciding the filtering criteria and parameters and (IS, OOS) indication generation approach for the multi-beam RLM according to the configuration;

deciding the upwards and downwards mutual indications between RLF and BFR, and their (parallel or cascaded processing) relationship with RLM according to the configuration;

influencing the BFR state machine (counters, timers) based on the indications based on the configured upper level (RRC, RLC, RLF, RLM, RACH, etc.) status or events;

influencing the RLF state machine (counters, timers) based on the indications at the configured (beam, reference signal, channel, carrier, direction, or cell) level; and

determining a RLF status at the configured (cell or link) level of configured (single or Y number of multiple) beams.

59. The method according to claim 43, wherein the method further comprising:

receiving a radio resource control (RRC) signal;

determining an available (UL or DL) path at RLF or RRC layer;

indicating to BFR the availability of the path; and

influencing the BFR state machine with optimization by redirecting or speeding up a BFR requesting through the path as an alternative.

60. The method according to claim 39, further comprising:

learning RLC or RACH or HO status at upper layer;

indicating to lower layer the status; and

influencing the BFR state machine by optimizing BFR process with speedup or early termination of its states, steps, timers, or counters.

61. The method according to claim 39, wherein the receiving indications from a physical or MAC layer (i.e., L1 or L2), unifying the individual BFR indications with or without RLM indications, and sending the unified (BFR, RLM) indication or forwarding received indications as is, is performed by a functional module in the physical layer, or a module in the second layer, or a module in the third layer, or them jointly.

62. The method of claim 39, wherein the utilization of the (unified) indications may influence the RLF state machine by optimizing or speeding up RLF declaration or state transition or early termination of certain state, reset or stop certain timers, and/or reset or stop certain counters.

63. The method of any of claims 1-63, wherein the methods related to UE can be mirrored designed similarly and accordingly, to the network devices.

64. A method for determining radio link recovery or beam failure recovery (BFR) indications in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams;

determining a signal quality metric for each of the multiple beams;

evaluating the determined signal quality metrics of multiple diversity of physical-layer transmission paths for executing link recovery operations of signaling, link failure detection, new beam identification, and link failure recovery request and response;

performing the link recovery operations by fully exploiting the configured multiple paths at the physical layer for configured link recovery operations under configured or timer-based constraints;

determining the link recovery operation status during the link recovery process;

generating link recovery indications according to the link recovery operation status; and

sending the link recovery indication(s) from physical layer to an upper layer.

65. The method of claim 64, wherein the link recovery operation status can be generated stepwise at any step during the link recovery operation process.

66. The method of claim 64, wherein the link recovery indicates nothing in the middle of its process, but only the final indication after results of all steps of the configured or timer-driven link recovery operation status are determined by the physical layer

67. The method of any of claims 65-67, wherein the success of link recovery is final only if all steps in the link recovery process have succeeded under a timer constraint, and wherein the failure of link recovery is final if there is a failure of any step in the process under a timer constraint.

68. The method of claim 1, wherein the signal quality evaluated for executing link recovery operation may derive link quality metrics based only on specific reference signal of serving control channel only.

69. The method of any of claims 65-68, wherein the signal quality metrics may be evaluated by sum-average, weighted sum, or threshold comparison of metrics from multiple configured paths.

70. The method of any of claims 65-69, wherein by configured multipath diversity exploitation, the link failure detection may be accomplished when ALL the SSB and CSI-RS signal metrics of the serving control channel drop below a threshold over a configured time period; wherein the link failure recovery may be accomplished when ANY of the SSB or CSI-RS signal metrics of the serving control channel exceeds a threshold over a configured time period.

71. A method for multi-beam Radio Link Monitoring (RLM) in a user equipment (UE), comprising:

receiving and processing downlink (DL) reference signals from multiple beams of a serving link; and

determining a signal quality metric for each of the multiple beams;

evaluating the determined signal quality metrics based on network configured multi-beam RLM criteria, including beam-specific metrics filtering, X best beam(s) selection based on filtered metrics versus configured thresholds, derivation of a unique serving link quality metrics from multiple selected beams according to the configured method and reference signal, carrier, channel, or cell;

evaluating the derived serving radio link metrics by following configured RLM criteria to generate the first or periodic RLM indication(s); and

sending the RLM indication(s) to the other module(s).

72. The method of claim 71, wherein the configured derivation methods of link metrics include filtering, or weighted sum, moving average, or SINR-to-BLER table lookup of multiple beam-specific signal metrics.

73. The method of claim 71 or 72, wherein the configured RLM criteria for deriving radio link metrics may include RSRP, RSRQ, or control channel BLER versus.

74. The method of any of claims 71-73, wherein the RLM indication(s) include beam-specific signal metrics, multi-beam derived link metrics, generated In-Sync (IS) or Out-Of-Sync (OOS).

75. The method of claims 71-74, wherein the RLM indications (e.g, signal metrics or link metrics) may be utilized by the link recovery in operations such as beam failure detection, or new beam identification.

76. The method of claim 64 or claim 71, wherein the RLM and link recovery operations may work independently.

77. The method of claim 64 or claim 71, wherein the multiple beams comprise at least one of: multiple beams with a network device of the same or different reference signals, multiple beams on same or different frequency carriers, multiple beams of same or different (DL/UL) directions, multiple beams of the same or different reference signals, multiple beams on same or different channels, multiple beams from same or different network devices in a same or different cells.

78. The method according to claim 64, wherein the link failure recovery indication refers to at least one beam-formed radio link, a serving link or channel of one or multiple beams, a reference signal of the beam, a component carrier, and identification of an associated base station or cell.

79. The method according to claim 64, further comprising detecting link quality by deriving carrier-level, channel-level, or cell-level link quality metric based on the beam quality metric of a single or multiple beam(s) and of a specific reference signal.

80. The method according to claim any of claims 65-79, wherein the weight is defined for per-reference signal, for per-beam, for per-channel, for per-direction, for per-carrier, OR for per-cell, and the weight is a digital number or a linear scalar, the weight sum is linear or non-linear functions.

81. The method according to any of claims 65-79, further comprising configuration methods of at least one of below:

receiving a radio resource control (RRC) configuration signal;

determining what or how indications of link recovery or RLM are generated, used, or multi-path diversity exploited by following the radio link configuration by the RRC signal;

deciding the multipath exploitation method and parameters according to the configuration;

deciding the filtering criteria and parameters and IS, OOSindication generation approach for the multi-beam RLM and multi-path link recovery according to the configuration;

deciding the upwards and downwards mutual indications between RLM and link recovery (parallel or cascaded processing) relationship according to the configuration;

influencing the link recovery state machine based on the indications based on the configured upper level status or events;

82. The method of any of claims 71-81, wherein the methods related to UE can be mirrored designed similarly and accordingly, to the network devices.

83. A method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), comprising:

receiving the physical layer link recovery operations generated status indication according to upper layer configuration, single or multiple-path channel states, wherein the indication may be periodic, aperiodic, or event-driven, and path refers to a communication path of a specific reference signal, beam, data or control channel, etc, the RLM generated first and periodic IS or OOS indication, wherein the RLM considers single or multiple-path serving channel states, both indications in parallel, receiving only from RLM indications that may be generated by the link recovery but processed by RLM;

detecting radio link according to configuration of a specific reference signal or beam or channel or carrier or cell, or across multiple of them;

unifying one or multiple of the received indication(s) or detected radio link quality according to configuration;

sending the unified indication(s) to a RLF;

utilizing the indication(s) to influence the RLF state machine with control parameters for RLF declaration, wherein the influence function is to speed up, delay, or optimize the RLF state machine, its state transition, its parameters, or early termination of certain state reset or stop certain timers, reset or stop certain counters, etc., and wherein the parameters include RLF counters and timers such as N310, T310, N311, T311, T312, etc.

84. The method of claim 83, wherein the link recovery indications refers to an aperiodic indication corresponding to a link recovery success, or an aperiodic indication corresponding to a link recovery failure, or a periodic or event-based link recovery status, and wherein the link recovery status refers to failure detection instance, identified new beams, measured reference signal strength or control or data channel quality, feasibility of the identified beam path according to a configured criteria, and stepwise success or failure under a timer constraint, and final success or failure of the whole link recovery process.

85. The method of claim 83, wherein the RLM operations and RLM indication generations are part of RLF, and the RLM operations are part of link recovery operations.

86. The method of claim 83 wherein the method may be located at one of RLF, RLM, or link recovery modules or distributively across them, or distributively across different protocol layers or multiple paths, and wherein the link recovery and RLM indications may be input into the method in parallel, or only through RLM after RLM-based processing .

87. The method of claim 83 wherein a unified indication sent to RLF is solely based on the indication of whether link recovery operations were a success or failure, or on link recover generated status indication, or on RLM generated periodic IS or OOS indication, or multiple of them.

88. The method of claim 83, further comprising:

producing a link recovery operations configuration command or a RLF or RLC or RRC or RLM status indication from upper layers to the physical layer to influence the link recovery operations, wherein the configuration command may refer to a report request, multiple path configuration, or parameter configuration of the link recovery from upper layer to physical layer, wherein the request may refer to beam reporting in link recovery, wherein the parameters may refer to specific link recovery reference signals or transmission paths, timers or counters, or number of newly identified beams and its metrics thresholds.

89. The method according to claim 83 , wherein the multiple paths may further comprise at least one of: multiple beams with a network device of the same or different reference signals, multiple beams on same or different frequency carriers, multiple beams of same or different downlink and uplink directions, multiple beams of the same or different reference signals, multiple beams on same or different channels, multiple beams from same or different network devices in a same or different cells, on a same or different RATs, or any combination of them.

90. The method according to claim 83, wherein the link recovery and RLM indication refers to at least one path comprising one beam-formed radio link, a serving link or data or control (PDCCH) channel of one or multiple beams, a reference signal (CSI-RS or SSB or DM-RS) of the beam, a component carrier, and an associated base station or cell;

wherein if the method may consider only a single path comprising a single reference signal, beam, channel, carrier, or cell, or their combination.

91. The method according to claim 83, further comprising detecting a link quality by deriving carrier-level, channel-level, or cell-level link quality metric based on the radio quality metric of a single or multiple beam(s) and of a specific or multiple reference signal(s).

92. The method according to claim 91, further referring to the detection operations by RLM channel measurement, beam failure detection or new beam identification in link recovery operations, or independent or shared or combined operations of them..

93. The method according to any one of claims 83 to 91, wherein by configuration the link recovery indications comprising at least one of:

only the periodic or aperiodic IS or OOS; or

only the aperiodic link recovery status indication; or

only the eventual link recovery success status indication; or

both the eventual and the stepwise BFR success indication, wherein each steps is out of the link recovery process; or

only the eventual BFR failure status indication; or

both the eventual and the stepwise link recovery failure indication; or

both the IS and OOS, and the eventual link recovery success or failure status indication.

