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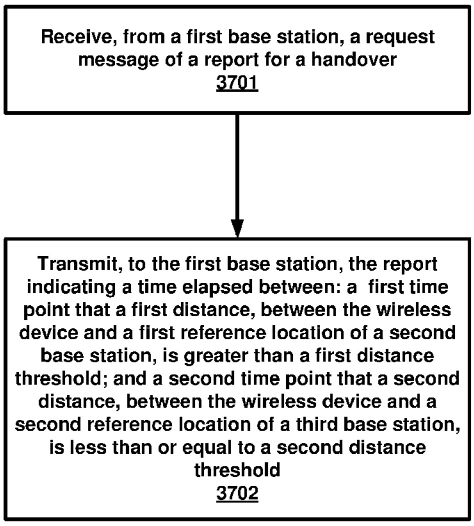

FIG. 37

(57) **Abstract:** A wireless device receives from a first base station a request for a report associated with a handover. The wireless device transmits to the first base station, the report comprising an indication of a time elapsed between a first time point and a second time point. The first time point is a time that a first distance becomes greater than a first distance threshold. The first distance is between the wireless device and a reference location of a second base station. The second time point is a time that a second distance is less than or equal to a second threshold. The second distance is between the wireless device and a reference location of a third base station.

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[Continued on next page]

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TITLE

Conditional Handover Report

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/411,629, filed September 30, 2022, which is hereby incorporated by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Examples of several of the various embodiments of the present disclosure are described herein with reference to the drawings.

[0003] FIG. 1A and FIG. 1B illustrate example mobile communication networks in which embodiments of the present disclosure may be implemented.

[0004] FIG. 2A and FIG. 2B respectively illustrate a New Radio (NR) user plane and control plane protocol stack.

[0005] FIG. 3 illustrates an example of services provided between protocol layers of the NR user plane protocol stack of FIG. 2A.

[0006] FIG. 4A illustrates an example downlink data flow through the NR user plane protocol stack of FIG. 2A.

[0007] FIG. 4B illustrates an example format of a MAC subheader in a MAC PDU.

[0008] FIG. 5A and FIG. 5B respectively illustrate a mapping between logical channels, transport channels, and physical channels for the downlink and uplink.

[0009] FIG. 6 is an example diagram showing RRC state transitions of a UE.

[0010] FIG. 7 illustrates an example configuration of an NR frame into which OFDM symbols are grouped.

[0011] FIG. 8 illustrates an example configuration of a slot in the time and frequency domain for an NR carrier.

[0012] FIG. 9 illustrates an example of bandwidth adaptation using three configured BWPs for an NR carrier.

[0013] FIG. 10A illustrates three carrier aggregation configurations with two component carriers.

[0014] FIG. 10B illustrates an example of how aggregated cells may be configured into one or more PUCCH groups.

[0015] FIG. 11A illustrates an example of an SS/PBCH block structure and location.

[0016] FIG. 11B illustrates an example of CSI-RSs that are mapped in the time and frequency domains.

[0017] FIG. 12A and FIG. 12B respectively illustrate examples of three downlink and uplink beam management procedures.

[0018] FIG. 13A, FIG. 13B, and FIG. 13C respectively illustrate a four-step contention-based random access procedure, a two-step contention-free random access procedure, and another two-step random access procedure.

[0019] FIG. 14A illustrates an example of CORESET configurations for a bandwidth part.

[0020] FIG. 14B illustrates an example of a CCE-to-REG mapping for DCI transmission on a CORESET and PDCCH processing.

[0021] FIG. 15 illustrates an example of a wireless device in communication with a base station.

[0022] FIG. 16A, FIG. 16B, FIG. 16C, and FIG. 16D illustrate example structures for uplink and downlink transmission.

[0023] FIG. 17A illustrates an example of NTN architecture corresponding to a satellite with on-board transparent payload model as per an aspect of an embodiment of the present disclosure.

[0024] FIG. 17B illustrates an example NTN architecture corresponding to a satellite with on-board regenerative payload model as per an aspect of an embodiment of the present disclosure.

[0025] FIG. 18 illustrates examples of deployments of various platform types.

[0026] FIG. 19 illustrates examples of propagation delay corresponding to satellites types of different altitudes and different elevation angle (degrees).

[0027] FIG. 20A and FIG. 20B illustrate examples of service link with maximum propagation delay of the cell/beam.

[0028] FIG. 21A illustrates an example that UE1 locates near cell center and UE2 locates at cell edge in terrestrial network.

[0029] FIG. 21B illustrates an example that UE1 locates near cell center and UE2 locates at cell edge in NTN.

[0030] FIG. 22 illustrates an example of an NTN.

[0031] FIG. 23 illustrates an example of reporting a UE measurement information after a successful handover.

[0032] FIG. 24 illustrates an example of reporting a UE measurement information after a handover failure.

[0033] FIG. 25 illustrates an example of reporting a UE measurement information after an RLF detection.

[0034] FIG. 26A and FIG.26B illustrate examples that a UE performs (e.g., initiates and/or triggers) CHO to a CHO candidate cell.

[0035] FIG. 27A and FIG.27B illustrate examples that a UE performs (e.g., initiates and/or triggers) CHO to a CHO candidate cell.

[0036] FIG. 28 illustrates an example scenario where a UE is approaching the target cell (e.g. CHO candidate cell) from inside the first cell boundary of the source cell.

[0037] FIG. 29 illustrates an example scenario that the UE approaches to the target cell while the UE is located outside of the second cell boundary of the source cell.

[0038] FIG. 30 illustrates an example scenario where the UE gets inside the third cell boundary of the target cell.

[0039] FIG. 31 illustrates an example scenario where the UE gets inside the fourth cell boundary of the target cell.

[0040] FIG. 32 illustrates an embodiment which shows the UE procedure by time since the CHO configuration is configured until the CHO is executed.

[0041] FIG. 33 illustrates an example that the UE may receive a handover command from a first base station.

[0042] FIG. 34 illustrates an example that the UE may receive a handover command from a first base station.

[0043] FIG. 35 illustrates an example that the the UE may receive a handover command from a first base station.

[0044] FIG. 36 illustrates an example that the UE the UE may receive a handover command from a first base station.

[0045] FIG. 37 illustrates an example flow diagram of example embodiments as per an aspect of an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0046] In the present disclosure, various embodiments are presented as examples of how the disclosed techniques may be implemented and/or how the disclosed techniques may be practiced in environments and scenarios. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the scope. In fact, after reading the description, it will be apparent to one skilled in the relevant art how to implement alternative embodiments. The present embodiments should not be limited by any of the described exemplary embodiments. The embodiments of the present disclosure will be described with reference to the accompanying drawings. Limitations, features, and/or elements from the disclosed example embodiments may be combined to create further embodiments within the scope of the disclosure. Any figures which highlight the functionality and advantages, are presented for example purposes only. The disclosed architecture is sufficiently flexible and configurable, such that it may be utilized in ways other than that shown. For example, the actions listed in any flowchart may be re-ordered or only optionally used in some embodiments.

[0047] Embodiments may be configured to operate as needed. The disclosed mechanism may be performed when certain criteria are met, for example, in a wireless device, a base station, a radio environment, a network, a combination of the above, and/or the like. Example criteria may be based, at least in part, on for example, wireless device or network node configurations, traffic load, initial system set up, packet sizes, traffic characteristics, a combination of the above, and/or the like. When the one or more criteria are met, various example embodiments may be applied. Therefore, it may be possible to implement example embodiments that selectively implement disclosed protocols.

[0048] A base station may communicate with a mix of wireless devices. Wireless devices and/or base stations may support multiple technologies, and/or multiple releases of the same technology. Wireless devices may have some specific capability(ies) depending on wireless device category and/or capability(ies). When this disclosure refers to a base station communicating with a plurality of wireless devices, this disclosure may refer to a subset of the total wireless devices in a coverage area. This disclosure may refer to, for example, a plurality of wireless devices of a given LTE or 5G release with a given capability and in a given sector of the base station. The plurality of wireless devices in this disclosure may refer to a selected plurality of wireless devices, and/or a subset of total wireless devices in a coverage area which perform according to disclosed methods, and/or the like. There may be a plurality of base stations or a plurality of wireless devices in a coverage area that may not comply with the disclosed methods, for example, those wireless devices or base stations may perform based on older releases of LTE or 5G technology.

[0049] In this disclosure, “a” and “an” and similar phrases are to be interpreted as “at least one” and “one or more.” Similarly, any term that ends with the suffix “(s)” is to be interpreted as “at least one” and “one or more.” In this disclosure, the term “may” is to be interpreted as “may, for example.” In other words, the term “may” is indicative that the phrase following the term “may” is an example of one of a multitude of suitable possibilities that may, or may not, be employed by one or more of the various embodiments. The terms “comprises” and “consists of”, as used herein, enumerate one or more components of the element being described. The term “comprises” is interchangeable with “includes” and does not exclude unenumerated components from being included in the element being described. By contrast, “consists of” provides a complete enumeration of the one or more components of the element being described. The term “based on”, as used herein, should be interpreted as “based at least in part on” rather than, for example, “based solely on”. The term “and/or” as used herein represents any possible combination of enumerated elements. For example, “A, B, and/or C” may represent A; B; C; A and B; A and C; B and C; or A, B, and C.

[0050] If A and B are sets and every element of A is an element of B, A is called a subset of B. In this specification, only non-empty sets and subsets are considered. For example, possible subsets of B = {cell1, cell2} are: {cell1}, {cell2}, and {cell1, cell2}. The phrase “based on” (or equally “based at least on”) is indicative that the phrase following the term “based on” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “in response to” (or equally “in response at least to”) is indicative that the phrase following the phrase “in response to” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “depending on” (or equally “depending at least to”) is indicative that the phrase following the phrase “depending on” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments. The phrase “employing/using” (or equally “employing/using at least”) is indicative that the phrase following the phrase “employing/using” is an example of one of a multitude of suitable possibilities that may, or may not, be employed to one or more of the various embodiments.

[0051] The term configured may relate to the capacity of a device whether the device is in an operational or non-operational state. Configured may refer to specific settings in a device that effect the operational characteristics of the device whether the device is in an operational or non-operational state. In other words, the hardware, software, firmware, registers, memory values, and/or the like may be “configured” within a device, whether the device is in an operational or nonoperational state, to provide the device with specific characteristics. Terms such as “a control message to cause in a device” may mean that a control message has parameters that may be used to configure specific characteristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

[0052] In this disclosure, parameters (or equally called, fields, or Information elements: IEs) may comprise one or more information objects, and an information object may comprise one or more other objects. For example, if parameter (IE) N comprises parameter (IE) M, and parameter (IE) M comprises parameter (IE) K, and parameter (IE) K comprises parameter (information element) J. Then, for example, N comprises K, and N comprises J. In an example embodiment, when one or more messages comprise a plurality of parameters, it implies that a parameter in the plurality of parameters is in at least one of the one or more messages, but does not have to be in each of the one or more messages.

[0053] Many features presented are described as being optional through the use of “may” or the use of parentheses. For the sake of brevity and legibility, the present disclosure does not explicitly recite each and every permutation that may be obtained by choosing from the set of optional features. The present disclosure is to be interpreted as explicitly disclosing all such permutations. For example, a system described as having three optional features may be embodied in seven ways, namely with just one of the three possible features, with any two of the three possible features or with three of the three possible features.

[0054] Many of the elements described in the disclosed embodiments may be implemented as modules. A module is defined here as an element that performs a defined function and has a defined interface to other elements. The modules described in this disclosure may be implemented in hardware, software in combination with hardware, firmware, wetware (e.g. hardware with a biological element) or a combination thereof, which may be behaviorally equivalent. For example, modules may be implemented as a software routine written in a computer language configured to be executed by a hardware machine (such as C, C++, Fortran, Java, Basic, Matlab or the like) or a modeling/simulation program such as Simulink, Stateflow, GNU Octave, or LabVIEWMathScript. It may be possible to implement modules using physical hardware that incorporates discrete or programmable analog, digital and/or quantum hardware. Examples of programmable hardware comprise: computers, microcontrollers, microprocessors, application-specific integrated circuits (ASICs); field programmable gate arrays (FPGAs); and complex programmable logic devices (CPLDs). Computers, microcontrollers and microprocessors are programmed using languages such as assembly, C, C++ or the like. FPGAs, ASICs and CPLDs are often programmed using hardware description languages (HDL) such as VHSIC hardware description language (VHDL) or Verilog that configure connections between internal hardware modules with lesser functionality on a programmable device. The mentioned technologies are often used in combination to achieve the result of a functional module.

[0055] FIG. 1A illustrates an example of a mobile communication network 100 in which embodiments of the present disclosure may be implemented. The mobile communication network 100 may be, for example, a public land mobile network (PLMN) run by a network operator. As illustrated in FIG. 1A, the mobile communication network 100 includes a core network (CN) 102, a radio access network (RAN) 104, and a wireless device 106.

[0056] The CN 102 may provide the wireless device 106 with an interface to one or more data networks (DNs), such as public DNs (e.g., the Internet), private DNs, and/or intra-operator DNs. As part of the interface functionality, the CN 102 may set up end-to-end connections between the wireless device 106 and the one or more DNs, authenticate the wireless device 106, and provide charging functionality.

[0057] The RAN 104 may connect the CN 102 to the wireless device 106 through radio communications over an air interface. As part of the radio communications, the RAN 104 may provide scheduling, radio resource management, and retransmission protocols. The communication direction from the RAN 104 to the wireless device 106 over the air interface is known as the downlink and the communication direction from the wireless device 106 to the RAN 104 over the air interface is known as the uplink. Downlink transmissions may be separated from uplink transmissions using frequency division duplexing (FDD), time-division duplexing (TDD), and/or some combination of the two duplexing techniques.

[0058] The term wireless device may be used throughout this disclosure to refer to and encompass any mobile device or fixed (non-mobile) device for which wireless communication is needed or usable. For example, a wireless device may be a telephone, smart phone, tablet, computer, laptop, sensor, meter, wearable device, Internet of Things (IoT) device, vehicle road side unit (RSU), relay node, automobile, and/or any combination thereof. The term wireless device encompasses other terminology, including user equipment (UE), user terminal (UT), access terminal (AT), mobile station, handset, wireless transmit and receive unit (WTRU), and/or wireless communication device.

[0059] The RAN 104 may include one or more base stations (not shown). The term base station may be used throughout this disclosure to refer to and encompass a Node B (associated with UMTS and/or 3G standards), an Evolved Node B (eNB, associated with E-UTRA and/or 4G standards), a remote radio head (RRH), a baseband processing unit coupled to one or more RRHs, a repeater node or relay node used to extend the coverage area of a donor node, a Next Generation Evolved Node B (ng-eNB), a Generation Node B (gNB, associated with NR and/or 5G standards), an access point (AP, associated with, for example, WiFi or any other suitable wireless communication standard), and/or any combination thereof. A base station may comprise at least one gNB Central Unit (gNB-CU) and at least one a gNB Distributed Unit (gNB-DU).

[0060] A base station included in the RAN 104 may include one or more sets of antennas for communicating with the wireless device 106 over the air interface. For example, one or more of the base stations may include three sets of antennas to respectively control three cells (or sectors). The size of a cell may be determined by a range at which a receiver (e.g., a base station receiver) can successfully receive the transmissions from a transmitter (e.g., a wireless device transmitter) operating in the cell. Together, the cells of the base stations may provide radio coverage to the wireless device 106 over a wide geographic area to support wireless device mobility.

[0061] In addition to three-sector sites, other implementations of base stations are possible. For example, one or more of the base stations in the RAN 104 may be implemented as a sectored site with more or less than three sectors. One or more of the base stations in the RAN 104 may be implemented as an access point, as a baseband processing unit coupled to several remote radio heads (RRHs), and/or as a repeater or relay node used to extend the coverage area of a donor node. A baseband processing unit coupled to RRHs may be part of a centralized or cloud RAN architecture, where the baseband processing unit may be either centralized in a pool of baseband processing units or virtualized. A repeater node may amplify and rebroadcast a radio signal received from a donor node. A relay node may perform the same/similar functions as a repeater node but may decode the radio signal received from the donor node to remove noise before amplifying and rebroadcasting the radio signal.

[0062] The RAN 104 may be deployed as a homogenous network of macrocell base stations that have similar antenna patterns and similar high-level transmit powers. The RAN 104 may be deployed as a heterogeneous network. In heterogeneous networks, small cell base stations may be used to provide small coverage areas, for example, coverage areas that overlap with the comparatively larger coverage areas provided by macrocell base stations. The small coverage areas may be provided in areas with high data traffic (or so-called “hotspots”) or in areas with weak macrocell coverage. Examples of small cell base stations include, in order of decreasing coverage area, microcell base stations, picocell base stations, and femtocell base stations or home base stations.

[0063] The Third-Generation Partnership Project (3GPP) was formed in 1998 to provide global standardization of specifications for mobile communication networks similar to the mobile communication network 100 in FIG. 1A. To date, 3GPP has produced specifications for three generations of mobile networks: a third generation (3G) network known as Universal Mobile Telecommunications System (UMTS), a fourth generation (4G) network known as Long-Term Evolution (LTE), and a fifth generation (5G) network known as 5G System (5GS). Embodiments of the present disclosure are described with reference to the RAN of a 3GPP 5G network, referred to as next-generation RAN (NG-RAN). Embodiments may be applicable to RANs of other mobile communication networks, such as the RAN 104 in FIG. 1A, the RANs of earlier 3G and 4G networks, and those of future networks yet to be specified (e.g., a 3GPP 6G network). NG-RAN implements 5G radio access technology known as New Radio (NR) and may be provisioned to implement 4G radio access technology or other radio access technologies, including non-3GPP radio access technologies.

[0064] FIG. 1B illustrates another example mobile communication network 150 in which embodiments of the present disclosure may be implemented. Mobile communication network 150 may be, for example, a PLMN run by a network operator. As illustrated in FIG. 1B, mobile communication network 150 includes a 5G core network (5G-CN) 152, an NG-RAN 154, and UEs 156A and 156B (collectively UEs 156). These components may be implemented and operate in the same or similar manner as corresponding components described with respect to FIG. 1A.

[0065] The 5G-CN 152 provides the UEs 156 with an interface to one or more DNs, such as public DNs (e.g., the Internet), private DNs, and/or intra-operator DNs. As part of the interface functionality, the 5G-CN 152 may set up end-to-end connections between the UEs 156 and the one or more DNs, authenticate the UEs 156, and provide charging functionality. Compared to the CN of a 3GPP 4G network, the basis of the 5G-CN 152 may be a service-based architecture. This means that the architecture of the nodes making up the 5G-CN 152 may be defined as network functions that offer services via interfaces to other network functions. The network functions of the 5G-CN 152 may be implemented in several ways, including as network elements on dedicated or shared hardware, as software instances running on dedicated or shared hardware, or as virtualized functions instantiated on a platform (e.g., a cloud-based platform).

[0066] As illustrated in FIG. 1B, the 5G-CN 152 includes an Access and Mobility Management Function (AMF) 158A and a User Plane Function (UPF) 158B, which are shown as one component AMF/UPF 158 in FIG. 1B for ease of illustration. The UPF 158B may serve as a gateway between the NG-RAN 154 and the one or more DNs. The UPF 158B may perform functions such as packet routing and forwarding, packet inspection and user plane policy rule enforcement, traffic usage reporting, uplink classification to support routing of traffic flows to the one or more DNs, quality of service (QoS) handling for the user plane (e.g., packet filtering, gating, uplink/downlink rate enforcement, and uplink traffic verification), downlink packet buffering, and downlink data notification triggering. The UPF 158B may serve as an anchor point for intra-/inter-Radio Access Technology (RAT) mobility, an external protocol (or packet) data unit (PDU) session point of interconnect to the one or more DNs, and/or a branching point to support a multi-homed PDU session. The UEs 156 may be configured to receive services through a PDU session, which is a logical connection between a UE and a DN.

[0067] The AMF 158A may perform functions such as Non-Access Stratum (NAS) signaling termination, NAS signaling security, Access Stratum (AS) security control, inter-CN node signaling for mobility between 3GPP access networks, idle mode UE reachability (e.g., control and execution of paging retransmission), registration area management, intra-system and inter-system mobility support, access authentication, access authorization including checking of roaming rights, mobility management control (subscription and policies), network slicing support, and/or session management function (SMF) selection. NAS may refer to the functionality operating between a CN and a UE, and AS may refer to the functionality operating between the UE and a RAN.

[0068] The 5G-CN 152 may include one or more additional network functions that are not shown in FIG. 1B for the sake of clarity. For example, the 5G-CN 152 may include one or more of a Session Management Function (SMF), an NR Repository Function (NRF), a Policy Control Function (PCF), a Network Exposure Function (NEF), a Unified Data Management (UDM), an Application Function (AF), and/or an Authentication Server Function (AUSF).

[0069] The NG-RAN 154 may connect the 5G-CN 152 to the UEs 156 through radio communications over the air interface. The NG-RAN 154 may include one or more gNBs, illustrated as gNB 160A and gNB 160B (collectively gNBs 160) and/or one or more ng-eNBs, illustrated as ng-eNB 162A and ng-eNB 162B (collectively ng-eNBs 162). The gNBs 160 and ng-eNBs 162 may be more generically referred to as base stations. The gNBs 160 and ng-eNBs 162 may include one or more sets of antennas for communicating with the UEs 156 over an air interface. For example, one or more of the gNBs 160 and/or one or more of the ng-eNBs 162 may include three sets of antennas to respectively control three cells (or sectors). Together, the cells of the gNBs 160 and the ng-eNBs 162 may provide radio coverage to the UEs 156 over a wide geographic area to support UE mobility.

[0070] As shown in FIG. 1B, the gNBs 160 and/or the ng-eNBs 162 may be connected to the 5G-CN 152 by means of an NG interface and to other base stations by an Xn interface. The NG and Xn interfaces may be established using direct physical connections and/or indirect connections over an underlying transport network, such as an internet protocol (IP) transport network. The gNBs 160 and/or the ng-eNBs 162 may be connected to the UEs 156 by means of a Uu interface. For example, as illustrated in FIG. 1B, gNB 160A may be connected to the UE 156A by means of a Uu interface. The NG, Xn, and Uu interfaces are associated with a protocol stack. The protocol stacks associated with the interfaces may be used by the network elements in FIG. 1B to exchange data and signaling messages and may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user. The control plane may handle signaling messages of interest to the network elements.

[0071] The gNBs 160 and/or the ng-eNBs 162 may be connected to one or more AMF/UPF functions of the 5G-CN 152, such as the AMF/UPF 158, by means of one or more NG interfaces. For example, the gNB 160A may be connected to the UPF 158B of the AMF/UPF 158 by means of an NG-User plane (NG-U) interface. The NG-U interface may provide delivery (e.g., non-guaranteed delivery) of user plane PDUs between the gNB 160A and the UPF 158B. The gNB 160A may be connected to the AMF 158A by means of an NG-Control plane (NG-C) interface. The NG-C interface may provide, for example, NG interface management, UE context management, UE mobility management, transport of NAS messages, paging, PDU session management, and configuration transfer and/or warning message transmission.

[0072] The gNBs 160 may provide NR user plane and control plane protocol terminations towards the UEs 156 over the Uu interface. For example, the gNB 160A may provide NR user plane and control plane protocol terminations toward the UE 156A over a Uu interface associated with a first protocol stack. The ng-eNBs 162 may provide Evolved UMTS Terrestrial Radio Access (E-UTRA) user plane and control plane protocol terminations towards the UEs 156 over a Uu interface, where E-UTRA refers to the 3GPP 4G radio-access technology. For example, the ng-eNB 162B may provide E-UTRA user plane and control plane protocol terminations towards the UE 156B over a Uu interface associated with a second protocol stack.

[0073] The 5G-CN 152 was described as being configured to handle NR and 4G radio accesses. It will be appreciated by one of ordinary skill in the art that it may be possible for NR to connect to a 4G core network in a mode known as “non-standalone operation.” In non-standalone operation, a 4G core network is used to provide (or at least support) control-plane functionality (e.g., initial access, mobility, and paging). Although only one AMF/UPF 158 is shown in FIG. 1B, one gNB or ng-eNB may be connected to multiple AMF/UPF nodes to provide redundancy and/or to load share across the multiple AMF/UPF nodes.

[0074] As discussed, an interface (e.g., Uu, Xn, and NG interfaces) between the network elements in FIG. 1B may be associated with a protocol stack that the network elements use to exchange data and signaling messages. A protocol stack may include two planes: a user plane and a control plane. The user plane may handle data of interest to a user, and the control plane may handle signaling messages of interest to the network elements.

[0075] FIG. 2A and FIG. 2B respectively illustrate examples of NR user plane and NR control plane protocol stacks for the Uu interface that lies between a UE 210 and a gNB 220. The protocol stacks illustrated in FIG. 2A and FIG. 2B may be the same or similar to those used for the Uu interface between, for example, the UE 156A and the gNB 160A shown in FIG. 1B.

[0076] FIG. 2A illustrates a NR user plane protocol stack comprising five layers implemented in the UE 210 and the gNB 220. At the bottom of the protocol stack, physical layers (PHYs) 211 and 221 may provide transport services to the higher layers of the protocol stack and may correspond to layer 1 of the Open Systems Interconnection (OSI) model. The next four protocols above PHYs 211 and 221 comprise media access control layers (MACs) 212 and 222, radio link control layers (RLCs) 213 and 223, packet data convergence protocol layers (PDCPs) 214 and 224, and service data application protocol layers (SDAPs) 215 and 225. Together, these four protocols may make up layer 2, or the data link layer, of the OSI model.

[0077] FIG. 3 illustrates an example of services provided between protocol layers of the NR user plane protocol stack. Starting from the top of FIG. 2A and FIG. 3, the SDAPs 215 and 225 may perform QoS flow handling. The UE 210 may receive services through a PDU session, which may be a logical connection between the UE 210 and a DN. The PDU session may have one or more QoS flows. A UPF of a CN (e.g., the UPF 158B) may map IP packets to the one or more QoS flows of the PDU session based on QoS requirements (e.g., in terms of delay, data rate, and/or error rate). The SDAPs 215 and 225 may perform mapping/de-mapping between the one or more QoS flows and one or more data radio bearers. The mapping/de-mapping between the QoS flows and the data radio bearers may be determined by the SDAP 225 at the gNB 220. The SDAP 215 at the UE 210 may be informed of the mapping between the QoS flows and the data radio bearers through reflective mapping or control signaling received from the gNB 220. For reflective mapping, the SDAP 225 at the gNB 220 may mark the downlink packets with a QoS flow indicator (QFI), which may be observed by the SDAP 215 at the UE 210 to determine the mapping/de-mapping between the QoS flows and the data radio bearers.

[0078] The PDCPs 214 and 224 may perform header compression/decompression to reduce the amount of data that needs to be transmitted over the air interface, ciphering/deciphering to prevent unauthorized decoding of data transmitted over the air interface, and integrity protection (to ensure control messages originate from intended sources. The PDCPs 214 and 224 may perform retransmissions of undelivered packets, in-sequence delivery and reordering of packets, and removal of packets received in duplicate due to, for example, an intra-gNB handover. The PDCPs 214 and 224 may perform packet duplication to improve the likelihood of the packet being received and, at the receiver, remove any duplicate packets. Packet duplication may be useful for services that require high reliability.

[0079] Although not shown in FIG. 3, PDCPs 214 and 224 may perform mapping/de-mapping between a split radio bearer and RLC channels in a dual connectivity scenario. Dual connectivity is a technique that allows a UE to connect to two cells or, more generally, two cell groups: a master cell group (MCG) and a secondary cell group (SCG). A split bearer is when a single radio bearer, such as one of the radio bearers provided by the PDCPs 214 and 224 as a service to the SDAPs 215 and 225, is handled by cell groups in dual connectivity. The PDCPs 214 and 224 may map/de-map the split radio bearer between RLC channels belonging to cell groups.

[0080] The RLCs 213 and 223 may perform segmentation, retransmission through Automatic Repeat Request (ARQ), and removal of duplicate data units received from MACs 212 and 222, respectively. The RLCs 213 and 223 may support three transmission modes: transparent mode (TM); unacknowledged mode (UM); and acknowledged mode (AM). Based on the transmission mode an RLC is operating, the RLC may perform one or more of the noted functions. The RLC configuration may be per logical channel with no dependency on numerologies and/or Transmission Time Interval (TTI) durations. As shown in FIG. 3, the RLCs 213 and 223 may provide RLC channels as a service to PDCPs 214 and 224, respectively.

[0081] The MACs 212 and 222 may perform multiplexing/demultiplexing of logical channels and/or mapping between logical channels and transport channels. The multiplexing/demultiplexing may include multiplexing/demultiplexing of data units, belonging to the one or more logical channels, into/from Transport Blocks (TBs) delivered to/from the PHYs 211 and 221. The MAC 222 may be configured to perform scheduling, scheduling information reporting, and priority handling between UEs by means of dynamic scheduling. Scheduling may be performed in the gNB 220 (at the MAC 222) for downlink and uplink. The MACs 212 and 222 may be configured to perform error correction through Hybrid Automatic Repeat Request (HARQ) (e.g., one HARQ entity per carrier in case of Carrier Aggregation (CA)), priority handling between logical channels of the UE 210 by means of logical channel prioritization, and/or padding. The MACs 212 and 222 may support one or more numerologies and/or transmission timings. In an example, mapping restrictions in a logical channel prioritization may control which numerology and/or transmission timing a logical channel may use. As shown in FIG. 3, the MACs 212 and 222 may provide logical channels as a service to the RLCs 213 and 223.

[0082] The PHYs 211 and 221 may perform mapping of transport channels to physical channels and digital and analog signal processing functions for sending and receiving information over the air interface. These digital and analog signal processing functions may include, for example, coding/decoding and modulation/demodulation. The PHYs 211 and 221 may perform multi-antenna mapping. As shown in FIG. 3, the PHYs 211 and 221 may provide one or more transport channels as a service to the MACs 212 and 222.

[0083] FIG. 4A illustrates an example downlink data flow through the NR user plane protocol stack. FIG. 4A illustrates a downlink data flow of three IP packets (*n*, *n+1*, and *m*) through the NR user plane protocol stack to generate two TBs at the gNB 220. An uplink data flow through the NR user plane protocol stack may be similar to the downlink data flow depicted in FIG. 4A.

[0084] The downlink data flow of FIG. 4A begins when SDAP 225 receives the three IP packets from one or more QoS flows and maps the three packets to radio bearers. In FIG. 4A, the SDAP 225 maps IP packets *n* and *n+1* to a first radio bearer 402 and maps IP packet *m* to a second radio bearer 404. An SDAP header (labeled with an “H” in FIG. 4A) is added to an IP packet. The data unit from/to a higher protocol layer is referred to as a service data unit (SDU) of the lower protocol layer and the data unit to/from a lower protocol layer is referred to as a protocol data unit (PDU) of the higher protocol layer. As shown in FIG. 4A, the data unit from the SDAP 225 is an SDU of lower protocol layer PDCP 224 and is a PDU of the SDAP 225.

[0085] The remaining protocol layers in FIG. 4A may perform their associated functionality (e.g., with respect to FIG. 3), add corresponding headers, and forward their respective outputs to the next lower layer. For example, the PDCP 224 may perform IP-header compression and ciphering and forward its output to the RLC 223. The RLC 223 may optionally perform segmentation (e.g., as shown for IP packet *m* in FIG. 4A) and forward its output to the MAC 222. The MAC 222 may multiplex a number of RLC PDUs and may attach a MAC subheader to an RLC PDU to form a transport block. In NR, the MAC subheaders may be distributed across the MAC PDU, as illustrated in FIG. 4A. In LTE, the MAC subheaders may be entirely located at the beginning of the MAC PDU. The NR MAC PDU structure may reduce processing time and associated latency because the MAC PDU subheaders may be computed before the full MAC PDU is assembled.

[0086] FIG. 4B illustrates an example format of a MAC subheader in a MAC PDU. The MAC subheader includes: an SDU length field for indicating the length (e.g., in bytes) of the MAC SDU to which the MAC subheader corresponds; a logical channel identifier (LCID) field for identifying the logical channel from which the MAC SDU originated to aid in the demultiplexing process; a flag (F) for indicating the size of the SDU length field; and a reserved bit (R) field for future use.

[0087] FIG. 4B further illustrates MAC control elements (CEs) inserted into the MAC PDU by a MAC, such as MAC 223 or MAC 222. For example, FIG. 4B illustrates two MAC CEs inserted into the MAC PDU. MAC CEs may be inserted at the beginning of a MAC PDU for downlink transmissions (as shown in FIG. 4B) and at the end of a MAC PDU for uplink transmissions. MAC CEs may be used for in-band control signaling. Example MAC CEs include: scheduling-related MAC CEs, such as buffer status reports and power headroom reports; activation/deactivation MAC CEs, such as those for activation/deactivation of PDCP duplication detection, channel state information (CSI) reporting, sounding reference signal (SRS) transmission, and prior configured components; discontinuous reception (DRX) related MAC CEs; timing advance MAC CEs; and random access related MAC CEs. A MAC CE may be preceded by a MAC subheader with a similar format as described for MAC SDUs and may be identified with a reserved value in the LCID field that indicates the type of control information included in the MAC CE.

[0088] Before describing the NR control plane protocol stack, logical channels, transport channels, and physical channels are first described as well as a mapping between the channel types. One or more of the channels may be used to carry out functions associated with the NR control plane protocol stack described later below.

[0089] FIG. 5A and FIG. 5B illustrate, for downlink and uplink respectively, a mapping between logical channels, transport channels, and physical channels. Information is passed through channels between the RLC, the MAC, and the PHY of the NR protocol stack. A logical channel may be used between the RLC and the MAC and may be classified as a control channel that carries control and configuration information in the NR control plane or as a traffic channel that carries data in the NR user plane. A logical channel may be classified as a dedicated logical channel that is dedicated to a specific UE or as a common logical channel that may be used by more than one UE. A logical channel may also be defined by the type of information it carries. The set of logical channels defined by NR include, for example:

- a paging control channel (PCCH) for carrying paging messages used to page a UE whose location is not known to the network on a cell level;
- a broadcast control channel (BCCH) for carrying system information messages in the form of a master information block (MIB) and several system information blocks (SIBs), wherein the system information messages may be used by the UEs to obtain information about how a cell is configured and how to operate within the cell;
- a common control channel (CCCH) for carrying control messages together with random access;
- a dedicated control channel (DCCH) for carrying control messages to/from a specific the UE to configure the UE; and
- a dedicated traffic channel (DTCH) for carrying user data to/from a specific the UE.

[0090] Transport channels are used between the MAC and PHY layers and may be defined by how the information they carry is transmitted over the air interface. The set of transport channels defined by NR include, for example:

- a paging channel (PCH) for carrying paging messages that originated from the PCCH;
- a broadcast channel (BCH) for carrying the MIB from the BCCH;

- a downlink shared channel (DL-SCH) for carrying downlink data and signaling messages, including the SIBs from the BCCH;
- an uplink shared channel (UL-SCH) for carrying uplink data and signaling messages; and
- a random access channel (RACH) for allowing a UE to contact the network without any prior scheduling.

[0091] The PHY may use physical channels to pass information between processing levels of the PHY. A physical channel may have an associated set of time-frequency resources for carrying the information of one or more transport channels. The PHY may generate control information to support the low-level operation of the PHY and provide the control information to the lower levels of the PHY via physical control channels, known as L1/L2 control channels. The set of physical channels and physical control channels defined by NR include, for example:

- a physical broadcast channel (PBCH) for carrying the MIB from the BCH;
- a physical downlink shared channel (PDSCH) for carrying downlink data and signaling messages from the DL-SCH, as well as paging messages from the PCH;
- a physical downlink control channel (PDCCH) for carrying downlink control information (DCI), which may include downlink scheduling commands, uplink scheduling grants, and uplink power control commands;
- a physical uplink shared channel (PUSCH) for carrying uplink data and signaling messages from the UL-SCH and in some instances uplink control information (UCI) as described below;
- a physical uplink control channel (PUCCH) for carrying UCI, which may include HARQ acknowledgments, channel quality indicators (CQI), pre-coding matrix indicators (PMI), rank indicators (RI), and scheduling requests (SR); and
- a physical random access channel (PRACH) for random access.

[0092] Similar to the physical control channels, the physical layer generates physical signals to support the low-level operation of the physical layer. As shown in FIG. 5A and FIG. 5B, the physical layer signals defined by NR include: primary synchronization signals (PSS), secondary synchronization signals (SSS), channel state information reference signals (CSI-RS), demodulation reference signals (DMRS), sounding reference signals (SRS), and phase-tracking reference signals (PT-RS). These physical layer signals will be described in greater detail below.

[0093] FIG. 2B illustrates an example NR control plane protocol stack. As shown in FIG. 2B, the NR control plane protocol stack may use the same/similar first four protocol layers as the example NR user plane protocol stack. These four protocol layers include the PHYs 211 and 221, the MACs 212 and 222, the RLCs 213 and 223, and the PDCPs 214 and 224. Instead of having the SDAPs 215 and 225 at the top of the stack as in the NR user plane protocol stack, the NR control plane stack has radio resource controls (RRCs) 216 and 226 and NAS protocols 217 and 237 at the top of the NR control plane protocol stack.

[0094] The NAS protocols 217 and 237 may provide control plane functionality between the UE 210 and the AMF 230 (e.g., the AMF 158A) or, more generally, between the UE 210 and the CN. The NAS protocols 217 and 237 may provide control plane functionality between the UE 210 and the AMF 230 via signaling messages, referred to as NAS messages. There is no direct path between the UE 210 and the AMF 230 through which the NAS messages can be transported. The NAS messages may be transported using the AS of the Uu and NG interfaces. NAS protocols 217 and 237 may provide control plane functionality such as authentication, security, connection setup, mobility management, and session management.

[0095] The RRCs 216 and 226 may provide control plane functionality between the UE 210 and the gNB 220 or, more generally, between the UE 210 and the RAN. The RRCs 216 and 226 may provide control plane functionality between the UE 210 and the gNB 220 via signaling messages, referred to as RRC messages. RRC messages may be transmitted between the UE 210 and the RAN using signaling radio bearers and the same/similar PDCP, RLC, MAC, and PHY protocol layers. The MAC may multiplex control-plane and user-plane data into the same transport block (TB). The RRCs 216 and 226 may provide control plane functionality such as: broadcast of system information related to AS and NAS; paging initiated by the CN or the RAN; establishment, maintenance and release of an RRC connection between the UE 210 and the RAN; security functions including key management; establishment, configuration, maintenance and release of signaling radio bearers and data radio bearers; mobility functions; QoS management functions; the UE measurement reporting and control of the reporting; detection of and recovery from radio link failure (RLF); and/or NAS message transfer. As part of establishing an RRC connection, RRCs 216 and 226 may establish an RRC context, which may involve configuring parameters for communication between the UE 210 and the RAN.

[0096] FIG. 6 is an example diagram showing RRC state transitions of a UE. The UE may be the same or similar to the wireless device 106 depicted in FIG. 1A, the UE 210 depicted in FIG. 2A and FIG. 2B, or any other wireless device described in the present disclosure. As illustrated in FIG. 6, a UE may be in at least one of three RRC states: RRC connected 602 (e.g., RRC_CONNECTED), RRC idle 604 (e.g., RRC_IDLE), and RRC inactive 606 (e.g., RRC_INACTIVE).

[0097] In RRC connected 602, the UE has an established RRC context and may have at least one RRC connection with a base station. The base station may be similar to one of the one or more base stations included in the RAN 104 depicted in FIG. 1A, one of the gNBs 160 or ng-eNBs 162 depicted in FIG. 1B, the gNB 220 depicted in FIG. 2A and FIG. 2B, or any other base station described in the present disclosure. The base station with which the UE is connected may have the RRC context for the UE. The RRC context, referred to as the UE context, may comprise parameters for communication between the UE and the base station. These parameters may include, for example: one or more AS contexts; one or more radio link configuration parameters; bearer configuration information (e.g., relating to a data radio bearer, signaling radio bearer, logical channel, QoS flow, and/or PDU session); security information; and/or PHY, MAC, RLC, PDCP, and/or SDAP layer configuration information. While in RRC connected 602, mobility of the UE may be managed by the RAN (e.g., the RAN 104 or the NG-RAN 154). The UE may measure the signal levels (e.g., reference signal levels) from a serving cell and neighboring cells and report these measurements to the base station currently serving the UE. The UE's serving base station may request a handover to a cell of one of the neighboring base stations based on the reported measurements. The RRC state may transition from RRC connected 602 to RRC idle 604 through a connection release procedure 608 or to RRC inactive 606 through a connection inactivation procedure 610.

[0098] In RRC idle 604, an RRC context may not be established for the UE. In RRC idle 604, the UE may not have an RRC connection with the base station. While in RRC idle 604, the UE may be in a sleep state for the majority of the time (e.g., to conserve battery power). The UE may wake up periodically (e.g., once in every discontinuous reception cycle) to monitor for paging messages from the RAN. Mobility of the UE may be managed by the UE through a procedure known as cell reselection. The RRC state may transition from RRC idle 604 to RRC connected 602 through a connection establishment procedure 612, which may involve a random access procedure as discussed in greater detail below.

[0099] In RRC inactive 606, the RRC context previously established is maintained in the UE and the base station. This allows for a fast transition to RRC connected 602 with reduced signaling overhead as compared to the transition from RRC idle 604 to RRC connected 602. While in RRC inactive 606, the UE may be in a sleep state and mobility of the UE may be managed by the UE through cell reselection. The RRC state may transition from RRC inactive 606 to RRC connected 602 through a connection resume procedure 614 or to RRC idle 604 though a connection release procedure 616 that may be the same as or similar to connection release procedure 608.

[0100] An RRC state may be associated with a mobility management mechanism. In RRC idle 604 and RRC inactive 606, mobility is managed by the UE through cell reselection. The purpose of mobility management in RRC idle 604 and RRC inactive 606 is to allow the network to be able to notify the UE of an event via a paging message without having to broadcast the paging message over the entire mobile communications network. The mobility management mechanism used in RRC idle 604 and RRC inactive 606 may allow the network to track the UE on a cell-group level so that the paging message may be broadcast over the cells of the cell group that the UE currently resides within instead of the entire mobile communication network. The mobility management mechanisms for RRC idle 604 and RRC inactive 606 track the UE on a cell-group level. They may do so using different granularities of grouping. For example, there may be three levels of cell-grouping granularity: individual cells; cells within a RAN area identified by a RAN area identifier (RAI); and cells within a group of RAN areas, referred to as a tracking area and identified by a tracking area identifier (TAI).

[0101] Tracking areas may be used to track the UE at the CN level. The CN (e.g., the CN 102 or the 5G-CN 152) may provide the UE with a list of TAIs associated with a UE registration area. If the UE moves, through cell reselection, to a cell associated with a TAI not included in the list of TAIs associated with the UE registration area, the UE may perform a registration update with the CN to allow the CN to update the UE's location and provide the UE with a new the UE registration area.

[0102] RAN areas may be used to track the UE at the RAN level. For a UE in RRC inactive 606 state, the UE may be assigned a RAN notification area. A RAN notification area may comprise one or more cell identities, a list of RAIs, or a list of TAIs. In an example, a base station may belong to one or more RAN notification areas. In an example, a cell may belong to one or more RAN notification areas. If the UE moves, through cell reselection, to a cell not included in the RAN notification area assigned to the UE, the UE may perform a notification area update with the RAN to update the UE's RAN notification area.

[0103] A base station storing an RRC context for a UE or a last serving base station of the UE may be referred to as an anchor base station. An anchor base station may maintain an RRC context for the UE at least during a period of time that the UE stays in a RAN notification area of the anchor base station and/or during a period of time that the UE stays in RRC inactive 606.

[0104] A gNB, such as gNBs 160 in FIG. 1B, may be split in two parts: a central unit (gNB-CU), and one or more distributed units (gNB-DU). A gNB-CU may be coupled to one or more gNB-DUs using an F1 interface. The gNB-CU may comprise the RRC, the PDCP, and the SDAP. A gNB-DU may comprise the RLC, the MAC, and the PHY.

[0105] In NR, the physical signals and physical channels (discussed with respect to FIG. 5A and FIG. 5B) may be mapped onto orthogonal frequency divisional multiplexing (OFDM) symbols. OFDM is a multicarrier communication scheme that transmits data over *F* orthogonal subcarriers (or tones). Before transmission, the data may be mapped to a series of complex symbols (e.g., M-quadrature amplitude modulation (M-QAM) or M-phase shift keying (M-PSK) symbols), referred to as source symbols, and divided into *F* parallel symbol streams. The *F* parallel symbol streams may be treated as though they are in the frequency domain and used as inputs to an Inverse Fast Fourier Transform (IFFT) block that transforms them into the time domain. The IFFT block may take in *F* source symbols at a time, one from each of the *F* parallel symbol streams, and use each source symbol to modulate the amplitude and phase of one of *F* sinusoidal basis functions that correspond to the *F* orthogonal subcarriers. The output of the IFFT block may be *F* time-domain samples that represent the summation of the *F* orthogonal subcarriers. The *F* time-domain samples may form a single OFDM symbol. After some processing (e.g., addition of a cyclic prefix) and up-conversion, an OFDM symbol provided by the IFFT block may be transmitted over the air interface on a carrier frequency. The *F* parallel symbol streams may be mixed using an FFT block before being processed by the IFFT block. This operation produces Discrete Fourier Transform (DFT)-precoded OFDM symbols and may be used by UEs in the uplink to reduce the peak to average power ratio (PAPR). Inverse processing may be performed on the OFDM symbol at a receiver using an FFT block to recover the data mapped to the source symbols.

[0106] FIG. 7 illustrates an example configuration of an NR frame into which OFDM symbols are grouped. An NR frame may be identified by a system frame number (SFN). The SFN may repeat with a period of 1024 frames. As illustrated, one NR frame may be 10 milliseconds (ms) in duration and may include 10 subframes that are 1 ms in duration. A subframe may be divided into slots that include, for example, 14 OFDM symbols per slot.

[0107] The duration of a slot may depend on the numerology used for the OFDM symbols of the slot. In NR, a flexible numerology is supported to accommodate different cell deployments (e.g., cells with carrier frequencies below 1 GHz up to cells with carrier frequencies in the mm-wave range). A numerology may be defined in terms of subcarrier spacing and cyclic prefix duration. For a numerology in NR, subcarrier spacings may be scaled up by powers of two from a baseline subcarrier spacing of 15 kHz, and cyclic prefix durations may be scaled down by powers of two from a baseline cyclic prefix duration of 4.7 μs. For example, NR defines numerologies with the following subcarrier spacing/cyclic prefix duration combinations: 15 kHz/4.7 μs; 30 kHz/2.3 μs; 60 kHz/1.2 μs; 120 kHz/0.59 μs; and 240 kHz/0.29 μs.

[0108] A slot may have a fixed number of OFDM symbols (e.g., 14 OFDM symbols). A numerology with a higher subcarrier spacing has a shorter slot duration and, correspondingly, more slots per subframe. FIG. 7 illustrates this numerology-dependent slot duration and slots-per-subframe transmission structure (the numerology with a subcarrier spacing of 240 kHz is not shown in FIG. 7 for ease of illustration). A subframe in NR may be used as a numerology-independent time reference, while a slot may be used as the unit upon which uplink and downlink transmissions are scheduled. To support low latency, scheduling in NR may be decoupled from the slot duration and start at any OFDM symbol and last for as many symbols as needed for a transmission. These partial slot transmissions may be referred to as mini-slot or subslot transmissions.

[0109] FIG. 8 illustrates an example configuration of a slot in the time and frequency domain for an NR carrier. The slot includes resource elements (REs) and resource blocks (RBs). An RE is the smallest physical resource in NR. An RE spans one OFDM symbol in the time domain by one subcarrier in the frequency domain as shown in FIG. 8. An RB spans twelve consecutive REs in the frequency domain as shown in FIG. 8. An NR carrier may be limited to a width of 275 RBs or 275×12 = 3300 subcarriers. Such a limitation, if used, may limit the NR carrier to 50, 100, 200, and 400 MHz for subcarrier spacings of 15, 30, 60, and 120 kHz, respectively, where the 400 MHz bandwidth may be set based on a 400 MHz per carrier bandwidth limit.

[0110] FIG. 8 illustrates a single numerology being used across the entire bandwidth of the NR carrier. In other example configurations, multiple numerologies may be supported on the same carrier.

[0111] NR may support wide carrier bandwidths (e.g., up to 400 MHz for a subcarrier spacing of 120 kHz). Not all UEs may be able to receive the full carrier bandwidth (e.g., due to hardware limitations). Also, receiving the full carrier bandwidth may be prohibitive in terms of UE power consumption. In an example, to reduce power consumption and/or for other purposes, a UE may adapt the size of the UE's receive bandwidth based on the amount of traffic the UE is scheduled to receive. This is referred to as bandwidth adaptation.

[0112] NR defines bandwidth parts (BWPs) to support UEs not capable of receiving the full carrier bandwidth and to support bandwidth adaptation. In an example, a BWP may be defined by a subset of contiguous RBs on a carrier. A UE may be configured (e.g., via RRC layer) with one or more downlink BWPs and one or more uplink BWPs per serving cell (e.g., up to four downlink BWPs and up to four uplink BWPs per serving cell). At a given time, one or more of the configured BWPs for a serving cell may be active. These one or more BWPs may be referred to as active BWPs of the serving cell. When a serving cell is configured with a secondary uplink carrier, the serving cell may have one or more first active BWPs in the uplink carrier and one or more second active BWPs in the secondary uplink carrier.

[0113] For unpaired spectra, a downlink BWP from a set of configured downlink BWPs may be linked with an uplink BWP from a set of configured uplink BWPs if a downlink BWP index of the downlink BWP and an uplink BWP index of the uplink BWP are the same. For unpaired spectra, a UE may expect that a center frequency for a downlink BWP is the same as a center frequency for an uplink BWP.

[0114] For a downlink BWP in a set of configured downlink BWPs on a primary cell (PCell), a base station may configure a UE with one or more control resource sets (CORESETs) for at least one search space. A search space is a set of locations in the time and frequency domains where the UE may find control information. The search space may be a UE-specific search space or a common search space (potentially usable by a plurality of UEs). For example, a base station may configure a UE with a common search space, on a PCell or on a primary secondary cell (PSCell), in an active downlink BWP.

[0115] For an uplink BWP in a set of configured uplink BWPs, a BS may configure a UE with one or more resource sets for one or more PUCCH transmissions. A UE may receive downlink receptions (e.g., PDCCH or PDSCH) in a downlink BWP according to a configured numerology (e.g., subcarrier spacing and cyclic prefix duration) for the downlink BWP. The UE may transmit uplink transmissions (e.g., PUCCH or PUSCH) in an uplink BWP according to a configured numerology (e.g., subcarrier spacing and cyclic prefix length for the uplink BWP).

[0116] One or more BWP indicator fields may be provided in Downlink Control Information (DCI). A value of a BWP indicator field may indicate which BWP in a set of configured BWPs is an active downlink BWP for one or more downlink receptions. The value of the one or more BWP indicator fields may indicate an active uplink BWP for one or more uplink transmissions.

[0117] A base station may semi-statically configure a UE with a default downlink BWP within a set of configured downlink BWPs associated with a PCell. If the base station does not provide the default downlink BWP to the UE, the default downlink BWP may be an initial active downlink BWP. The UE may determine which BWP is the initial active downlink BWP based on a CORESET configuration obtained using the PBCH.

[0118] A base station may configure a UE with a BWP inactivity timer value for a PCell. The UE may start or restart a BWP inactivity timer at any appropriate time. For example, the UE may start or restart the BWP inactivity timer (*a*) when the UE detects a DCI indicating an active downlink BWP other than a default downlink BWP for a paired spectra operation; or (*b*) when a UE detects a DCI indicating an active downlink BWP or active uplink BWP other than a default downlink BWP or uplink BWP for an unpaired spectra operation. If the UE does not detect DCI during an interval of time (e.g., 1 ms or 0.5 ms), the UE may run the BWP inactivity timer toward expiration (for example, increment from zero to the BWP inactivity timer value, or decrement from the BWP inactivity timer value to zero). When the BWP inactivity timer expires, the UE may switch from the active downlink BWP to the default downlink BWP.

[0119] In an example, a base station may semi-statically configure a UE with one or more BWPs. A UE may switch an active BWP from a first BWP to a second BWP in response to receiving a DCI indicating the second BWP as an active BWP and/or in response to an expiry of the BWP inactivity timer (e.g., if the second BWP is the default BWP).

[0120] Downlink and uplink BWP switching (where BWP switching refers to switching from a currently active BWP to a not currently active BWP) may be performed independently in paired spectra. In unpaired spectra, downlink and uplink BWP switching may be performed simultaneously. Switching between configured BWPs may occur based on RRC signaling, DCI, expiration of a BWP inactivity timer, and/or an initiation of random access.

[0121] FIG. 9 illustrates an example of bandwidth adaptation using three configured BWPs for an NR carrier. A UE configured with the three BWPs may switch from one BWP to another BWP at a switching point. In the example illustrated in FIG. 9, the BWPs include: a BWP 902 with a bandwidth of 40 MHz and a subcarrier spacing of 15 kHz; a

BWP 904 with a bandwidth of 10 MHz and a subcarrier spacing of 15 kHz; and a BWP 906 with a bandwidth of 20 MHz and a subcarrier spacing of 60 kHz. The BWP 902 may be an initial active BWP, and the BWP 904 may be a default BWP. The UE may switch between BWPs at switching points. In the example of FIG. 9, the UE may switch from the BWP 902 to the BWP 904 at a switching point 908. The switching at the switching point 908 may occur for any suitable reason, for example, in response to an expiry of a BWP inactivity timer (indicating switching to the default BWP) and/or in response to receiving a DCI indicating BWP 904 as the active BWP. The UE may switch at a switching point 910 from active BWP 904 to BWP 906 in response receiving a DCI indicating BWP 906 as the active BWP. The UE may switch at a switching point 912 from active BWP 906 to BWP 904 in response to an expiry of a BWP inactivity timer and/or in response receiving a DCI indicating BWP 904 as the active BWP. The UE may switch at a switching point 914 from active BWP 904 to BWP 902 in response receiving a DCI indicating BWP 902 as the active BWP.

[0122] If a UE is configured for a secondary cell with a default downlink BWP in a set of configured downlink BWPs and a timer value, UE procedures for switching BWPs on a secondary cell may be the same/similar as those on a primary cell. For example, the UE may use the timer value and the default downlink BWP for the secondary cell in the same/similar manner as the UE would use these values for a primary cell.

[0123] To provide for greater data rates, two or more carriers can be aggregated and simultaneously transmitted to/from the same UE using carrier aggregation (CA). The aggregated carriers in CA may be referred to as component carriers (CCs). When CA is used, there are a number of serving cells for the UE, one for a CC. The CCs may have three configurations in the frequency domain.

[0124] FIG. 10A illustrates the three CA configurations with two CCs. In the intraband, contiguous configuration 1002, the two CCs are aggregated in the same frequency band (frequency band A) and are located directly adjacent to each other within the frequency band. In the intraband, non-contiguous configuration 1004, the two CCs are aggregated in the same frequency band (frequency band A) and are separated in the frequency band by a gap. In the interband configuration 1006, the two CCs are located in frequency bands (frequency band A and frequency band B).

[0125] In an example, up to 32 CCs may be aggregated. The aggregated CCs may have the same or different bandwidths, subcarrier spacing, and/or duplexing schemes (TDD or FDD). A serving cell for a UE using CA may have a downlink CC. For FDD, one or more uplink CCs may be optionally configured for a serving cell. The ability to aggregate more downlink carriers than uplink carriers may be useful, for example, when the UE has more data traffic in the downlink than in the uplink.

[0126] When CA is used, one of the aggregated cells for a UE may be referred to as a primary cell (PCell). The PCell may be the serving cell that the UE initially connects to at RRC connection establishment, reestablishment, and/or handover. The PCell may provide the UE with NAS mobility information and the security input. UEs may have different PCells. In the downlink, the carrier corresponding to the PCell may be referred to as the downlink primary CC (DL PCC). In the uplink, the carrier corresponding to the PCell may be referred to as the uplink primary CC (UL PCC). The other aggregated cells for the UE may be referred to as secondary cells (SCells). In an example, the SCells may be configured after the PCell is configured for the UE. For example, an SCell may be configured through an RRC

Connection Reconfiguration procedure. In the downlink, the carrier corresponding to an SCell may be referred to as a downlink secondary CC (DL SCC). In the uplink, the carrier corresponding to the SCell may be referred to as the uplink secondary CC (UL SCC).

[0127] Configured SCells for a UE may be activated and deactivated based on, for example, traffic and channel conditions. Deactivation of an SCell may mean that PDCCH and PDSCH reception on the SCell is stopped and PUSCH, SRS, and CQI transmissions on the SCell are stopped. Configured SCells may be activated and deactivated using a MAC CE with respect to FIG. 4B. For example, a MAC CE may use a bitmap (e.g., one bit per SCell) to indicate which SCells (e.g., in a subset of configured SCells) for the UE are activated or deactivated. Configured SCells may be deactivated in response to an expiration of an SCell deactivation timer (e.g., one SCell deactivation timer per SCell).

[0128] Downlink control information, such as scheduling assignments and scheduling grants, for a cell may be transmitted on the cell corresponding to the assignments and grants, which is known as self-scheduling. The DCI for the cell may be transmitted on another cell, which is known as cross-carrier scheduling. Uplink control information (e.g., HARQ acknowledgments and channel state feedback, such as CQI, PMI, and/or RI) for aggregated cells may be transmitted on the PUCCH of the PCell. For a larger number of aggregated downlink CCs, the PUCCH of the PCell may become overloaded. Cells may be divided into multiple PUCCH groups.

[0129] FIG. 10B illustrates an example of how aggregated cells may be configured into one or more PUCCH groups. A PUCCH group 1010 and a PUCCH group 1050 may include one or more downlink CCs, respectively. In the example of FIG. 10B, the PUCCH group 1010 includes three downlink CCs: a PCell 1011, an SCell 1012, and an SCell 1013. The PUCCH group 1050 includes three downlink CCs in the present example: a PCell 1051, an SCell 1052, and an SCell 1053. One or more uplink CCs may be configured as a PCell 1021, an SCell 1022, and an SCell 1023. One or more other uplink CCs may be configured as a primary Scell (PSCell) 1061, an SCell 1062, and an SCell 1063. Uplink control information (UCI) related to the downlink CCs of the PUCCH group 1010, shown as UCI 1031, UCI 1032, and UCI 1033, may be transmitted in the uplink of the PCell 1021. Uplink control information (UCI) related to the downlink CCs of the PUCCH group 1050, shown as UCI 1071, UCI 1072, and UCI 1073, may be transmitted in the uplink of the PSCell 1061. In an example, if the aggregated cells depicted in FIG. 10B were not divided into the PUCCH group 1010 and the PUCCH group 1050, a single uplink PCell to transmit UCI relating to the downlink CCs, and the PCell may become overloaded. By dividing transmissions of UCI between the PCell 1021 and the PSCell 1061, overloading may be prevented.

[0130] A cell, comprising a downlink carrier and optionally an uplink carrier, may be assigned with a physical cell ID and a cell index. The physical cell ID or the cell index may identify a downlink carrier and/or an uplink carrier of the cell, for example, depending on the context in which the physical cell ID is used. A physical cell ID may be determined using a synchronization signal transmitted on a downlink component carrier. A cell index may be determined using RRC messages. In the disclosure, a physical cell ID may be referred to as a carrier ID, and a cell index may be referred to as a carrier index. For example, when the disclosure refers to a first physical cell ID for a first downlink carrier, the disclosure may mean the first physical cell ID is for a cell comprising the first downlink carrier. The same/similar concept may apply to, for example, a carrier activation. When the disclosure indicates that a first carrier is activated, the specification may mean that a cell comprising the first carrier is activated.

[0131] In CA, a multi-carrier nature of a PHY may be exposed to a MAC. In an example, a HARQ entity may operate on a serving cell. A transport block may be generated per assignment/grant per serving cell. A transport block and potential HARQ retransmissions of the transport block may be mapped to a serving cell.

[0132] In the downlink, a base station may transmit (e.g., unicast, multicast, and/or broadcast) one or more Reference Signals (RSs) to a UE (e.g., PSS, SSS, CSI-RS, DMRS, and/or PT-RS, as shown in FIG. 5A). In the uplink, the UE may transmit one or more RSs to the base station (e.g., DMRS, PT-RS, and/or SRS, as shown in FIG. 5B). The PSS and the SSS may be transmitted by the base station and used by the UE to synchronize the UE to the base station. The PSS and the SSS may be provided in a synchronization signal (SS) / physical broadcast channel (PBCH) block that includes the PSS, the SSS, and the PBCH. The base station may periodically transmit a burst of SS/PBCH blocks.

[0133] FIG. 11A illustrates an example of an SS/PBCH block's structure and location. A burst of SS/PBCH blocks may include one or more SS/PBCH blocks (e.g., 4 SS/PBCH blocks, as shown in FIG. 11A). Bursts may be transmitted periodically (e.g., every 2 frames or 20 ms). A burst may be restricted to a half-frame (e.g., a first half-frame having a duration of 5 ms). It will be understood that FIG. 11A is an example, and that these parameters (number of SS/PBCH blocks per burst, periodicity of bursts, position of burst within the frame) may be configured based on, for example: a carrier frequency of a cell in which the SS/PBCH block is transmitted; a numerology or subcarrier spacing of the cell; a configuration by the network (e.g., using RRC signaling); or any other suitable factor. In an example, the UE may assume a subcarrier spacing for the SS/PBCH block based on the carrier frequency being monitored, unless the radio network configured the UE to assume a different subcarrier spacing.

[0134] The SS/PBCH block may span one or more OFDM symbols in the time domain (e.g., 4 OFDM symbols, as shown in the example of FIG. 11A) and may span one or more subcarriers in the frequency domain (e.g., 240 contiguous subcarriers). The PSS, the SSS, and the PBCH may have a common center frequency. The PSS may be transmitted first and may span, for example, 1 OFDM symbol and 127 subcarriers. The SSS may be transmitted after the PSS (e.g., two symbols later) and may span 1 OFDM symbol and 127 subcarriers. The PBCH may be transmitted after the PSS (e.g., across the next 3 OFDM symbols) and may span 240 subcarriers.

[0135] The location of the SS/PBCH block in the time and frequency domains may not be known to the UE (e.g., if the UE is searching for the cell). To find and select the cell, the UE may monitor a carrier for the PSS. For example, the UE may monitor a frequency location within the carrier. If the PSS is not found after a certain duration (e.g., 20 ms), the UE may search for the PSS at a different frequency location within the carrier, as indicated by a synchronization raster. If the PSS is found at a location in the time and frequency domains, the UE may determine, based on a known structure of the SS/PBCH block, the locations of the SSS and the PBCH, respectively. The SS/PBCH block may be a cell-defining SS block (CD-SSB). In an example, a primary cell may be associated with a CD-SSB. The CD-SSB may be located on a synchronization raster. In an example, a cell selection/search and/or reselection may be based on the CD-SSB.

[0136] The SS/PBCH block may be used by the UE to determine one or more parameters of the cell. For example, the UE may determine a physical cell identifier (PCI) of the cell based on the sequences of the PSS and the SSS, respectively. The UE may determine a location of a frame boundary of the cell based on the location of the SS/PBCH block. For example, the SS/PBCH block may indicate that it has been transmitted in accordance with a transmission pattern, wherein a SS/PBCH block in the transmission pattern is a known distance from the frame boundary.

[0137] The PBCH may use a QPSK modulation and may use forward error correction (FEC). The FEC may use polar coding. One or more symbols spanned by the PBCH may carry one or more DMRSs for demodulation of the PBCH. The PBCH may include an indication of a current system frame number (SFN) of the cell and/or a SS/PBCH block timing index. These parameters may facilitate time synchronization of the UE to the base station. The PBCH may include a master information block (MIB) used to provide the UE with one or more parameters. The MIB may be used by the UE to locate remaining minimum system information (RMSI) associated with the cell. The RMSI may include a System Information Block Type 1 (SIB1). The SIB1 may contain information needed by the UE to access the cell. The UE may use one or more parameters of the MIB to monitor PDCCH, which may be used to schedule PDSCH. The PDSCH may include the SIB1. The SIB1 may be decoded using parameters provided in the MIB. The PBCH may indicate an absence of SIB1. Based on the PBCH indicating the absence of SIB1, the UE may be pointed to a frequency. The UE may search for an SS/PBCH block at the frequency to which the UE is pointed.

[0138] The UE may assume that one or more SS/PBCH blocks transmitted with a same SS/PBCH block index are quasi co-located (QCLed) (e.g., having the same/similar Doppler spread, Doppler shift, average gain, average delay, and/or spatial Rx parameters). The UE may not assume QCL for SS/PBCH block transmissions having different SS/PBCH block indices.

[0139] SS/PBCH blocks (e.g., those within a half-frame) may be transmitted in spatial directions (e.g., using different beams that span a coverage area of the cell). In an example, a first SS/PBCH block may be transmitted in a first spatial direction using a first beam, and a second SS/PBCH block may be transmitted in a second spatial direction using a second beam.

[0140] In an example, within a frequency span of a carrier, a base station may transmit a plurality of SS/PBCH blocks. In an example, a first PCI of a first SS/PBCH block of the plurality of SS/PBCH blocks may be different from a second PCI of a second SS/PBCH block of the plurality of SS/PBCH blocks. The PCIs of SS/PBCH blocks transmitted in different frequency locations may be different or the same.

[0141] The CSI-RS may be transmitted by the base station and used by the UE to acquire channel state information (CSI). The base station may configure the UE with one or more CSI-RSs for channel estimation or any other suitable purpose. The base station may configure a UE with one or more of the same/similar CSI-RSs. The UE may measure the one or more CSI-RSs. The UE may estimate a downlink channel state and/or generate a CSI report based on the measuring of the one or more downlink CSI-RSs. The UE may provide the CSI report to the base station. The base station may use feedback provided by the UE (e.g., the estimated downlink channel state) to perform link adaptation.

[0142] The base station may semi-statically configure the UE with one or more CSI-RS resource sets. A CSI-RS resource may be associated with a location in the time and frequency domains and a periodicity. The base station may selectively activate and/or deactivate a CSI-RS resource. The base station may indicate to the UE that a CSI-RS resource in the CSI-RS resource set is activated and/or deactivated.

[0143] The base station may configure the UE to report CSI measurements. The base station may configure the UE to provide CSI reports periodically, aperiodically, or semi-persistently. For periodic CSI reporting, the UE may be configured with a timing and/or periodicity of a plurality of CSI reports. For aperiodic CSI reporting, the base station may request a CSI report. For example, the base station may command the UE to measure a configured CSI-RS resource and provide a CSI report relating to the measurements. For semi-persistent CSI reporting, the base station may configure the UE to transmit periodically, and selectively activate or deactivate the periodic reporting. The base station may configure the UE with a CSI-RS resource set and CSI reports using RRC signaling.

[0144] The CSI-RS configuration may comprise one or more parameters indicating, for example, up to 32 antenna ports. The UE may be configured to employ the same OFDM symbols for a downlink CSI-RS and a control resource set (CORESET) when the downlink CSI-RS and CORESET are spatially QCLed and resource elements associated with the downlink CSI-RS are outside of the physical resource blocks (PRBs) configured for the CORESET. The UE may be configured to employ the same OFDM symbols for downlink CSI-RS and SS/PBCH blocks when the downlink CSI-RS and SS/PBCH blocks are spatially QCLed and resource elements associated with the downlink CSI-RS are outside of PRBs configured for the SS/PBCH blocks.

[0145] Downlink DMRSs may be transmitted by a base station and used by a UE for channel estimation. For example, the downlink DMRS may be used for coherent demodulation of one or more downlink physical channels (e.g., PDSCH). An NR network may support one or more variable and/or configurable DMRS patterns for data demodulation. At least one downlink DMRS configuration may support a front-loaded DMRS pattern. A front-loaded DMRS may be mapped over one or more OFDM symbols (e.g., one or two adjacent OFDM symbols). A base station may semi-statically configure the UE with a number (e.g. a maximum number) of front-loaded DMRS symbols for PDSCH. A DMRS configuration may support one or more DMRS ports. For example, for single user-MIMO, a DMRS configuration may support up to eight orthogonal downlink DMRS ports per UE. For multiuser-MIMO, a DMRS configuration may support up to 4 orthogonal downlink DMRS ports per UE. A radio network may support (e.g., at least for CP-OFDM) a common DMRS structure for downlink and uplink, wherein a DMRS location, a DMRS pattern, and/or a scrambling sequence may be the same or different. The base station may transmit a downlink DMRS and a corresponding PDSCH using the same precoding matrix. The UE may use the one or more downlink DMRSs for coherent demodulation/channel estimation of the PDSCH.

[0146] In an example, a transmitter (e.g., a base station) may use a precoder matrices for a part of a transmission bandwidth. For example, the transmitter may use a first precoder matrix for a first bandwidth and a second precoder matrix for a second bandwidth. The first precoder matrix and the second precoder matrix may be different based on the first bandwidth being different from the second bandwidth. The UE may assume that a same precoding matrix is used across a set of PRBs. The set of PRBs may be denoted as a precoding resource block group (PRG).

[0147] A PDSCH may comprise one or more layers. The UE may assume that at least one symbol with DMRS is present on a layer of the one or more layers of the PDSCH. A higher layer may configure up to 3 DMRSs for the PDSCH.

[0148] Downlink PT-RS may be transmitted by a base station and used by a UE for phase-noise compensation. Whether a downlink PT-RS is present or not may depend on an RRC configuration. The presence and/or pattern of the downlink PT-RS may be configured on a UE-specific basis using a combination of RRC signaling and/or an association with one or more parameters employed for other purposes (e.g., modulation and coding scheme (MCS)), which may be indicated by DCI. When configured, a dynamic presence of a downlink PT-RS may be associated with one or more DCI parameters comprising at least MCS. An NR network may support a plurality of PT-RS densities defined in the time and/or frequency domains. When present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. The UE may assume a same precoding for a DMRS port and a PT-RS port. A number of PT-RS ports may be fewer than a number of DMRS ports in a scheduled resource. Downlink PT-RS may be confined in the scheduled time/frequency duration for the UE. Downlink PT-RS may be transmitted on symbols to facilitate phase tracking at the receiver.

[0149] The UE may transmit an uplink DMRS to a base station for channel estimation. For example, the base station may use the uplink DMRS for coherent demodulation of one or more uplink physical channels. For example, the UE may transmit an uplink DMRS with a PUSCH and/or a PUCCH. The uplink DM-RS may span a range of frequencies that is similar to a range of frequencies associated with the corresponding physical channel. The base station may configure the UE with one or more uplink DMRS configurations. At least one DMRS configuration may support a front-loaded DMRS pattern. The front-loaded DMRS may be mapped over one or more OFDM symbols (e.g., one or two adjacent OFDM symbols). One or more uplink DMRSs may be configured to transmit at one or more symbols of a PUSCH and/or a PUCCH. The base station may semi-statically configure the UE with a number (e.g. maximum number) of front-loaded DMRS symbols for the PUSCH and/or the PUCCH, which the UE may use to schedule a single-symbol DMRS and/or a double-symbol DMRS. An NR network may support (e.g., for cyclic prefix orthogonal frequency division multiplexing (CP-OFDM)) a common DMRS structure for downlink and uplink, wherein a DMRS location, a DMRS pattern, and/or a scrambling sequence for the DMRS may be the same or different.

[0150] A PUSCH may comprise one or more layers, and the UE may transmit at least one symbol with DMRS present on a layer of the one or more layers of the PUSCH. In an example, a higher layer may configure up to three DMRSs for the PUSCH.

[0151] Uplink PT-RS (which may be used by a base station for phase tracking and/or phase-noise compensation) may or may not be present depending on an RRC configuration of the UE. The presence and/or pattern of uplink PT-RS may be configured on a UE-specific basis by a combination of RRC signaling and/or one or more parameters employed for other purposes (e.g., Modulation and Coding Scheme (MCS)), which may be indicated by DCI. When configured, a dynamic presence of uplink PT-RS may be associated with one or more DCI parameters comprising at least MCS. A radio network may support a plurality of uplink PT-RS densities defined in time/frequency domain. When present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. The UE may assume a same precoding for a DMRS port and a PT-RS port. A number of PT-RS ports may be fewer than a number of DMRS ports in a scheduled resource. For example, uplink PT-RS may be confined in the scheduled time/frequency duration for the UE.

[0152] SRS may be transmitted by a UE to a base station for channel state estimation to support uplink channel dependent scheduling and/or link adaptation. SRS transmitted by the UE may allow a base station to estimate an uplink channel state at one or more frequencies. A scheduler at the base station may employ the estimated uplink channel state to assign one or more resource blocks for an uplink PUSCH transmission from the UE. The base station may semi-statically configure the UE with one or more SRS resource sets. For an SRS resource set, the base station may configure the UE with one or more SRS resources. An SRS resource set applicability may be configured by a higher layer (e.g., RRC) parameter. For example, when a higher layer parameter indicates beam management, an SRS resource in a SRS resource set of the one or more SRS resource sets (e.g., with the same/similar time domain behavior, periodic, aperiodic, and/or the like) may be transmitted at a time instant (e.g., simultaneously). The UE may transmit one or more SRS resources in SRS resource sets. An NR network may support aperiodic, periodic and/or semi-persistent SRS transmissions. The UE may transmit SRS resources based on one or more trigger types, wherein the one or more trigger types may comprise higher layer signaling (e.g., RRC) and/or one or more DCI formats. In an example, at least one DCI format may be employed for the UE to select at least one of one or more configured SRS resource sets. An SRS trigger type 0 may refer to an SRS triggered based on a higher layer signaling. An SRS trigger type 1 may refer to an SRS triggered based on one or more DCI formats. In an example, when PUSCH and SRS are transmitted in a same slot, the UE may be configured to transmit SRS after a transmission of a PUSCH and a corresponding uplink DMRS.

[0153] The base station may semi-statically configure the UE with one or more SRS configuration parameters indicating at least one of following: a SRS resource configuration identifier; a number of SRS ports; time domain behavior of an SRS resource configuration (e.g., an indication of periodic, semi-persistent, or aperiodic SRS); slot, mini-slot, and/or subframe level periodicity; offset for a periodic and/or an aperiodic SRS resource; a number of OFDM symbols in an SRS resource; a starting OFDM symbol of an SRS resource; an SRS bandwidth; a frequency hopping bandwidth; a cyclic shift; and/or an SRS sequence ID.

[0154] An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed. If a first symbol and a second symbol are transmitted on the same antenna port, the receiver may infer the channel (e.g., fading gain, multipath delay, and/or the like) for conveying the second symbol on the antenna port, from the channel for conveying the first symbol on the antenna port. A first antenna port and a second antenna port may be referred to as quasi co-located (QCLed) if one or more large-scale properties of the channel over which a first symbol on the first antenna port is conveyed may be inferred from the channel over which a second symbol on a second antenna port is conveyed. The one or more large-scale properties may comprise at least one of: a delay spread; a Doppler spread; a Doppler shift; an average gain; an average delay; and/or spatial Receiving (Rx) parameters.