94. The method of claim 83, wherein by configuration the unification method may simply consider the received indications as direct inputs, or convert a link recovery success status indication into one or multiple IS(s), or convert the failure status into one or multiple OOS(s), or use link recovery IS or OOS to replace or be counted as one or multiple RLM's IS or OOS, or treat a link recovery aperiodic IS or OOS indication as a RLM indication but with special weights,, or use link recovery indications (IS or OOS or success and failure) to influence the periodic RLM IS or OOS indications, or use the link recovery success or failure status to influence RLM state machine.

95. The method of claim 94, wherein a link recovery indication (IS or OOS) may be given the same or different weight than RLM generated periodic indication (IS or OOS) in upper layer unification or RLF counting process, and wherein the link recovery indications may influence the RLM indications or RLM state machines by triggering, stopping, or resetting any of the state machine parameters, such as the RLM indication generation, report periodicity, report starting points, etc.

96. The method according to claim 83, wherein the unification method may be configured to:

combine or select or filter the IS indications from same or different sources of RLM or link recovery, and detected radio link quality corresponding to the same or different reference signals or beams or other paths; It may filter or combine or select the detected radio link quality metrics by mathematical summarization such as weighted sum (count) across one or multiple beams, signals, carriers, directions, control or data channels, cells. Same to the combination of OOS indications.

97. The method of claim 83, wherein the unification method may further comprise counting IS from RLM plus IS from link recovery in a weighted manner but against the same RLF timer and counter.

98. The method according to claim 96 or 99, wherein the weight is configured for per-reference signal, for per-beam, for per-channel, for per-direction, for per-carrier, or for per-cell, and the weight is a digital number or a linear scalar, and the weight sum is linear or non-linear functions.

99. The method according to any of claims 83-95, wherein by configuration the unifying the individual link recovery indications comprises at least one of, for a configured or a targeted multiple-path radio link:

determining a common out-of-sync (OOS) which indicates the common or cell-specific DL control channel that meets the OOS indication generation condition;

determining a UE-specific or dedicated OOS indication which indicates the UE-specific DL control channel that meets the OOS indication generation condition;

determining a link recovery failure status indicating either eventual link recovery failure or stepwise failure, wherein the stepwise failure is out of the link recovery process;

determining a timer or event triggered OOS indication following a configured periodicity or aperiodic event trigger condition; and

combining the above indications, and generating a unified OOS indication indicating a common link status for the radio link; and

the same unification applies to IS too.

100. A method for detecting network radio (NR) radio link failure (RLF) in a user equipment (UE), comprising by configuration:

learning RLC or RLF or RACH or handover status at upper layer;

indicating to lower layer the link recovery or RLM or BM status; and

influencing the link recovery state machine by optimizing link recovery process with speedup or early termination of its states, steps, timers, or counters.

101. The method according to any of claims 83 to 99, further comprising configuration methods of at least one of below:

receiving a radio resource control (RRC) or MAC CE or physical-layer configuration signal;

determining what or how indications of link recovery or RLM are generated, used, or unfied by following the radio link configuration by the RRC signal;

deciding the unification method and multiple path parameters according to the configuration;

deciding the filtering criteria and parameters and (IS or OOS) indication generation approach for the multi-beam RLM according to the configuration;

deciding the upwards and downwards mutual indications between RLF and link recovery, and their parallel or cascaded processing relationship with RLM for unifying or processing link recovery indications before forwarding them as is in-between;

influencing the link recovery state machine (counters, timers) based on the indications based on the configured upper level (RRC, RLC, RLF, RLM, RACH, etc.) status or events;

influencing the RLF state machine (counters, timers) based on the indications at the configured (beam, reference signal, channel, carrier, direction, or cell) level;

determining a RLF status at the configured (cell or link) level for configured single or Y number of multiple beams; And determining an available alternative path after link failure, including an uplink or downlink path, reserved or contention-based RACH resources, at a different carrier or channel or cell, at RLF or RRC layer; and

indicating to link recovery the availability of an alternative path; and

influencing the BFR state machine with optimization, including redirecting or speeding up a BFR requesting through the path as an alternative.

102. The method of any of claims 83-102, wherein the methods related to UE can be mirrored designed similarly and accordingly, to the network devices .

103. The method of claim 64, wherein the link recovery indication is periodic, aperiodic, and event-driven.

104. The method of claim 64, wherein the link recovery indication is periodic, aperiodic, or event-driven.

105. The method of claim 104, wherein the aperiodic indication corresponds to a link recovery success, or the aperiodic indication corresponds to a link recovery failure.

106. The method of claim 104, wherein the periodic includes identified beams, measured signal strength or channel quality, feasibility of the identified beam path according to configured criteria, and stepwise success or failure under a timer constraint.

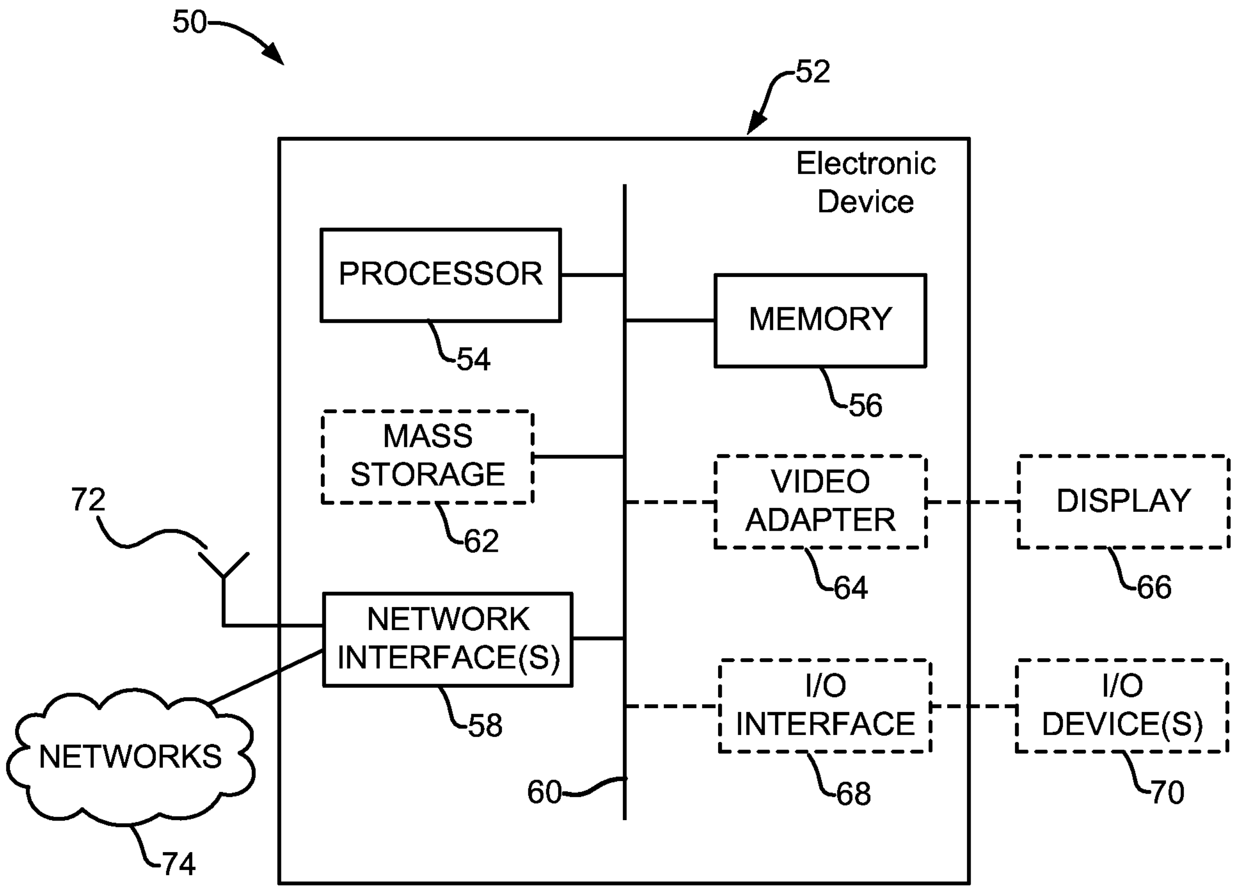

50
52
Electronic Device
PROCESSOR
54
MEMORY
56
MASS STORAGE
62
VIDEO ADAPTER
64
DISPLAY
66
72
NETWORK INTERFACE(S)
58
NETWORKS
74
I/O INTERFACE
68
I/O DEVICE(S)
70
60