[0155] Channels that use beamforming require beam management. Beam management may comprise beam measurement, beam selection, and beam indication. A beam may be associated with one or more reference signals. For example, a beam may be identified by one or more beamformed reference signals. The UE may perform downlink beam measurement based on downlink reference signals (e.g., a channel state information reference signal (CSI-RS)) and generate a beam measurement report. The UE may perform the downlink beam measurement procedure after an RRC connection is set up with a base station.

[0156] FIG. 11B illustrates an example of channel state information reference signals (CSI-RSs) that are mapped in the time and frequency domains. A square shown in FIG. 11B may span a resource block (RB) within a bandwidth of a cell. A base station may transmit one or more RRC messages comprising CSI-RS resource configuration parameters indicating one or more CSI-RSs. One or more of the following parameters may be configured by higher layer signaling (e.g., RRC and/or MAC signaling) for a CSI-RS resource configuration: a CSI-RS resource configuration identity, a number of CSI-RS ports, a CSI-RS configuration (e.g., symbol and resource element (RE) locations in a subframe), a CSI-RS subframe configuration (e.g., subframe location, offset, and periodicity in a radio frame), a CSI-RS power parameter, a CSI-RS sequence parameter, a code division multiplexing (CDM) type parameter, a frequency density, a transmission comb, quasi co-location (QCL) parameters (e.g., QCL-scramblingidentity, crs-portscount, mbsfn-subframeconfiglist, csi-rs-configZPid, qcl-csi-rs-configNZPid), and/or other radio resource parameters.

[0157] The three beams illustrated in FIG. 11B may be configured for a UE in a UE-specific configuration. Three beams are illustrated in FIG. 11B (beam #1, beam #2, and beam #3), more or fewer beams may be configured. Beam #1 may be allocated with CSI-RS 1101 that may be transmitted in one or more subcarriers in an RB of a first symbol. Beam #2 may be allocated with CSI-RS 1102 that may be transmitted in one or more subcarriers in an RB of a second symbol. Beam #3 may be allocated with CSI-RS 1103 that may be transmitted in one or more subcarriers in an RB of a third symbol. By using frequency division multiplexing (FDM), a base station may use other subcarriers in a same RB (for example, those that are not used to transmit CSI-RS 1101) to transmit another CSI-RS associated with a beam for another UE. By using time domain multiplexing (TDM), beams used for the UE may be configured such that beams for the UE use symbols from beams of other UEs.

[0158] CSI-RSs such as those illustrated in FIG. 11B (e.g., CSI-RS 1101, 1102, 1103) may be transmitted by the base station and used by the UE for one or more measurements. For example, the UE may measure a reference signal received power (RSRP) of configured CSI-RS resources. The base station may configure the UE with a reporting configuration and the UE may report the RSRP measurements to a network (for example, via one or more base stations) based on the reporting configuration. In an example, the base station may determine, based on the reported measurement results, one or more transmission configuration indication (TCI) states comprising a number of reference signals. In an example, the base station may indicate one or more TCI states to the UE (e.g., via RRC signaling, a MAC CE, and/or a DCI). The UE may receive a downlink transmission with a receive (Rx) beam determined based on the one or more TCI states. In an example, the UE may or may not have a capability of beam correspondence. If the UE has the capability of beam correspondence, the UE may determine a spatial domain filter of a transmit (Tx) beam based on a spatial domain filter of the corresponding Rx beam. If the UE does not have the capability of beam correspondence, the UE may perform an uplink beam selection procedure to determine the spatial domain filter of the Tx beam. The UE may perform the uplink beam selection procedure based on one or more sounding reference signal (SRS) resources configured to the UE by the base station. The base station may select and indicate uplink beams for the UE based on measurements of the one or more SRS resources transmitted by the UE.

[0159] In a beam management procedure, a UE may assess (e.g., measure) a channel quality of one or more beam pair links, a beam pair link comprising a transmitting beam transmitted by a base station and a receiving beam received by the UE. Based on the assessment, the UE may transmit a beam measurement report indicating one or more beam pair quality parameters comprising, e.g., one or more beam identifications (e.g., a beam index, a reference signal index, or the like), RSRP, a precoding matrix indicator (PMI), a channel quality indicator (CQI), and/or a rank indicator (RI).

[0160] FIG. 12A illustrates examples of three downlink beam management procedures: P1, P2, and P3. Procedure P1 may enable a UE measurement on transmit (Tx) beams of a transmission reception point (TRP) (or multiple TRPs), e.g., to support a selection of one or more base station Tx beams and/or UE Rx beams (shown as ovals in the top row and bottom row, respectively, of P1). Beamforming at a TRP may comprise a Tx beam sweep for a set of beams (shown, in the top rows of P1 and P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Beamforming at a UE may comprise an Rx beam sweep for a set of beams (shown, in the bottom rows of P1 and P3, as ovals rotated in a clockwise direction indicated by the dashed arrow). Procedure P2 may be used to enable a UE measurement on Tx beams of a TRP (shown, in the top row of P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). The UE and/or the base station may perform procedure P2 using a smaller set of beams than is used in procedure P1, or using narrower beams than the beams used in procedure P1. This may be referred to as beam refinement. The UE may perform procedure P3 for Rx beam determination by using the same Tx beam at the base station and sweeping an Rx beam at the UE.

[0161] FIG. 12B illustrates examples of three uplink beam management procedures: U1, U2, and U3. Procedure U1 may be used to enable a base station to perform a measurement on Tx beams of a UE, e.g., to support a selection of one or more UE Tx beams and/or base station Rx beams (shown as ovals in the top row and bottom row, respectively, of U1). Beamforming at the UE may include, e.g., a Tx beam sweep from a set of beams (shown in the bottom rows of U1 and U3 as ovals rotated in a clockwise direction indicated by the dashed arrow). Beamforming at the base station may include, e.g., an Rx beam sweep from a set of beams (shown, in the top rows of U1 and U2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Procedure U2 may be used to enable the base station to adjust its Rx beam when the UE uses a fixed Tx beam. The UE and/or the base station may perform procedure U2 using a smaller set of beams than is used in procedure P1, or using narrower beams than the beams used in procedure

P1. This may be referred to as beam refinement The UE may perform procedure U3 to adjust its Tx beam when the base station uses a fixed Rx beam.

[0162] A UE may initiate a beam failure recovery (BFR) procedure based on detecting a beam failure. The UE may transmit a BFR request (e.g., a preamble, a UCI, an SR, a MAC CE, and/or the like) based on the initiating of the BFR procedure. The UE may detect the beam failure based on a determination that a quality of beam pair link(s) of an associated control channel is unsatisfactory (e.g., having an error rate higher than an error rate threshold, a received signal power lower than a received signal power threshold, an expiration of a timer, and/or the like).

[0163] The UE may measure a quality of a beam pair link using one or more reference signals (RSs) comprising one or more SS/PBCH blocks, one or more CSI-RS resources, and/or one or more demodulation reference signals (DMRSs). A quality of the beam pair link may be based on one or more of a block error rate (BLER), an RSRP value, a signal to interference plus noise ratio (SINR) value, a reference signal received quality (RSRQ) value, and/or a CSI value measured on RS resources. The base station may indicate that an RS resource is quasi co-located (QCLed) with one or more DM-RSs of a channel (e.g., a control channel, a shared data channel, and/or the like). The RS resource and the one or more DMRSs of the channel may be QCLed when the channel characteristics (e.g., Doppler shift, Doppler spread, average delay, delay spread, spatial Rx parameter, fading, and/or the like) from a transmission via the RS resource to the UE are similar or the same as the channel characteristics from a transmission via the channel to the UE.

[0164] A network (e.g., a gNB and/or an ng-eNB of a network) and/or the UE may initiate a random access procedure. A UE in an RRC_IDLE state and/or an RRC_INACTIVE state may initiate the random access procedure to request a connection setup to a network. The UE may initiate the random access procedure from an RRC_CONNECTED state. The UE may initiate the random access procedure to request uplink resources (e.g., for uplink transmission of an SR when there is no PUCCH resource available) and/or acquire uplink timing (e.g., when uplink synchronization status is non-synchronized). The UE may initiate the random access procedure to request one or more system information blocks (SIBs) (e.g., other system information such as SIB2, SIB3, and/or the like). The UE may initiate the random access procedure for a beam failure recovery request. A network may initiate a random access procedure for a handover and/or for establishing time alignment for an SCell addition.

[0165] FIG. 13A illustrates a four-step contention-based random access procedure. Prior to initiation of the procedure, a base station may transmit a configuration message 1310 to the UE. The procedure illustrated in FIG. 13A comprises transmission of four messages: a Msg 1 1311, a Msg 2 1312, a Msg 3 1313, and a Msg 4 1314. The Msg 1 1311 may include and/or be referred to as a preamble (or a random access preamble). The Msg 2 1312 may include and/or be referred to as a random access response (RAR).

[0166] The configuration message 1310 may be transmitted, for example, using one or more RRC messages. The one or more RRC messages may indicate one or more random access channel (RACH) parameters to the UE. The one or more RACH parameters may comprise at least one of following: general parameters for one or more random access procedures (e.g., RACH-configGeneral); cell-specific parameters (e.g., RACH-ConfigCommon); and/or dedicated parameters (e.g., RACH-configDedicated). The base station may broadcast or multicast the one or more RRC messages to one or more UEs. The one or more RRC messages may be UE-specific (e.g., dedicated RRC messages transmitted to a UE in an RRC_CONNECTED state and/or in an RRC_INACTIVE state). The UE may determine, based on the one or more RACH parameters, a time-frequency resource and/or an uplink transmit power for transmission of the Msg 1 1311 and/or the Msg 3 1313. Based on the one or more RACH parameters, the UE may determine a reception timing and a downlink channel for receiving the Msg 2 1312 and the Msg 4 1314.

[0167] The one or more RACH parameters provided in the configuration message 1310 may indicate one or more Physical RACH (PRACH) occasions available for transmission of the Msg 1 1311. The one or more PRACH occasions may be predefined. The one or more RACH parameters may indicate one or more available sets of one or more PRACH occasions (e.g., prach-ConfigIndex). The one or more RACH parameters may indicate an association between (a) one or more PRACH occasions and (b) one or more reference signals. The one or more RACH parameters may indicate an association between (a) one or more preambles and (b) one or more reference signals. The one or more reference signals may be SS/PBCH blocks and/or CSI-RSs. For example, the one or more RACH parameters may indicate a number of SS/PBCH blocks mapped to a PRACH occasion and/or a number of preambles mapped to a SS/PBCH blocks.

[0168] The one or more RACH parameters provided in the configuration message 1310 may be used to determine an uplink transmit power of Msg 1 1311 and/or Msg 3 1313. For example, the one or more RACH parameters may indicate a reference power for a preamble transmission (e.g., a received target power and/or an initial power of the preamble transmission). There may be one or more power offsets indicated by the one or more RACH parameters. For example, the one or more RACH parameters may indicate: a power ramping step; a power offset between SSB and CSI-RS; a power offset between transmissions of the Msg 1 1311 and the Msg 3 1313; and/or a power offset value between preamble groups. The one or more RACH parameters may indicate one or more thresholds based on which the UE may determine at least one reference signal (e.g., an SSB and/or CSI-RS) and/or an uplink carrier (e.g., a normal uplink (NUL) carrier and/or a supplemental uplink (SUL) carrier).

[0169] The Msg 1 1311 may include one or more preamble transmissions (e.g., a preamble transmission and one or more preamble retransmissions). An RRC message may be used to configure one or more preamble groups (e.g., group A and/or group B). A preamble group may comprise one or more preambles. The UE may determine the preamble group based on a pathloss measurement and/or a size of the Msg 3 1313. The UE may measure an RSRP of one or more reference signals (e.g., SSBs and/or CSI-RSs) and determine at least one reference signal having an RSRP above an RSRP threshold (e.g., rsrp-ThresholdSSB and/or rsrp-ThresholdCSI-RS). The UE may select at least one preamble associated with the one or more reference signals and/or a selected preamble group, for example, if the association between the one or more preambles and the at least one reference signal is configured by an RRC message.

[0170] The UE may determine the preamble based on the one or more RACH parameters provided in the configuration message 1310. For example, the UE may determine the preamble based on a pathloss measurement, an

RSRP measurement, and/or a size of the Msg 3 1313. As another example, the one or more RACH parameters may indicate: a preamble format; a maximum number of preamble transmissions; and/or one or more thresholds for determining one or more preamble groups (e.g., group A and group B). A base station may use the one or more RACH parameters to configure the UE with an association between one or more preambles and one or more reference signals (e.g., SSBs and/or CSI-RSs). If the association is configured, the UE may determine the preamble to include in Msg 1 1311 based on the association. The Msg 1 1311 may be transmitted to the base station via one or more PRACH occasions. The UE may use one or more reference signals (e.g., SSBs and/or CSI-RSs) for selection of the preamble and for determining of the PRACH occasion. One or more RACH parameters (e.g., ra-ssb-OccasionMskIndex and/or ra-OccasionList) may indicate an association between the PRACH occasions and the one or more reference signals.

[0171] The UE may perform a preamble retransmission if no response is received following a preamble transmission. The UE may increase an uplink transmit power for the preamble retransmission. The UE may select an initial preamble transmit power based on a pathloss measurement and/or a target received preamble power configured by the network. The UE may determine to retransmit a preamble and may ramp up the uplink transmit power. The UE may receive one or more RACH parameters (e.g., PREAMBLE_POWER_RAMPING_STEP) indicating a ramping step for the preamble retransmission. The ramping step may be an amount of incremental increase in uplink transmit power for a retransmission. The UE may ramp up the uplink transmit power if the UE determines a reference signal (e.g., SSB and/or CSI-RS) that is the same as a previous preamble transmission. The UE may count a number of preamble transmissions and/or retransmissions (e.g., PREAMBLE_TRANSMISSION_COUNTER). The UE may determine that a random access procedure completed unsuccessfully, for example, if the number of preamble transmissions exceeds a threshold configured by the one or more RACH parameters (e.g., preambleTransMax).

[0172] The Msg 2 1312 received by the UE may include an RAR. In some scenarios, the Msg 2 1312 may include multiple RARs corresponding to multiple UEs. The Msg 2 1312 may be received after or in response to the transmitting of the Msg 1 1311. The Msg 2 1312 may be scheduled on the DL-SCH and indicated on a PDCCH using a random access RNTI (RA-RNTI). The Msg 2 1312 may indicate that the Msg 1 1311 was received by the base station. The Msg 2 1312 may include a time-alignment command that may be used by the UE to adjust the UE's transmission timing, a scheduling grant for transmission of the Msg 3 1313, and/or a Temporary Cell RNTI (TC-RNTI). After transmitting a preamble, the UE may start a time window (e.g., ra-ResponseWindow) to monitor a PDCCH for the Msg 2 1312. The UE may determine when to start the time window based on a PRACH occasion that the UE uses to transmit the preamble. For example, the UE may start the time window one or more symbols after a last symbol of the preamble (e.g., at a first PDCCH occasion from an end of a preamble transmission). The one or more symbols may be determined based on a numerology. The PDCCH may be in a common search space (e.g., a Type1-PDCCH common search space) configured by an RRC message. The UE may identify the RAR based on a Radio Network Temporary Identifier (RNTI). RNTIs may be used depending on one or more events initiating the random access procedure. The UE may use random access RNTI (RA-RNTI). The RA-RNTI may be associated with PRACH occasions in which the UE transmits a preamble. For example, the UE may determine the RA-RNTI based on: an OFDM symbol index; a slot index; a frequency domain index; and/or a UL carrier indicator of the PRACH occasions. An example of RA-RNTI may be as follows:

$$\text{RA-RNTI} = 1 + s\_id + 14 \times t\_id + 14 \times 80 \times f\_id + 14 \times 80 \times 8 \times ul\_carrier\_id$$

where s_id may be an index of a first OFDM symbol of the PRACH occasion (e.g., $0 \leq s\_id < 14$), t_id may be an index of a first slot of the PRACH occasion in a system frame (e.g., $0 \leq t\_id < 80$), f_id may be an index of the PRACH occasion in the frequency domain (e.g., $0 \leq f\_id < 8$), and ul_carrier_id may be a UL carrier used for a preamble transmission (e.g., 0 for an NUL carrier, and 1 for an SUL carrier).

[0173] The UE may transmit the Msg 3 1313 in response to a successful reception of the Msg 2 1312 (e.g., using resources identified in the Msg 2 1312). The Msg 3 1313 may be used for contention resolution in, for example, the contention-based random access procedure illustrated in FIG. 13A. In some scenarios, a plurality of UEs may transmit a same preamble to a base station and the base station may provide an RAR that corresponds to a UE. Collisions may occur if the plurality of UEs interpret the RAR as corresponding to themselves. Contention resolution (e.g., using the Msg 3 1313 and the Msg 4 1314) may be used to increase the likelihood that the UE does not incorrectly use an identity of another the UE. To perform contention resolution, the UE may include a device identifier in the Msg 3 1313 (e.g., a C-RNTI if assigned, a TC-RNTI included in the Msg 2 1312, and/or any other suitable identifier).

[0174] The Msg 4 1314 may be received after or in response to the transmitting of the Msg 3 1313. If a C-RNTI was included in the Msg 3 1313, the base station will address the UE on the PDCCH using the C-RNTI. If the UE's unique C-RNTI is detected on the PDCCH, the random access procedure is determined to be successfully completed. If a TC-RNTI is included in the Msg 3 1313 (e.g., if the UE is in an RRC_IDLE state or not otherwise connected to the base station), Msg 4 1314 will be received using a DL-SCH associated with the TC-RNTI. If a MAC PDU is successfully decoded and a MAC PDU comprises the UE contention resolution identity MAC CE that matches or otherwise corresponds with the CCCH SDU sent (e.g., transmitted) in Msg 3 1313, the UE may determine that the contention resolution is successful and/or the UE may determine that the random access procedure is successfully completed.

[0175] The UE may be configured with a supplementary uplink (SUL) carrier and a normal uplink (NUL) carrier. An initial access (e.g., random access procedure) may be supported in an uplink carrier. For example, a base station may configure the UE with two separate RACH configurations: one for an SUL carrier and the other for an NUL carrier. For random access in a cell configured with an SUL carrier, the network may indicate which carrier to use (NUL or SUL). The UE may determine the SUL carrier, for example, if a measured quality of one or more reference signals is lower than a broadcast threshold. Uplink transmissions of the random access procedure (e.g., the Msg 1 1311 and/or the Msg 3 1313) may remain on the selected carrier. The UE may switch an uplink carrier during the random access procedure (e.g., between the Msg 1 1311 and the Msg 3 1313) in one or more cases. For example, the UE may determine and/or switch an uplink carrier for the Msg 1 1311 and/or the Msg 3 1313 based on a channel clear assessment (e.g., a listen-before-talk).

[0176] FIG. 13B illustrates a two-step contention-free random access procedure. Similar to the four-step contention-based random access procedure illustrated in FIG. 13A, a base station may, prior to initiation of the procedure, transmit a configuration message 1320 to the UE. The configuration message 1320 may be analogous in some respects to the configuration message 1310. The procedure illustrated in FIG. 13B comprises transmission of two messages: a Msg 1 1321 and a Msg 2 1322. The Msg 1 1321 and the Msg 2 1322 may be analogous in some respects to the Msg 1 1311 and a Msg 2 1312 illustrated in FIG. 13A, respectively. As will be understood from FIGS. 13A and 13B, the contention-free random access procedure may not include messages analogous to the Msg 3 1313 and/or the Msg 4 1314.

[0177] The contention-free random access procedure illustrated in FIG. 13B may be initiated for a beam failure recovery, other SI request, SCell addition, and/or handover. For example, a base station may indicate or assign to the UE the preamble to be used for the Msg 1 1321. The UE may receive, from the base station via PDCCH and/or RRC, an indication of a preamble (e.g., ra-PreambleIndex).

[0178] After transmitting a preamble, the UE may start a time window (e.g., ra-ResponseWindow) to monitor a PDCCH for the RAR. In the event of a beam failure recovery request, the base station may configure the UE with a separate time window and/or a separate PDCCH in a search space indicated by an RRC message (e.g., recoverySearchSpaceId). The UE may monitor for a PDCCH transmission addressed to a Cell RNTI (C-RNTI) on the search space. In the contention-free random access procedure illustrated in FIG. 13B, the UE may determine that a random access procedure successfully completes after or in response to transmission of Msg 1 1321 and reception of a corresponding Msg 2 1322. The UE may determine that a random access procedure successfully completes, for example, if a PDCCH transmission is addressed to a C-RNTI. The UE may determine that a random access procedure successfully completes, for example, if the UE receives an RAR comprising a preamble identifier corresponding to a preamble transmitted by the UE and/or the RAR comprises a MAC sub-PDU with the preamble identifier. The UE may determine the response as an indication of an acknowledgement for an SI request.

[0179] FIG. 13C illustrates another two-step random access procedure. Similar to the random access procedures illustrated in FIGS. 13A and 13B, a base station may, prior to initiation of the procedure, transmit a configuration message 1330 to the UE. The configuration message 1330 may be analogous in some respects to the configuration message 1310 and/or the configuration message 1320. The procedure illustrated in FIG. 13C comprises transmission of two messages: a Msg A 1331 and a Msg B 1332.

[0180] Msg A 1331 may be transmitted in an uplink transmission by the UE. Msg A 1331 may comprise one or more transmissions of a preamble 1341 and/or one or more transmissions of a transport block 1342. The transport block 1342 may comprise contents that are similar and/or equivalent to the contents of the Msg 3 1313 illustrated in FIG. 13A. The transport block 1342 may comprise UCI (e.g., an SR, a HARQ ACK/NACK, and/or the like). The UE may receive the Msg B 1332 after or in response to transmitting the Msg A 1331. The Msg B 1332 may comprise contents that are similar and/or equivalent to the contents of the Msg 2 1312 (e.g., an RAR) illustrated in FIGS. 13A and 13B and/or the Msg 4 1314 illustrated in FIG. 13A.

[0181] The UE may initiate the two-step random access procedure in FIG. 13C for licensed spectrum and/or unlicensed spectrum. The UE may determine, based on one or more factors, whether to initiate the two-step random access procedure. The one or more factors may be: a radio access technology in use (e.g., LTE, NR, and/or the like);

whether the UE has valid TA or not; a cell size; the UE's RRC state; a type of spectrum (e.g., licensed vs. unlicensed); and/or any other suitable factors.

[0182] The UE may determine, based on two-step RACH parameters included in the configuration message 1330, a radio resource and/or an uplink transmit power for the preamble 1341 and/or the transport block 1342 included in the Msg A 1331. The RACH parameters may indicate a modulation and coding schemes (MCS), a time-frequency resource, and/or a power control for the preamble 1341 and/or the transport block 1342. A time-frequency resource for transmission of the preamble 1341 (e.g., a PRACH) and a time-frequency resource for transmission of the transport block 1342 (e.g., a PUSCH) may be multiplexed using FDM, TDM, and/or CDM. The RACH parameters may enable the UE to determine a reception timing and a downlink channel for monitoring for and/or receiving Msg B 1332.

[0183] The transport block 1342 may comprise data (e.g., delay-sensitive data), an identifier of the UE, security information, and/or device information (e.g., an International Mobile Subscriber Identity (IMSI)). The base station may transmit the Msg B 1332 as a response to the Msg A 1331. The Msg B 1332 may comprise at least one of following: a preamble identifier; a timing advance command; a power control command; an uplink grant (e.g., a radio resource assignment and/or an MCS); a UE identifier for contention resolution; and/or an RNTI (e.g., a C-RNTI or a TC-RNTI). The UE may determine that the two-step random access procedure is successfully completed if: a preamble identifier in the Msg B 1332 is matched to a preamble transmitted by the UE; and/or the identifier of the UE in Msg B 1332 is matched to the identifier of the UE in the Msg A 1331 (e.g., the transport block 1342).

[0184] A UE and a base station may exchange control signaling. The control signaling may be referred to as L1/L2 control signaling and may originate from the PHY layer (e.g., layer 1) and/or the MAC layer (e.g., layer 2). The control signaling may comprise downlink control signaling transmitted from the base station to the UE and/or uplink control signaling transmitted from the UE to the base station.

[0185] The downlink control signaling may comprise: a downlink scheduling assignment; an uplink scheduling grant indicating uplink radio resources and/or a transport format; a slot format information; a preemption indication; a power control command; and/or any other suitable signaling. The UE may receive the downlink control signaling in a payload transmitted by the base station on a physical downlink control channel (PDCCH). The payload transmitted on the PDCCH may be referred to as downlink control information (DCI). In some scenarios, the PDCCH may be a group common PDCCH (GC-PDCCH) that is common to a group of UEs.

[0186] A base station may attach one or more cyclic redundancy check (CRC) parity bits to a DCI in order to facilitate detection of transmission errors. When the DCI is intended for a UE (or a group of the UEs), the base station may scramble the CRC parity bits with an identifier of the UE (or an identifier of the group of the UEs). Scrambling the CRC parity bits with the identifier may comprise Modulo-2 addition (or an exclusive OR operation) of the identifier value and the CRC parity bits. The identifier may comprise a 16-bit value of a radio network temporary identifier (RNTI).

[0187] DCIs may be used for different purposes. A purpose may be indicated by the type of RNTI used to scramble the CRC parity bits. For example, a DCI having CRC parity bits scrambled with a paging RNTI (P-RNTI) may indicate paging information and/or a system information change notification. The P-RNTI may be predefined as "FFFE" in hexadecimal. A DCI having CRC parity bits scrambled with a system information RNTI (SI-RNTI) may indicate a broadcast transmission of the system information. The SI-RNTI may be predefined as “FFFF” in hexadecimal. A DCI having CRC parity bits scrambled with a random access RNTI (RA-RNTI) may indicate a random access response (RAR). A DCI having CRC parity bits scrambled with a cell RNTI (C-RNTI) may indicate a dynamically scheduled unicast transmission and/or a triggering of PDCCH-ordered random access. A DCI having CRC parity bits scrambled with a temporary cell RNTI (TC-RNTI) may indicate a contention resolution (e.g., a Msg 3 analogous to the Msg 3 1313 illustrated in FIG. 13A). Other RNTIs configured to the UE by a base station may comprise a Configured Scheduling RNTI (CS-RNTI), a Transmit Power Control-PUCCH RNTI (TPC-PUCCH-RNTI), a Transmit Power Control-PUSCH RNTI (TPC-PUSCH-RNTI), a Transmit Power Control-SRS RNTI (TPC-SRS-RNTI), an Interruption RNTI (INT-RNTI), a Slot Format Indication RNTI (SFI-RNTI), a Semi-Persistent CSI RNTI (SP-CSI-RNTI), a Modulation and Coding Scheme Cell RNTI (MCS-C-RNTI), and/or the like.

[0188] Depending on the purpose and/or content of a DCI, the base station may transmit the DCIs with one or more DCI formats. For example, DCI format 0_0 may be used for scheduling of PUSCH in a cell. DCI format 0_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 0_1 may be used for scheduling of PUSCH in a cell (e.g., with more DCI payloads than DCI format 0_0). DCI format 1_0 may be used for scheduling of PDSCH in a cell. DCI format 1_0 may be a fallback DCI format (e.g., with compact DCI payloads). DCI format 1_1 may be used for scheduling of PDSCH in a cell (e.g., with more DCI payloads than DCI format 1_0). DCI format 2_0 may be used for providing a slot format indication to a group of UEs. DCI format 2_1 may be used for notifying a group of UEs of a physical resource block and/or OFDM symbol where the UE may assume no transmission is intended to the UE. DCI format 2_2 may be used for transmission of a transmit power control (TPC) command for PUCCH or PUSCH. DCI format 2_3 may be used for transmission of a group of TPC commands for SRS transmissions by one or more UEs. DCI format(s) for new functions may be defined in future releases. DCI formats may have different DCI sizes, or may share the same DCI size.

[0189] After scrambling a DCI with a RNTI, the base station may process the DCI with channel coding (e.g., polar coding), rate matching, scrambling and/or QPSK modulation. A base station may map the coded and modulated DCI on resource elements used and/or configured for a PDCCH. Based on a payload size of the DCI and/or a coverage of the base station, the base station may transmit the DCI via a PDCCH occupying a number of contiguous control channel elements (CCEs). The number of the contiguous CCEs (referred to as aggregation level) may be 1, 2, 4, 8, 16, and/or any other suitable number. A CCE may comprise a number (e.g., 6) of resource-element groups (REGs). A REG may comprise a resource block in an OFDM symbol. The mapping of the coded and modulated DCI on the resource elements may be based on mapping of CCEs and REGs (e.g., CCE-to-REG mapping).

[0190] FIG. 14A illustrates an example of CORESET configurations for a bandwidth part. The base station may transmit a DCI via a PDCCH on one or more control resource sets (CORESETs). A CORESET may comprise a time-frequency resource in which the UE tries to decode a DCI using one or more search spaces. The base station may configure a CORESET in the time-frequency domain. In the example of FIG. 14A, a first CORESET 1401 and a second

CORESET 1402 occur at the first symbol in a slot. The first CORESET 1401 overlaps with the second CORESET 1402 in the frequency domain. A third CORESET 1403 occurs at a third symbol in the slot. A fourth CORESET 1404 occurs at the seventh symbol in the slot. CORESETs may have a different number of resource blocks in frequency domain.

[0191] FIG. 14B illustrates an example of a CCE-to-REG mapping for DCI transmission on a CORESET and PDCCH processing. The CCE-to-REG mapping may be an interleaved mapping (e.g., for the purpose of providing frequency diversity) or a non-interleaved mapping (e.g., for the purposes of facilitating interference coordination and/or frequency-selective transmission of control channels). The base station may perform different or same CCE-to-REG mapping on different CORESETs. A CORESET may be associated with a CCE-to-REG mapping by RRC configuration. A CORESET may be configured with an antenna port quasi co-location (QCL) parameter. The antenna port QCL parameter may indicate QCL information of a demodulation reference signal (DMRS) for PDCCH reception in the CORESET.

[0192] The base station may transmit, to the UE, RRC messages comprising configuration parameters of one or more CORESETs and one or more search space sets. The configuration parameters may indicate an association between a search space set and a CORESET. A search space set may comprise a set of PDCCH candidates formed by CCEs at a given aggregation level. The configuration parameters may indicate: a number of PDCCH candidates to be monitored per aggregation level; a PDCCH monitoring periodicity and a PDCCH monitoring pattern; one or more DCI formats to be monitored by the UE; and/or whether a search space set is a common search space set or a UE-specific search space set. A set of CCEs in the common search space set may be predefined and known to the UE. A set of CCEs in the UE-specific search space set may be configured based on the UE’s identity (e.g., C-RNTI).

[0193] As shown in FIG. 14B, the UE may determine a time-frequency resource for a CORESET based on RRC messages. The UE may determine a CCE-to-REG mapping (e.g., interleaved or non-interleaved, and/or mapping parameters) for the CORESET based on configuration parameters of the CORESET. The UE may determine a number (e.g., at most 10) of search space sets configured on the CORESET based on the RRC messages. The UE may monitor a set of PDCCH candidates according to configuration parameters of a search space set. The UE may monitor a set of PDCCH candidates in one or more CORESETs for detecting one or more DCIs. Monitoring may comprise decoding one or more PDCCH candidates of the set of the PDCCH candidates according to the monitored DCI formats. Monitoring may comprise decoding a DCI content of one or more PDCCH candidates with possible (or configured) PDCCH locations, possible (or configured) PDCCH formats (e.g., number of CCEs, number of PDCCH candidates in common search spaces, and/or number of PDCCH candidates in the UE-specific search spaces) and possible (or configured) DCI formats. The decoding may be referred to as blind decoding. The UE may determine a DCI as valid for the UE, in response to CRC checking (e.g., scrambled bits for CRC parity bits of the DCI matching a RNTI value). The UE may process information contained in the DCI (e.g., a scheduling assignment, an uplink grant, power control, a slot format indication, a downlink preemption, and/or the like).

[0194] The UE may transmit uplink control signaling (e.g., uplink control information (UCI)) to a base station. The uplink control signaling may comprise hybrid automatic repeat request (HARQ) acknowledgements for received DL-

SCH transport blocks. The UE may transmit the HARQ acknowledgements after receiving a DL-SCH transport block. Uplink control signaling may comprise channel state information (CSI) indicating channel quality of a physical downlink channel. The UE may transmit the CSI to the base station. The base station, based on the received CSI, may determine transmission format parameters (e.g., comprising multi-antenna and beamforming schemes) for a downlink transmission. Uplink control signaling may comprise scheduling requests (SR). The UE may transmit an SR indicating that uplink data is available for transmission to the base station. The UE may transmit a UCI (e.g., HARQ acknowledgements (HARQ-ACK), CSI report, SR, and the like) via a physical uplink control channel (PUCCH) or a physical uplink shared channel (PUSCH). The UE may transmit the uplink control signaling via a PUCCH using one of several PUCCH formats.

[0195] There may be five PUCCH formats and the UE may determine a PUCCH format based on a size of the UCI (e.g., a number of uplink symbols of UCI transmission and a number of UCI bits). PUCCH format 0 may have a length of one or two OFDM symbols and may include two or fewer bits. The UE may transmit UCI in a PUCCH resource using PUCCH format 0 if the transmission is over one or two symbols and the number of HARQ-ACK information bits with positive or negative SR (HARQ-ACK/SR bits) is one or two. PUCCH format 1 may occupy a number between four and fourteen OFDM symbols and may include two or fewer bits. The UE may use PUCCH format 1 if the transmission is four or more symbols and the number of HARQ-ACK/SR bits is one or two. PUCCH format 2 may occupy one or two OFDM symbols and may include more than two bits. The UE may use PUCCH format 2 if the transmission is over one or two symbols and the number of UCI bits is two or more. PUCCH format 3 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 3 if the transmission is four or more symbols, the number of UCI bits is two or more and PUCCH resource does not include an orthogonal cover code. PUCCH format 4 may occupy a number between four and fourteen OFDM symbols and may include more than two bits. The UE may use PUCCH format 4 if the transmission is four or more symbols, the number of UCI bits is two or more and the PUCCH resource includes an orthogonal cover code.

[0196] The base station may transmit configuration parameters to the UE for a plurality of PUCCH resource sets using, for example, an RRC message. The plurality of PUCCH resource sets (e.g., up to four sets) may be configured on an uplink BWP of a cell. A PUCCH resource set may be configured with a PUCCH resource set index, a plurality of PUCCH resources with a PUCCH resource being identified by a PUCCH resource identifier (e.g., pucch-Resourceid), and/or a number (e.g. a maximum number) of UCI information bits the UE may transmit using one of the plurality of PUCCH resources in the PUCCH resource set. When configured with a plurality of PUCCH resource sets, the UE may select one of the plurality of PUCCH resource sets based on a total bit length of the UCI information bits (e.g., HARQ-ACK, SR, and/or CSI). If the total bit length of UCI information bits is two or fewer, the UE may select a first PUCCH resource set having a PUCCH resource set index equal to “0”. If the total bit length of UCI information bits is greater than two and less than or equal to a first configured value, the UE may select a second PUCCH resource set having a PUCCH resource set index equal to “1”. If the total bit length of UCI information bits is greater than the first configured value and less than or equal to a second configured value, the UE may select a third PUCCH resource set having a

PUCCH resource set index equal to "2". If the total bit length of UCI information bits is greater than the second configured value and less than or equal to a third value (e.g., 1406), the UE may select a fourth PUCCH resource set having a PUCCH resource set index equal to "3".

[0197] After determining a PUCCH resource set from a plurality of PUCCH resource sets, the UE may determine a PUCCH resource from the PUCCH resource set for UCI (HARQ-ACK, CSI, and/or SR) transmission. The UE may determine the PUCCH resource based on a PUCCH resource indicator in a DCI (e.g., with a DCI format 1_0 or DCI for 1_1) received on a PDCCH. A three-bit PUCCH resource indicator in the DCI may indicate one of eight PUCCH resources in the PUCCH resource set. Based on the PUCCH resource indicator, the UE may transmit the UCI (HARQ-ACK, CSI and/or SR) using a PUCCH resource indicated by the PUCCH resource indicator in the DCI.

[0198] FIG. 15 illustrates an example of a wireless device 1502 in communication with a base station 1504 in accordance with embodiments of the present disclosure. The wireless device 1502 and base station 1504 may be part of a mobile communication network, such as the mobile communication network 100 illustrated in FIG. 1A, the mobile communication network 150 illustrated in FIG. 1B, or any other communication network. Only one wireless device 1502 and one base station 1504 are illustrated in FIG. 15, but it will be understood that a mobile communication network may include more than one UE and/or more than one base station, with the same or similar configuration as those shown in FIG. 15.

[0199] The base station 1504 may connect the wireless device 1502 to a core network (not shown) through radio communications over the air interface (or radio interface) 1506. The communication direction from the base station 1504 to the wireless device 1502 over the air interface 1506 is known as the downlink, and the communication direction from the wireless device 1502 to the base station 1504 over the air interface is known as the uplink. Downlink transmissions may be separated from uplink transmissions using FDD, TDD, and/or some combination of the two duplexing techniques.

[0200] In the downlink, data to be sent to the wireless device 1502 from the base station 1504 may be provided to the processing system 1508 of the base station 1504. The data may be provided to the processing system 1508 by, for example, a core network. In the uplink, data to be sent to the base station 1504 from the wireless device 1502 may be provided to the processing system 1518 of the wireless device 1502. The processing system 1508 and the processing system 1518 may implement layer 3 and layer 2 OSI functionality to process the data for transmission. Layer 2 may include an SDAP layer, a PDCP layer, an RLC layer, and a MAC layer, for example, with respect to FIG. 2A, FIG. 2B, FIG. 3, and FIG. 4A. Layer 3 may include an RRC layer as with respect to FIG. 2B.