Figure 1

2/X

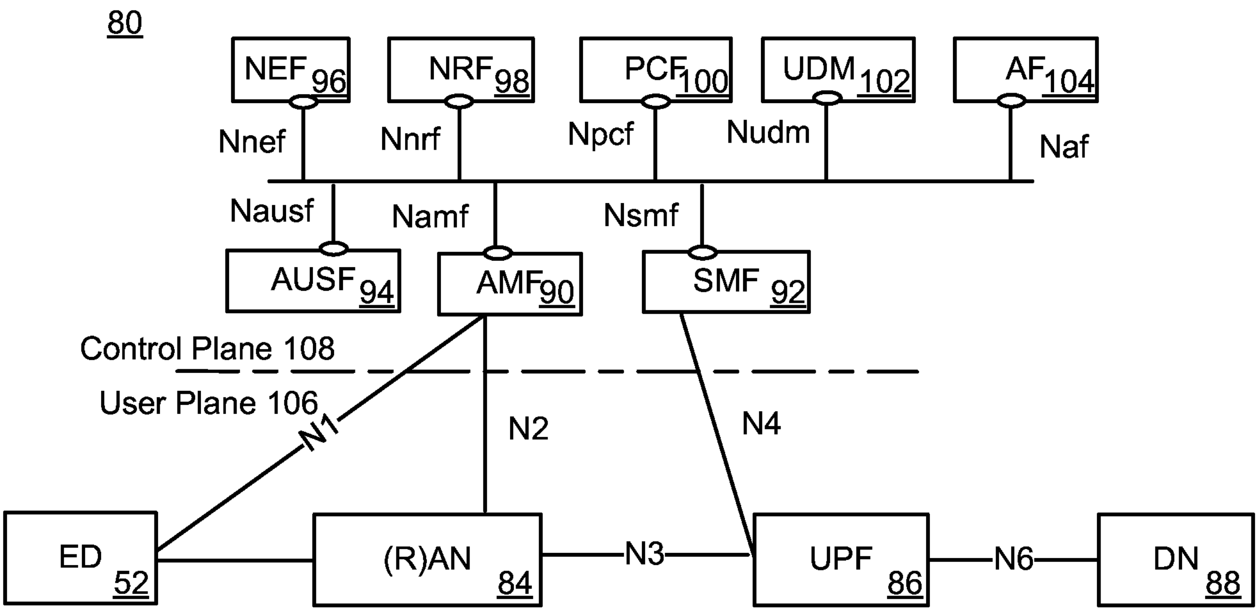


Figure 2

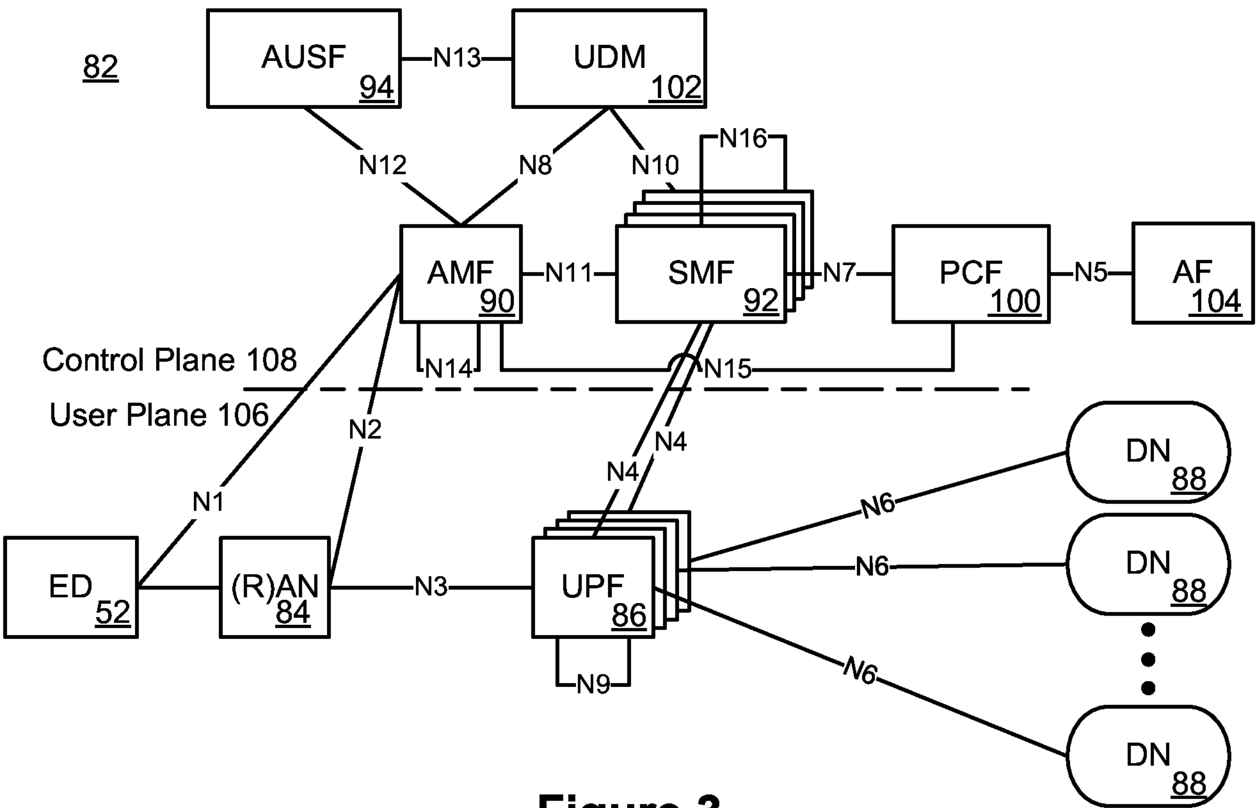


Figure 3

3/X

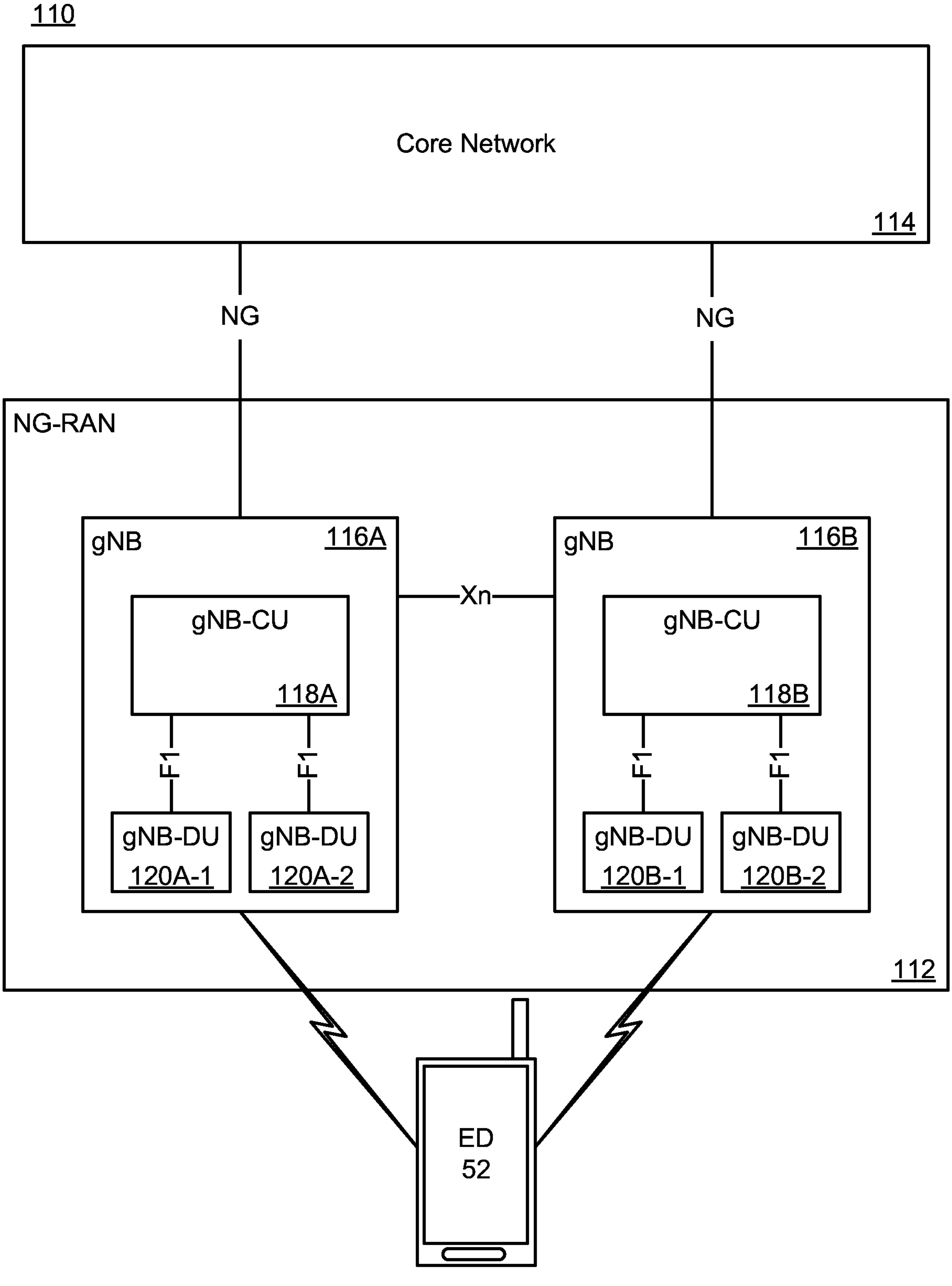

110
Core Network
114
NG
NG
NG-RAN
gNB
116A
gNB-CU
118A
F1
F1
gNB-DU
120A-1
gNB-DU
120A-2
Xn
gNB
116B
gNB-CU
118B
F1
F1
gNB-DU
120B-1
gNB-DU
120B-2
112
ED
52