[0201] After being processed by processing system 1508, the data to be sent to the wireless device 1502 may be provided to a transmission processing system 1510 of base station 1504. Similarly, after being processed by the processing system 1518, the data to be sent to base station 1504 may be provided to a transmission processing system 1520 of the wireless device 1502. The transmission processing system 1510 and the transmission processing system 1520 may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. 2A, FIG. 2B, FIG. 3, and FIG. 4A. For transmit processing, the PHY layer may perform, for example, forward error correction coding of transport channels, interleaving, rate matching, mapping of transport channels to physical channels, modulation of physical channel, multiple-input multiple-output (MIMO) or multi-antenna processing, and/or the like.

[0202] At the base station 1504, a reception processing system 1512 may receive the uplink transmission from the wireless device 1502. At the wireless device 1502, a reception processing system 1522 may receive the downlink transmission from base station 1504. The reception processing system 1512 and the reception processing system 1522 may implement layer 1 OSI functionality. Layer 1 may include a PHY layer with respect to FIG. 2A, FIG. 2B, FIG. 3, and FIG. 4A. For receive processing, the PHY layer may perform, for example, error detection, forward error correction decoding, deinterleaving, demapping of transport channels to physical channels, demodulation of physical channels, MIMO or multi-antenna processing, and/or the like.

[0203] As shown in FIG. 15, a wireless device 1502 and the base station 1504 may include multiple antennas. The multiple antennas may be used to perform one or more MIMO or multi-antenna techniques, such as spatial multiplexing (e.g., single-user MIMO or multi-user MIMO), transmit/receive diversity, and/or beamforming. In other examples, the wireless device 1502 and/or the base station 1504 may have a single antenna.

[0204] The processing system 1508 and the processing system 1518 may be associated with a memory 1514 and a memory 1524, respectively. Memory 1514 and memory 1524 (e.g., one or more non-transitory computer readable mediums) may store computer program instructions or code that may be executed by the processing system 1508 and/or the processing system 1518 to carry out one or more of the functionalities discussed in the present application. Although not shown in FIG. 15, the transmission processing system 1510, the transmission processing system 1520, the reception processing system 1512, and/or the reception processing system 1522 may be coupled to a memory (e.g., one or more non-transitory computer readable mediums) storing computer program instructions or code that may be executed to carry out one or more of their respective functionalities.

[0205] The processing system 1508 and/or the processing system 1518 may comprise one or more controllers and/or one or more processors. The one or more controllers and/or one or more processors may comprise, for example, a general-purpose processor, a digital signal processor (DSP), a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) and/or other programmable logic device, discrete gate and/or transistor logic, discrete hardware components, an on-board unit, or any combination thereof. The processing system 1508 and/or the processing system 1518 may perform at least one of signal coding/processing, data processing, power control, input/output processing, and/or any other functionality that may enable the wireless device 1502 and the base station 1504 to operate in a wireless environment.

[0206] The processing system 1508 and/or the processing system 1518 may be connected to one or more peripherals 1516 and one or more peripherals 1526, respectively. The one or more peripherals 1516 and the one or more peripherals 1526 may include software and/or hardware that provide features and/or functionalities, for example, a speaker, a microphone, a keypad, a display, a touchpad, a power source, a satellite transceiver, a universal serial bus (USB) port, a hands-free headset, a frequency modulated (FM) radio unit, a media player, an Internet browser, an electronic control unit (e.g., for a motor vehicle), and/or one or more sensors (e.g., an accelerometer, a gyroscope, a temperature sensor, a radar sensor, a lidar sensor, an ultrasonic sensor, a light sensor, a camera, and/or the like). The processing system 1508 and/or the processing system 1518 may receive user input data from and/or provide user output data to the one or more peripherals 1516 and/or the one or more peripherals 1526. The processing system 1518 in the wireless device 1502 may receive power from a power source and/or may be configured to distribute the power to the other components in the wireless device 1502. The power source may comprise one or more sources of power, for example, a battery, a solar cell, a fuel cell, or any combination thereof. The processing system 1508 and/or the processing system 1518 may be connected to a GPS chipset 1517 and a GPS chipset 1527, respectively. The GPS chipset 1517 and the GPS chipset 1527 may be configured to provide geographic location information of the wireless device 1502 and the base station 1504, respectively.

[0207] FIG. 16A illustrates an example structure for uplink transmission. A baseband signal representing a physical uplink shared channel may perform one or more functions. The one or more functions may comprise at least one of: scrambling; modulation of scrambled bits to generate complex-valued symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; transform precoding to generate complex-valued symbols; precoding of the complex-valued symbols; mapping of precoded complex-valued symbols to resource elements; generation of complex-valued time-domain Single Carrier-Frequency Division Multiple Access (SC-FDMA) or CP-OFDM signal for an antenna port; and/or the like. In an example, when transform precoding is enabled, a SC-FDMA signal for uplink transmission may be generated. In an example, when transform precoding is not enabled, an CP-OFDM signal for uplink transmission may be generated by FIG. 16A. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0208] FIG. 16B illustrates an example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued SC-FDMA or CP-OFDM baseband signal for an antenna port and/or a complex-valued Physical Random Access Channel (PRACH) baseband signal. Filtering may be employed prior to transmission.

[0209] FIG. 16C illustrates an example structure for downlink transmissions. A baseband signal representing a physical downlink channel may perform one or more functions. The one or more functions may comprise: scrambling of coded bits in a codeword to be transmitted on a physical channel; modulation of scrambled bits to generate complex-valued modulation symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; precoding of the complex-valued modulation symbols on a layer for transmission on the antenna ports; mapping of complex-valued modulation symbols for an antenna port to resource elements; generation of complex-valued time-domain OFDM signal for an antenna port; and/or the like. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0210] FIG. 16D illustrates another example structure for modulation and up-conversion of a baseband signal to a carrier frequency. The baseband signal may be a complex-valued OFDM baseband signal for an antenna port. Filtering may be employed prior to transmission.

[0211] A wireless device may receive from a base station one or more messages (e.g. RRC messages) comprising configuration parameters of a plurality of cells (e.g. primary cell, secondary cell). The wireless device may communicate with at least one base station (e.g. two or more base stations in dual-connectivity) via the plurality of cells. The one or more messages (e.g. as a part of the configuration parameters) may comprise parameters of physical, MAC, RLC, PCDP, SDAP, RRC layers for configuring the wireless device. For example, the configuration parameters may comprise parameters for configuring physical and MAC layer channels, bearers, etc. For example, the configuration parameters may comprise parameters indicating values of timers for physical, MAC, RLC, PCDP, SDAP, RRC layers, and/or communication channels.

[0212] A timer may begin running once it is started and continue running until it is stopped or until it expires. A timer may be started if it is not running or restarted if it is running. A timer may be associated with a value (e.g. the timer may be started or restarted from a value or may be started from zero and expire once it reaches the value). The duration of a timer may not be updated until the timer is stopped or expires (e.g., due to BWP switching). A timer may be used to measure a time period/window for a process. When the specification refers to an implementation and procedure related to one or more timers, it will be understood that there are multiple ways to implement the one or more timers. For example, it will be understood that one or more of the multiple ways to implement a timer may be used to measure a time period/window for the procedure. For example, a random access response window timer may be used for measuring a window of time for receiving a random access response. In an example, instead of starting and expiry of a random access response window timer, the time difference between two time stamps may be used. When a timer is restarted, a process for measurement of time window may be restarted. Other example implementations may be provided to restart a measurement of a time window.

[0213] A satellite may comprise a spaceborne/airborne vehicle (e.g., satellite, balloon, air ship, high altitude platform station, unmanned/uncrewed aircraft system, space-borne platform, drone, and the like). The spaceborne vehicle may, for example, provide a structure, power, commanding, telemetry, attitude control for the satellite, and possibly an appropriate thermal environment, radiation shielding. The satellite may be referred to, for example, as an NTN base station. The satellite may be referred to, for example, as a (serving) satellite. The satellite may be referred to, for example, as an NTN payload. The satellite may comprise, for example, an NTN payload. The NTN payload, for example, may be a network node embarked on board the satellite. The satellite may, for example, orbit the Earth.

[0214] The satellite may be a part of a bent-pipe/transparent payload non-terrestrial network (NTN) communication link/system. The satellite may forward a signal with amplification between a service link and a feeder link, for example, based on the satellite being part of the bent-pipe/transparent payload NTN system. The satellite may forward the signal with frequency change/conversion/shift between a service link and a feeder link, for example, based on the satellite being part of the bent-pipe/transparent payload NTN system. The satellite may operate, for example, as a repeater based on the satellite being part of the bent-pipe/transparent payload NTN system. The satellite may operate, for example, as a relay node based on the satellite being part of the bent-pipe/transparent payload NTN system. The satellite may operate, for example, as a regenerator based on the satellite being part of the bent-pipe/transparent payload NTN system. The service link may connect the satellite and the UE on earth. The feeder link may connect the satellite and an NTN gateway on earth. A terrestrial base station may comprise the NTN gateway. The terrestrial base station may be connected to a core network.

[0215] The satellite may be a part of a regenerative payload NTN communication link/system. The satellite may be equipped with on-board processing. The on-board processing may comprise demodulating and decoding a received signal. The demodulating and decoding procedures may be different for the service link and the feeder link. The on-board processing, for example, may comprise at least two demodulating and at least two decoding procedures. The at least two demodulating procedures may comprise a first demodulating procedure and a second demodulating procedure. The at least two decoding procedures may comprise a first decoding procedure and a second decoding procedure. The satellite, for example, may apply the first demodulating procedure to the signal that the satellite receives on the feeder link. The satellite may apply the second demodulating procedure for the signal that the satellite receives on the service link. The satellite, for example, may apply the first decoding procedure to the signal that the satellite receives on the feeder link. The satellite may apply the second decoding procedure for the signal that the satellite receives on the service link. The on-board processing may comprise regenerating the signal. The regenerating procedure may be different for the service link and the feeder link. The on-board processing, for example, may comprise at least two regenerating procedures. The at least two regenerating procedures may comprise a first regenerating procedure and a second regenerating procedure. The satellite, for example, may apply the first regenerating procedure to the signal that the satellite receives on the feeder link. The satellite may apply the second regenerating procedure to the signal that the satellite receives on the service link.

[0216] A UE may transmit an uplink signal to the satellite (or the NTN base station). The satellite may transmit the uplink signal to a terrestrial base station (or the NTN gateway). If the satellite transmits the uplink signal to the NTN gateway, the NTN gateway may transmit the uplink signal to a terrestrial base station. The terrestrial base station may transmit the uplink signal to the core network. The satellite may transmit the uplink signal to a different satellite, for example, over/via an inter-satellite link.

[0217] The UE may receive a downlink signal from the satellite (or the NTN base station). The satellite may receive the downlink signal from a terrestrial base station (or the NTN gateway). The satellite may receive the downlink signal from a different satellite, for example, over/via the inter-satellite link. The terrestrial base station may receive the downlink signal from the core network.

[0218] A base station/gNB/eNB in NTN may comprise the NTN gateway. The base station/gNB/eNB in NTN may comprise the satellite/NTN base station/NTN payload. The base station/gNB/eNB in NTN may comprise the feeder link. The feeder link may connect the NTN gateway and the satellite. The base station/gNB/eNB in NTN may comprise non-NTN infrastructure that perform(s) gNB/eNB functions. The non-NTN infrastructure may be referred to, for example, as a terrestrial base station/terrestrial gNB/terrestrial eNB. The base station/gNB/eNB (or a portion of the base station/gNB/eNB) in NTN may be referred to, for example, as an NTN service link provisioning system. In an example, the NTN gateway may be referred to as a terrestrial base station/terrestrial gNB/terrestrial eNB.

[0219] FIG. 17A and FIG. 17B illustrate an example of NTN architectures in which a satellite is used as part of a network as per embodiments of the present disclosure.

[0220] FIG. 17A illustrates an example of NTN architecture corresponding to a satellite with on-board transparent payload model as per an aspect of an embodiment of the present disclosure. The NTN architecture may comprise a UE, a satellite, an NTN gateway, a base station or gNB/eNB, a core network, and/or a data network. The satellite may behave as a remote radio unit (RRU) communicating with the NTN gateway. The satellite may implement frequency conversion and/or radio frequency (RF) amplification in the uplink direction. The satellite may implement frequency conversion and/or radio frequency amplification in the downlink direction. The NTN gateway may connect to a base station. In an example, the base station may be on the ground. A UE may transmit and receive via the satellite (e.g., as a relay or a repeater or a regenerator). The satellite (e.g., an RRU) may correspond to an analog RF repeater that repeats the signal from a service link (e.g., between the satellite and the UE) to a feeder link (e.g., between the NTN gateway and the satellite), and vice-versa.

[0221] FIG. 17B illustrates an example NTN architecture corresponding to a satellite with on-board regenerative payload model as per an aspect of an embodiment of the present disclosure. The NTN architecture may comprise a UE, a satellite, an NTN gateway, a core network, and/or the like. The satellite may regenerate signals received from earth (e.g., from a UE or from an NTN gateway). The satellite may regenerate the signal by decoding and re-encoding the signal. The satellite may regenerate the signal by amplifying the signal. The satellite may regenerate the signal by frequency shifting the signal. The satellite may regenerate the signal by changing the carrier frequency of the signal. In an example, the satellite may behave as a base station.

[0222] In an example, the NTN may comprise an earth fixed cell/beam. An NTN earth fixed cell/beam may be referred to, for example, as an NTN earth centric cell/beam. One or more satellites providing earth fixed cell/beam may cover a same (geographical) areas all/most of/a plurality of the time. The one or more satellites providing the earth fixed cell/beam may be one or more geostationary/geosynchronous satellite orbit (GEO/GSO) satellites. In an example, an NTN earth fixed cell/beam may be provisioned by beam(s) continuously covering same geographical areas all the time.

[0223] In an example, the NTN may be/comprise a quasi-earth fixed cell/beam. A quasi-earth fixed cell/beam may be referred to, for example, as a quasi-earth centric cell/beam. One or more satellites in the quasi-earth fixed cell/beam may cover a (geographical) area for a fixed duration time and then cover a different (geographical) area for a next fixed duration of time. In an example, a quasi-earth fixed cell/beam may be provisioned by beam(s) covering one geographic area for a limited period of time and a different geographic area during another period of time. For example, the one or more satellites providing quasi-earth fixed cell/beam may cover a first (geographical) area at a first time. The one or more satellites in the quasi-earth fixed cell/beam may cover the first (geographical) area at a second time. The one or more satellites providing the quasi-earth fixed cell/beam may cover a second (geographical) area at a third time. The one or more satellites providing the quasi-earth fixed cell/beam may use steerable beams (and/or beam steering). The one or more satellites providing the quasi-earth fixed cell/beam may be one or more non-GSO (NGSO) or non-GEO satellites (e.g., one or more low-earth orbit (LEO) satellites, one or more medium earth orbit (MEO) satellites, and the like).

[0224] In an example, the NTN may be/comprise an earth moving cell/beam. The (geographical) area covered by one or more satellites in the earth moving cell/beam may move/slide over the Earth surface. In an example, an earth moving cell/beam may be provisioned by beam(s) whose coverage area slides over the Earth surface. For example, the one or more satellites providing the earth moving cell/beam may cover a first (geographical) area at a first time. The one or more satellites providing the earth moving (cell) system/coverage may cover a second (geographical) area at a second time. The one or more satellites providing the earth moving (cell) system/coverage may not use/generate steerable beams (or beam steering). The one or more satellites providing the earth moving (cell) system/coverage may use/generate, for example, fixed beams. The one or more satellites in the NTN earth moving (cell) system/coverage may use/generate, for example, non-steerable beams. The cell coverage covered by the one or more satellites providing the earth moving cell/beam may change by time. The one or more satellites providing the earth moving cell/beam may be one or more non-GSO (NGSO) or non-GEO (NGEO) satellites (e.g., one or more low-earth orbit (LEO) satellites, one or more medium earth orbit (MEO) satellites, and the like).

[0225] In an example, one or more satellites in an NTN may be one or more NGSO/NGEO satellites. The NTN may be/comprise, for example, an earth fixed cell/beam. The NTN may be/comprise, for example, quasi-earth fixed cell/beam. In another example, one or more satellites in an NTN may be one or more GSO/GEO satellites. The NTN may be/comprise, for example, NTN earth fixed cell/beam.

[0226] FIG. 18 illustrates examples of deployments of various platform types. The platform types may be satellite types. In an example, a satellite may be placed into a Low-Earth Orbit (LEO) at an altitude between 250 km to 1500 km, with orbital periods ranging from 90 to 130 minutes. A mean orbital velocity needed to maintain a stable LEO may be 7.8 km/s and may be reduced with increased orbital altitude. A mean orbital velocity for circular orbit of 200 km may be 7.79 km/s. A mean orbital velocity for circular orbit 1500 km may be 7.12 km/s. From the perspective of a given point on the surface of the earth, the position of the LEO satellite may change. The LEO satellite may provide quasi-earth fixed cell/beam. The LEO satellite may provide earth moving cell/beam.

[0227] In an example, a satellite may be placed into a medium-earth orbit (MEO) at an altitude between 5000 to 20000 km, with orbital periods ranging from 2 hours to 14 hours. The MEO satellite may provide quasi-earth fixed cell/beam. The MEO satellite may provide earth moving cell/beam.

[0228] In an example, a satellite may be placed into a geostationary satellite earth orbit (GEO) at 35,786 km altitude, and directly above the equator. This may equate to an orbital velocity of 3.07 km/s and an orbital period of 1,436 minutes, which equates to almost one sidereal day (23.934461223 hours). From the perspective of a given point on the surface of the earth, the position of the GEO may not move. The GEO may provide earth-fixed cell/beam.

[0229] In an example, an NTN may be a network or network segment that uses a space-borne vehicle to embark a transmission equipment relay node or a base station. While a terrestrial network is a network located on the surface of the earth, an NTN may be a network which uses a satellite as an access network, a backhaul interface network, or both. A satellite may generate several beams over a given area.

[0230] In an example, a footprint of a beam of a satellite may be in an elliptical shape (e.g., which may be considered as a cell). The footprint of a beam may be referred to as a spotbeam. The footprint of a beam may be referred to as a beam footprint. The footprint of a beam may move over the Earth's surface with the satellite movement. The footprint of a beam may be Earth fixed with one or more beam pointing mechanisms used by the satellite to compensate for its motion. The size of a beam footprint may depend on the system design and may range from tens of kilometers to a few thousand kilometers.

[0231] The footprints of one or more beams may be a considered a cell. The footprint of one or more beams may be referred to be a beam. The beam may be associated with one or more aspects of a cell. For example, the beam may be associated with a cell-specific reference signal (CRS), for example, a beam-specific reference signal. In another example, the beam may be associated with a physical cell ID (PCI) or a physical beam ID. The terms cell and beam may be used interchangeably to refer to one or more footprints of at least one beam.

[0232] A UE may be in a range (or a coverage area) of a serving/primary cell/beam. One or more cells/beams (e.g., non-serving/neighbor/assisting/candidate cells/beams) may be installed within the range (or the coverage area) of the serving cell/beam.

[0233] In an example, a propagation delay (e.g., between a satellite and the ground or between multiple satellites) may be the amount of time it takes for the head of the signal to travel from a sender to a receiver or vice versa. For uplink, the sender may be a UE and the receiver may be a base station/access network. For downlink, the sender may be a base station/access network and the receiver may be a UE. The propagation delay may vary depending on a distance between the sender and the receiver.

[0234] FIG. 19 illustrates examples of propagation delay corresponding to satellites types of different altitudes and different elevation angle (degrees). The propagation delay in the figure may be one-way latency. In an example, one-way latency may be an amount of time required to propagate through a telecommunication system from a terminal (e.g. UE) to the receiver (e.g., base station, eNB, gNB, RRU of a base station).

[0235] In an example, for the transparent satellite model of GEO case, the round-trip propagation time (RTT) may comprise service link delay (e.g., between the satellite and the UE) and feeder link delay (e.g., between the NTN gateway and the satellite). The RTT may be four times of 138.9 milliseconds (approximately 556 milliseconds).

[0236] In an example, an RTT of the GEO satellite may be more than a few seconds if processing time and congestion are considered. In an example, an RTT of a terrestrial network (e.g., NR, E-UTRA, LTE) may be negligible. The RTT of a terrestrial network may be less than 1 millisecond. In an example, the RTT of a GEO satellite may be hundreds of times longer than the RTT of a terrestrial network.

[0237] In an example, a maximum RTT of a LEO satellite with transparent payload with altitude of 600km may be 25.77 milliseconds. The differential RTT may be 3.12 milliseconds. The differential RTT within a beam of the satellite may be calculated based on the maximum diameter of the beam footprint at nadir. In an example, the differential RTT may imply the difference between communication latency that two UEs (e.g., one UE may be located close to the edge of the cell/beam and the other UE may be located close to the center of the cell/beam) may experience while communicating with an NTN node. In an example, for a LEO satellite with transparent payload with altitude of 1200km, the maximum RTD of may be 41.77 milliseconds. The differential RTT may be 3.18 milliseconds.

[0238] FIG. 20A and FIG. 20B illustrate examples of service link with maximum propagation delay of the cell/beam. In an example, an NTN may comprise at least one of: a transparent satellite, feeder link, ground/terrestrial gNB/eNB, a cell/beam, and service links of two wireless users.

[0239] In an example, as shown in FIG. 20A and/or FIG. 20B, a first UE (e.g., UE1) may be located closer to the cell/beam center than a second UE (e.g., UE2). In an example, the first UE (e.g., UE1) may not be at/close to the cell/beam center but may be otherwise closer to the satellite than the second UE (UE2). The UE1 may have smaller RTT compared to the UE2. For example, the RTT seen by UE1 may be 3.18 milliseconds lower than the RTT seen by UE2 for an NTN with LEO satellite with transparent payload with altitude of 1200km.

[0240] In an example, the UE may receive information from the base station in a downlink message (e.g., SIB or RRC message) to estimate a location of the satellite. The UE may use the location of the satellite to estimate/determine/calculate/compute the propagation delay of the service link. For example, the UE may receive the satellite ephemeris via a downlink message (e.g., SIB or RRC message). For example, the UE may receive the satellite ephemeris via one or more configuration parameters from the base station. The satellite ephemeris may indicate a state vector indicating the coordinates of the satellite. The satellite ephemeris may indicate an orbital velocity of the satellite. In another example, the satellite ephemeris may comprise one or more Kepler orbit elements or orbital elements or Keplerian elements, e.g., semi-major axis, eccentricity, argument of periapsis, longitude of ascending node, inclination, and true anomaly at epoch time of the satellite. The UE may determine/calculate/compute/estimate the location of the satellite based on the satellite ephemeris. For example, the UE may determine/calculate/deduce/compute/estimate the Cartesian coordinates of the satellite at any given time instant using the satellite ephemeris.

[0241] In an example, the satellite ephemeris may be periodically broadcast by the satellite as part of system information (e.g., RRC message or SIB). The system information message/signal/command (e.g., SIB) may comprise an indication indicating the rate at which the calculation of RTT performed by the UE based on the satellite ephemeris should be updated. In an example, the UE may adjust the calculated RTT during a timer period based on the indicated rate. The timer period may indicate a duration between two consecutive receptions of the satellite ephemeris by the UE.

[0242] In an example, the satellite ephemeris may not accurately provide the location of the satellite if the periodicity during which the satellite ephemeris is broadcast is relatively long. For example, the location of the satellite determined by the UE may be inaccurate due to an expiry of the satellite ephemeris. The periodicity of the satellite ephemeris broadcast may be set such that the satellite ephemeris may be updated before expiry. The periodicity of the satellite ephemeris broadcast may, for example, depend on altitude of the satellite. For example, the periodicity of the satellite ephemeris broadcast may be larger for a GEO satellite than the periodicity of the satellite ephemeris broadcast for a

LEO satellite. The periodicity of the satellite ephemeris broadcast may further depend on velocity of the satellite. For example, a UE on earth may have visibility of at least two satellites. The at least two satellites may be a first satellite and a second satellite. The first satellite may move at/with a first velocity. The second satellite may move at/with a second velocity. The first velocity may be greater/higher than the second velocity. The periodicity of the satellite ephemeris broadcast may be smaller for the first satellite than the periodicity of the satellite ephemeris for the second satellite. The satellite ephemeris broadcast may increase signaling overhead. The satellite ephemeris broadcast may increase the communication latency in an NTN.

[0243] In an example, the satellite ephemeris may not accurately provide the location of the satellite when required. For example, the location of the satellite determined by the UE may be accurate at the time the UE receives the satellite ephemeris but may be inaccurate by the time the UE uses the determined satellite location, for example, for random-access preamble transmission (e.g., MSG1), or random-access MSG3 transmission, or MSG5 transmission.

[0244] In an example, the satellite ephemeris may not accurately provide the location of the satellite if the movement of the satellite gradually drifts from the predicted orbital movement at the UE using the satellite ephemeris.

[0245] In an example, the satellite ephemeris data may provide the UE with a correction margin to help the UE compensate for the inaccuracy of the satellite ephemeris data. In an example, the UE may use the correction margin of the satellite ephemeris data to partially account for the drift of the satellite from the orbit of the satellite.

[0246] In an example, a reference location of a cell may be broadcast as a part of RRC message (e.g., RRCReconfiguration message, SIB). The reference location may describe a coordination in a geographic shape. The geographic shape may be ellipsoid point. The ellipsoide point may be a point on the su`rface of the ellipsoid. The ellipsoid point may comprise at least one of degrees of longitude, degrees of latitude, and sign of latitude (e.g., north, or south).

[0247] In an example, the reference location of a cell may be provided via quasi-earth fixed cell. The UE may calculate the distance between the UE and the reference location of a cell. The location of the UE may be based on GNSS positioning information.

[0248] In an example, a reference location of a serving cell may be used for measurement rule in RRC_IDLE/INACTIVE state. The UE in RRC_IDLE/INACTIVE state may calculate the distance between the UE and the reference location of the serving cell. For example, the UE may choose not to perform intra-frequency measurements if the distance between UE and the serving cell reference location is shorter than a threshold. In an another example, the UE may choose not to perform inter-frequency measurements if the distance between UE and the serving cell reference location is shorter than a threshold.

[0249] In an example, a reference location of a serving cell and a reference location of a CHO candidate target cell may be used for CHO execution condition. The UE state may calculate the distance between the UE and reference location of the serving cell. The UE may calculate the distance between the UE and reference location of the CHO candidate target cell. For example, the UE may perform CHO to the CHO candidate target cell if the distance between UE and a reference location of the seving cell becomes larger than a first threshold and the distance between UE and a reference location of the CHO candidate cell becomes shorter than a second threshold. The reference location of the serving cell, reference location of the CHO candidate target cell, the first threshold, and the second threshold may be provided in an RRC message (e.g., RRCReconfiguration message, SIB).

[0250] In an example, a Timing Advance (e.g., in NTN 5G NR) may be based on the orthogonal frequency-division multiple access (OFDMA) as the multi-access scheme in the uplink. The transmissions from different wireless devices in a cell/beam may need to be time-aligned at the gNB/eNB and/or the satellite to maintain uplink orthogonality. Time alignment may be achieved by using different timing advance (TA) values at different UEs to compensate for their different propagation delays or RTT. In an example, the transmissions from different UEs in a cell/beam may need to be time-aligned at the gNB/eNB. The TA value may comprise the service link delay and the feeder link delay. In another example, the transmissions from different UE in a cell/beam may need to be time-aligned at the satellite. The TA value may comprise the service link delay. In another example, the transmissions from different UE in a cell/beam may need to be time-aligned at a non-terrestrial point on the feeder link. The TA value may comprise the service link delay and a non-zero fraction of the feeder link delay. In another example, the transmissions from different UE in a cell/beam may need to be time-aligned at a non-terrestrial point on the service link. The TA value may comprise a non-zero fraction of the service link delay.

[0251] In NTNs, the size of the cells/beams may be larger than the size of cells in terrestrial networks. For example, the maximum footprint of GEO NTN cell/beam may be 3500 kilometers and the maximum footprint of LEO NTN cell/beam may be 1000 kilometers. The size of cell of the terrestrial network may be less than a kilometer to a few kilometers. Different UEs in NTN may experience different propagation delays between the satellite and the UE due to the large footprint of the beam/cell. Different UEs in NTN may experience different propagation delays between the NTN gateway and the UE due to the large footprint of the beam/cell. Different UEs in NTN may experience different propagation delays between the gNB/eNB and the UE due to the large footprint of the cell/beam.

[0252] A differential delay between two UEs may indicate the difference between the one way propagation delay of the service link for the two UEs. A maximum differential delay may indicate the difference between the maximum one way delay (i.e., one way propagation delay experienced by a UE that is located at a point farthest away from the satellite) and the minimum one way delay (i.e., one way propagation delay experienced by a UE that is located at a point that is closest to the satellite) of/in the service link. For example, a UE that is at/close to the cell/beam center may be at a point that is closest to the satellite. A UE that is at/close to the cell/beam edge/boundary may be at a point that is farthest away from the satellite. The maximum differential delay for a LEO satellite based NTN may be 3.18 milliseconds. The maximum differential delay for a GEO satellite based NTN may be 10.3 milliseconds. The maximum differential delay in a terrestrial network may be less than one millisecond. The base station may receive random-access preambles transmitted by different NTN UEs at/in/on the same RACH occasion at different times based on the differential delay between the UEs.

[0253] In an example, the base station may use an expanded preamble reception window when operating in an NTN to receive random-access preambles transmitted in/on/at the same RACH occasion. For example, the base station may use a preamble reception window that starts from [RACH occasion timing + 2*minimum one way propagation delay] and end at [RACH occasion + 2*maximum one way propagation delay]. Using an expanded preamble reception window may increase the time gap between two consecutive supported RACH occasions. For example, the time gap between two consecutive supported RACH occasions may be greater than 2*(maximum differential delay). A limited number of PRACH configurations (e.g., 3 for GEO satellite based NTNs) may support the time gap between two consecutive supported RACH occasions to be greater than 2*(maximum differential delay). Based on the network traffic type, the limited number of PRACH configurations may support a small number of UEs in a given area, i.e., the limited number of PRACH configurations may support a small UE density. For example, the supported UE density may be 51 UEs per square kilometer when each UE accesses the RACH once every 10 minutes for an NTN served by a LEO satellite with a cell/beam coverage area of 26000 square kilometers. In an example, the UEs may pre-compensate random-access preamble transmission based on a TA value to compensate for the long RTT to allow for a smaller preamble reception window at the base station (e.g., 1 ms). This may allow for a larger number of UE density (e.g., 60,000 UEs per square kilometer). In an example, the random-access procedure may be a four-step random access procedure. In an example, the random-access procedure may be a two-step random access procedure.

[0254] FIG. 21A and FIG. 21A illustrate examples of received signal strength when UE is in terrestrial network and NTN.

[0255] FIG. 21A illustrates an example that UE1 locates near cell center and UE2 locates at cell edge in terrestrial network. The received signal strength (e.g., RSRP) decreases when a UE moves from cell center to cell edge. The difference of received signal strength between the UE1 and UE2 may be clear.

[0256] FIG. 21B illustrates an example that UE1 locates near cell center and UE2 locates at cell edge in NTN. The difference of received signal strength between the UE1 and UE2 may be smaller than the case in terrestrial network, as illustrated in FIG. 21A. In NTN, the high received signal strength may not mean that the UE is at cell center. For example, UE at cell edge may have high received signal strength.

[0257] FIG. 22 illustrates an example of an NTN. The gNB depicted in FIG. 22 may be subdivided into non-NTN infrastructure gNB functions and an NTN Service Link provisioning System. The NTN infrastructure shown in FIG. 22 may be (thought of being) subdivided into an NTN Service Link provisioning System and an NTN Control function. The NTN Service Link provisioning System may comprise one or more NTN payloads and NTN Gateways. The NTN payload may be embarked on a spaceborne (or airborne) vehicle. The NTN payload may provide a structure, power, commanding, telemetry, and /or attitude control for the satellite. The NTN payload may provide an appropriate thermal environment and/or radiation shielding. The NTN Service Link provisioning System may map the NR-Uu radio protocol over radio resources of the NTN infrastructure (e.g., beams, channels, Tx power, and the like). The NTN control function may control the spaceborne (or airborne) vehicle(s). The NTN control function may control one or more radio resources of the NTN infrastructure (e.g., NTN payload(s) and NTN Gateway(s)). The NTN control function may provide control data, e.g., satellite ephemeris, to the non-NTN infrastructure gNB functions of the gNB.

[0258] The NTN may provide non-terrestrial access to the UE by means of an NTN payload and an NTN Gateway, depicting a service link between the NTN payload and the UE, and a feeder link between the NTN Gateway and the NTN payload. The NTN payload may (also) be referred to as a satellite.

[0259] The NTN payload may transparently forward a radio protocol received from the UE (e.g., via the service link) to the NTN Gateway (e.g., via the feeder link) and vice-versa. The following connectivity may be supported by the NTN payload:

- A gNB may serve multiple (e.g., more than one, plurality, and the like) NTN payloads;
- An NTN payload may be served by multiple (e.g., more than one, plurality, and the like) gNBs.

[0260] The NTN payload may change a carrier frequency, before re-transmitting it on the service link, and vice versa (e.g., respectively on the feeder link).

[0261] For NTN, the following may apply in addition to Network Identities:

- A Tracking Area may correspond to a fixed geographical area. Any respective mapping may be configured in a radio access network (RAN).
- A mapped cell identity (ID).

[0262] Non-Geosynchronous orbit (NGSO) may include Low Earth Orbit at altitude approximately between 300 km and 1500 km. NGSO may include Medium Earth Orbit at altitude approximately between 7000 km and 25000 km.

[0263] At least three types of service links may be supported:

- Earth-fixed (system/service link/cell/cell system): provisioned by beam(s) continuously covering the same geographical areas a plurality of (e.g., all) the time (e.g., the case of GSO satellites);
- Quasi-Earth-fixed (system/service link/cell/cell system): provisioned by beam(s) covering one geographic area for a limited period and a different geographic area during another period (e.g., a case of NGSO satellites generating steerable beams);
- Earth-moving (system/service link/cell/cell system): provisioned by beam(s) whose coverage area slides over the Earth surface (e.g., a case of NGSO satellites generating fixed or non-steerable beams).

[0264] With NGSO satellites, the gNB may provide either quasi-Earth-fixed cell coverage or Earth-moving cell coverage. The gNB operating with GSO satellite may provide Earth fixed cell coverage.

[0265] The UE supporting NTN may be GNSS-capable.

[0266] In case of NGSO NTN, a service link switch may refer to a change of serving satellite.

[0267] In an NTN, the UE may be configured to report a timing advance (TA) of the UE. The UE may be configured to report the TA, for example, during random-access procedure in RRC_IDLE and/or RRC_INACTIVE state. The UE may be configured to report the TA, for example, during random-access procedure in RRC_CONNECTED state (e.g., using event-triggered reporting; for RRC re-establishment procedure, if an indication is broadcasted by the target cell's SI; for handover, the UE may trigger TA report if the target cell indicates the TA report in a handover command).

[0268] To accommodate the long propagation delay, user plane procedures may be adapted. For example, for downlink, HARQ feedback may be enabled or disabled per HARQ process. For example, for uplink, the UE may be configured with a HARQ mode A or HARQ mode B per HARQ process. For example, a maximum number of HARQ processes may be extended to 32. For example, value ranges of MAC (e.g., *sr-ProhibitTimer* and *configuredGrantTimer*), RLC (e.g., *t-Reassembly*) and PDCP (e.g., *discardTimer* and *t-reordering*) layer timers may be extended.

[0269] For example, the gNB may ensure proper configuration of HARQ feedback (e.g., enabled or disabled) for HARQ processes used by a semi persistent scheduling (SPS) configuration and of HARQ mode for HARQ processes used by a configured grant (CG) configuration.

[0270] If a logical channel is configured with *allowedHARQ-mode*, the logical channel may (only) be mapped to a HARQ process with a same HARQ mode.

[0271] To accommodate the long propagation delays, several NR timings involving DL-UL timing interaction may be enhanced by the support of two scheduling offsets: K_{offset} and k_{mac}.

[0272] Timing relationships modified for NTN using K_{offset} may be transmission timing of DCI scheduled PUSCH including CSI transmission on PUSCH, transmission timing of random-access response (RAR) grant or fallbackRAR grant scheduled PUSCH, timing of the first PUSCH transmission opportunity in type-2 configured grant, transmission timing of HARQ-ACK on physical uplink control channel (PUCCH) including HARQ-ACK on PUCCH to message B (MsgB) in 2-step random access, transmission timing of PDCCH ordered physical random access channel (PRACH), timing of the adjustment of uplink transmission timing upon reception of a corresponding timing advance command, transmission timing of aperiodic sounding reference signal (SRS), and/or CSI reference resource timing.

[0273] k_{mac} may be a scheduling offset supported in NTN for MAC CE timing relationships enhancement. The k_{mac} may be provided by the network (e.g., via SIB, RRC configuration, and the like) in response to downlink and uplink frame timing not being aligned at the gNB. The k_{mac} may be needed for UE action and assumption on downlink configuration indicated by a MAC-CE command in PDSCH. The K_{mac} may be used in beam failure recovery, where after a PRACH transmission in uplink slot n the UE monitors the corresponding PDCCH starting from downlink slot "n + k_{mac} + 4" within a corresponding RAR window.