Figure 4

4/X

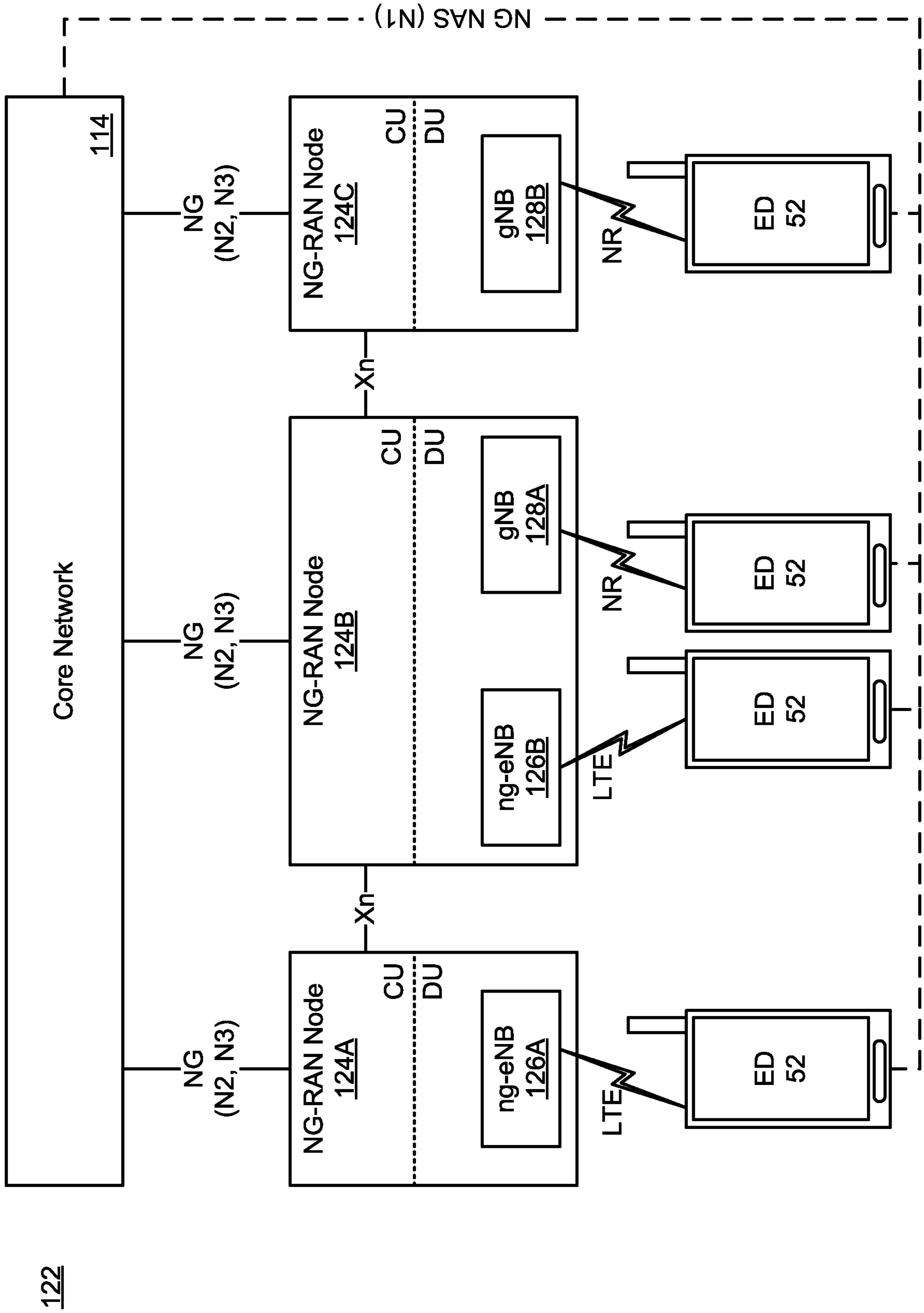
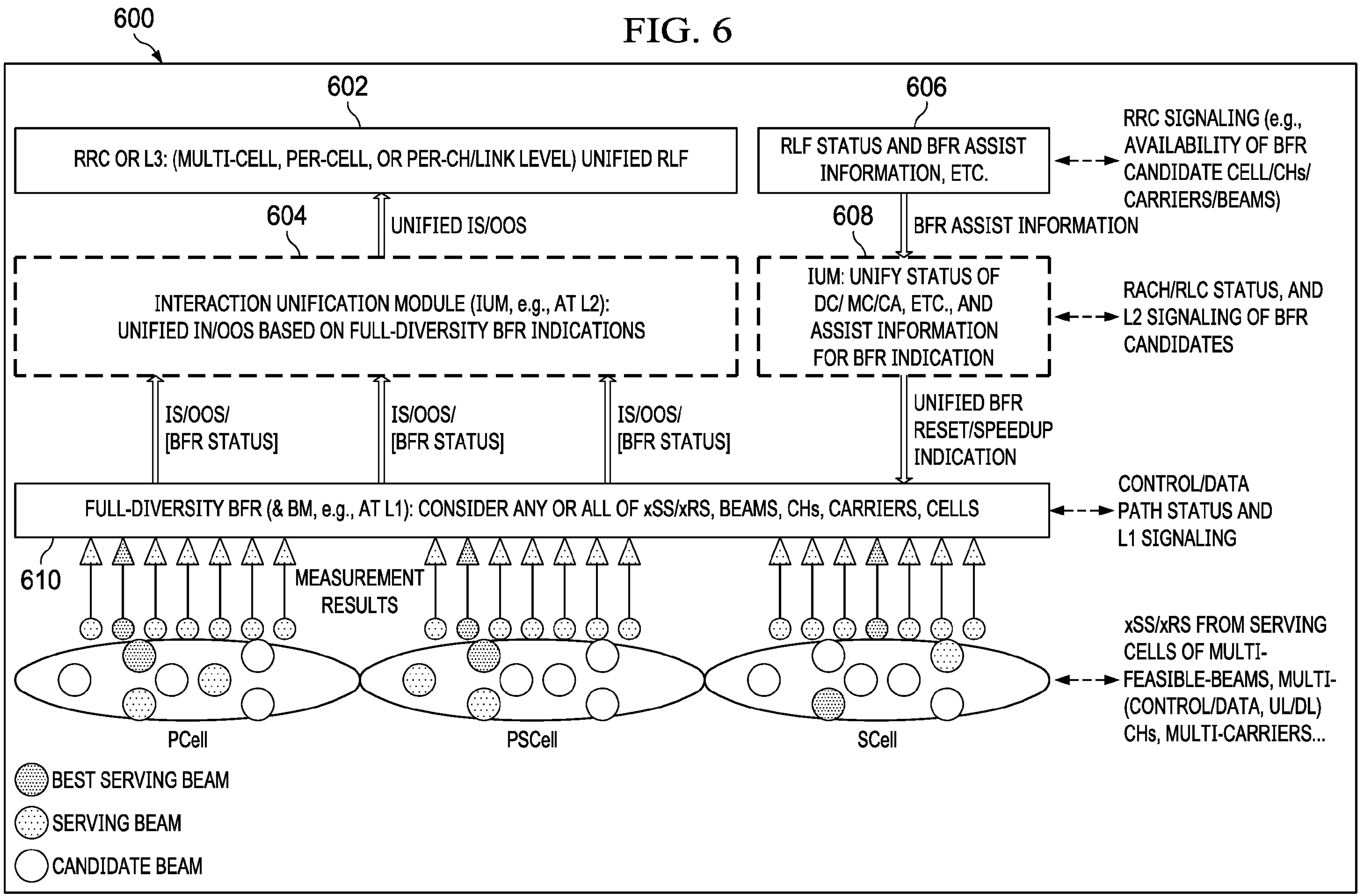

122
Core Network
114
NG
(N2, N3)
NG
(N2, N3)
NG
(N2, N3)
NG-RAN Node
124A
NG-RAN Node
124B
NG-RAN Node
124C
CU
DU
CU
DU
CU
DU
Xn
Xn
ng-eNB
126A
ng-eNB
126B
gNB
128A
gNB
128B
LTE
LTE
NR
NR
ED
52
ED
52
ED
52
ED
52
NG NAS (N1)

Figure 5

FIG. 6


600
602
RRC OR L3: (MULTI-CELL, PER-CELL, OR PER-CH/LINK LEVEL) UNIFIED RLF
606
RLF STATUS AND BFR ASSIST INFORMATION, ETC.
RRC SIGNALING (e.g., AVAILABILITY OF BFR CANDIDATE CELL/CHs/ CARRIERS/BEAMS)
604
UNIFIED IS/OOS
608
BFR ASSIST INFORMATION
INTERACTION UNIFICATION MODULE (IUM, e.g., AT L2): UNIFIED IN/OOS BASED ON FULL-DIVERSITY BFR INDICATIONS
IUM: UNIFY STATUS OF DC/ MC/CA, ETC., AND ASSIST INFORMATION FOR BFR INDICATION
RACH/RLC STATUS, AND L2 SIGNALING OF BFR CANDIDATES
IS/OOS/ [BFR STATUS]
IS/OOS/ [BFR STATUS]
IS/OOS/ [BFR STATUS]
UNIFIED BFR RESET/SPEEDUP INDICATION
FULL-DIVERSITY BFR (& BM, e.g., AT L1): CONSIDER ANY OR ALL OF xSS/xRS, BEAMS, CHs, CARRIERS, CELLS
CONTROL/DATA PATH STATUS AND L1 SIGNALING
610
MEASUREMENT RESULTS
xSS/xRS FROM SERVING CELLS OF MULTI-FEASIBLE-BEAMS, MULTI-(CONTROL/DATA, UL/DL) CHs, MULTI-CARRIERS...
PCell
PSCell
SCell
BEST SERVING BEAM
SERVING BEAM
CANDIDATE BEAM

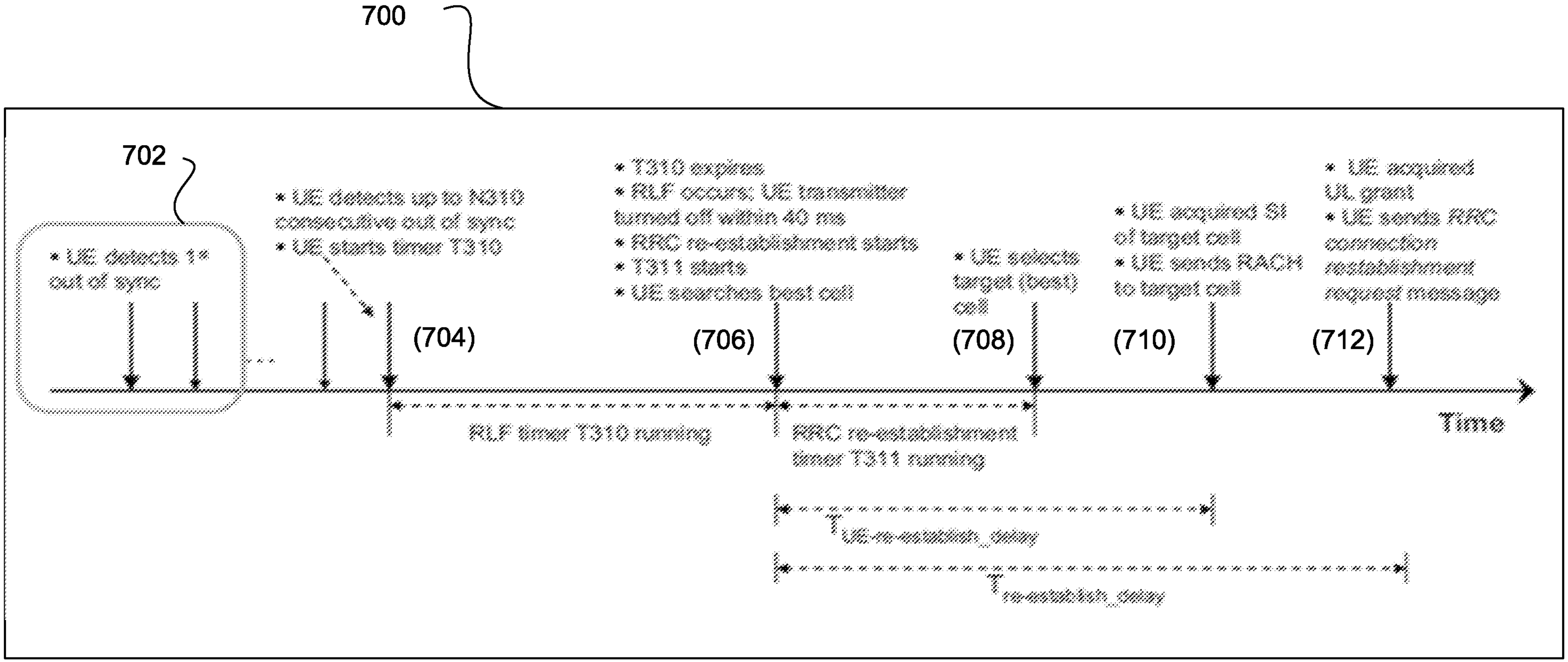

700
702
• UE detects 1st out of sync
• UE detects up to N310 consecutive out of sync
• UE starts timer T310
(704)
• T310 expires
• RLF occurs; UE transmitter turned off within 40 ms
• RRC re-establishment starts
• T311 starts
• UE searches best cell
(706)
• UE selects target (best) cell
(708)
• UE acquired SI of target cell
• UE sends RACH to target cell
(710)
• UE acquired UL grant
• UE sends RRC connection reestablishment request message
(712)
Time
RLF timer T310 running
RRC re-establishment timer T311 running
T UE-re-establish_delay
T re-establish_delay