[0274] In response to a UE being provided with a k_{mac}, when the UE transmits a PUCCH with HARQ-ACK information in uplink slot n corresponding to a PDSCH carrying a MAC CE command on a downlink configuration, the UE action and assumption on the downlink configuration may be applied starting from the first slot that is after slot $n + 3N_{slot}^{subframe,\mu} + k_{\mathrm{mac}}$, where μ is the SCS configuration for the PUCCH.

[0275] To accommodate long propagation delays experienced in NTN on both service link and feeder link, the UE may (be able to) perform time pre-compensation for (all) uplink transmissions (e.g., PRACH preamble transmissions, uplink transmissions during the RRC_CONNECTED-state, and the like). To perform the pre-compensation, the UE may be assisted by GNSS (e.g., in/within the UE). To perform the pre-compensation, the UE may be assisted by the network (e.g., gNB). The gNB may periodically broadcast NTN assistance information. The NTN assistance information may comprise serving satellite ephemeris. The NTN assistance information may comprise higher layer Common-TA-related parameters. The higher layer Common-TA-related parameters may be used to calculate the common round-trip delay (RTD) e.g. delay on the feeder link.

[0276] The following formula for TA calculation may be applied by the UE for PRACH preamble transmission and in RRC_CONNECTED state: $T_{\mathrm{TA}} = \left(N_{\mathrm{TA}} + N_{\mathrm{TA,offset}} + N_{\mathrm{TA,adj}}^{\mathrm{common}} + N_{\mathrm{TA,adj}}^{\mathrm{UE}}\right) \times T_{\mathrm{c}}$ where N_{TA} may be a timing advance (or a timing advance value) between downlink and uplink, and $N_{\mathrm{TA,offset}}$ may be a fixed offset used to calculate the timing advance. For example, for msgA transmission on PUSCH, $N_{\mathrm{TA}} = 0$ may be used by the UE. $N_{\mathrm{TA,adj}}^{\mathrm{common}}$ may be network-controlled common TA. $N_{\mathrm{TA,adj}}^{\mathrm{common}}$may include any timing offset considered necessary by the network (e.g. feeder link delay/delay of the feeder link). $N_{\mathrm{TA,adj}}^{\mathrm{common}}$ may be derived from higher-layer parameters (e.g., *TACommon*, *TACommonDrift*, and *TACommonDriftVariation*) if configured, otherwise $N_{\mathrm{TA,adj}}^{\mathrm{common}} = 0$. $N_{\mathrm{TA,adj}}^{\mathrm{UE}}$ may be self-estimated TA by the UE to pre-compensate for delay of the service link (e.g., service link delay). $N_{\mathrm{TA,adj}}^{\mathrm{UE}}$may be computed by the UE based on a position of the UE and serving satellite-ephemeris-related higher-layers parameters if configured, otherwise $N_{\mathrm{TA,adj}}^{\mathrm{UE}} = 0$. T_c may be a NR basic time unit.

[0277] The UE may (be capable to) use an acquired GNSS position (of the UE) and serving satellite ephemeris information (when provided by the network) to calculate frequency pre-compensation to counter shift instantaneous Doppler shift experienced on the service link. The pre-compensation of the instantaneous Doppler shift experienced on the service link may be performed by the UE. Management of Doppler shift experienced over the feeder link as well as any transponder frequency error whether it is introduced in Downlink or Uplink may be network implementation.

[0278] The network (e.g., gNB) may broadcast multiple Tracking Area Codes per PLMN in an NTN cell. A tracking area code change in the System Information may be under network control, e.g., it may not be exactly synchronized with real-time illumination of beams on ground. The UE may determine a network type (e.g., terrestrial or non-terrestrial) implicitly by the existence of scheduling information of SIB19 in SIB1. Non-NTN capable UEs may be prevented from accessing an NTN cell.

[0279] The satellite ephemeris (or NTN ephemeris) may be divided into serving cell's satellite ephemeris and neighboring cell's satellite ephemeris.

[0280] At least in the quasi-earth fixed cell scenario, the UE may perform time-based and location-based cell selection/reselection. Timing information and location information associated to a (NTN) cell may be provided via system information (e.g., SIB, NTN-specific SIB, and the like). The timing information may refer to a time when a serving cell may stop serving a geographical area. The location information may refer to a reference location of the serving cell or neighboring cells. The location information may be used to assist cell reselection in NTN with, for example, a condition based on the distance between the UE and the reference location of the serving cell and/or neighbor cells. The UE may support mobility between radio access technologies based on different orbit (GSO, NGSO at different altitude, and the like).

[0281] A feeder link switch over may be a procedure where the feeder link is changed from a source NTN Gateway to a target NTN Gateway for a specific NTN payload. The feeder link switch over may be a Transport Network Layer procedure. Both hard and soft feeder link switch over may be applicable to NTN.

[0282] A feeder link switch over may result in transferring an established connection for affected UE between two gNBs. For soft feeder link switch over, an NTN payload may be able to connect to more than one NTN Gateway during a given period, e.g., a temporary overlap may be ensured during a transition between the feeder links. For hard feeder link switch over, an NTN payload may only connect to one NTN Gateway at any given time, e.g., a radio link interruption may occur during a transition between the feeder links.

[0283] An NTN Control function may determine a point in time when a feeder link switch over between two gNBs is performed. A transfer of the affected UEs' context between the two gNBs at feeder link switch over may be performed by means of either NG based or Xn based handover. The transfer may depend on the gNBs' implementation and configuration information provided to the gNBs by the NTN Control function.

[0284] During mobility between NTN and Terrestrial Network, a UE may not be required to connect to both NTN and Terrestrial Network at the same time. The mobility between NTN and Terrestrial Network may be referred to as NTN-Terrestrial Network hand-over. NTN-Terrestrial Network hand-over may refer to mobility in both directions, e.g., from NTN to Terrestrial Network (hand-in) and from Terrestrial Network to NTN (hand-out).

[0285] A UE may receive a conditional handover (CHO) configuration. The CHO configuration may be a conditional reconfiguration. The CHO configuration may include one or more CHO candidate cells. Each CHO candidate cell may comprise CHO execution condition. The UE may execute CHO to the Cho candidate cell based on the comprised CHO execution condition. For example, UE can execute CHO to a CHO candidate cell if all the configured CHO execution condition(s) of the CHO candidate cell is fulfilled. Up to two CHO execution conditions can be configured for a CHO candidate cell.

[0286] The CHO execution condition for a CHO candidate cell may comprise:

- A cell quality-based CHO execution condition (event A3, event A4, event A5); and/or
- A time-based CHO execution condition (e.g., condEvent T1, or event T1); and/or
- A location-based CHO execution condition (e.g., event D1).

[0287] A cell quality-based CHO execution condition may be based on measurement results of a cell quality (e.g., RSRP, RSRQ, or SINR).

[0288] In an example, event A3 may be satisfied if measured cell quality of the CHO candidate cell is offset higher than the SpCell (e.g., PCell, or SPCell). The event A3 may be condEvent A3.

[0289] In an example, event A4 may be satisfied if measured cell quality of the CHO candidate cell is higher than a threshold. The event A4 may be condEvent A4.

[0290] In an example, event A5 may be satisfied if measured cell quality of the SpCell (e.g., PCell, or SPCell) is lower than a first threshold and measured cell quality of the CHO candidate cell is higher than a second threshold. The event A5 may be condEvent A5.

[0291] A time-based CHO execution condition (e.g., event T1, or condEvent T1) may comprise a time period. The time period may comprise a starting time point of the time period and a time duration of the time period. End time point of the time period may be the time duration after the starting time point of the time period. For example, the time period may comprise a starting time point as 9:00 UTC and a time duration as 10 minutes. Then the time period may start at 9:00 UTC and lasts 10 minutes. The time period may be from 9:00 UTC to 9:10 UTC. The time-based CHO execution condition may be satisfied when the time measured at UE is after the starting time point of the time period and before the end time point of the time period.

[0292] A location-based CHO execution condition may comprise a first reference location which is associated to serving cell (e.g., PCell, SPCell) and a second reference location which is associated to the CHO candidate cell (e.g., CHO target cell). The location-based CHO execution condition may be satisfied when the distance between the UE and the first reference location is higher than a first threshold and the distance between the UE and the second reference location is lower than a second threshold.

[0293] A time-based CHO execution condition or a location-based CHO execution condition may be configured together with a cell quality-based CHO execution condition (e.g., event A3, event A4, or A5). A time-based CHO execution condition and a location-based CHO execution may not be configured together for a CHO candidate cell.

[0294] The (NTN) base station/network may configure:

- multiple SMTCs in parallel per carrier and/or for a given set of cells depending on UE capabilities using propagation delay difference, feeder link delay, and/or serving/neighbour satellite cell ephemeris; and/or
- measurement gaps using a same propagation delay difference as computed for SMTC.

[0295] The adjustment of SMTCs may be possible under network control for connected mode and under UE control based on UE location information and ephemeris for idle/inactive modes.

[0296] Upon network request, after AS security in connected mode is established, a UE may report coarse UE location information (e.g., X most Significant Bits of GNSS coordinates of the UE with accuracy around 2km level) to the NG-RAN without receiving any prior explicit user consent. If user consent is available at the UE, the UE may report the coarse UE location information. Else, the UE may respond "no coarse GNSS location available". Periodic location reporting may be configured by gNB to obtain UE location update of mobile UE in RRC_CONNECTED mode/state.

[0297] The base station (e.g., gNB) may transmit/broadcast the NTN-specific SIB. The NTN-specific SIB may be, for example, SIB19. The NTN-specific SIB may comprise satellite assistance information. For example, the NTN-specific SIB may comprise ephemeris data. For example, the NTN-specific SIB may comprise common TA parameters. For example, the NTN-specific SIB may comprise common TA parameters. For example, the NTN-specific SIB may comprise k-offset. For example, the NTN-specific SIB may comprise a validity duration for UL synchronization information. For example, the NTN-specific SIB may comprise an epoch time. For example, the NTN-specific SIB may comprise a reference location of a (NTN) cell provided via NTN quasi-Earth fixed system.

[0298] The NTN-specific SIB may comprise a t-service. The t-service may indicate time information on when a (NTN) cell provided via NTN quasi-Earth fixed system is going to stop serving an area the (NTN) cell is currently covering. The t-service may count a number of universal time coordinated (UTC) seconds in 10 ms units since 00:00:00 on Gregorian calendar date 1 January, 1900 (midnight between Sunday, December 31, 1899 and Monday, January 1, 1900).

[0299] Upon receiving the NTN-specific SIB, the UE may instruct lower layers to start or restart *ntn-UlSyncValidityDuration* from the subframe/slot indicated by the epoch time. The UE may attempt to re-acquire the NTN-specific SIB before end of a duration indicated by *ntn-UlSyncValidityDuration* and the epoch time.

[0300] Support for bandwidth limited low complexity (BL) UEs, UEs in enhanced coverage, and/or narrowband Internet-of-Things (NB-IoT) UEs over NTN may be applicable. UEs not supporting NTN may be barred from an NTN cell.

[0301] In NTN, BL UEs, UEs in enhanced coverage, and NB-IoT wire UEs with GNSS capability may be supported.

[0302] To accommodate long propagation delays in NTN, increased timer values and window sizes, or delayed starting times may be supported for the physical layer and/or for higher layers.

[0303] UL segmented transmission may be supported for UL transmission with repetitions in NTN. The UE may apply UE pre-compensation per segment of UL transmission of PUSCH/PUCCH/PRACH for eMTC and NPUSCH/NPRACH for NB-IoT from one segment to a next segment.

[0304] To accommodate the long propagation delays, several IoT timings involving DL-UL timing interaction may be enhanced by the support of two scheduling offsets: K_{offset} and K_{mac}. K_{offset} may be a round-trip time between the UE and an uplink time synchronization reference point (RP). K_{offset} may correspond to a sum of a service link RTT and a common TA if indicated. K_{mac} may be a round trip time between the RP and the eNB/gNB.

[0305] DL and UL may frame aligned at the uplink time synchronization RP with an offset given by $\mathrm{N}_{\mathrm{TA,offset}}$.

[0306] Timing relationships that may be modified for NB-IoT using K_{offset} are summarized as follows:

- A transmission timing of NPDCCH scheduled NPUSCH format 1.
- A transmission timing of random access response (RAR) grant scheduled NPUSCH format 1.
- A transmission timing of HARQ-ACK on NPUSCH format 2.
- A transmission timing of NPDCCH ordered NB-IoT physical random access channel (NPRACH).
- A timing of the adjustment of uplink transmission timing upon reception of a corresponding timing advance command.

[0307] Timing relationships that may be modified for eMTC using K_{offset} are summarized as follows:

- A transmission timing of MPDCCH scheduled PUSCH.
- A transmission timing of random access response (RAR) grant scheduled PUSCH.
- A timing of the first PUSCH transmission opportunity in UL SPS.
- A transmission timing of HARQ-ACK on physical uplink control channel (PUCCH).
- A transmission timing of MPDCCH ordered physical random access channel (PRACH).
- A timing of the adjustment of uplink transmission timing upon reception of a corresponding timing advance command.
- A transmission timing of aperiodic sounding reference signal (SRS).
- A CSI reference resource timing.
- A transmission timing of a preamble retransmission.

[0308] For initial access, information of K_{offset} may be carried in system information. Update of the K_{offset} after initial access may be supported. A UE-specific K_{offset} may be provided and updated by network/gNB/eNB/base station with MAC CE.

[0309] K_{mac} is a scheduling offset that may be supported in NTN for MAC CE timing relationships enhancement. K_{mac} may be provided by the network if downlink and uplink frame timing are not aligned at eNB. K_{mac} may be needed for UE action and assumption on downlink configuration indicated by a MAC-CE command in (N)PDSCH. The K_{mac} may also be used in pre-configured uplink resources, in response to the UE initiating an (N)PUSCH transmission using pre-configured uplink resources ending in subframe n, the UE shall start or restart to monitor the N/MPDCCH from DL subframe $n + 4 + K_{\mathrm{mac}}$.

[0310] For a serving cell, a network/eNB/gNB may broadcast ephemeris information and common TA parameters for the UE to autonomously perform TA pre-compensation. For the serving cell, the network/gNB/eNB may broadcast ephemeris information and common TA parameters for the UE to autonomously perform frequency shift pre-compensation.

[0311] The UE may acquire a GNSS position of the UE before connecting to an NTN cell to ensure the UE is synchronized. The UE may acquire satellite ephemeris and common TA before connected to the NTN cell to ensure the UE is synchronized. Before performing random-access, the UE may autonomously pre-compensate a TA for the long propagation delay as well as the frequency doppler shift by considering the common TA, position of the UE and a satellite position through the satellite ephemeris.

[0312] In RRC_CONNECTED mode, the UE may continuously update the TA and frequency pre-compensation. The UE may not be expected to perform GNSS acquisition. One or more timers may ensure that the UE does not perform any transmissions due to outdated satellite ephemeris, common TA, or GNSS position. In connected mode, upon outdated satellite ephemeris and common TA, the UE may re-acquire one or more broadcasted parameters. Upon outdated GNSS position the UE may move to RRC_IDLE mode.

[0313] The UE may be configured to report TA at initial access or in the RRC_CONEECTED mode. In the RRC_CONEECTED mode, triggered reporting of the TA may be supported.

[0314] The UE may be capable of using an acquired GNSS position of UE and the satellite ephemeris information (when provided by the network/gNB/eNB) to calculate frequency pre-compensation to counter shift an instantaneous Doppler shift experienced on a service link.

[0315] The management of Doppler shift experienced over a feeder link as well as any transponder frequency error whether introduced in DL or UL may be left to network implementation.

[0316] As a satellite moves on a specified orbit, for example, in case of a NGSO satellite, a satellite beams coverage area may move and cover different portions of a geographical area due to an orbital movement of the satellite. As a consequence, a UE located in a concerned geographical area may experience a situation of discontinuous coverage, due to, for example, a sparse satellites constellation deployment.

[0317] To enable the UE to save power during periods of no coverage, the network/gNB/eNB may provide satellite assistance information (e.g. satellite ephemeris parameters, a start-time of upcoming satellite's coverage, end-time of satellite's coverage, and the like) ephemeris parameters to enable the UE to predict when coverage will be provided by upcoming satellites. Predicting out of coverage and in coverage may be up to UE implementation. When out of coverage, the UE may not be required to perform access stratum functions.

[0318] A feeder link switch over may be a procedure where a feeder link is changed from a source NTN Gateway to a target NTN Gateway for a specific NTN payload. The feeder link switch over may be a Transport Network Layer procedure. Both hard and soft feeder link switch over may be applicable to NTN.

[0319] A feeder link switch over may result in transferring an established connection for affected UE between two eNBs/gNBs/base stations.

[0320] For soft feeder link switch over, an NTN payload may be able to connect to more than one NTN Gateway during a given period, e.g., a temporary overlap may be ensured during transition between feeder links. For hard feeder link switch over, an NTN payload may only connect to one NTN Gateway at any given time, e.g., a radio link interruption may occur during a transition between the feeder links.

[0321] An NTN control function may determine a point in time when the feeder link switch over between two eNBs/gNBs/base stations is performed. For BL UEs and UEs in enhanced coverage, transfer of the affected UEs' contexts between the two eNBs/gNBs/base stations at the feeder link switch over may be performed by means of either S1 based or X2 based handover. The transfer may depend on implementations of the two eNBs/gNBs/base stations and configuration information provided to the two eNBs/gNBs/base stations by the NTN control function.

[0322] When a UE performs a handover or detects an RLF, the UE may store a UE measurement information. The UE measurement information may comprise information about the handover or the RLF. The UE measurement information may comprise successful handover report (e.g., SuccessHO-Report), handover failure report, or RLF report (e.g. RLF-Report). Then the UE may transmit an indication to the base station that the UE measurement information is available. The base station may request the UE to report the UE measurement information to the base station.

[0323] FIG. 23 illustrates an example of reporting a UE measurement information after a successful handover. The UE measurement information may comprise a successful handover report. The UE may receive, from a cell 1, a handover command to a cell 2. In response to the handover command, the UE may execute handover to the cell 2. Execution of the handover may comprise initiating the Random Access procedure. When the Random Access procedure is completed, the UE may perform actions for the successful handover report determination. Based on result of the successful handover report determination, the UE may store the successful handover report. If the successful handover report is available at the UE, the UE may transmit, to the cell 2, an availability indication which indicates that the successful handover report is available at the UE (e.g., successHO-InfoAvailable). The UE may perform mobility to a cell 3. The mobility to the cell 3 may comprise performing handover to the cell 3. The mobility to the cell 3 may comprise performing Random Access procedure with the cell 3 after state transition to RRC_IDLE/INACTIVE state. After performing mobility to the cell 3, the cell 3 may transmit, to the UE, a request indication to report the successful handover report. In response to receiving the request indication, the UE may transmit the successful handover report to the cell 3. The cell 3 may be cell 2 if the UE did not perform the mobility to the cell 3. The cell 3 may be the cell 2 if the UE does not change the PCell after performing the successful handover report determination. The cell 3 may be different with the cell 2 if the UE changes the PCell for one or more times after the successful handover report determination.

[0324] In an example of successful handover report determination, the UE may store the successful handover information if the ratio between the value of the elapsed time of the timer T304 and the configured value of the timer T304 is greater than a threshold (e.g., thresholdPercentageT304), if the threshold was configured to the UE.

[0325] In an example of performing the successful handover report determination, the UE may store the successful handover information if the ratio between the value of the elapsed time of the timer T310 and the configured value of the timer T310 is greater than a threshold (e.g., thresholdPercentageT310), if the threshold was configured to the UE.

[0326] In an example of performing the successful handover report determination, the UE may store the successful handover information if the T312 associated to the measurement identity of the target cell was running at the time of initiating the execution of the reconfiguration with sync procedure and if the ratio between the value of the elapsed time of the timer T312 and the configured value of the timer T312 is greater than a threshold (e.g., thresholdPercentageT312), if the threshold was configured to the UE.

[0327] In an example of performing the successful handover report determination, the UE may store the successful handover information if an indication of DAPS handover failure reporting (e.g., sourceDAPS-FailureReporting) is provided to the UE before executing the last handover and is set to true and if the last executed handover was a DAPS handover and if an RLF occurred at the source PCell during the DAPS handover while T304 was running.

[0328] FIG. 24 illustrates an example of reporting a UE measurement information after a handover failure. The UE measurement information may comprise an RLF report. The UE may receive, from a cell 1, a handover command to a cell 2. In response to the handover command, the UE may perform and/or execute handover to the cell 2. Execution of the handover may comprise initiating the Random Access procedure. To perform and/or execute handover to the cell 2, the UE may perform the Random Access procedure with the cell 2. After execution of the handover, the handover may fail. The handover may fail if the Random Access procedure problem is detected and/or indicated. The handover may fail if the timer T304 expires. The handover failure may comprise RLF detection. In response to the RLF detection, the UE may perform the RLF report content determination. Based on result of the RLF content determination, the UE may store the RLF report. The RLF report may comprise a handover failure report. After the RLF detection, the UE may perform RRC re-establishment procedure with a cell 3. The UE may transmit *RRCReestablishmentRequest* message to the cell 3. The RRC re-establishment procedure may be completed when the UE receives *RRCReestablishmentComplete* message from the cell 3. As a result of completing the RRC re-establishment procedure between the UE and the cell 3, the UE may establish connection to the cell 3. If the RLF report is available at the UE, the UE may transmit, to the cell 3, an availability indication which indicates that the RLF report is available (e.g., *rlf-*

InfoAvailable) at the UE. The cell 3 may transmit, to the UE, a request indication to report the RLF report. In response to receiving the request indication, the UE may transmit the RLF report to the cell 3.

[0329] FIG. 25 illustrates an example of reporting a UE measurement information after an RLF detection. The UE measurements information may comprise an RLF report. The UE may be connected to a cell 1. While connected to the cell 1, the UE may detect an RLF. In response to the RLF detection, the UE may perform RLF report content determination. Based on result of the RLF content determination, the UE may store the radio link failure information in the RLF report. The RLF report may comprise handover failure report. After the RLF detection, the UE may perform RRC re-establishment procedure with a cell 2. The UE may transmit *RRCReestablishmentRequest* message to the cell 2. The RRC re-establishment procedure may be completed when the UE receives *RRCReestablishmentComplete* message from the cell 2. As a result of completing the RRC re-establishment procedure between the UE and the cell 2, the UE may establish connection to the cell 2. If the RLF report is available at the UE, the UE may transmit, to the cell 2, an availability indication which indicates that the RLF report is available (e.g., *rlf-InfoAvailable*). After completing the RRC re-establishment procedure, the UE may perform mobility to a cell 3. Performing the mobility to the cell 3 may comprise performing handover to the cell 3. Performing the mobility to the cell 3 may comprise performing Random Access procedure with the cell 3 after state transition to RRC_IDLE/INACTIVE state. The cell 3 may transmit, to the UE, a request indication to report the RLF report. The cell 3 may be the cell 2 if the UE does not perform mobility to the cell 3 and/or does not change the PCell. In response to receiving the request indication, the UE may transmit the RLF report to the cell 3.

[0330] In the present disclosure (e.g., from FIG 23 to FIG. 37), in response to the RLF detection, the UE may perform and/or initiate the RRC connection re-establishment procedure, e.g., if AS security has been activated. The RRC connection re-establishment procedure may comprise a Random Access procedure with a cell. When the RRC connection re-establishment procedure is completed, the UE establishes a RRC connection to the cell that the UE performed and/or initiated the RRC connection re-establishment procedure.

[0331] The RLF detection may be based on one or more RLF events comprising at least one of:

- upon T310 expiry in source SpCell (e.g., PCell);
- upon T312 expiry in PCell;
- upon random access problem indication from source MCG MAC;
- upon indication from MCG RLC (e.g., source MCG RLC) that the maximum number of retransmissions has been reached;
- upon consistent uplink LBT failure indication from source MCG MAC; or
- upon BH RLF indication received on BAP entity from the MCG, if connected as an IAB-node.

[0332] In response to the RLF detection, the wireless device performs the connection re-establishment procedure if AS security has been activated. If the connection re-establishment procedure is successfully completed, the RRC connection is recovered.

[0333] FIG. 26A and FIG.26B illustrate examples that a UE performs (e.g., initiates and/or triggers) CHO to a CHO candidate cell. The UE may transmit a successful handover report to the base station after the CHO is completed. The CHO execution condition of the CHO candidate cell may comprise event Ax and event D1. For example, the CHO execution condition may be fulfilled when the event Ax and the event D1 are fulfilled. The UE may execute CHO to the CHO candidate cell when the CHO execution condition is fulfilled. The event Ax may comprise event A3, event A4, or event A5. For example, a configuration of the event D1 may comprise configuration parameters indicating condition D1-1 and condition D1-2. For example, the UE may determine whether the condition D1-1 and/or the condition D1-2 are fulfilled using the configuration parameters. For example, the UE may determine that the event D1 is fulfilled (e.g., is satisfied) if the condition D1-1 and/or the condition D1-2 are fulfilled.

[0334] In FIG. 26A, the event D1 may be fulfilled first in time and the event Ax may be fulfilled second in time. The time point t_{D1} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled earlier. The time point t_{D2} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled later. At the time point t_{D2}, the event D1 may be fulfilled. For example, if the condition D1-1 is fulfilled earlier than the condition D1-1, the condition D1-1 may be fulfilled at the time point t_{D1} and the condition D1-2 may be fulfilled at the time point t_{D2}, and the event D1 may be fulfilled at the time point t_{D2}. The time point t_A may indicate a time point that the event Ax is fulfilled. The time point $t_{CHO\text{-}config}$ may indicate a time point that the UE may receive a CHO configuration. The CHO configuration may comprise the CHO execution condition of the CHO candidate cell. The time point $t_{CHO\text{-}execute}$ may indicate a time point that the UE executes the CHO to the CHO candidate cell. After the CHO execution to the CHO candidate cell, the CHO may be completed. After the CHO completion, the UE may transmit the successful handover report to a base station.

[0335] In FIG. 26B, the event Ax may be fulfilled first in time and the event D1 may be fulfilled second in time. The time point t_{D1} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled earlier. The time point t_{D2} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled later. At the time point t_{D2}, the event D1 may be fulfilled. For example, if the condition D1-1 is fulfilled earlier than the condition D1-1, the condition D1-1 may be fulfilled at the time point t_{D1} and the condition D1-2 may be fulfilled at the time point t_{D2}, and the event D1 may be fulfilled at the time point t_{D2}. The time point t_A may indicate a time point that the event Ax is fulfilled. The time point $t_{CHO\text{-}config}$ may indicate a time point that the UE may receive a CHO configuration. The CHO configuration may comprise the CHO execution condition of the CHO candidate cell. The time point $t_{CHO\text{-}execute}$ may indicate a time point that the UE executes the CHO to the CHO candidate cell. After the CHO execution to the CHO candidate cell, the CHO may be completed. After the CHO completion, the UE may transmit the successful handover report to a base station.

[0336] FIG. 27A and FIG.27B illustrate examples that a UE performs (e.g., initiates and/or triggers) CHO to a CHO candidate cell. The UE may execute CHO to the CHO candidate cell and the CHO may fail. The UE may detect an RLF. In response to the RLF detection, the UE may store the RLF information in a RLF report. After storing the RLF information, the UE may transmit the RLF report to the base station. The CHO execution condition of the CHO candidate cell may comprise event Ax and event D1. For example, the CHO execution condition may be fulfilled when the event Ax and the event D1 are fulfilled. The UE may execute CHO to the CHO candidate cell when the CHO execution condition is fulfilled. The event Ax may comprise event A3, event A4, or event A5. For example, a configuration of the event D1 may comprise configuration parameters indicating condition D1-1 and condition D1-2. For example, the UE may determine whether the condition D1-1 and/or the condition D1-2 are fulfilled using the configuration parameters. For example, the UE may determine that the event D1 is fulfilled (e.g., is satisfied) if the condition D1-1 and/or the condition D1-2 are fulfilled.

[0337] In FIG. 27A, the event D1 may be fulfilled first in time and the event Ax may be fulfilled second in time. The time point t_{D1} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled earlier. The time point t_{D2} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled later. At the time point t_{D2}, the event D1 may be fulfilled. For example, if the condition D1-1 is fulfilled earlier than the condition D1-1, the condition D1-1 may be fulfilled at the time point t_{D1} and the condition D1-2 may be fulfilled at the time point t_{D2}, and the event D1 may be fulfilled at the time point t_{D2}. The time point t_A may indicate a time point that the event Ax is fulfilled. The time point $t_{CHO\text{-}config}$ may indicate a time point that the UE may receive a CHO configuration. The CHO configuration may comprise the CHO execution condition of the CHO candidate cell. The time point $t_{CHO\text{-}execute}$ may indicate a time point that the UE executes the CHO to the CHO candidate cell. The time point t_{RLF} may indicate a time point that the UE detects an RLF. After the CHO execution to the CHO candidate cell, the UE may detect (e.g., determine) a CHO failure. When the UE detects the CHO failure, the UE may detect an RLF. In response to the RLF detection, the UE may store an RLF information in an RLF report. The UE may transmit the RLF report to a base station.

[0338] In FIG. 27B the event Ax may be fulfilled first in time and the event D1 may be fulfilled second in time. The time point t_{D1} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled earlier. The time point t_{D2} may indicate a time point that the condition D1-1 or the condition D1-2 is fulfilled, whichever fulfilled later. At the time point t_{D2}, the event D1 may be fulfilled. For example, if the condition D1-1 is fulfilled earlier than the condition D1-1, the condition D1-1 may be fulfilled at the time point t_{D1} and the condition D1-2 may be fulfilled at the time point t_{D2}, and the event D1 may be fulfilled at the time point t_{D2}. The time point t_A may indicate a time point that the event Ax is fulfilled. The time point $t_{CHO\text{-}config}$ may indicate a time point that the UE may receive a CHO configuration. The CHO configuration may comprise the CHO execution condition of the CHO candidate cell. The time point $t_{CHO\text{-}execute}$ may indicate a time point that the UE executes the CHO to the CHO candidate cell. The time point t_{RLF} may indicate a time point that the UE detects an RLF. After the CHO execution to the CHO candidate cell, the UE may detect (e.g., determine) a CHO failure. When the UE detects the CHO failure, the UE may detect an RLF. In response to the RLF detection, the UE may store an RLF information in an RLF report. The UE may transmit the RLF report to a base station.

[0339] In an example, the RLF report may comprise:

- timeSinceCHO-Reconfig: the time elapsed between the receiving of the CHO configuration of the CHO candidate cell and CHO execution to the CHO candidate cell. For example, in FIG. 26A, timeSinceCHO-Reconfig may be a time elapsed from $t_{CHO\text{-}config}$ to $t_{CHO\text{-}execute}$ and/or a time interval between $t_{CHO\text{-}config}$ and $t_{CHO\text{-}execute}$. For example, timeSinceCHO-Reconfig in FIG. 26B, FIG. 27A, FIG. 27B, and/or FIG. 32 may be the same definition as the one in FIG. 26A. For example, timeSinceCHO-Reconfig in FIG. 26B, FIG. 27A, FIG. 27B, and/or FIG. 32 may be a time elapsed from $t_{CHO\text{-}config}$ to $t_{CHO\text{-}execute}$ and/or a time interval between $t_{CHO\text{-}config}$ and $t_{CHO\text{-}execute}$.
- timeBetweenEvents: the elapsed time between fulfilling the configured CHO execution conditions for a CHO candidate cell to which executed CHO. For example, in FIG. 26A, timeBetweenEvents may be a time elapsed from t_{D2} to t_A (or from t_A to t_{D2}) and/or a time interval (e.g., period) between t_{D2} and t_A. For example, timeBetweenEvents in FIG. 26B, FIG. 27A, FIG. 27B, and/or FIG. 32 may be the same definition as the one in FIG. 26A. For example, timeBetweenEvents in FIG. 26B, FIG. 27A, FIG. 27B, and/or FIG. 32 may be a time elapsed from t_{D2} to t_A (or from t_A to t_{D2}) and/or a time interval (e.g., period) between t_{D2} and t_A.
- timeConnFailure: the time elapsed between the CHO execution to the CHO candidate cell and RLF detection. For example, in FIG. 27A and/or FIG. 27B, timeConnFailure may be a time elapsed from $t_{CHO\text{-}execute}$ to t_{RLF} and/or a time interval (e.g., period) between $t_{CHO\text{-}execute}$ to t_{RLF}.

[0340] In an example, when the CHO execution condition of a CHO candidate cell comprises event D1 and event Ax (e.g., event A3, event A4, or event A5), the RLF report may comprise a time length parameter (e.g., timeBetweenEvents) which may indicate the elapsed time between the time point of fulfilling the event Ax and the time point of fulfilling the event D1. Upon the UE transmits the RLF report comprising the parameter, if the value of the parameter is longer than the base station had expected, the value may indicate that it took long time to fulfil the event D1 since the event Ax is fulfilled. For example, the long value of the time length parameter may indicate that the elapsed time since the measured RSRP of the source cell becomes lower than a threshold until the distance between the UE and the target cell (e.g., CHO candidate cell) becomes lower than a threshold is long. Upon receiving the RLF report comprising long value of the time length parameter, according to existing technologies, the base station may change the CHO execution of the CHO candidate cell when the base station configures the CHO execution of the CHO candidate cell in the next time. For example, when the base station configures CHO execution condition of the CHO candidate cell to a UE, the base station may configure a lower value on a distance threshold of the condition D1-1 of the event D1 of the CHO execution condition (e.g., referenceLocation1) and/or configure a higher value on a distance threshold of the condition D1-2 of the event D1 of the CHO execution condition (e.g., referenceLocation1). Based on the changed CHO configuration, the elapsed time between the time point fulfilling the event Ax and the time point fulfilling the event D1 may be shorter than the one that transmitted to the base station in the RLF report.

[0341] In an example, when a UE executes a CHO to a CHO candidate cell, wherein the CHO execution condition comprises event D1 and event Ax (e.g., event A3, event A4, or event A5), a first time length which may indicate an elapsed time between the time point fulfilling the event D1 and the time point fulfilling the event Ax (e.g., timeBetweenEvents) may be shorter than the base station expected and a second time length which may indicate an elapsed time between the time point fulfilling the condition D1-1 of the event D1 and the time point fulfilling the condition D1-2 of the event D1 may be longer than the base station expected. For example, the long value of the second time length may indicate that the elapsed time since the time point that the distance between the UE and the source cell becomes larger than a threshold until the time point that the distance between the UE and the target cell (e.g., CHO candidate cell) becomes lower than a threshold is long. The value of the second time length being long may indicate that:

- the UE may execute another handover or CHO after completing the CHO; and/or
- the UE may detect an RLF after performing the CHO.

The RLF report comprises the first time length and does not comprise the second time length. For example, when a UE detects a CHO failure, the value of the first time length may be short and the value of the second time length may be long. Upon transmitting the RLF report to the base station, the short value of the first time length is indicated to the base station and the long value of the second time length is not indicated to the base station. The base station may consider that the base station does not need to change the CHO execution condition of the CHO candidate cell. If not changed CHO execution condition is configured to a UE, the UE may execute another handover or CHO after completing the CHO or the UE may detect an RLF after performing the CHO.

[0342] FIG. 28 illustrates an example scenario where a UE is approaching the target cell (e.g. CHO candidate cell) from inside the first cell boundary of the source cell. CHO execution condition of the target cell may be event A4 and event D1. The UE may move toward the target cell and get out of the second cell boundary of the source cell (e.g., second cell boundary of the source cell in FIG. 28). After the UE gets out of the second cell boundary of the source cell, the distance between the UE and the reference point of the source cell may be higher than a first distance threshold (e.g., UE may fulfil the condition D1-1) at t_{D1}.

[0343] In the example illustrated in FIG. 28, the source cell may provide a CHO configuration to the UE. The CHO configuration may comprise CHO execution condition of the target cell. The UE may execute CHO to the target cell when the CHO execution condition of the target cell is fulfilled.

[0344] In the example illustrated in FIG. 28, the first cell boundary (of the source cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A1, or event A5). For example, if the UE is located inside the first cell boundary of the source cell, the measured RSRP of the source cell may be higher than a threshold. For example, if the UE is located inside the first cell boundary of the source cell, the UE may consider that the condition A1-1 of the event A1 is satisfied/fulfilled. For example, if the UE is located outside the first cell boundary of the source cell, the measured RSRP of the source cell may be lower than a threshold. For example, if the UE is located outside the first cell boundary of the source cell, the UE may consider that the condition A5-1 of the event A5 is satisfied/fulfilled.

[0345] In the example illustrated in FIG. 28, the second cell boundary (of the source cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the source cell. For example, if the UE is located outside the second boundary of the source cell, the distance between the UE and the reference point of the source cell is higher than a threshold. For example, if the

UE is located outside the second boundary of the source cell, the UE may consider that the condition D1-1 of the event D1 is satisfied/fulfilled.

[0346] In the example illustrated in FIG. 28, the third cell boundary (of the target cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A4, or event A5). For example, if the UE is located inside the third cell boundary of the target cell, the measured RSRP of the target cell may be higher than a threshold. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A4-1 of the event A4 is satisfied/fulfilled. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A5-2 of the event A5 is satisfied/fulfilled.

[0347] In the example illustrated in FIG. 28, the fourth cell boundary (of the target cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the target cell. For example, if the UE is located outside the fourth boundary of the target cell, the distance between the UE and the reference point of the target cell is lower than a threshold. For example, if the UE is located outside the fourth boundary of the target cell, the UE may consider that the condition D1-2 of the event D1 is satisfied/fulfilled.

[0348] In the example illustrated in FIG. 28, the source cell may provide (quasi-)earth fixed cell/beam. The cell coverage of the source cell may be fixed for a time period.