Figure 7

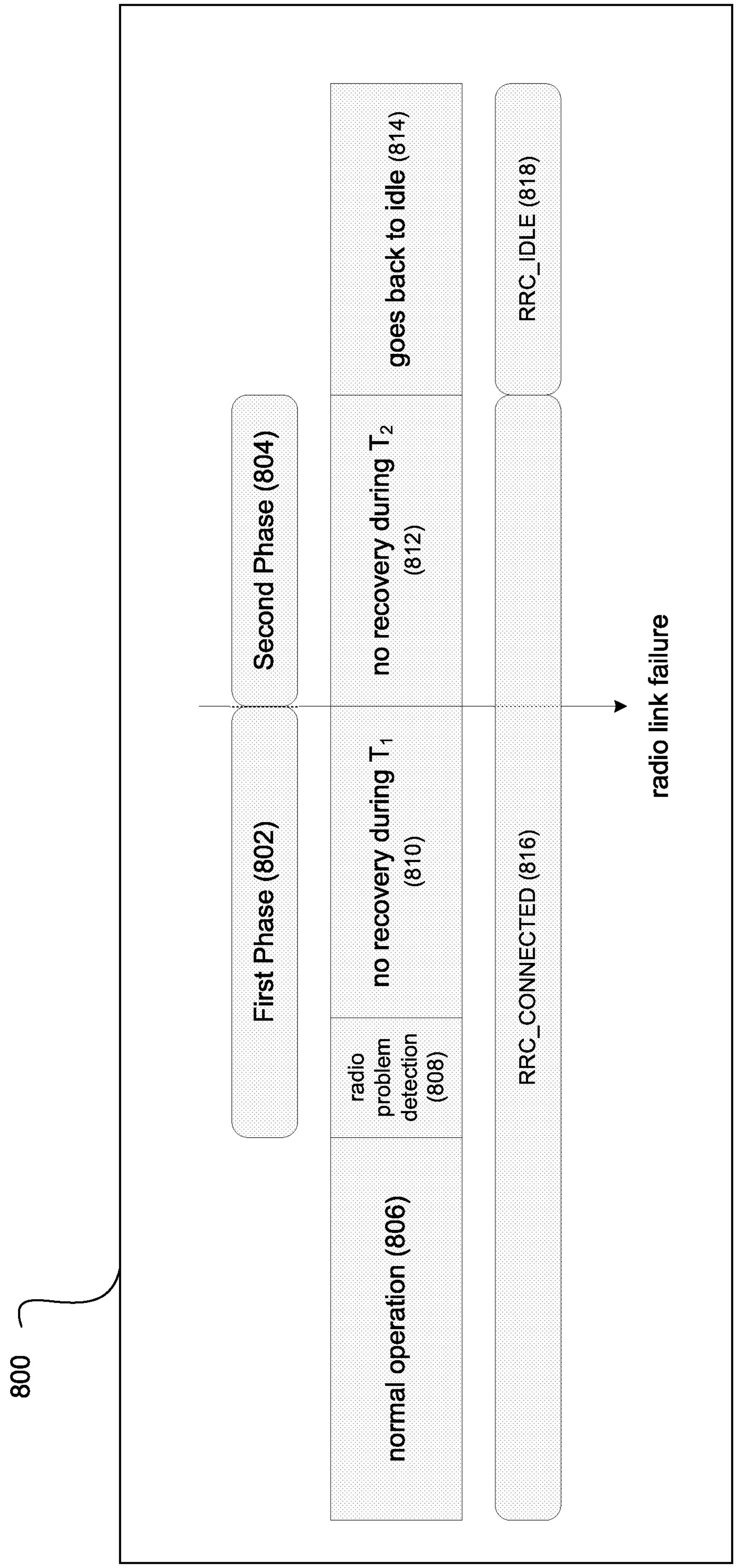

800
First Phase (802)
Second Phase (804)
normal operation (806)
radio problem detection (808)
no recovery during T_1 (810)
no recovery during T_2 (812)
goes back to idle (814)
RRC_CONNECTED (816)
RRC_IDLE (818)
radio link failure

Figure 8

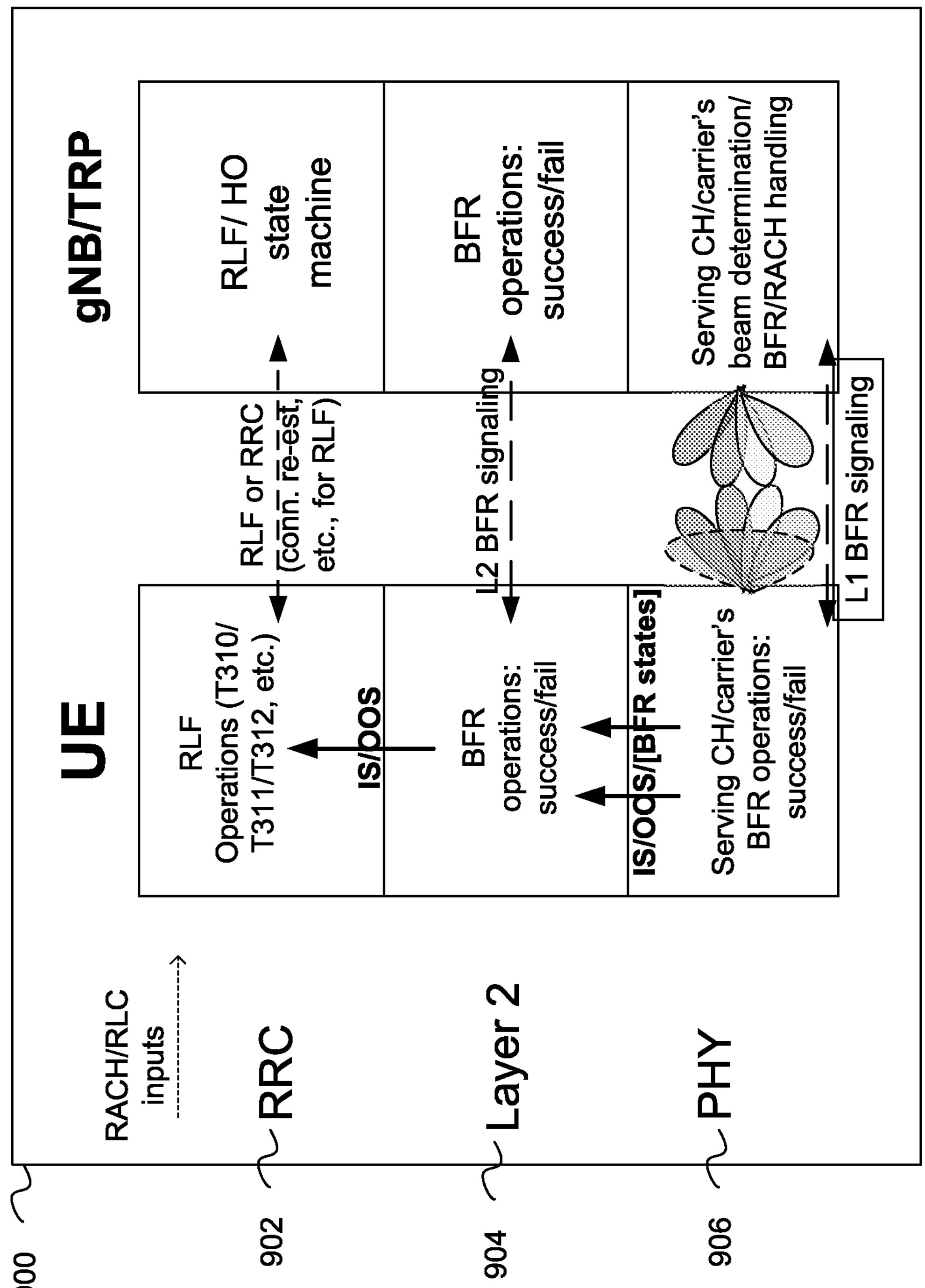

900
902
904
906
RACH/RLC inputs
RRC
Layer 2
PHY
UE
RLF Operations (T310/ T311/T312, etc.)
IS/OOS
BFR operations: success/fail
IS/OOS/[BFR states]
Serving CH/carrier's BFR operations: success/fail
gNB/TRP
RLF/ HO state machine
BFR operations: success/fail
Serving CH/carrier's beam determination/ BFR/RACH handling
RLF or RRC (conn. re-est, etc., for RLF)
L2 BFR signaling
L1 BFR signaling

Figure 9

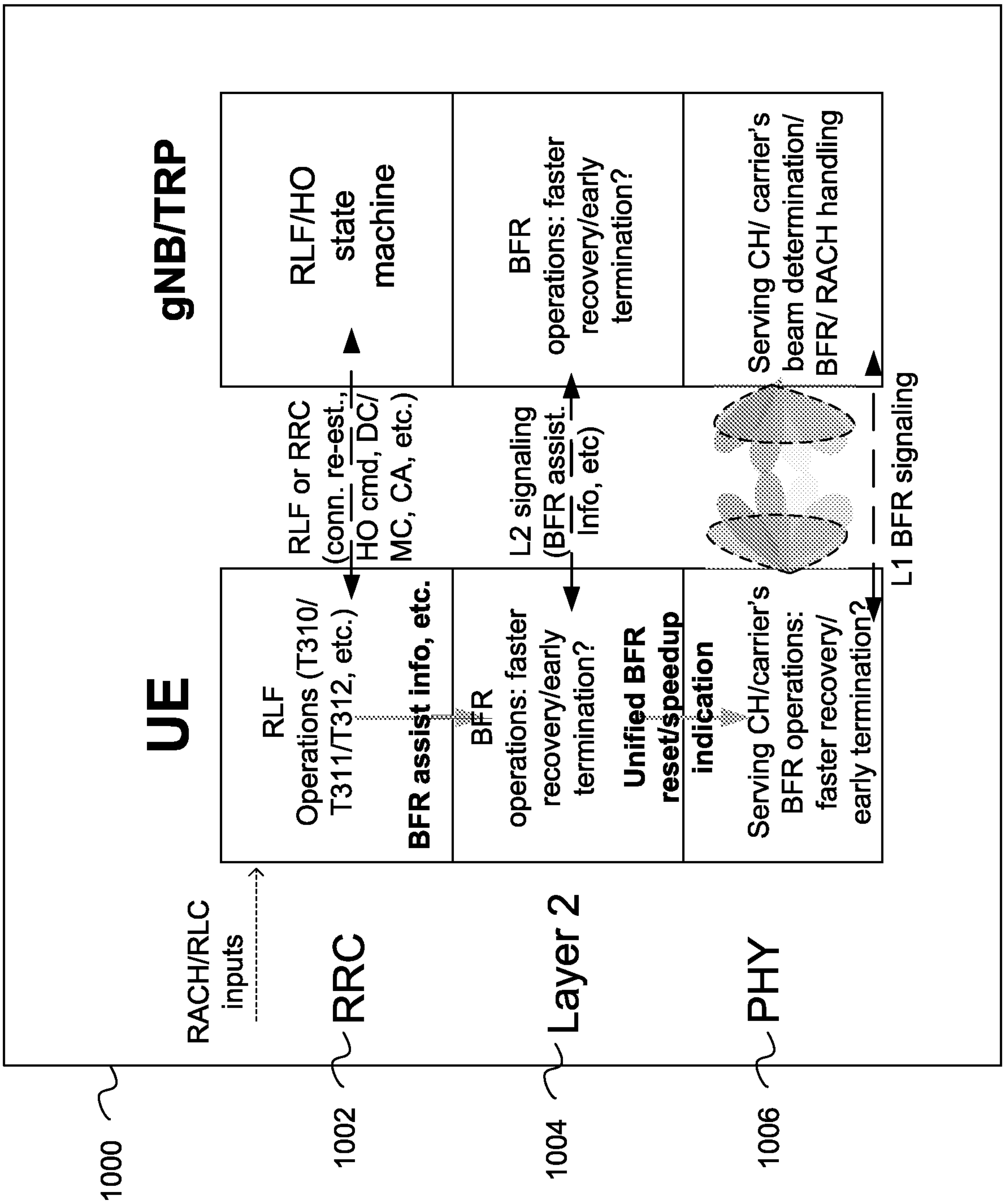

UE
gNB/TRP
RACH/RLC inputs
RRC
Layer 2
PHY
RLF Operations (T310/ T311/T312, etc.)
BFR assist info, etc.
BFR operations: faster recovery/early termination?
Unified BFR reset/speedup indication
Serving CH/carrier's BFR operations: faster recovery/ early termination?
RLF or RRC (conn. re-est., HO cmd, DC/ MC, CA, etc.)
L2 signaling (BFR assist. Info, etc)
L1 BFR signaling
RLF/HO state machine
BFR operations: faster recovery/early termination?
Serving CH/ carrier's beam determination/ BFR/ RACH handling
1000
1002
1004
1006