[0349] In the example illustrated in FIG. 28, the target cell may provide earth moving cell/beam. The cell coverage of the target cell may change by time. The cell coverage of the target cell may move to the direction of the "target cell direction" in the FIG. 28.

[0350] FIG. 29 illustrates an example scenario that the UE approaches to the target cell while the UE is located outside of the second cell boundary of the source cell. The UE may be located at outside of the third cell boundary of the target cell. The UE may consider that the condition D1-1 is fulfilled and the other CHO execution conditions, condition D1-2 and event A4, is not fulfilled at t_0.

[0351] In the scenario illustrated in FIG. 29, the first cell boundary (of the source cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A1, or event A5). For example, if the UE is located inside the first cell boundary of the source cell, the measured RSRP of the source cell may be higher than a threshold. For example, if the UE is located inside the first cell boundary of the source cell, the UE may consider that the condition A1-1 of the event A1 is satisfied/fulfilled. For example, if the UE is located outside the first cell boundary of the source cell, the measured RSRP of the source cell may be lower than a threshold. For example, if the UE is located outside the first cell boundary of the source cell, the UE may consider that the condition A5-1 of the event A5 is satisfied/fulfilled.

[0352] In the example illustrated in FIG. 29, the second cell boundary (of the source cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the source cell. For example, if the UE is located outside the second boundary of the source cell, the distance between the UE and the reference point of the source cell is higher than a threshold. For example, if the

UE is located outside the second boundary of the source cell, the UE may consider that the condition D1-1 of the event D1 is satisfied/fulfilled.

[0353] In the example illustrated in FIG. 29, the third cell boundary (of the target cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A4, or event A5). For example, if the UE is located inside the third cell boundary of the target cell, the measured RSRP of the target cell may be higher than a threshold. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A4-1 of the event A4 is satisfied/fulfilled. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A5-2 of the event A5 is satisfied/fulfilled.

[0354] In the example illustrated in FIG. 29, the fourth cell boundary (of the target cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the target cell. For example, if the UE is located outside the fourth boundary of the target cell, the distance between the UE and the reference point of the target cell is lower than a threshold. For example, if the UE is located outside the fourth boundary of the target cell, the UE may consider that the condition D1-2 of the event D1 is satisfied/fulfilled.

[0355] In the example illustrated in FIG. 29, the source cell may provide (quasi-)earth fixed cell/beam. The cell coverage of the source cell may be fixed for a time period.

[0356] In the example illustrated in FIG. 29, the target cell may provide earth moving cell/beam. The cell coverage of the target cell may change by time. The cell coverage of the target cell may move to the direction of the “target cell direction” in the FIG. 28.

[0357] FIG. 30 illustrates an example scenario where the UE gets inside the third cell boundary of the target cell. When the UE is located inside the third boundary, the measured RSRP of the target cell may be higher than a threshold. When the UE is located inside the third boundary of the target cell, the UE may consider that the event A4 is fulfilled.

[0358] In the scenario illustrated in FIG. 30, the first cell boundary (of the source cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A1, or event A5). For example, if the UE is located inside the first cell boundary of the source cell, the measured RSRP of the source cell may be higher than a threshold. For example, if the UE is located inside the first cell boundary of the source cell, the UE may consider that the condition A1-1 of the event A1 is satisfied/fulfilled. For example, if the UE is located outside the first cell boundary of the source cell, the measured RSRP of the source cell may be lower than a threshold. For example, if the UE is located outside the first cell boundary of the source cell, the UE may consider that the condition A5-1 of the event A5 is satisfied/fulfilled.

[0359] In the example illustrated in FIG. 30, the second cell boundary (of the source cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the source cell. For example, if the UE is located outside the second boundary of the source cell, the distance between the UE and the reference point of the source cell is higher than a threshold. For example, if the

UE is located outside the second boundary of the source cell, the UE may consider that the condition D1-1 of the event D1 is satisfied/fulfilled.

[0360] In the example illustrated in FIG. 30, the third cell boundary (of the target cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A4, or event A5). For example, if the UE is located inside the third cell boundary of the target cell, the measured RSRP of the target cell may be higher than a threshold. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A4-1 of the event A4 is satisfied/fulfilled. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A5-2 of the event A5 is satisfied/fulfilled.

[0361] In the example illustrated in FIG. 30, the fourth cell boundary (of the target cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the target cell. For example, if the UE is located outside the fourth boundary of the target cell, the distance between the UE and the reference point of the target cell is lower than a threshold. For example, if the UE is located outside the fourth boundary of the target cell, the UE may consider that the condition D1-2 of the event D1 is satisfied/fulfilled.

[0362] In the example illustrated in FIG. 30, the source cell may provide (quasi-)earth fixed cell/beam. The cell coverage of the source cell may be fixed for a time period.

[0363] In the example illustrated in FIG. 30, the target cell may provide earth moving cell/beam. The cell coverage of the target cell may change by time. The cell coverage of the target cell may move to the direction of the “target cell direction” in the FIG. 28.

[0364] FIG. 31 illustrates an example scenario where the UE gets inside the fourth cell boundary of the target cell. When the UE is located inside the fourth cell boundary of the target cell, the distance between the UE and the reference location of the target cell may be lower than a threshold. When the UE is located inside the fourth cell boundary of the target cell, the UE may consider that the condition D1-2 of the event D1 is fulfilled. When the condition D1-2 is fulfilled, the UE may execute CHO to the target cell.

[0365] In the scenario illustrated in FIG. 31, the first cell boundary (of the source cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A1, or event A5). For example, if the UE is located inside the first cell boundary of the source cell, the measured RSRP of the source cell may be higher than a threshold. For example, if the UE is located inside the first cell boundary of the source cell, the UE may consider that the condition A1-1 of the event A1 is satisfied/fulfilled. For example, if the UE is located outside the first cell boundary of the source cell, the measured RSRP of the source cell may be lower than a threshold. For example, if the UE is located outside the first cell boundary of the source cell, the UE may consider that the condition A5-1 of the event A5 is satisfied/fulfilled.

[0366] In the example illustrated in FIG. 31, the second cell boundary (of the source cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the source cell. For example, if the UE is located outside the second boundary of the source cell, the distance between the UE and the reference point of the source cell is higher than a threshold. For example, if the

UE is located outside the second boundary of the source cell, the UE may consider that the condition D1-1 of the event D1 is satisfied/fulfilled.

[0367] In the example illustrated in FIG. 31, the third cell boundary (of the target cell) may be determined based on a RSRP threshold associated with event Ax (e.g., event A4, or event A5). For example, if the UE is located inside the third cell boundary of the target cell, the measured RSRP of the target cell may be higher than a threshold. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A4-1 of the event A4 is satisfied/fulfilled. For example, if the UE is located inside the third cell boundary of the target cell, the UE may consider that the condition A5-2 of the event A5 is satisfied/fulfilled.

[0368] In the example illustrated in FIG. 31, the fourth cell boundary (of the target cell) may be determined based on a distance threshold associated with event D1 (e.g., condition D1-1 of event D1) and distance between the UE and the reference point of the target cell. For example, if the UE is located outside the fourth boundary of the target cell, the distance between the UE and the reference point of the target cell is lower than a threshold. For example, if the UE is located outside the fourth boundary of the target cell, the UE may consider that the condition D1-2 of the event D1 is satisfied/fulfilled.

[0369] In the example illustrated in FIG. 31, the source cell may provide (quasi-)earth fixed cell/beam. The cell coverage of the source cell may be fixed for a time period.

[0370] In the example illustrated in FIG. 31, the target cell may provide earth moving cell/beam. The cell coverage of the target cell may change by time. The cell coverage of the target cell may move to the direction of the "target cell direction" in the FIG. 28.

[0371] FIG. 32 illustrates an embodiment which shows the UE procedure by time since the CHO configuration is configured until the CHO is executed. The base station may configure the CHO configuration to the UE at $t_{CHO\text{-}config}$. At t_{D1}, the UE may get out of the second cell boundary of the source cell and the UE may consider that the condition D1-1 is fulfilled. After getting out of the second cell boundary of the source cell, the UE may approach to the target cell at t_0. The t_0 may be a time point after the t_{D1} and earlier than the t_A. At t_A, the UE may get inside the third cell boundary of the target cell and the UE may consider that the event A4 is fulfilled. At t_{D2}, the UE may get inside the fourth cell boundary of the target cell and the UE may consider that the condition D1-2 is fulfilled. At $t_{CHO\text{-}execute}$, the UE may execute CHO to the target cell. Thus, in existing technologies, after the CHO execution, if the CHO succeeds, the UE may transmit the successful handover report about the CHO to the base station. After the CHO execution, if the CHO fails, the UE may transmit the RLF report about the CHO failure to the base station.

[0372] In the embodiment illustrated in FIG. 32, the parameter timeBetweenEventsD1 may indicate an elapsed time between fulfilling the condition D1-1 and the condition D1-2. For example, in FIG. 32, timeBetweenEventsD1 may be a time elapsed from t_{D1} to t_{D2} (or from t_{D2} to t_{D1}) and/or a time interval (e.g., period) between t_{D1} and t_{D2}.

[0373] In the example scenario illustrated in FIG. 31, at the time point that the UE executes the CHO, the direction of the UE movement may be opposite from the target cell movement direction. After that, the target cell coverage may disappear soon from the UE. The UE may execute another handover to different cell or detect RLF after the CHO to the target. In the existing art, this information may not be indicated to the base station because the RLF report comprises the timeBetweenEvents and does not comprise the timeBetweenEventsD1. This scenario may lead to wasted overhead, frequency PCell change which may lead to signaling overhead, and/or temporary loss of data transmission.

[0374] In the embodiment illustrated in FIG. 32, if the successful handover report or the RLF report comprises the parameter timeBetweenEventsD1, the UE may indicate to the base station that the timeBetweenEvents is short and the timeBetweenEventsD1 is long. Based on the indication, base station may be able to consider the example scenarios shown in the in FIG. 28, FIG. 29, FIG. 30, FIG. 31, and FIG. 32 and respond accordingly. Specifically, in response to receiving the parameter timeBetweenEventsD1, the base station may change the handover configuration or CHO configuration in the next time that the UE can perform the CHO or handover earlier or to different cell, thereby the UE can avoid performing handover again immediately after performing a handover, signaling overhead, and/or RLF.

[0375] In an example, the UE may receive, from a first base station, a request message (e.g., UEInformationRequest) of a report for a handover. The request message may comprise a request indication (e.g., rlf-ReportReq). In response to the request message, the UE may transmit, to the first base station, a response message (e.g., UEInformationResponse) which comprises the report. The report may comprise a time value which indicates a time elapsed between:

- a first time point that a first distance is greater than a first distance threshold; and
- a second time point that a second distance is less than or equal to a second distance threshold.

The first distance may be a distance between the UE and a first reference location of a second base station. The second base station may be a source base station of the handover. The second distance may be a distance between the UE and a second reference location of a third base station. The third base station may be a target base station of the handover.

[0376] In an example, which is illustrated in FIG. 33, the UE may receive a handover command from a first base station. The handover command may comprise an one or more configuration parameters for a handover to a second base station. The UE may perform handover to the second base station based on the one or more configuration parameters. After performing the handover, the UE may receive, from a third base station, a request message (e.g., UEInformationRequest). The request message may comprise a request indication (e.g., rlf-ReportReq). In response to the request message, the UE may transmit, to the third base station, a response message (e.g., UEInformationResponse) which comprises a report for a handover. The report may comprise a time value which indicates the elapsed time between:

- a first time point that a first distance is greater than a first distance threshold; and
- a second time point that a second distance is less than or equal to a second distance threshold.

The first distance may be a distance between the UE and a first reference location of the first base station. The second distance may be a distance between the UE and a second reference location of the second base station.

[0377] In an example embodiment, which is illustrated in FIG. 34, the UE may receive a handover command from a first base station. The handover command may comprise an one or more configuration parameters for a handover to a second base station. The one or more configuration parameters may comprise:

- a first distance threshold;
- a second distance threshold;
- a first reference location of the first base station; and
- a second reference location of the second base station;

The UE may detect a radio link failure while performing one or more measurements based on the one or more configuration parameters. In response to the radio link failure, the UE may determine a time value which represents the elapsed time between:

- a first time point that a first distance is greater than a first distance threshold; and
- a second time point that a second distance is less than or equal to a second distance threshold.

The first distance may be a distance between the UE and a first reference location of the first base station. The second distance may be a distance between the UE and a second reference location of the second base station. In response to the detection of the radio link failure, the UE may perform RLF recovery. The performing RLF recovery may comprise the RRC re-establishment procedure. As a result of the RLF recovery, the UE may establish connection to a third base station. The UE may receive, from the third base station, a request message (e.g., UEInformationRequest). The request message may comprise a request indication (e.g., rlf-ReportReq). In response to the request message, the UE may transmit, to the third base station, a response message (e.g., UEInformationResponse) which comprises a report for a handover. The report may comprise the time value.

[0378] In an example embodiment, which is illustrates in FIG. 35, the UE may receive a handover command from a first base station. The handover command may comprise an one or more configuration parameters for a handover to a second base station. The one or more configuration parameters may comprise:

- a first distance threshold;
- a second distance threshold;
- a first reference location of the first base station; and
- a second reference location of the second base station;

The one or more configuration parameters may indicate one or more conditional handover execution conditions. The one or more conditional handover execution conditions may comprise distance conditions. The UE may determine whether at least one of conditional handover execution condition is fulfilled while performing one or more measurements based on the one or more configuration parameters. The UE may determine, based on the at least one of distance conditions being fulfilled, a time value based on the one or more measurements. The time value may indicate a time elapsed between:

- a first time point that a first distance is greater than a first distance threshold; and
- a second time point that a second distance is less than or equal to a second distance threshold.

The first distance may be a distance between the UE and a first reference location of the first base station. The second distance may be a distance between the UE and a second reference location of the second base station. The UE may perform a Random Access procedure with a third base station. The UE may receive, from a third base station, a request message (e.g., UEInformationRequest). The request message may comprise a request indication (e.g., rlf-ReportReq). In response to the request message, the UE may transmit, to the third base station, a response message (e.g., UEInformationResponse) which comprises a report for a handover. The report may comprise the time value.

[0379] In an example embodiment, which is illustrated in FIG. 36, the UE may receive a handover command from a first base station. The handover command may comprise an one or more configuration parameters for a handover to a second be station. The one or more configuration parameters may comprise:

- a first distance threshold;
- a second distance threshold;
- a first reference location of the first base station; and
- a second reference location of the second base station;

The one or more configuration parameters may comprise an one or more conditional handover execution conditions. The conditional handover execution condition may comprise at one or more distance conditions. The UE may determine whether at least one of conditional handover execution condition is fulfilled while performing one or more measurements based on the one or more configuration parameters. The UE may perform a Random Access procedure with the second base station based on the one or more distance conditions being fulfilled. Based on completing the random access procedure successfully, the UE may determine, based on the one or more measurements, a time value. The time value may indicate a time elapsed between:

- a first time point that a first distance is greater than a first distance threshold; and
- a second time point that a second distance is less than or equal to a second distance threshold.

The first distance may be a distance between the UE and a first reference location of the first base station. The second distance may be a distance between the UE and a second reference location of the second base station. The UE may perform a Random Access procedure with a third base station. The UE may receive, from a third base station, a request message (e.g., UEInformationRequest). The request message may comprise a request indication (e.g., rlf-ReportReq). In response to the request message, the UE may transmit, to the third base station, a response message (e.g., UEInformationResponse) which comprises a report for a handover. The report may comprise the time value.

[0380] In an example, wherein the handover comprises a conditional handover.

[0381] In an example, the one or more configuration parameters for the handover, wherein the one or more configuration parameters indicate:

the first distance threshold;

the second distance threshold;

the first reference location of the second base station; and

the second reference location of the third base station.

[0382] In an example, wherein the one or more configuration parameters comprise an indication of a cell associated with the third base station as a target cell of the handover.

[0383] In an example, further comprising:

determining that a first condition to execute the handover is fulfilled in response to the first distance being greater than the first distance threshold; and

determining, as the first time point, a first point in time of fulfilling the first condition.

[0384] In an example, wherein the first condition is fulfilled while a second condition to execute the handover is being fulfilled in response to the second distance being less than or equal to the second distance threshold.

[0385] In an example, further comprising:

determining that a second condition to execute the handover is fulfilled in response to the second distance being less than or equal to the second distance threshold; and

determining, as the second time point, a second point in time of fulfilling the second condition.

[0386] In an example, wherein the second condition is fulfilled while a first condition to execute the handover is being fulfilled in response to the first distance being greater than the first distance threshold.

[0387] In an example, wherein:

the first time point is a last point in time among a first plurality of time points;

each of the first plurality of time points is based on a respective distance of a first plurality of distances; and

each of the first plurality of distances is greater than the first distance threshold.

[0388] In an example, wherein:

the second time point is a last point in time among a second plurality of time points;

each of the second plurality of time points is based on a respective distance of a second plurality of distances; and

each of the second plurality of distances is less than or equal to the second distance threshold.

[0389] In an example, wherein the first time point is (e.g., occurs in time) earlier than the second time point.

[0390] In an example, wherein the second time point is (e.g., occurs in time) earlier than the first time point.

[0391] In an example, wherein the first message comprises a user equipment (UE) information request message (e.g., UEInformationRequest).

[0392] In an example, wherein the second message comprises a user equipment (UE) information response message (e.g. UEInformationResponse).

[0393] In an example, wherein the second base station is a source base station of the handover.

[0394] In an example, wherein the third base station is a target base station of the handover.

[0395] In an example, further comprising performing the handover to the third base station while the wireless device is connected to the second base station.

[0396] In an example, wherein the performing handover comprises performing a conditional handover evaluation that is based on the one or more configuration parameters.

[0397] In an example, wherein determining, during the condition handover evaluation, at least one of:

the first distance being greater than the first distance threshold; and

the second distance being less than or equal to the second distance threshold.

[0398] In an example, wherein the performing handover further comprises initiating a conditional reconfiguration execution.

[0399] In an example, further comprising determining one or more triggering conditions upon which the wireless device executes the handover.

[0400] In an example, further comprising performing, based on the initiating the conditional reconfiguration execution, a random access procedure with the third base station for the handover to the third base station.

[0401] In an example, wherein the third base station is the first base station.

[0402] In an example, wherein the first base station is a (e.g., serving) base station to which the wireless device is connected after performing the handover to the third base station.

[0403] In an example, wherein the first base station is a base station to which the UE maintains, keeps, and/or establishes an RRC Connection after determining a radio link failure (RLF).

[0404] In an example, further comprising performing a Random Access procedure with the first base station;

[0405] In an example, further comprising receiving, from the first base station and after performing the handover, at least one of:

an RRC Setup message;

an RRC Resume message; or

an RRC (Re-)establishment message.

[0406] In an example, wherein the report further comprises at least one of:

a first time measured by the wireless device based on (e.g., at) the first time point;

a second time measured at the wireless device based on (e.g., at) the second time point;

a first location of the wireless device based on (e.g., at) the first time point; or

a second location of the wireless device based on (e.g., at) the second time point.

[0407] In an example, wherein the first location of the wireless device comprises a location information of a user equipment (UE) (e.g., locationInfo).

[0408] In an example, wherein the location information of a user equipment (UE) comprises a common location information (e.g., CommonLocationInfo).

[0409] In an example, wherein the location information of a user equipment (UE) comprises a measured results for Bluetooth (e.g., bt-LocationInfo).

[0410] In an example, wherein the location information of a user equipment (UE) comprises a measured results for WLAN (e.g., wlan-LocationInfo).

[0411] In an example, wherein the location information of a user equipment (UE) comprises a sensor information (e.g., sensor-LocationInfo).

[0412] In an example, wherein the second location of the wireless device comprises a location information of a user equipment (UE) (e.g., locationInfo).

[0413] In an example, wherein the second location of the wireless device comprises a common location information (e.g., CommonLocationInfo).

[0414] In an example, wherein the second location of the wireless device comprises a measured results for Bluetooth (e.g., bt-LocationInfo).

[0415] In an example, wherein the second location of the wireless device comprises a measured results for WLAN (e.g., wlan-LocationInfo).

[0416] In an example, wherein the second location of the wireless device comprises a sensor information (e.g., sensor-LocationInfo).

[0417] In an example, further comprising determining a first entering condition, of the handover, being fulfilled at a time based on the first time point, wherein the determining the first entering condition is based on the first distance being greater than the first distance threshold.

[0418] In an example, further comprising determining a second entering condition, of the handover, being fulfilled at a time based on the second time point, wherein the determining the second entering condition is based on the second distance being less than or equal to the second distance threshold.

[0419] In an example, further comprising determining a radio link failure while performing one or more measurements based on the one or more configuration parameters.

[0420] In an example, wherein the radio link failure is associated with one of:

the second base station;

the third base station; or

the first base station.

[0421] In an example, further comprising determining a time value that indicates the time elapsed between the first time point and the second time point.

[0422] In an example, wherein the report comprises a radio link failure report (e.g., RLF-Report).

[0423] In an example, wherein the radio link failure report comprises the time value that indicates the time elapsed between the first time point and the second time point.

[0424] In an example, wherein the first message comprises an indication (e.g. rlf-ReportReq) to transmit, by the wireless device, the second message comprising the report.

[0425] In an example, wherein the transmitting the second message comprising the report is based on the first message comprising the indication.

[0426] In an example, wherein the determining the radio link failure is based on one or more RLF events comprising at least one of:

upon T310 expiry in source SpCell (e.g., PCell);

upon T312 expiry in PCell;

upon random access problem indication from source MCG MAC;

upon indication from MCG RLC (e.g., source MCG RLC) that the maximum number of retransmissions has been reached;

upon consistent uplink LBT failure indication from source MCG MAC; or

upon BH RLF indication received on BAP entity from the MCG, if connected as an IAB-node.

[0427] In an example, further comprising performing, based on the determining the radio link failure, an RLF recovery procedure.

[0428] In an example, wherein the RLF recovery procedure comprises an RRC connection re-establishment.

[0429] In an example, further comprising, performing the RLF recovery procedure results that the wireless device connected to a fourth base station.

[0430] In an example, wherein the RLF recovery procedure comprises a Random Access procedure with the first base station.

[0431] In an example, further comprising performing (and/or initiating), in response to determining the radio link failure, a random access procedure with the first base station.

[0432] In an example, wherein the one or more configuration parameters for the handover indicate one or more handover execution conditions.

[0433] In an example, further comprising performing the handover based on at least one of the one or more handover execution conditions being fulfilled.

[0434] In an example, further comprising determining that one or more handover events occur based on at least one of the one or more handover execution conditions being fulfilled, wherein the performing the handover is based on determining that at least one of the one or more handover events occurs.

[0435] In an example, wherein the one or more handover events comprises at least one of:

event A3;

event A4;

event A5;

event T1; and

event D1.

[0436] In an example, further comprising performing (or initiating) a Random Access procedure with the third base station for the handover to the third base station.

[0437] In an example, wherein the receiving the first message is in response to completing the Random Access procedure with the third base station successfully, wherein the third base station is the first base station.

[0438] In an example, wherein the report comprises a successful handover report (e.g., successHO-Report).

[0439] In an example, wherein the first message comprises an indication (e.g., successHO-ReportReq) to transmit, by the wireless device, the second message comprising the report.

[0440] In an example, further comprising starting T304 timer, wherein the transmitting the second message comprising report is based on a ratio, between the value of an elapsed time of the timer T304 and a timer value of the T304 timer, being greater than a T304 threshold value.

[0441] In an example, further comprising starting T310 timer, wherein the transmitting the second message comprising report is based on a ratio, between the value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T310 threshold value.

[0442] In an example, further comprising starting T312 timer, wherein the transmitting the second message comprising report is based on a ratio, between the value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T312 threshold value.

[0443] According to example embodiment(s) (e.g., referring to FIG. 34) in the present disclosure, a wireless device may receive, from a first base station, one or more configuration parameters for a handover to a second base station. For example, the one or more configuration parameters comprise: a first distance threshold; a second distance threshold; a first reference location of the second base station; and a second reference location of the third base station. The wireless device may determine radio link failure while performing one or more measurements based on the one or more configuration parameters. The wireless device may, in response to the radio link failure, determine a time value based on the one or more measurements for a report of the radio link failure. For example, the time value indicates a time elapsed between: a first time point when a first distance between the wireless device and the first reference location of the second base station is greater than the first distance threshold; and a second time point when a second distance between the wireless device and the second reference location of the third base station is less than the second distance threshold. The wireless device may perform a random access procedure with a third base station. The wireless device may receive, from the third base station, a first message requesting the report. The wireless device may transmit, to the third base station, a second message comprising the report, wherein the report comprises the time value.

[0444] According to example embodiment(s) (e.g., referring to FIG. 35) in the present disclosure, a wireless device may receive, from a first base station, one or more configuration parameters for a handover to a second base station. For example, the one or more configuration parameters comprise: a first distance threshold; a second distance threshold; a first reference location of the first base station; and a second reference location of the second base station. The wireless device may determine that at least one of conditional handover execution condition is fulfilled while performing one or more measurements based on the one or more configuration parameters. The wireless device may determine, based on the at least one of distance conditions being fulfilled, a time value based on the one or more measurements. For example, the time value indicates a time elapsed between: a first time point when a first distance between the wireless device and the first reference location of the first base station is greater than the first distance threshold; and a second time point when a second distance between the wireless device and the second reference location of the second base station is less than the second distance threshold. The wireless device may perform random access procedure with a third base station. The wireless device may receive, from the third base station, a first message requesting a report. The wireless device may transmit, to the third base station, a second message comprising the report. For example, the report comprises the time value.

[0445] According to example embodiment(s) (e.g., referring to FIG. 36) in the present disclosure, a wireless device may receive, from a first base station, one or more configuration parameters for a handover to a second base station. For example, the one or more configuration parameters comprise: a first distance threshold; a second distance threshold; a first reference location of the first base station; and a second reference location of the second base station. The wireless device may determine that one or more distance conditions for the handover are fulfilled while performing one or more measurements based on the one or more configuration parameters. The wireless device may perform, based on the one or more distance conditions are fulfilled , a random access procedure with the second base station. The wireless device may, based on completing the random access procedure successfully, determine a time value based on the one or more measurements. For example, the time value indicates a time elapsed between: a first time point when a first distance between the wireless device and a first reference location of the second base station is greater than the first distance threshold; and a second time point when a second distance between the wireless device and a second reference location of the third base station is less than the second distance threshold. The wireless device may receive, from a third base station, a first message requesting a report. The wireless device may transmit, to the third base station, a second message comprising the report, wherein the report comprises the time value.

[0446] According to example embodiment(s) (e.g., referring to FIG. 33) in the present disclosure, a wireless device may receive, from a first base station, one or more configuration parameters for a handover to a second base station. The wireless device may, after performing the handover based on the one or more configuration parameters, receive, from a third base station, a request message of a report for the handover. The wireless device may transmit, to the third base station, the report comprising a time value that indicates a time elapsed between: a first time point that a first distance, between the wireless device and a first reference location of the second base station, is greater than a first distance threshold; and a second time point that a second distance, between the wireless device and a second reference location of the third base station, is less than or equal to a second distance threshold.

[0447] FIG. 37 illustrates an example flow diagram of example embodiments as per an aspect of an embodiment of the present disclosure. According to example embodiment(s) (e.g., referring to FIG. xx) in the present disclosure, at 3701, a wireless device may receive, from a first base station, a request message of a report for a handover. At 3702, the wireless device may transmit, to the first base station, the report indicating a time elapsed between: a first time point that a first distance, between the wireless device and a first reference location of a second base station, is greater than a first distance threshold; and a second time point that a second distance, between the wireless device and a second reference location of a third base station, is less than or equal to a second distance threshold.

[0448] Either alone or in combination with any of the above or below features, the handover may comprise a conditional handover.

[0449] Either alone or in combination with any of the above or below features, the wireless device may receive, from the second base station, the one or more configuration parameters for the handover, wherein the one or more configuration parameters indicate: the first distance threshold; the second distance threshold; the first reference location of the second base station; and the second reference location of the third base station.

[0450] Either alone or in combination with any of the above or below features, the one or more configuration parameters may comprise an indication of a cell associated with the third base station as a target cell of the handover.

[0451] Either alone or in combination with any of the above or below features, the wireless device may determine that a first condition to execute the handover is fulfilled in response to the first distance being greater than the first distance threshold and determine, as the first time point, a first point in time of fulfilling the first condition.

[0452] Either alone or in combination with any of the above or below features, the first condition may be fulfilled while a second condition to execute the handover is being fulfilled in response to the second distance being less than or equal to the second distance threshold.

[0453] Either alone or in combination with any of the above or below features, the UE may determine that a second condition to execute the handover is fulfilled in response to the second distance being less than or equal to the second distance threshold and determine, as the second time point, a second point in time of fulfilling the second condition.

[0454] Either alone or in combination with any of the above or below features, the second condition may be fulfilled while a first condition to execute the handover is being fulfilled in response to the first distance being greater than the first distance threshold.

[0455] Either alone or in combination with any of the above or below features, the first time point may be a last point in time among a first plurality of time points; each of the first plurality of time points may be based on a respective distance of a first plurality of distances; and each of the first plurality of distances may be greater than the first distance threshold.

[0456] Either alone or in combination with any of the above or below features, the second time point may be a last point in time among a second plurality of time points; each of the second plurality of time points may be based on a respective distance of a second plurality of distances; and each of the second plurality of distances may be less than or equal to the second distance threshold.

[0457] Either alone or in combination with any of the above or below features, the first time point may be (e.g., occurs in time) earlier than the second time point.

[0458] Either alone or in combination with any of the above or below features, the second time point may be (e.g., occurs in time) earlier than the first time point.

[0459] Either alone or in combination with any of the above or below features, the first message may comprise a user equipment (UE) information request message (e.g., UEInformationRequest).

[0460] Either alone or in combination with any of the above or below features, the second message may comprise a user equipment (UE) information response message (e.g. UEInformationResponse).

[0461] Either alone or in combination with any of the above or below features, the second base station may be a source base station of the handover.

[0462] Either alone or in combination with any of the above or below features, the third base station may be a target base station of the handover.

[0463] Either alone or in combination with any of the above or below features, the wireless may perform the handover to the third base station while the wireless device is connected to the second base station.

[0464] Either alone or in combination with any of the above or below features, the performing handover may comprise performing a conditional handover evaluation that is based on the one or more configuration parameters.

[0465] Either alone or in combination with any of the above or below features, the wireless device may determine, during the condition handover evaluation, at least one of: the first distance being greater than the first distance threshold; and the second distance being less than or equal to the second distance threshold.

[0466] Either alone or in combination with any of the above or below features, the performing handover further comprises initiating a conditional reconfiguration execution.

[0467] Either alone or in combination with any of the above or below features, the wireless device may determine one or more triggering conditions upon which the wireless device executes the handover.

[0468] Either alone or in combination with any of the above or below features, the wireless device may perform, based on the initiating the conditional reconfiguration execution, a random access procedure with the third base station for the handover to the third base station.

[0469] Either alone or in combination with any of the above or below features, the third base station may be the first base station.

[0470] Either alone or in combination with any of the above or below features, the first base station may be a (e.g., serving) base station to which the wireless device is connected after performing the handover to the third base station.

[0471] Either alone or in combination with any of the above or below features, the first base station may a base station to which the wireless device maintains, keeps, and/or establishes an RRC Connection after determining a radio link failure (RLF).

[0472] Either alone or in combination with any of the above or below features, the wireless device may perform a random access procedure with the first base station;

[0473] Either alone or in combination with any of the above or below features, the wireless device may receive, from the first base station and after performing the handover, at least one of: an RRC Setup message; an RRC Resume message; or an RRC (Re-)establishment message.

[0474] Either alone or in combination with any of the above or below features, the report may comprise at least one of: a first time measured by the wireless device based on (e.g., at) the first time point; a second time measured at the wireless device based on (e.g., at) the second time point; a first location of the wireless device based on (e.g., at) the first time point; or a second location of the wireless device based on (e.g., at) the second time point.

[0475] Either alone or in combination with any of the above or below features, the first location of the wireless device may comprise a location information of a user equipment (UE) (e.g., locationInfo).

[0476] Either alone or in combination with any of the above or below features, the location information of a user equipment (UE) may comprise a common location information (e.g., CommonLocationInfo).

[0477] Either alone or in combination with any of the above or below features, the location information of a user equipment (UE) may comprise a measured results for Bluetooth (e.g., bt-LocationInfo).

[0478] Either alone or in combination with any of the above or below features, the location information of a user equipment (UE) may comprise a measured results for WLAN (e.g., wlan-LocationInfo).

[0479] Either alone or in combination with any of the above or below features, the location information of a user equipment (UE) may comprise a sensor information (e.g., sensor-LocationInfo).

[0480] Either alone or in combination with any of the above or below features, the second location of the wireless device may comprise a location information of a user equipment (UE) (e.g., locationInfo).

[0481] Either alone or in combination with any of the above or below features, the second location of the wireless device may comprise a common location information (e.g., CommonLocationInfo).

[0482] Either alone or in combination with any of the above or below features, the second location of the wireless device may comprise a measured results for Bluetooth (e.g., bt-LocationInfo).

[0483] Either alone or in combination with any of the above or below features, the second location of the wireless device may comprise a measured results for WLAN (e.g., wlan-LocationInfo).

[0484] Either alone or in combination with any of the above or below features, the second location of the wireless device may comprise a sensor information (e.g., sensor-LocationInfo).

[0485] Either alone or in combination with any of the above or below features, the wireless device may determine a first entering condition, of the handover, being fulfilled at a time based on the first time point. For example, the determining the first entering condition may be based on the first distance being greater than the first distance threshold.

[0486] Either alone or in combination with any of the above or below features, the wireless device may determine a second entering condition, of the handover, being fulfilled at a time based on the second time point. For example, the determining the second entering condition may be based on the second distance being less than or equal to the second distance threshold.

[0487] Either alone or in combination with any of the above or below features, the wireless device may determine a radio link failure while performing one or more measurements based on the one or more configuration parameters.

[0488] Either alone or in combination with any of the above or below features, the radio link failure may be associated with one of: the second base station; the third base station; or the first base station.

[0489] Either alone or in combination with any of the above or below features, the wireless device may determine a time value that indicates the time elapsed between the first time point and the second time point.

[0490] Either alone or in combination with any of the above or below features, the report may comprise a radio link failure report (e.g., RLF-Report).

[0491] Either alone or in combination with any of the above or below features, the radio link failure report may comprise the time value that indicates the time elapsed between the first time point and the second time point.

[0492] Either alone or in combination with any of the above or below features, the first message may comprise an indication (e.g. rlf-ReportReq) to transmit the second message comprising the report.

[0493] Either alone or in combination with any of the above or below features, the transmitting the second message comprising the report may be based on the first message comprising the indication.

[0494] Either alone or in combination with any of the above or below features, the determining the radio link failure may be based on one or more RLF events comprising at least one of: upon T310 expiry in source SpCell (e.g., PCell); upon T312 expiry in PCell; upon random access problem indication from source MCG MAC; upon indication from MCG RLC (e.g., source MCG RLC) that the maximum number of retransmissions has been reached; upon consistent uplink LBT failure indication from source MCG MAC; or upon BH RLF indication received on BAP entity from the MCG, if connected as an IAB-node.

[0495] Either alone or in combination with any of the above or below features, the wireless device may perform, based on the determining the radio link failure, an RLF recovery procedure.

[0496] Either alone or in combination with any of the above or below features, the RLF recovery procedure may comprise an RRC connection re-establishment.

[0497] Either alone or in combination with any of the above or below features, the wireless device may perform the RLF recovery procedure results that the wireless device is connected to a fourth base station.

[0498] Either alone or in combination with any of the above or below features, the RLF recovery procedure may comprise a random access procedure with the first base station.

[0499] Either alone or in combination with any of the above or below features, the wireless device may perform (and/or initiate), in response to determining the radio link failure, a random access procedure with the first base station.

[0500] Either alone or in combination with any of the above or below features, the one or more configuration parameters for the handover may indicate one or more handover execution conditions.

[0501] Either alone or in combination with any of the above or below features, the wireless device may perform the handover based on at least one of the one or more handover execution conditions being fulfilled.

[0502] Either alone or in combination with any of the above or below features, the wireless device may determine that one or more handover events occur based on at least one of the one or more handover execution conditions being fulfilled. For example, the performing the handover may be based on determining that at least one of the one or more handover events occurs.

[0503] Either alone or in combination with any of the above or below features, the one or more handover events may comprise at least one of: event A3; event A4; event A5; event T1; and event D1.

[0504] Either alone or in combination with any of the above or below features, the wireless device may perform (or initiate) a random access procedure with the third base station for the handover to the third base station.

[0505] Either alone or in combination with any of the above or below features, the receiving the first message may be in response to completing the random access procedure with the third base station successfully. For example, the third base station is the first base station.

[0506] Either alone or in combination with any of the above or below features, the report may comprise a successful handover report (e.g., successHO-Report).

[0507] Either alone or in combination with any of the above or below features, the first message may comprise an indication (e.g., successHO-ReportReq) to transmit the second message comprising the report.

[0508] Either alone or in combination with any of the above or below features, the wireless device may start T304 timer. For example, the transmitting the second message comprising report may be based on a ratio, between the value of an elapsed time of the timer T304 and a timer value of the T304 timer, being greater than a T304 threshold value.

[0509] Either alone or in combination with any of the above or below features, the wireless device may start T310 timer. For example, the transmitting the second message comprising report may be based on a ratio, between the value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T310 threshold value.

[0510] Either alone or in combination with any of the above or below features, the wireless device my start T312 timer. For example, the transmitting the second message comprising report is based on a ratio, between the value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T312 threshold value.

CLAIMS

1. A method comprising:

receiving, by a wireless device from a second base station, one or more configuration parameters for a handover, wherein the one or more configuration parameters indicate:

a first distance threshold;

a second distance threshold;

a reference location of a second base station; and

a reference location of a third base station;

determining a radio link failure while performing one or more measurements based on the one or more configuration parameters, wherein the radio link failure is associated with one of:

the second base station;

the third base station; or

the first base station;

determining, by the wireless device, a time elapsed between a first time point and a second time point;

performing, by the wireless device, based on the determining the radio link failure, an RLF recovery procedure comprising of at least one of:

an RRC connection re-establishment with the first base station; and/or

a random access procedure with the first base station;

receiving, by the wireless device from the first base station, a request for a report associated with the handover; and

transmitting, by the wireless device to the first base station, the report comprising an indication of the time elapsed between the first time point and the second time point, wherein:

the first time point is a time that the first distance becomes greater than the first distance threshold, wherein the first distance is between the wireless device and the reference location of the second base station; and

the second time point is a time that the first distance is less than or equal to a second threshold, wherein the second distance is the distance between the wireless device and the reference location of a third base station.

2. A method comprising:

receiving, by a wireless device from a first base station, a request for a report associated with a handover; and

transmitting, by the wireless device to the first base station, the report comprising an indication of a time elapsed between a first time point and a second time point, wherein:

the first time point is a time that a first distance becomes greater than a first distance threshold, wherein the first distance is between the wireless device and a reference location of a second base station; and

the second time point is a time that a second distance is less than or equal to a second threshold, wherein the second distance is between the wireless device and a reference location of a third base station.

3. The method of claim 2, wherein the handover is a conditional handover.

4. The method of any one of claims 2 to 3, wherein:

the first time point is the latest first time point among a plurality of first time points; or

the second time point is the latest second time point among a plurality of second time points.

5. The method of any one of claims 2 to 4, wherein:

the request for a report comprises a user equipment (UE) information request message; and/or

the report comprises a UE information response message.

6. The method of any one of claims 2 to 5, wherein the report further comprises at least one of:

a first time measured by the wireless device based on the first time point;

a second time measured by the wireless device based on the second time point;

a first location of the wireless device based on the first time point; and/or

a second location of the wireless device based on the second time point.

7. The method of any one of claims 2 to 6, wherein:

the first location of the wireless device comprises a location information of a UE; and/or

the second location of the wireless device comprises the location information of a UE.

8. The method of claim 7, wherein the location information of a UE comprises at least one of:

a common location information;

a measured results for Bluetooth;

a measured results for WLAN; and/or

a sensor information.

9. The method of any one of claims 2 to 8, wherein:

the second base station is a source base station of the handover; and/or

the third base station is a target base station of the handover.

10. The method of any one of claims 2 to 9, further comprising:

determining, by the wireless device, that a first condition to execute the handover is fulfilled in response to the first distance being greater than the first distance threshold;

determining, by the wireless device, that a second condition to execute the handover is fulfilled in response to the second distance being less than or equal to the second distance threshold;

determining, by the wireless device, the first time point based on a time when the first condition was fulfilled; and

determining, by the wireless device, the second time point based on a time when the second condition was fulfilled;

wherein:

the first condition is fulfilled before the second condition is fulfilled; or

the second condition is fulfilled before the first condition is fulfilled.

11. The method of any one of claims 2 to 10, further comprising receiving, by the wireless device from the second base station, one or more configuration parameters for the handover, wherein the one or more configuration parameters indicate:

the first distance threshold;

the second distance threshold;

the reference location of the second base station; and

the reference location of the third base station.

12. The method of claim 11, wherein the one or more configuration parameters further indicate that a cell associated with the third base station is a target cell of the handover.

13. The method of any one of claims 11 to 12, further comprising performing, by the wireless device, the handover to the third base station while the wireless device is connected to the second base station, wherein the performing the handover comprises performing, based on the one or more configuration parameters, a conditional handover evaluation comprised of at least one of:

the first distance being greater than the first distance threshold; and/or

the second distance being less than or equal to the second distance threshold.

14. The method of claim 13, wherein the performing of the handover further comprises initiating a conditional reconfiguration execution.

15. The method of claim 14, further comprising performing, by the wireless device, based on the initiating the conditional reconfiguration execution, a random access procedure with the third base station for the handover to the third base station.

16. The method of any one of claims 13 to 15, further comprising determining, by the wireless device, one or more triggering conditions upon which the wireless device executes the handover.

17. The method of any one of claims 13 to 16, wherein:

the wireless device is connected to the first base station after performing the handover to the third base station; and

the wireless device maintains, keeps, and/or establishes an RRC Connection to the first base station after determining a radio link failure (RLF).

18. The method of any one of claims 2 to 17, further comprising:

performing, by the wireless device, a random access procedure with the first base station; and

receiving, by the wireless device from the first base station and after performing the handover, at least one of:

an RRC Setup message;

an RRC Resume message; or

an RRC (Re-)establishment message.

19. The method of any one of claims 2 to 18, further comprising:

determining, by the wireless device, a first entering condition, of the handover, being fulfilled at a time based on the first time point, wherein the determining the first entering condition is based on the first distance being greater than the first distance threshold; and

determining, by the wireless device, a second entering condition, of the handover, being fulfilled at a time based on the second time point, wherein the determining the second entering condition is based on the second distance being less than or equal to the second distance threshold.

20. The method of any one of claims 11 to 13, further comprising determining, by the wireless device, a radio link failure while performing one or more measurements based on the one or more configuration parameters, wherein the radio link failure is associated with one of:

the second base station;

the third base station; or

the first base station.

21. The method of claim 20, further comprising determining, by the wireless device, the time elapsed between the first time point and the second time point.

22. The method of claim 21, wherein:

the request for a report comprises an indication to transmit, by the wireless device to the first base station, the report;

the transmitting the report is based on the request for a report comprising the indication; and

the report comprises a radio link failure report comprising the indication of the time elapsed between the first time point and the second time point.

23. The method of any one of claims 20 to 22, wherein the determining the radio link failure is based on one or more RLF events comprising at least one of:

T310 expiry in source SpCell (e.g., PCell);

T312 expiry in PCell;

random access problem indication from source MCG MAC;

indication from MCG RLC (e.g., source MCG RLC) that a maximum number of retransmissions has been reached;

consistent uplink LBT failure indication from source MCG MAC; and/or

BH RLF indication received on BAP entity from the MCG, if connected as an IAB-node.

24. The method of any one of claims 20 to 23, further comprising at least one of:

performing, by the wireless device, based on the determining the radio link failure, an RLF recovery procedure comprising of at least one of:

an RRC connection re-establishment; and/or

a random access procedure with the first base station.

25. The method of claim 24, wherein the wireless device is connected to a fourth base station based on performing the RLF recovery procedure.

26. The method of any one of claims 11 to 25, wherein:

the one or more configuration parameters for the handover indicate one or more handover execution conditions; and

the handover is based on at least one of the one or more handover execution conditions being fulfilled.

27. The method of claim 26, further comprising:

determining, by the wireless device, based on at least one of the one or more handover execution conditions being fulfilled, an occurrence of one or more handover events comprising at least one of:

event A3;

event A4;

event A5;

event T1; and/or

event D1;

wherein the handover is based on determining, by the wireless device, that at least one of the one or more handover events occurs.

28. The method of any one of claims 2 to 27, further comprising performing, by the wireless device, a random access procedure with the first base station for the handover to the first base station.

29. The method of claim 28, wherein:

the receiving the request for a report is in response to completing the random access procedure with the first base station successfully;

the request for a report comprises an indication to transmit, by the wireless device, the report; and

the report comprises a successful handover report.

30. The method of claim 29, further comprising at least one of:

starting T304 timer, wherein the transmitting the report is based on a ratio, between a value of an elapsed time of the timer T304 and a timer value of the T304 timer, being greater than a T304 threshold value;

starting T310 timer, wherein the transmitting the report is based on a ratio, between a value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T310 threshold value; and/or

starting T312 timer, wherein the transmitting the report is based on a ratio, between a value of an elapsed time of the timer T310 and a timer value of the T310 timer, being greater than a T312 threshold value.

31. An apparatus comprising one or more processors and memory storing instructions that, when executed by the one or more processors, cause the apparatus to perform the method of any one of claims 2 to 30.

32. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of an apparatus, cause the apparatus to perform the method of any one of claims 2 to 30.

33. A method comprising:

transmitting, from a first base station to a wireless device, a request for a report associated with a handover; and

receiving, by the base station from the wireless device, the report comprising an indication of a time elapsed between a first time point and a second time point, wherein:

the first time point is a time that a first distance becomes greater than a first distance threshold, wherein the first distance is between the wireless device and a reference location of a second base station; and

the second time point is a time that a second distance, the distance between the wireless device and a reference location of a third base station, is less than or equal to a second distance threshold.

34. The method of claim 33, wherein the handover is a conditional handover.

35. The method of any one of claims 33 to 34, wherein:

the first time point is the latest first time point among a plurality of first time points; and/or

the second time point is the latest second time point among a plurality of second time points.

36. The method of any one of claims 33 to 35, wherein:

the request for a report comprises a user equipment (UE) information request message; and/or

the report comprises a UE information response message.

37. The method of any one of claims 33 to 36, wherein the report further comprises at least one of:

a first time measured by the wireless device based on the first time point;

a second time measured by the wireless device based on the second time point;

a first location of the wireless device based on the first time point; and/or

a second location of the wireless device based on the second time point.

38. The method of any one of claims 33 to 37, wherein:

the first location of the wireless device comprises a location information of a UE; and/or

the second location of the wireless device comprises the location information of a UE.

39. The method of claim 38, wherein the location information of a UE comprises at least one of:

a common location information;

a measured results for Bluetooth;

a measured results for WLAN; and/or

a sensor information.

40. The method of any one of claims 33 to 39, wherein:

the second base station is a source base station of the handover; and/or

the third base station is a target base station of the handover.

41. The method of any one of claims 33 to 40, wherein:

the first base station is a base station to which the wireless device is connected after performing the handover to the third base station; and

the first base station is a base station to which the wireless device maintains, keeps, and/or establishes an RRC Connection after determining a radio link failure (RLF).

42. The method of any one of claims 33 to 41, further comprising transmitting, by the first base station and after performing the handover, at least one of:

an RRC Setup message;

an RRC Resume message; or

an RRC (Re-)establishment message.

43. The method of any one of claims 33 to 42, wherein:

the request for a report comprises an indication to transmit, to the first base station by the wireless device, the report;

the receiving the report is based on the request for a report comprising the indication; and

the report comprises a radio link failure report comprising the indication of the time elapsed between the first time point and the second time point.

44. The method of any one of claims 33 to 43, further comprising performing, by the first base station with the wireless device, a random access procedure for the handover to the first base station.

45. The method of claim 44, wherein:

the transmitting the request for a report is in response to completing the random access procedure with the first base station successfully;

the request for a report comprises an indication to transmit, to the first base station, by the wireless device, the report; and

the report comprises a successful handover report.

46. An apparatus comprising one or more processors and memory storing instructions that, when executed by the one or more processors, cause the apparatus to perform the method of any one of claims 33 to 45.

47. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of an apparatus, cause the apparatus to perform the method of any one of claims 33 to 45.

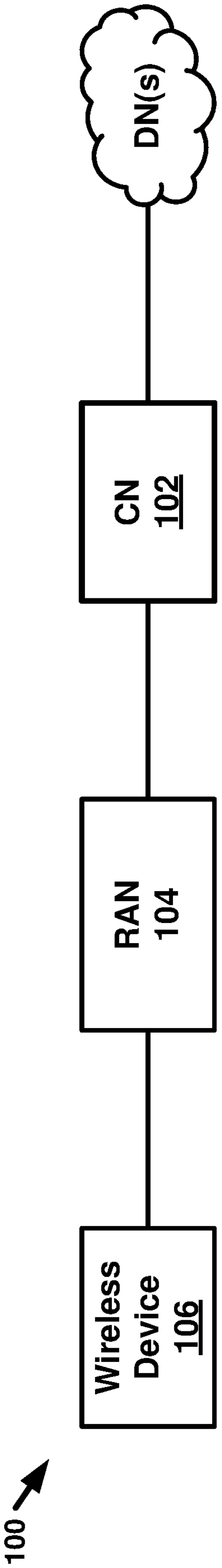
100
Wireless Device 106
RAN 104
CN 102
DN(s)

FIG. 1A

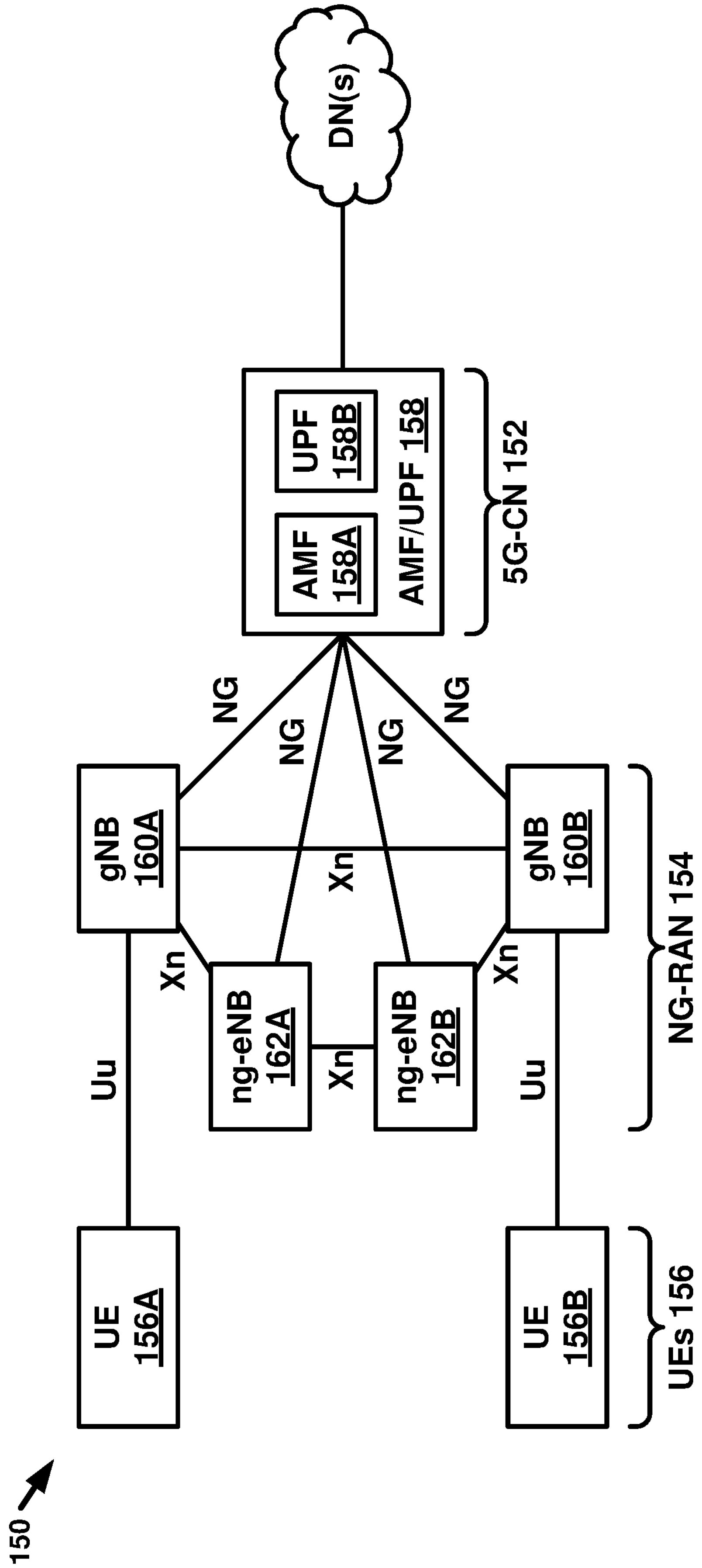
150
UE 156A
UE 156B
UEs 156
Uu
Uu
gNB 160A
gNB 160B
ng-eNB 162A
ng-eNB 162B
Xn
Xn
Xn
Xn
NG
NG
NG
NG
NG-RAN 154
AMF 158A
UPF 158B
AMF/UPF 158
5G-CN 152
DN(s)

FIG. 1B

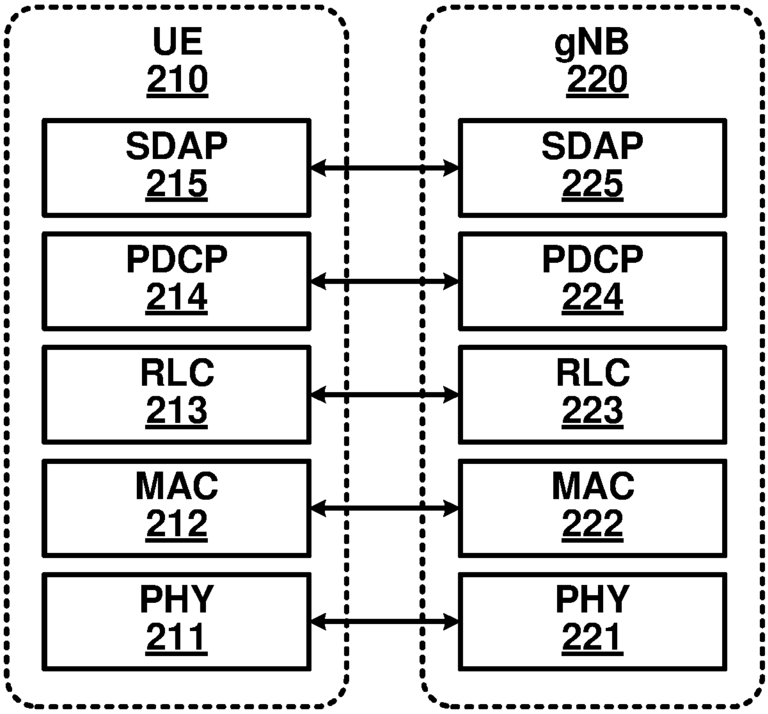
UE
210
SDAP
215
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
SDAP
225
PDCP
224
RLC
223
MAC
222
PHY
221

FIG. 2A

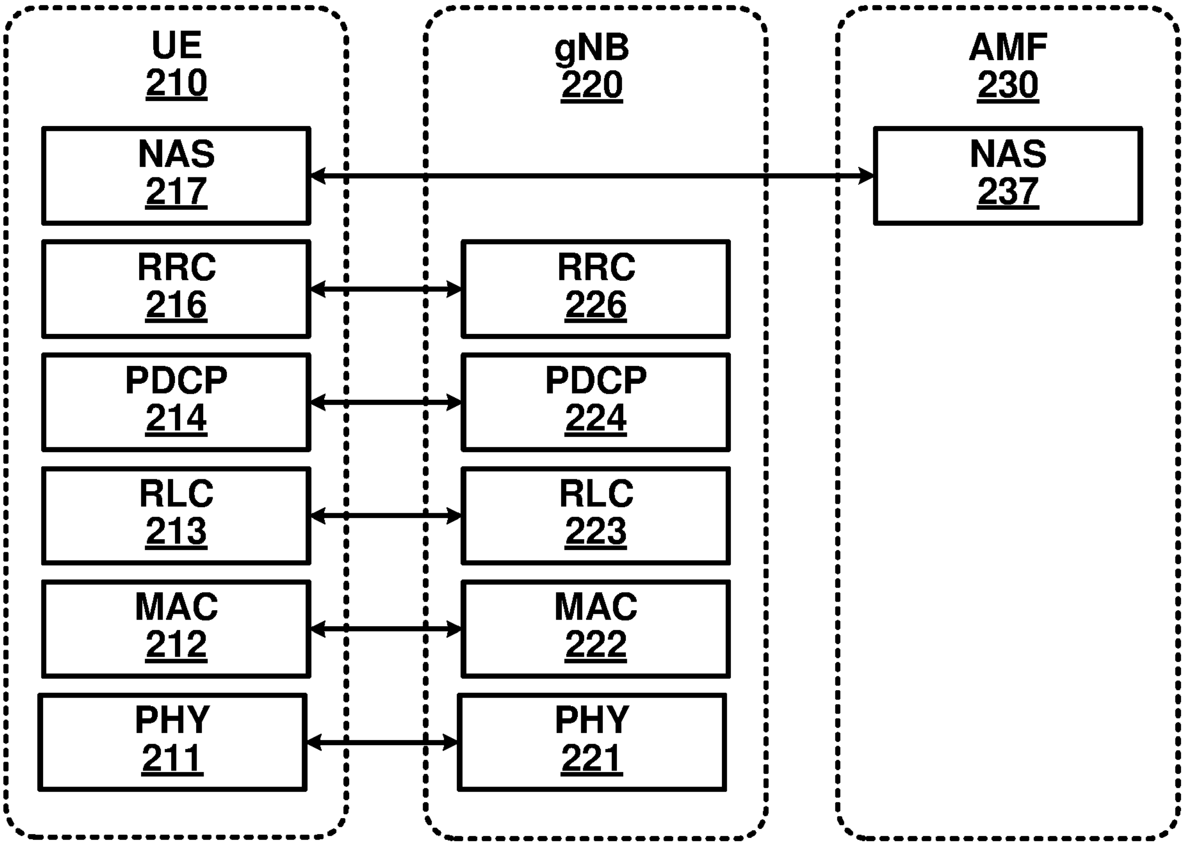
UE
210
NAS
217
RRC
216
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
RRC
226
PDCP
224
RLC
223
MAC
222
PHY
221
AMF
230
NAS
237

FIG. 2B

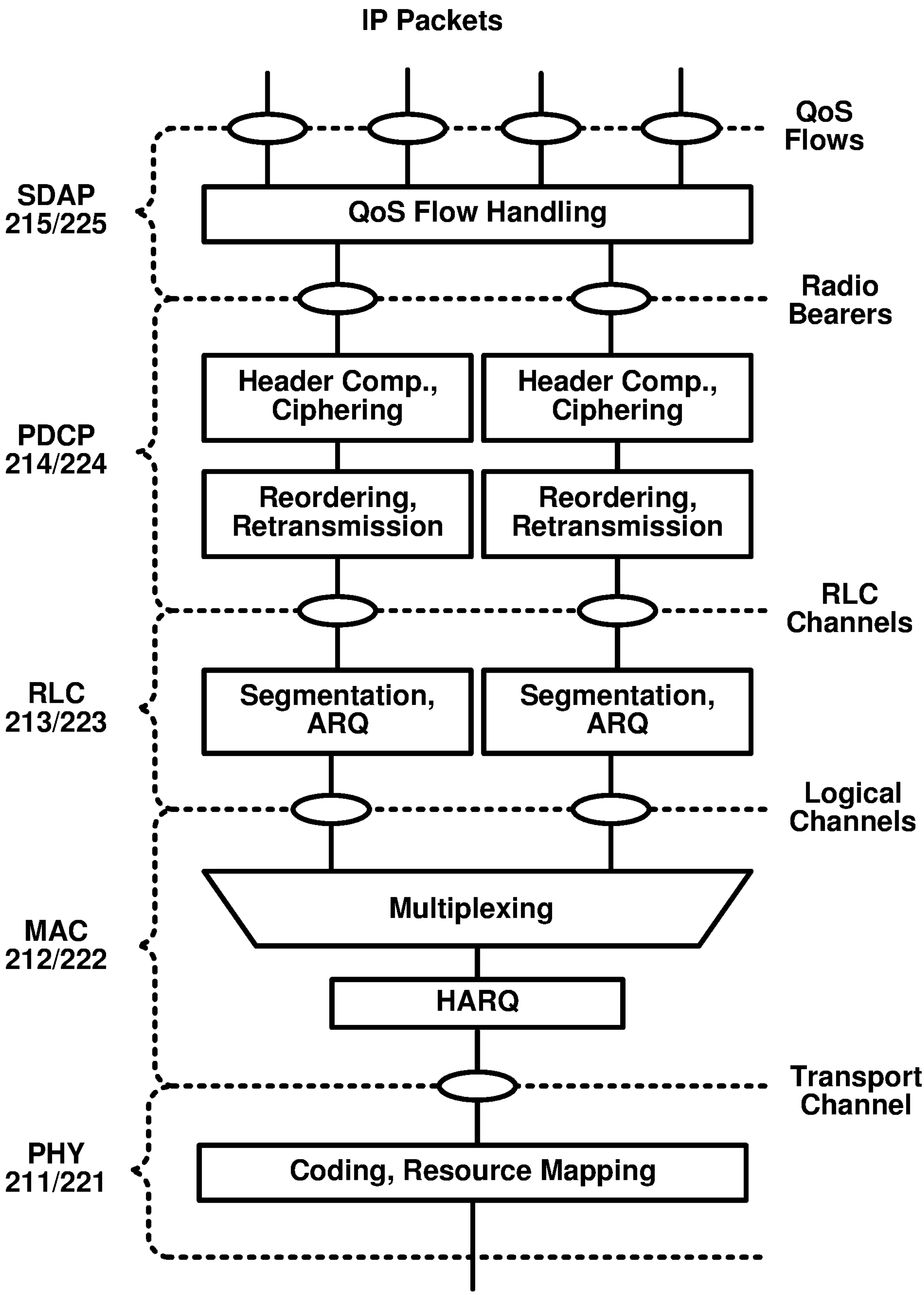
IP Packets
QoS Flows
SDAP 215/225
QoS Flow Handling
Radio Bearers
PDCP 214/224
Header Comp., Ciphering
Header Comp., Ciphering
Reordering, Retransmission
Reordering, Retransmission
RLC Channels
RLC 213/223
Segmentation, ARQ
Segmentation, ARQ
Logical Channels
MAC 212/222
Multiplexing
HARQ
Transport Channel
PHY 211/221
Coding, Resource Mapping

FIG. 3

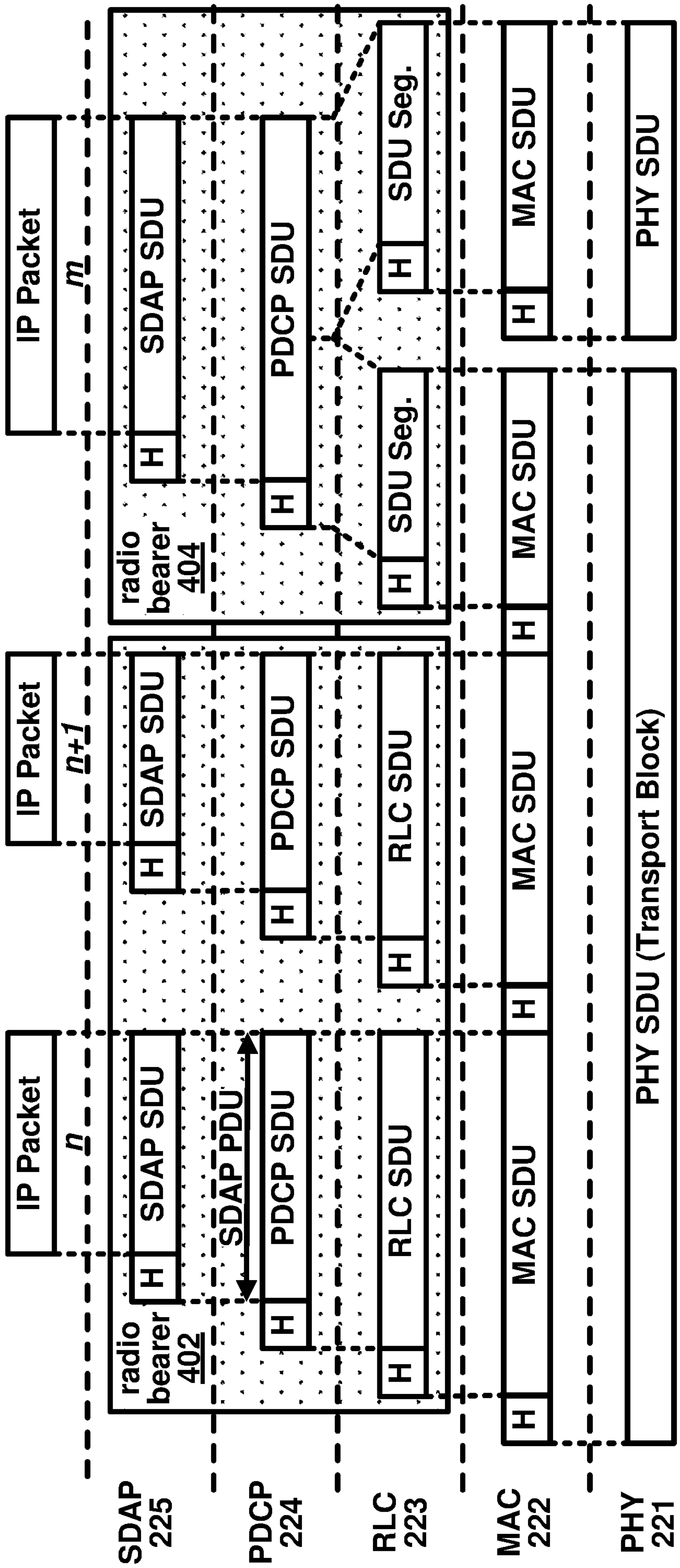
SDAP 225
PDCP 224
RLC 223
MAC 222
PHY 221
IP Packet n
IP Packet n+1
IP Packet m
radio bearer 402
radio bearer 404
H
SDAP SDU
SDAP PDU
PDCP SDU
RLC SDU
SDU Seg.
MAC SDU
PHY SDU
PHY SDU (Transport Block)

FIG. 4A

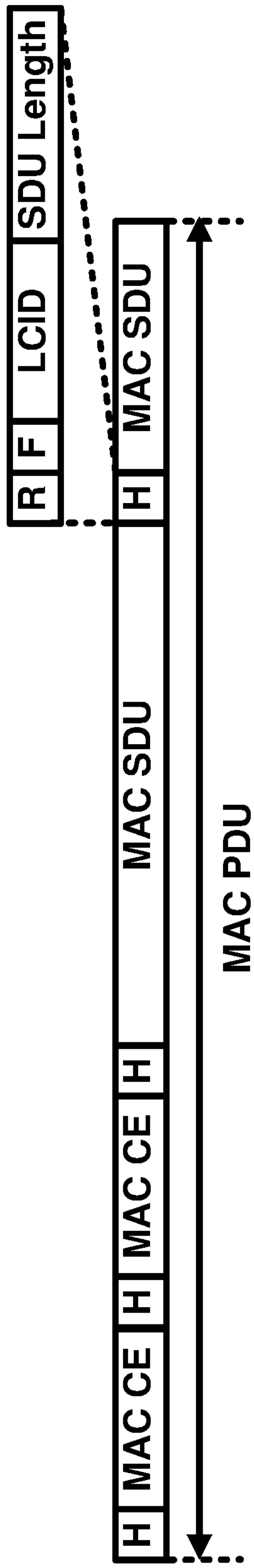
R
F
LCID
SDU Length
H
MAC CE
MAC SDU
MAC PDU

FIG. 4B

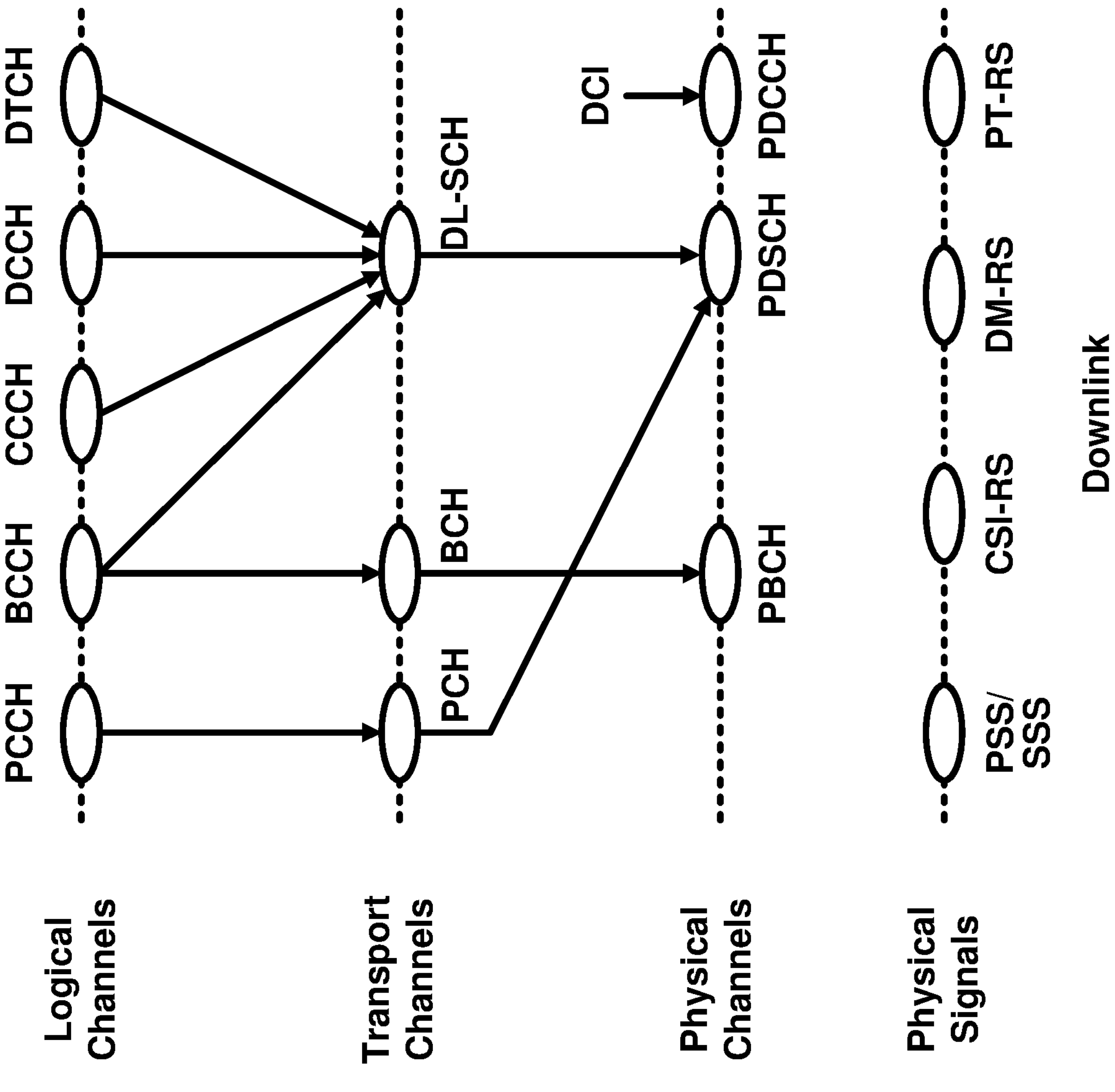
Logical Channels
Transport Channels
Physical Channels
Physical Signals
PCCH
BCCH
CCCH
DCCH
DTCH
PCH
BCH
DL-SCH
PBCH
PDSCH
PDCCH
DCI
PSS/ SSS
CSI-RS
DM-RS
PT-RS
Downlink