Figure 10

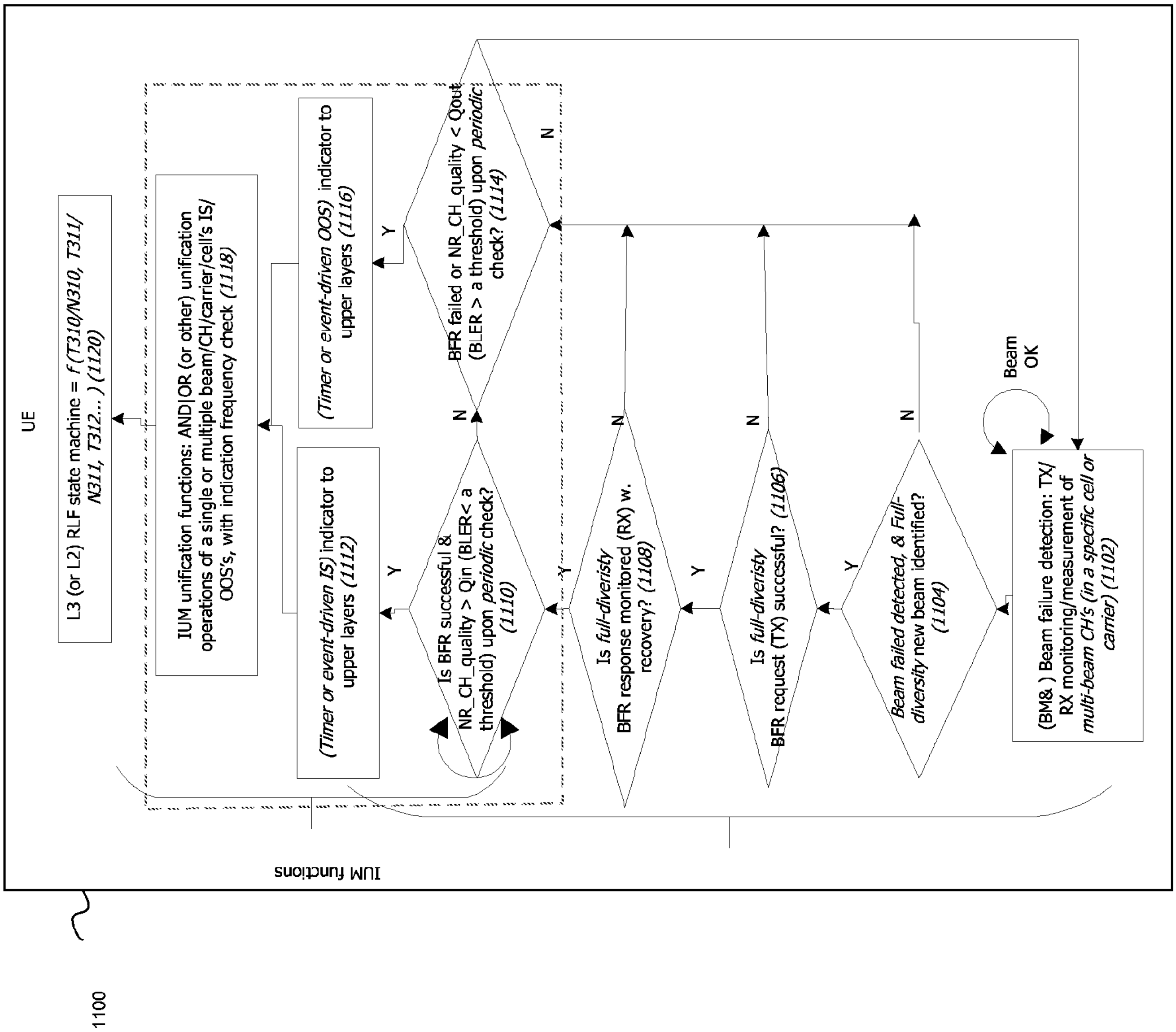

UE
L3 (or L2) RLF state machine = f (T310/N310, T311/ N311, T312...) (1120)
IUM unification functions: AND|OR (or other) unification operations of a single or multiple beam/CH/carrier/cell's IS/ OOS's, with indication frequency check (1118)
(Timer or event-driven IS) indicator to upper layers (1112)
(Timer or event-driven OOS) indicator to upper layers (1116)
Is BFR successful & NR_CH_quality > Qin (BLER< a threshold) upon periodic check? (1110)
BFR failed or NR_CH_quality < Qout (BLER > a threshold) upon periodic check? (1114)
Is full-diveristy BFR response monitored (RX) w. recovery? (1108)
Is full-diveristy BFR request (TX) successful? (1106)
Beam failed detected, & Full-diversity new beam identified? (1104)
(BM&) Beam failure detection: TX/ RX monitoring/measurement of multi-beam CH's (in a specific cell or carrier) (1102)
Beam OK
Y
N
IUM functions
1100

Figure 11

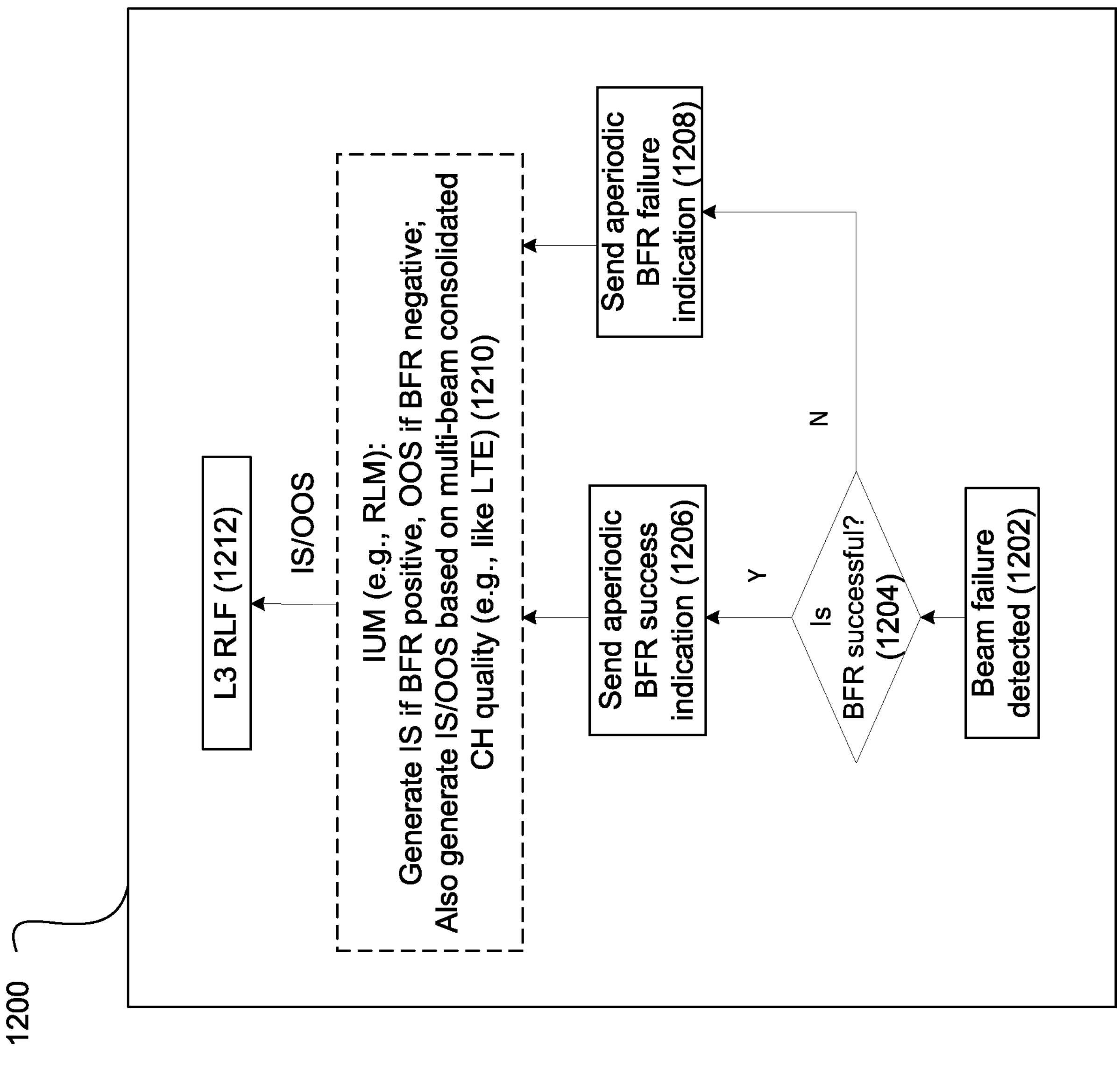

1200
Beam failure detected (1202)
Is BFR successful? (1204)
Y
N
Send aperiodic BFR success indication (1206)
Send aperiodic BFR failure indication (1208)
IUM (e.g., RLM):
Generate IS if BFR positive, OOS if BFR negative;
Also generate IS/OOS based on multi-beam consolidated CH quality (e.g., like LTE) (1210)
IS/OOS
L3 RLF (1212)

Figure 12

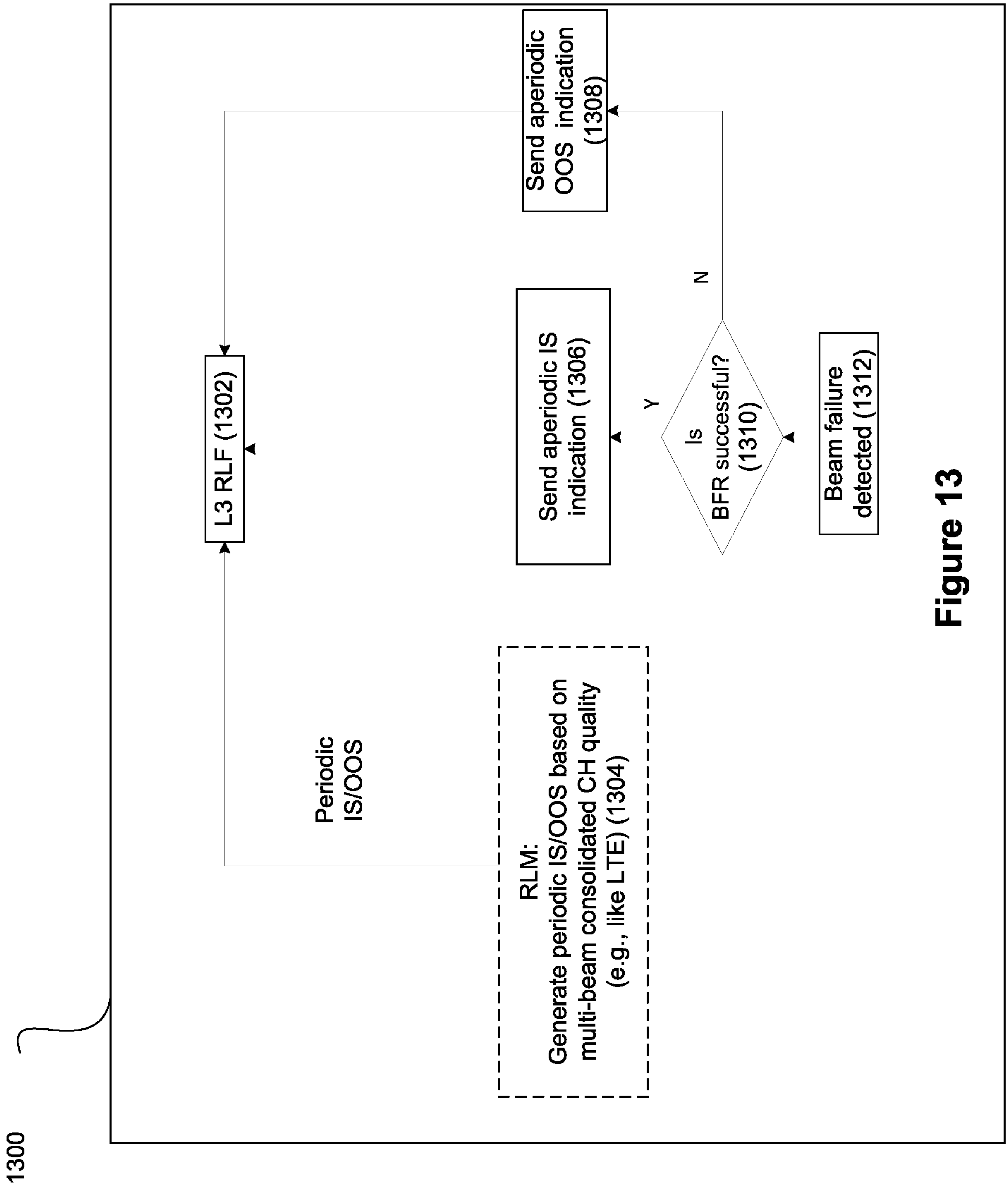

1300
L3 RLF (1302)
Periodic IS/OOS
RLM:
Generate periodic IS/OOS based on multi-beam consolidated CH quality (e.g., like LTE) (1304)
Send aperiodic IS indication (1306)
Send aperiodic OOS indication (1308)
Is BFR successful? (1310)
Y
N
Beam failure detected (1312)

Figure 13

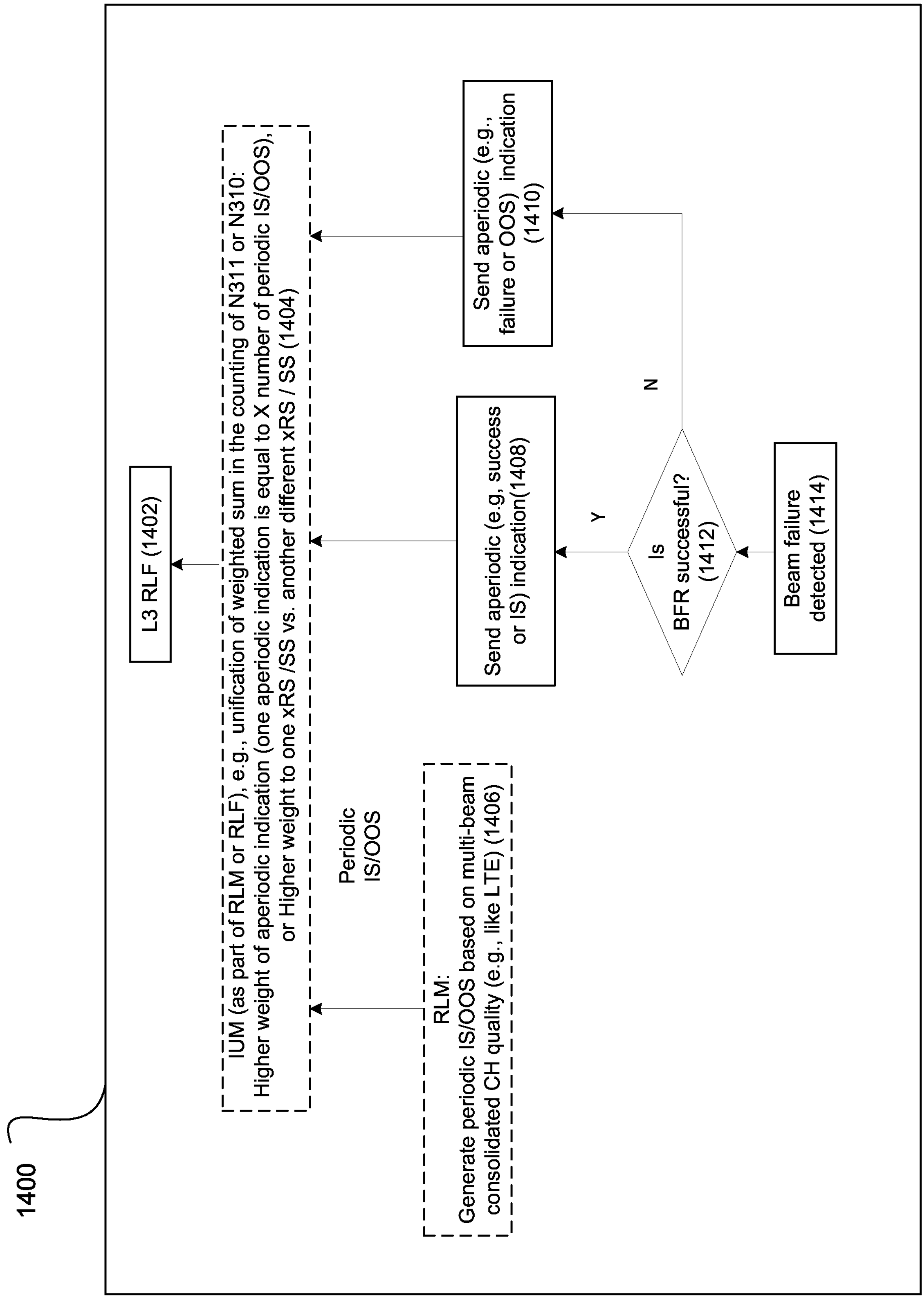
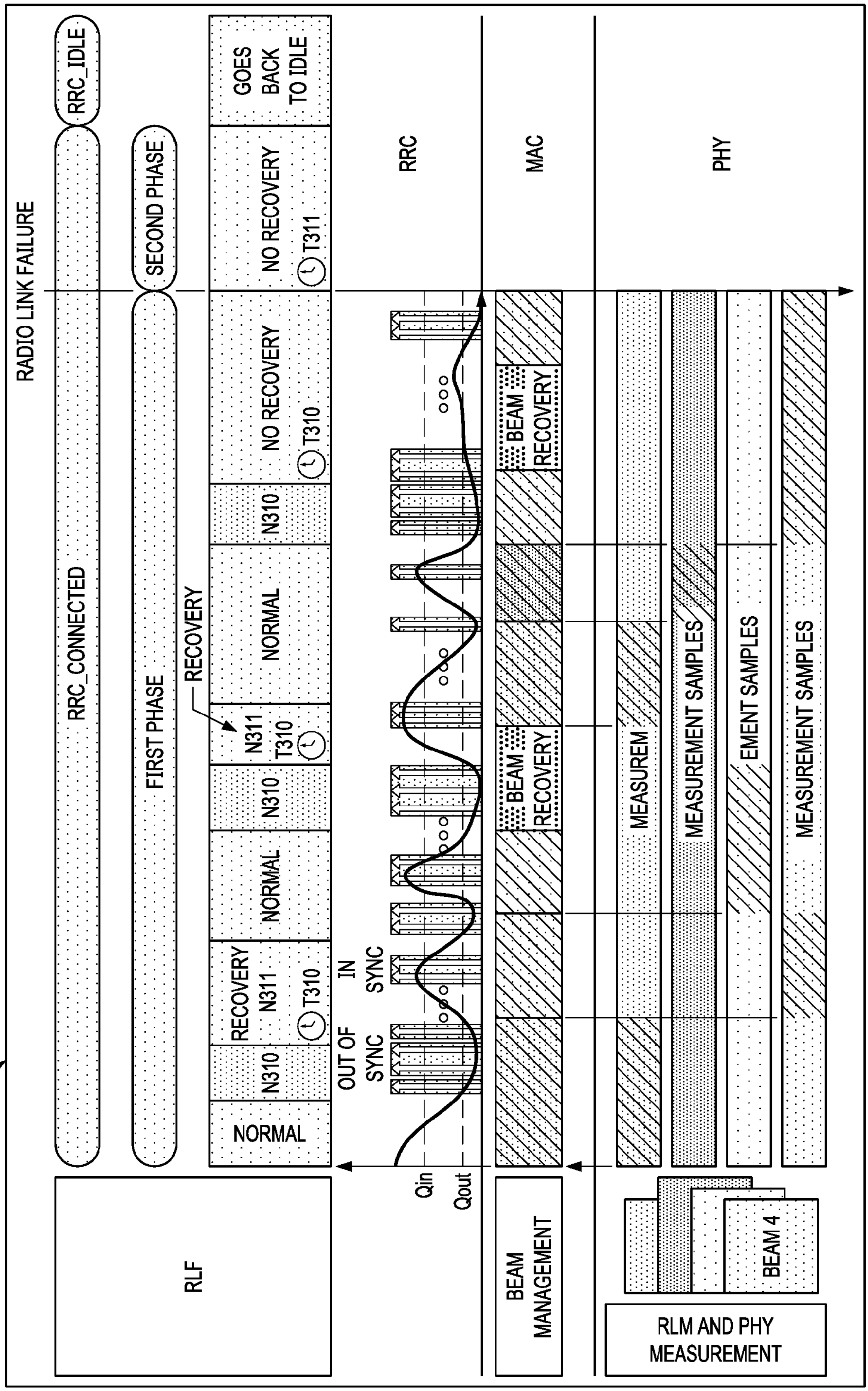

1400
L3 RLF (1402)
IUM (as part of RLM or RLF), e.g., unification of weighted sum in the counting of N311 or N310:
Higher weight of aperiodic indication (one aperiodic indication is equal to X number of periodic IS/OOS),
or Higher weight to one xRS /SS vs. another different xRS / SS (1404)
Periodic IS/OOS
RLM:
Generate periodic IS/OOS based on multi-beam consolidated CH quality (e.g., like LTE) (1406)
Send aperiodic (e.g, success or IS) indication(1408)
Send aperiodic (e.g., failure or OOS) indication (1410)
Y
N
Is BFR successful? (1412)
Beam failure detected (1414)

Figure 14

FIG. 15

1500



RECTIFIED SHEET (RULE 91) ISA/EP

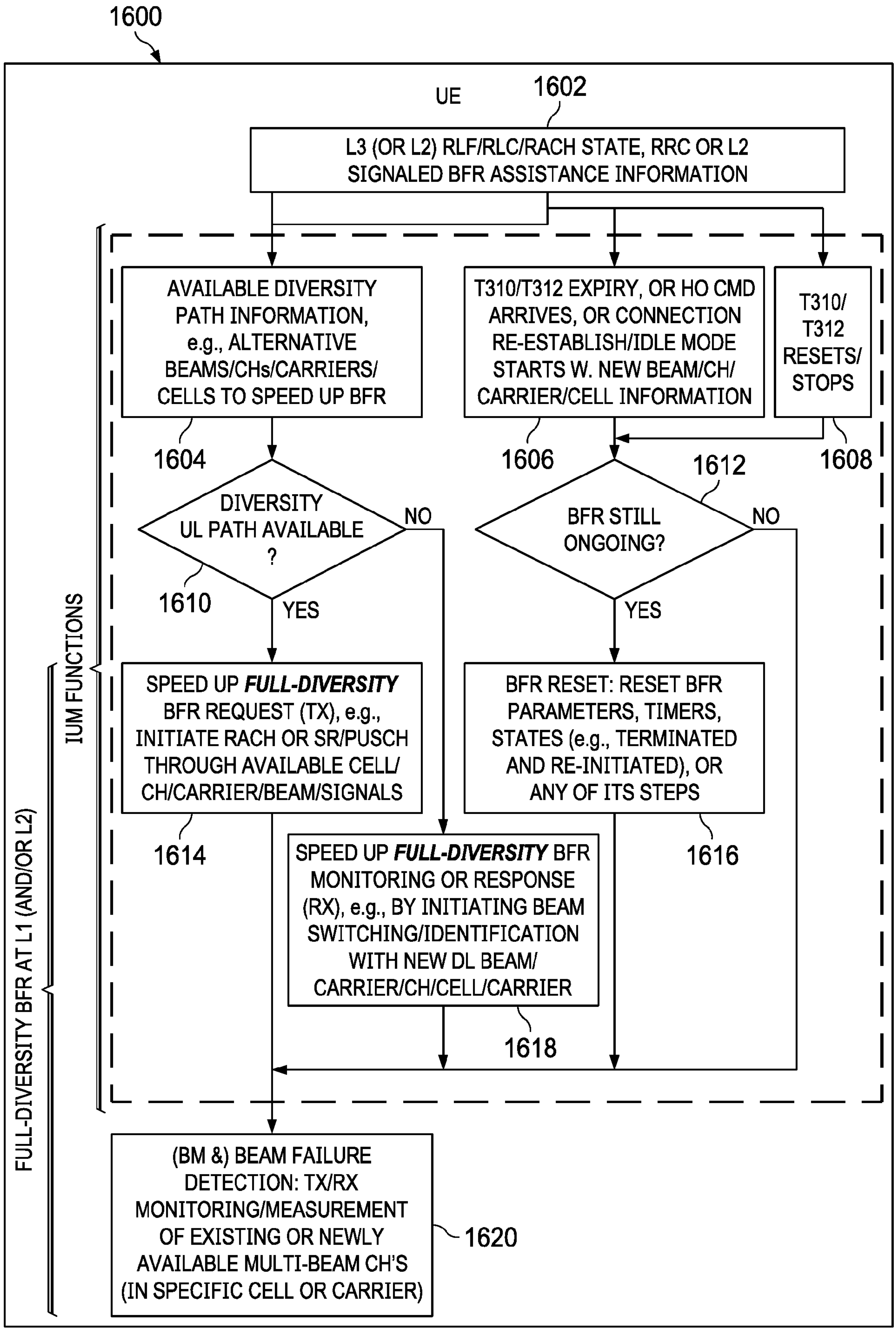

1600
UE
1602
L3 (OR L2) RLF/RLC/RACH STATE, RRC OR L2 SIGNALED BFR ASSISTANCE INFORMATION
AVAILABLE DIVERSITY PATH INFORMATION, e.g., ALTERNATIVE BEAMS/CHs/CARRIERS/ CELLS TO SPEED UP BFR
1604
T310/T312 EXPIRY, OR HO CMD ARRIVES, OR CONNECTION RE-ESTABLISH/IDLE MODE STARTS W. NEW BEAM/CH/ CARRIER/CELL INFORMATION
1606
T310/ T312 RESETS/ STOPS
1608
DIVERSITY UL PATH AVAILABLE ?
1610
NO
YES
BFR STILL ONGOING?
1612
NO
YES
SPEED UP FULL-DIVERSITY BFR REQUEST (TX), e.g., INITIATE RACH OR SR/PUSCH THROUGH AVAILABLE CELL/ CH/CARRIER/BEAM/SIGNALS
1614
BFR RESET: RESET BFR PARAMETERS, TIMERS, STATES (e.g., TERMINATED AND RE-INITIATED), OR ANY OF ITS STEPS
1616
SPEED UP FULL-DIVERSITY BFR MONITORING OR RESPONSE (RX), e.g., BY INITIATING BEAM SWITCHING/IDENTIFICATION WITH NEW DL BEAM/ CARRIER/CH/CELL/CARRIER
1618
IUM FUNCTIONS
FULL-DIVERSITY BFR AT L1 (AND/OR L2)
(BM &) BEAM FAILURE DETECTION: TX/RX MONITORING/MEASUREMENT OF EXISTING OR NEWLY AVAILABLE MULTI-BEAM CH'S (IN SPECIFIC CELL OR CARRIER)
1620

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/039368

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W76/19 H04W76/27 H04B7/0413 H04B7/08
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W H04B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NTT DOCOMO ET AL: "Discussion on NR RLM and RLF", 3GPP DRAFT; R1-1711071_DISCUSSION ON NR RLM AND RLF_FINAL, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Qingdao, P.R. China; 20170627 - 20170630 17 June 2017 (2017-06-17), XP051305364, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_AH/NR_AH_1706/Docs/ [retrieved on 2017-06-17]	1-3,5,6, 8-23, 28-30, 32-34, 39-42, 44-49, 51-58, 60-63, 68,69, 80-87, 89-99, 101,102
Y	Title, Section 1, Section 2.1, Section 2.3; figure 2	4,7,31, 35,43, 50,59,
	-/--	

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 September 2018	26/11/2018

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

4

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
		70,88
Y	INTEL CORPORATION: "Beam failure and radio link failure handlings", 3GPP DRAFT; R2-1707052, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG2, no. Qingdao, China; 20170627 - 20170629 17 June 2017 (2017-06-17), XP051307301, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG2_RL2/TSGR2_AHs/2017_06_NR/Docs/ [retrieved on 2017-06-17]	4,7,31, 35,43, 59,88
A	figure 2	1-3,5,6, 8-23, 28-30, 32-34, 39-42, 44-58, 60-63, 68-70, 80-87, 89-99, 101,102
Y	HUAWEI ET AL: "Discussion on remaining issues of radio link monitoring", 3GPP DRAFT; R1-1709921, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Qingdao, China; 20170627 - 20170630 17 June 2017 (2017-06-17), XP051304661, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_AH/NR_AH_1706/Docs/ [retrieved on 2017-06-17]	50,70
A	Section 3, Section 3.2	1-23, 28-35, 39-49, 51-63, 68,69, 80-99, 101,102

4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/039368

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-23, 28-35, 39-63, 68-70, 80-99, 101, 102

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-23, 28-35, 39-63, 68-70, 80-99, 101, 102

   A method for detecting network radio radio link failure in a user equipment, comprising: unifying one or multiple of the received indication(s) for the detected radio link for a specific reference signal or beam or channel or carrier or cell, or across multiple of them;sending the unified indication(s) to a RLF; and utilizing the unified indication(s) to influence the RLF state machine for fast and reliable RLF declaration.

   ---

2. claims: 24, 36, 37, 64-67, 76-79, 103-106

   A method for determining beam failure recovery indications in a user equipment, comprising: evaluating the determined beam quality metrics of multiple diversity of physical-layer transmission paths in terms of a separate beam, reference or synchronization signal, direction, carrier, data or control channel, cell or any combination thereof for executing BFR operations of signaling, beam identification, and beam failure recovery accomplishing the BFR operations by fully exploiting the diversities at the physical layer under network configuration and timer-based constraints;during the BFR process, determining the finalized BFR operation status;generating explicit BFR indications only when BFR operation status is final.

   ---

3. claims: 25-27, 38, 71-75

   A method for determining Radio Link Monitoring indications in a user equipment, comprising: evaluating the determined beam quality metrics based on network configured multi-beam RLM criteria, including beam-specific metrics filtering, X best beam(s) selection based on filtered metrics versus configured thresholds, derive a unique serving link metrics from multiple selected beams according to the configured method and specific reference signal, carrier, channel, or cell; evaluating the derived serving radio link metrics by following configured RLM criteria to generate periodic indication(s).

   ---

4. claim: 100

   A method for detecting network radio radio link failure in a user equipment, comprising by configuration: learning RLC or RLF or RACH or handover status at upper layer;indicating to lower layer the link recovery or RLM or BM status; and influencing the link recovery state machine by optimizing link recovery process with speedup or early termination of

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

its states, steps, timers, or counters.