FIG. 5A

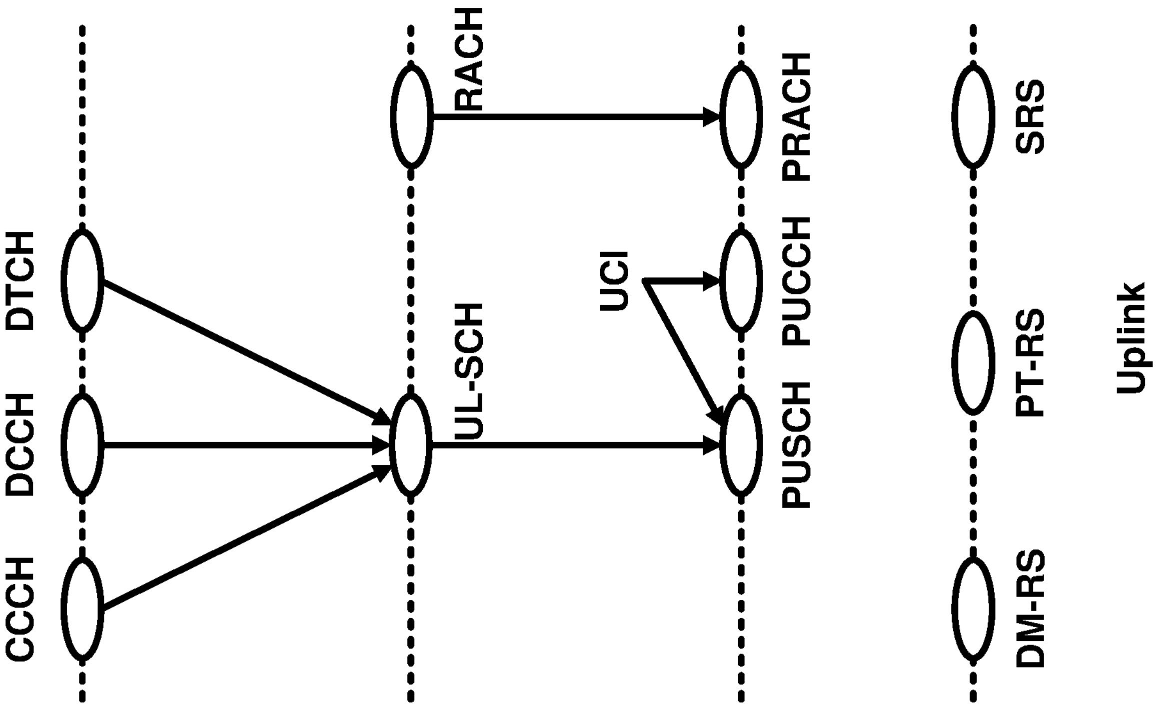
CCCH
DCCH
DTCH
UL-SCH
RACH
PUSCH
PUCCH
PRACH
UCI
DM-RS
PT-RS
SRS
Uplink

FIG. 5B

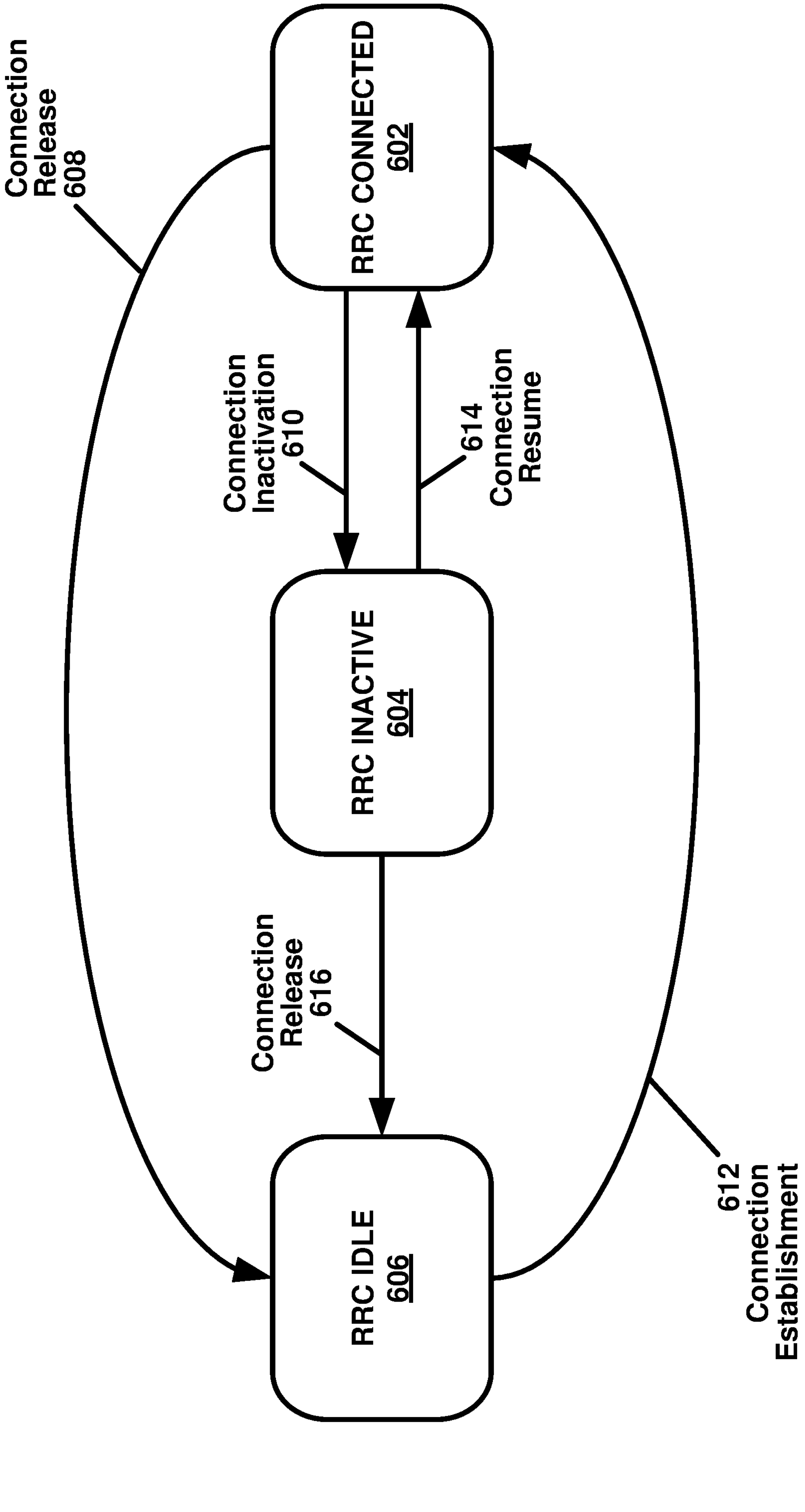
Connection Release 608
RRC CONNECTED 602
Connection Inactivation 610
614 Connection Resume
RRC INACTIVE 604
Connection Release 616
RRC IDLE 606
612 Connection Establishment

FIG. 6

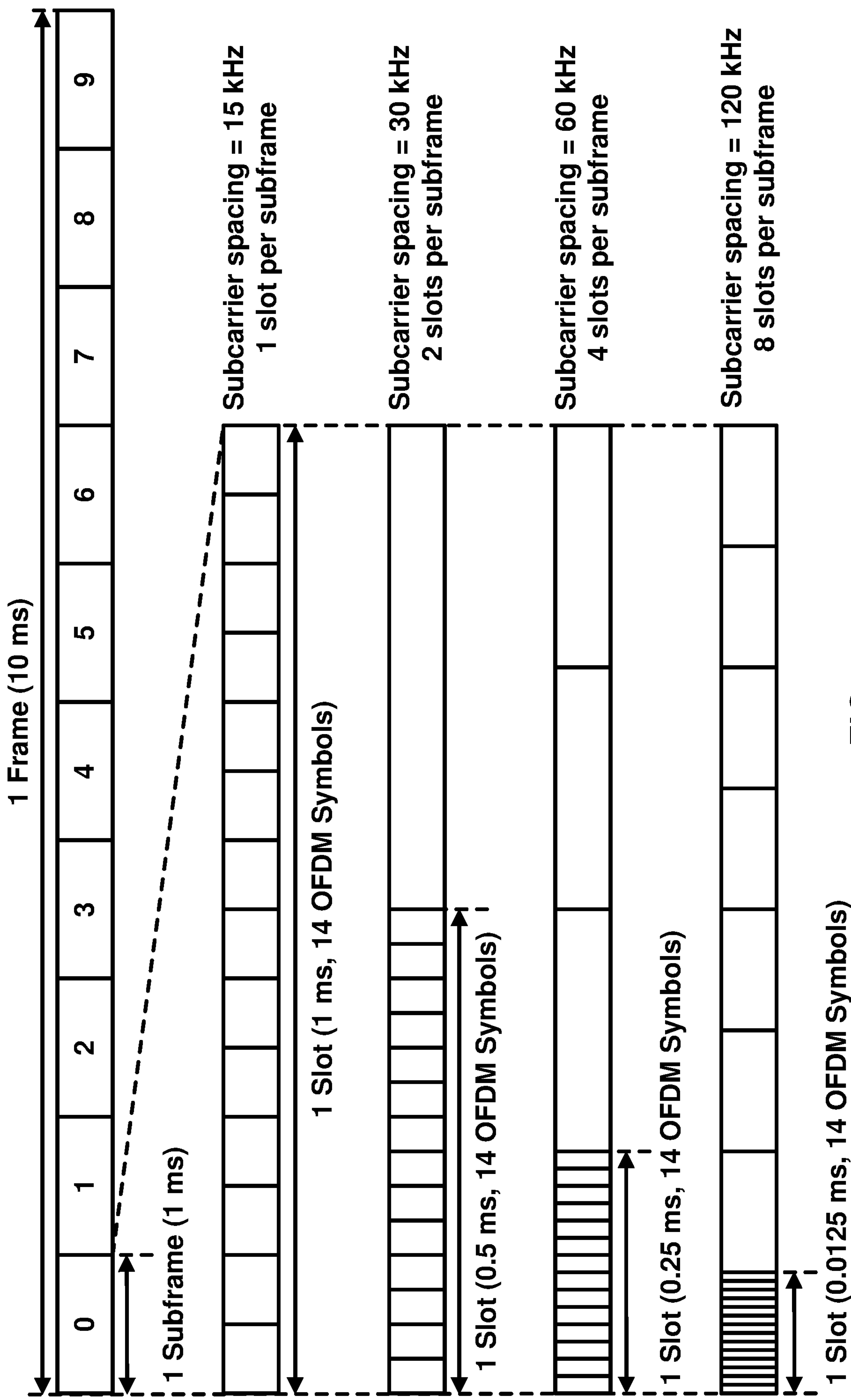
1 Frame (10 ms)
0
1
2
3
4
5
6
7
8
9
1 Subframe (1 ms)
Subcarrier spacing = 15 kHz
1 slot per subframe
1 Slot (1 ms, 14 OFDM Symbols)
Subcarrier spacing = 30 kHz
2 slots per subframe
1 Slot (0.5 ms, 14 OFDM Symbols)
Subcarrier spacing = 60 kHz
4 slots per subframe
1 Slot (0.25 ms, 14 OFDM Symbols)
Subcarrier spacing = 120 kHz
8 slots per subframe
1 Slot (0.0125 ms, 14 OFDM Symbols)

FIG. 7

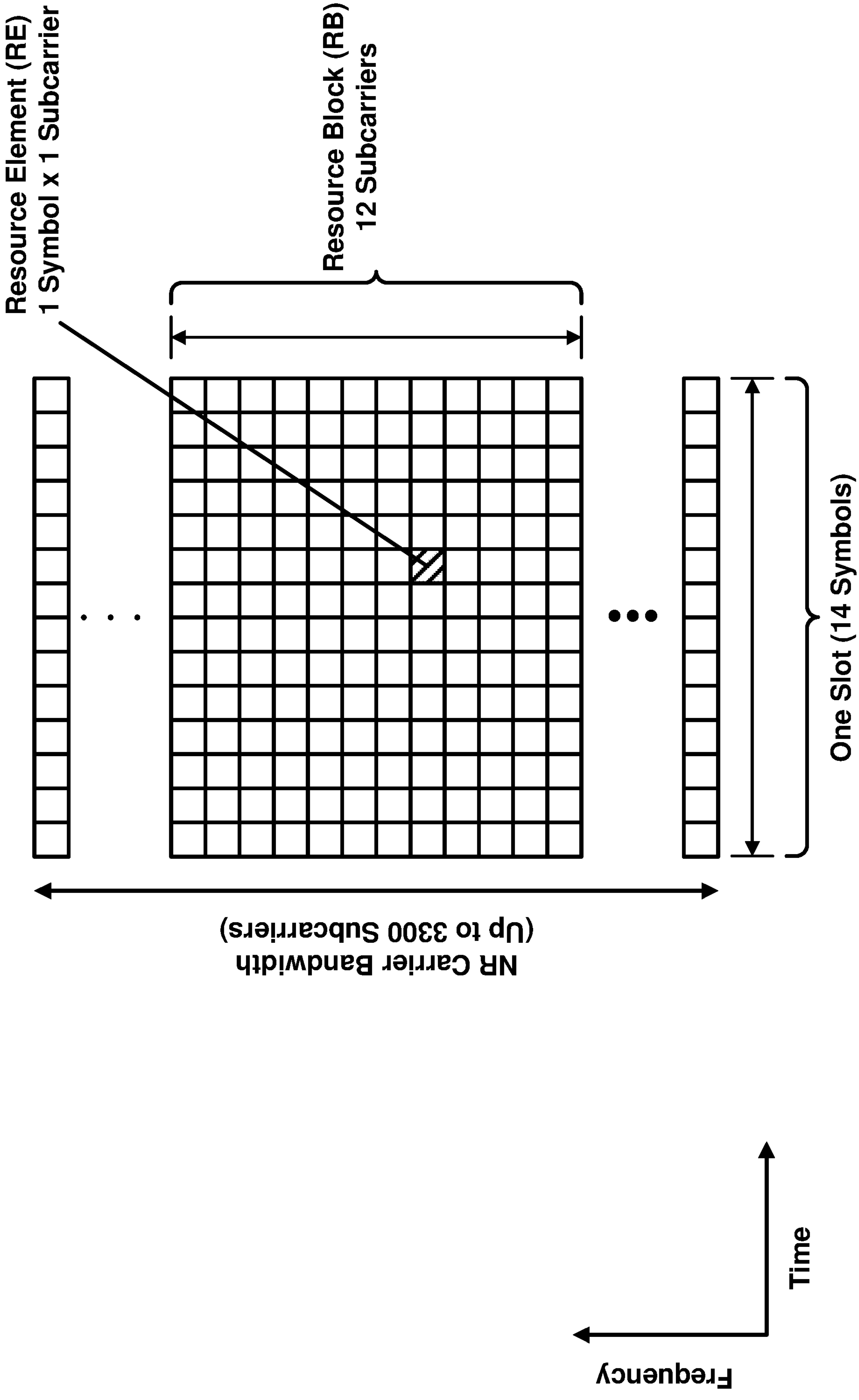
Resource Element (RE)
1 Symbol x 1 Subcarrier
Resource Block (RB)
12 Subcarriers
One Slot (14 Symbols)
NR Carrier Bandwidth
(Up to 3300 Subcarriers)
Time
Frequency

FIG. 8

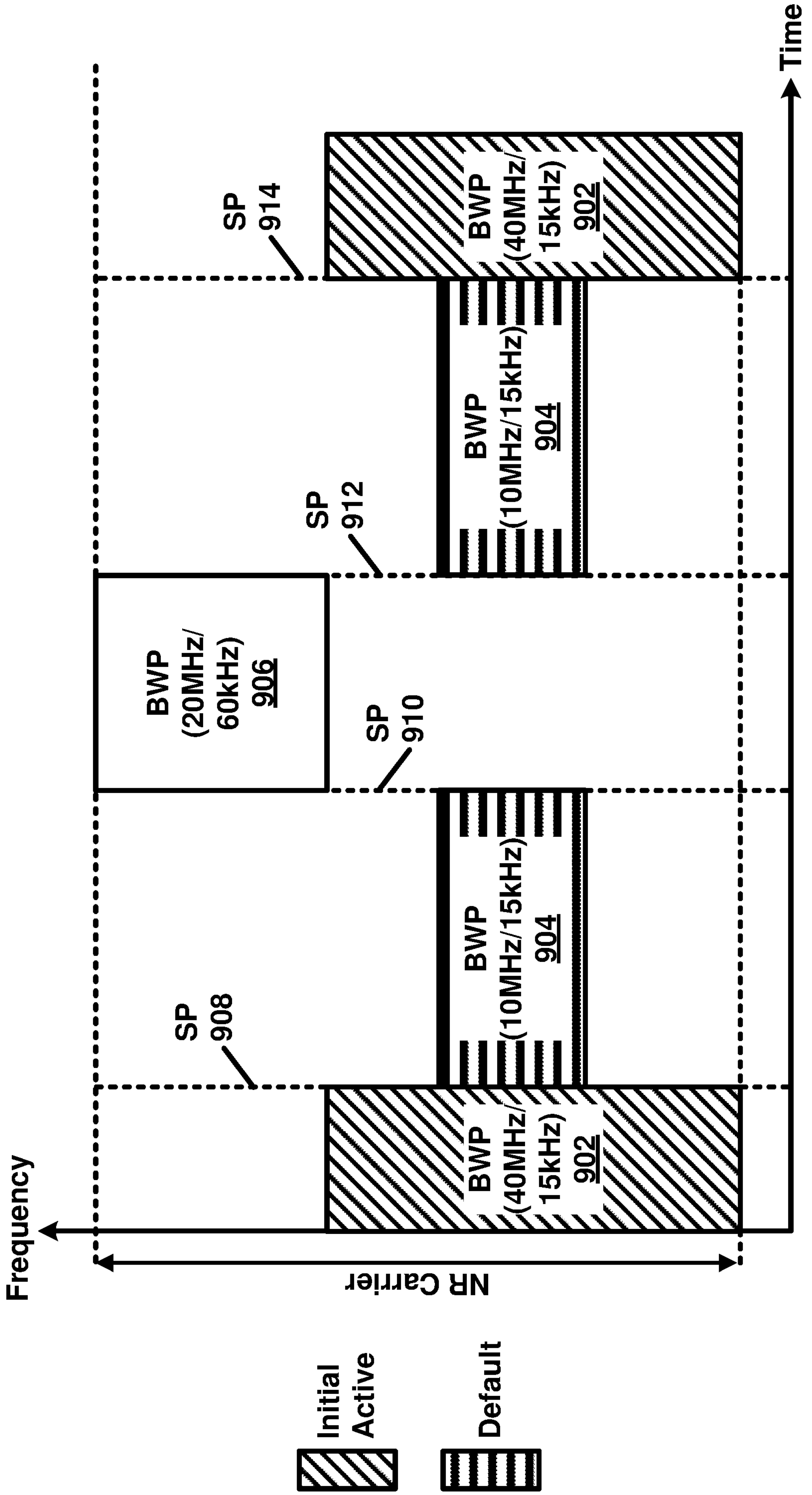
Time
Frequency
NR Carrier
SP 908
SP 910
SP 912
SP 914
BWP (40MHz/ 15kHz) 902
BWP (10MHz/15kHz) 904
BWP (20MHz/ 60kHz) 906
BWP (10MHz/15kHz) 904
BWP (40MHz/ 15kHz) 902
Initial Active
Default

FIG. 9

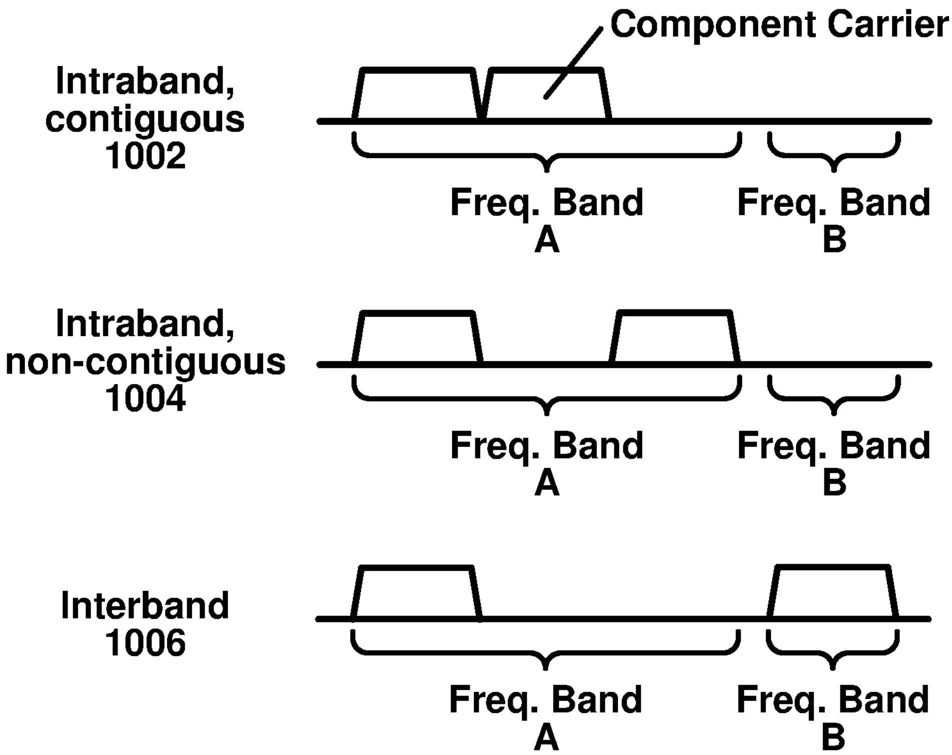

FIG. 10A

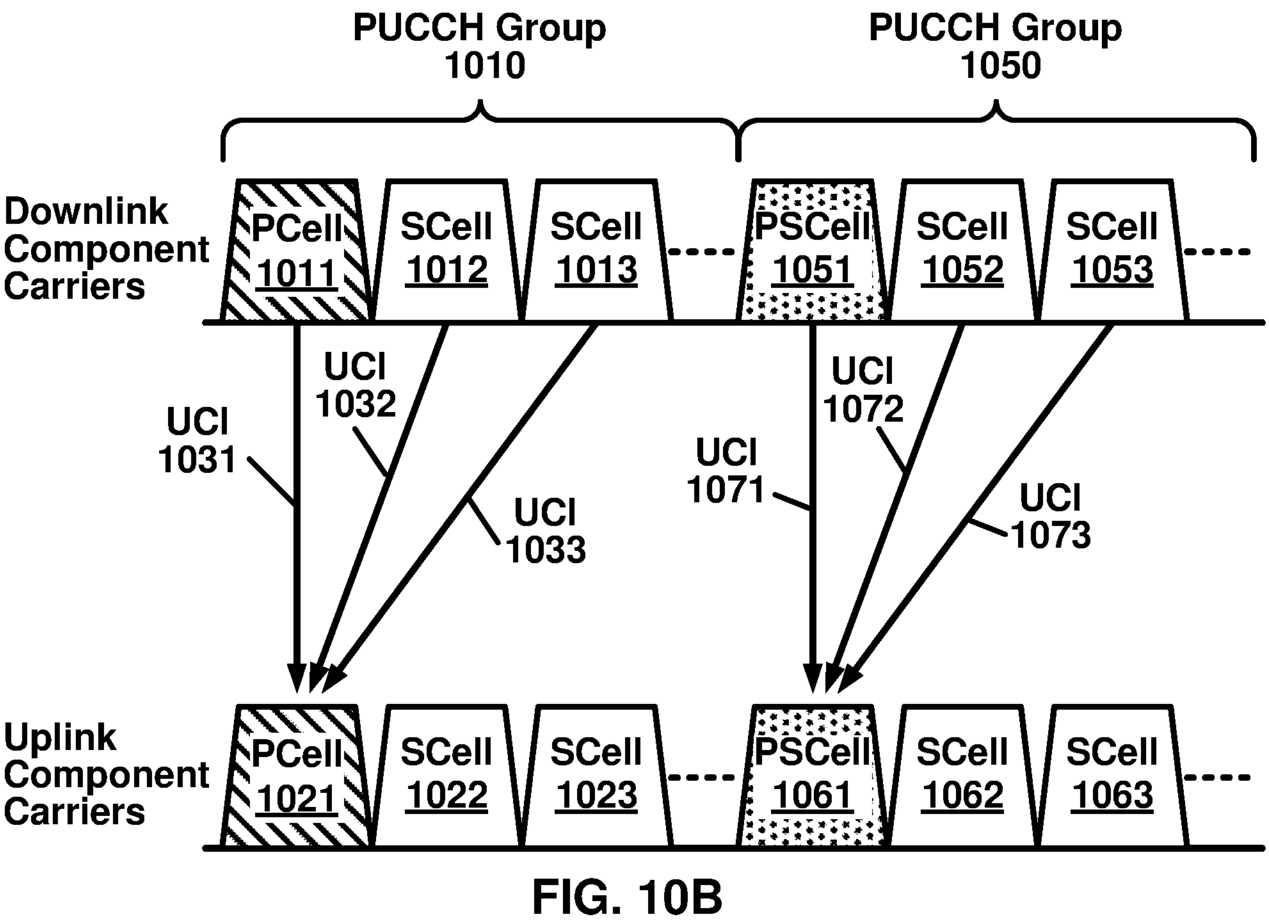

FIG. 10B

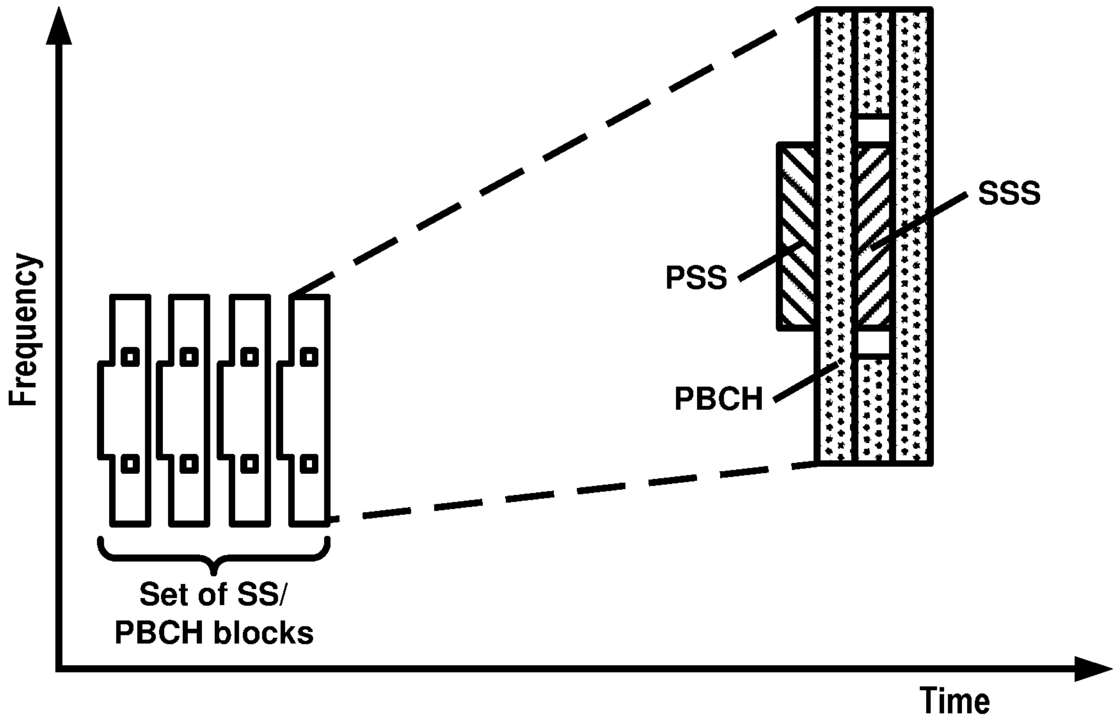

FIG. 11A

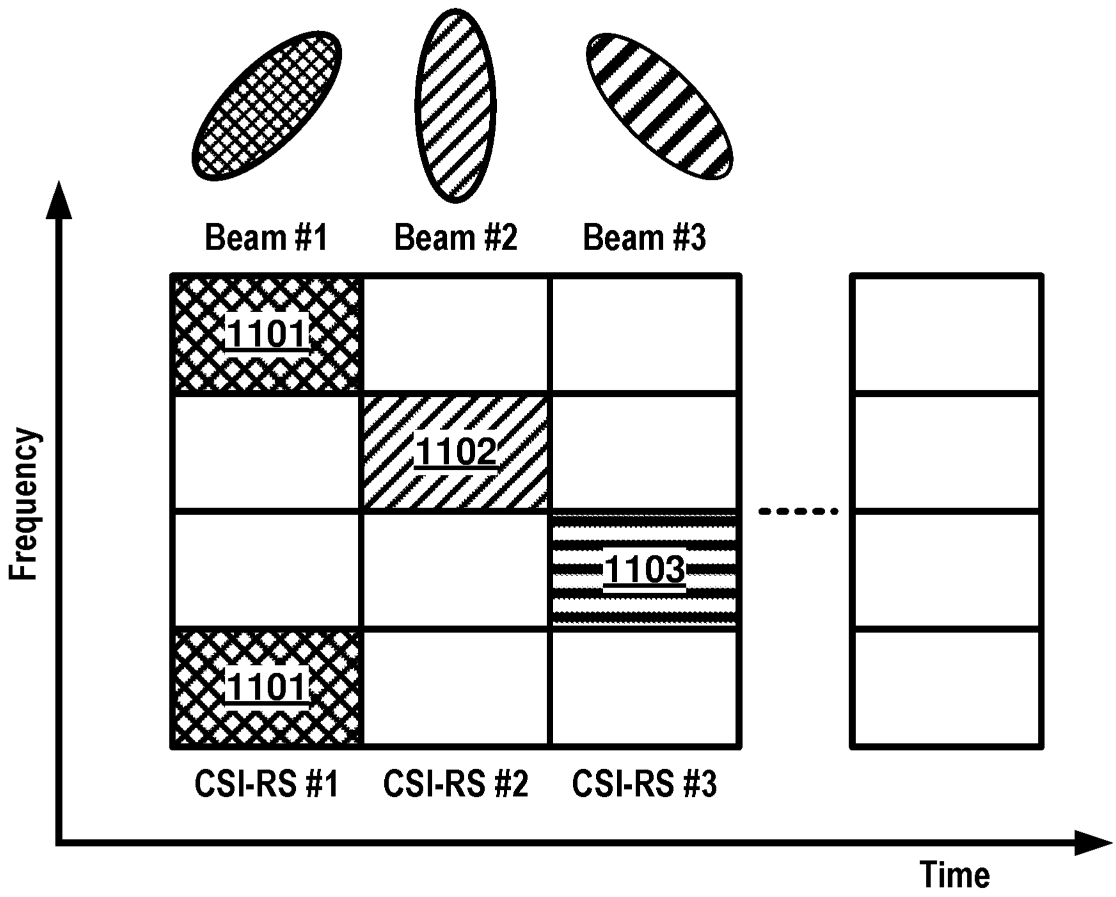

FIG. 11B

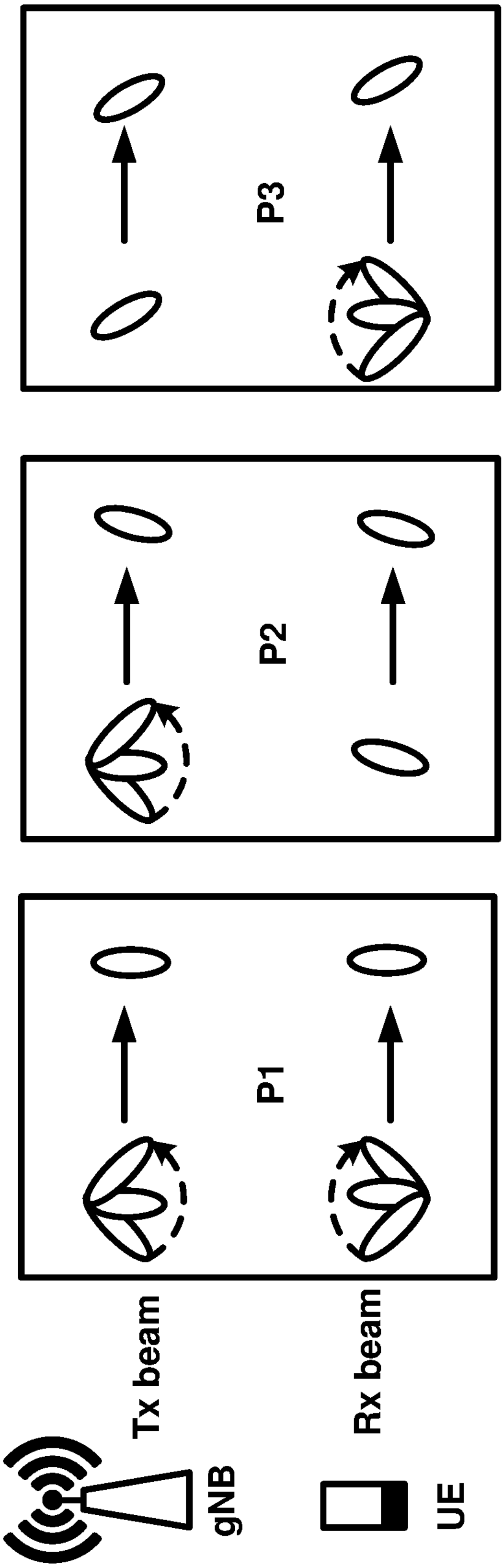

FIG. 12A

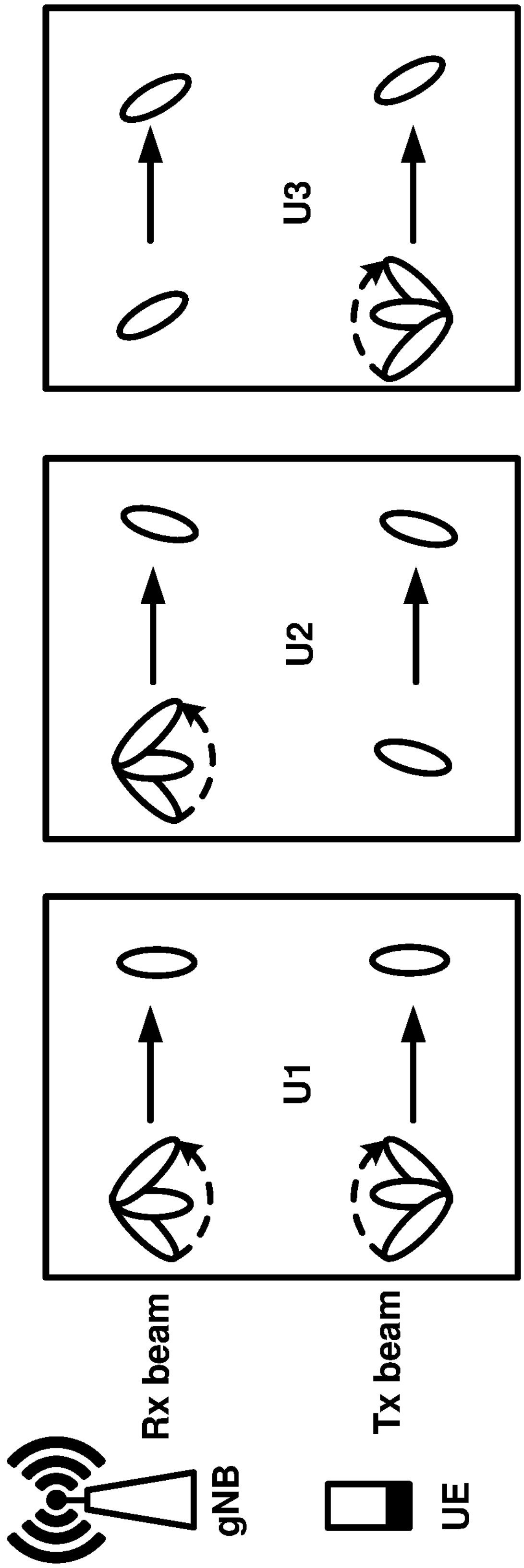

FIG. 12B

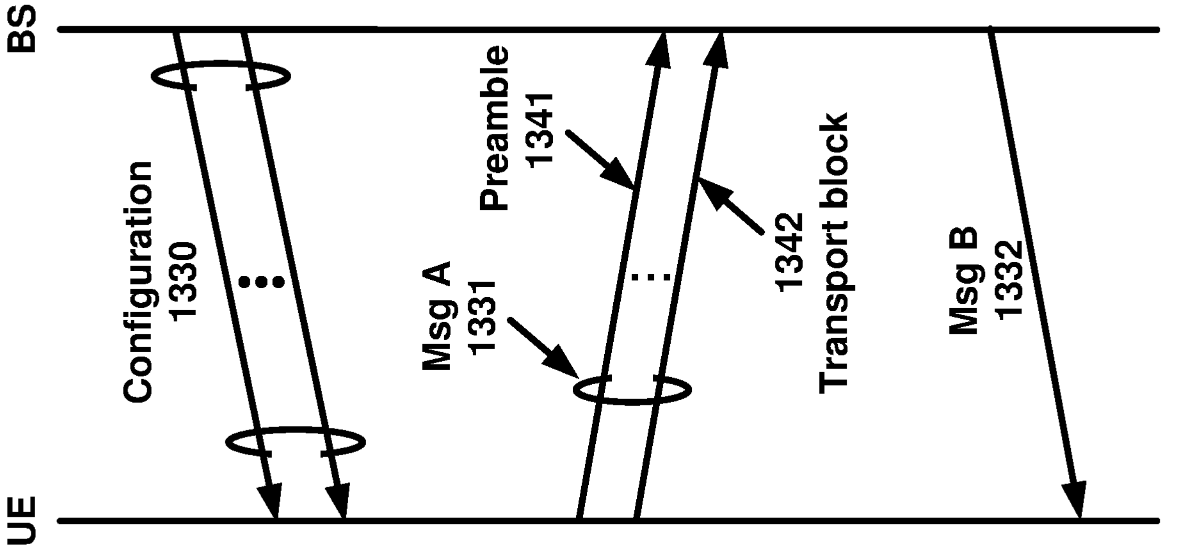

FIG. 13C

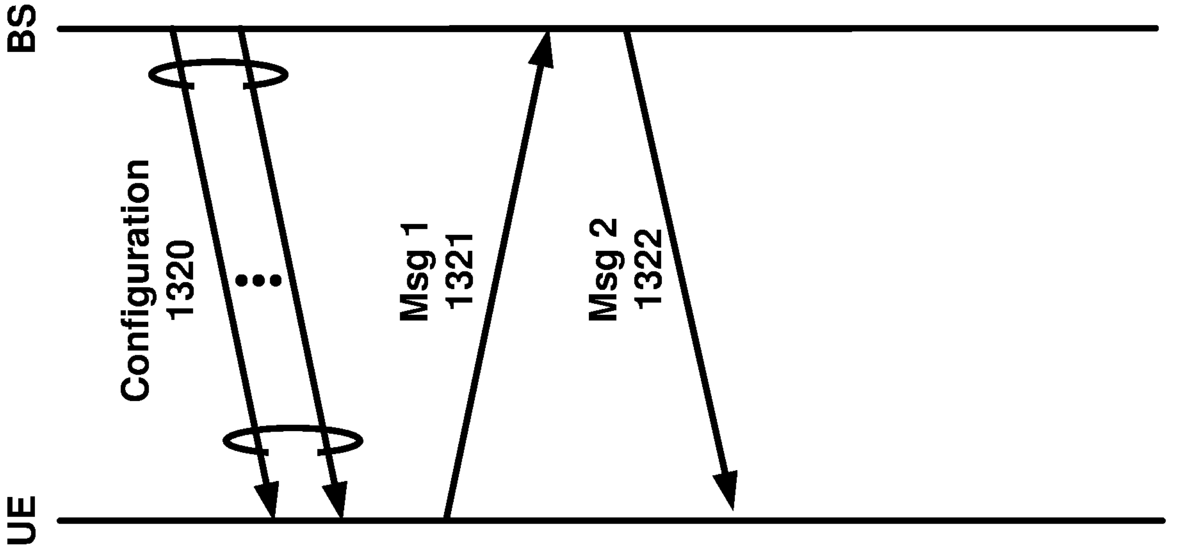

FIG. 13B

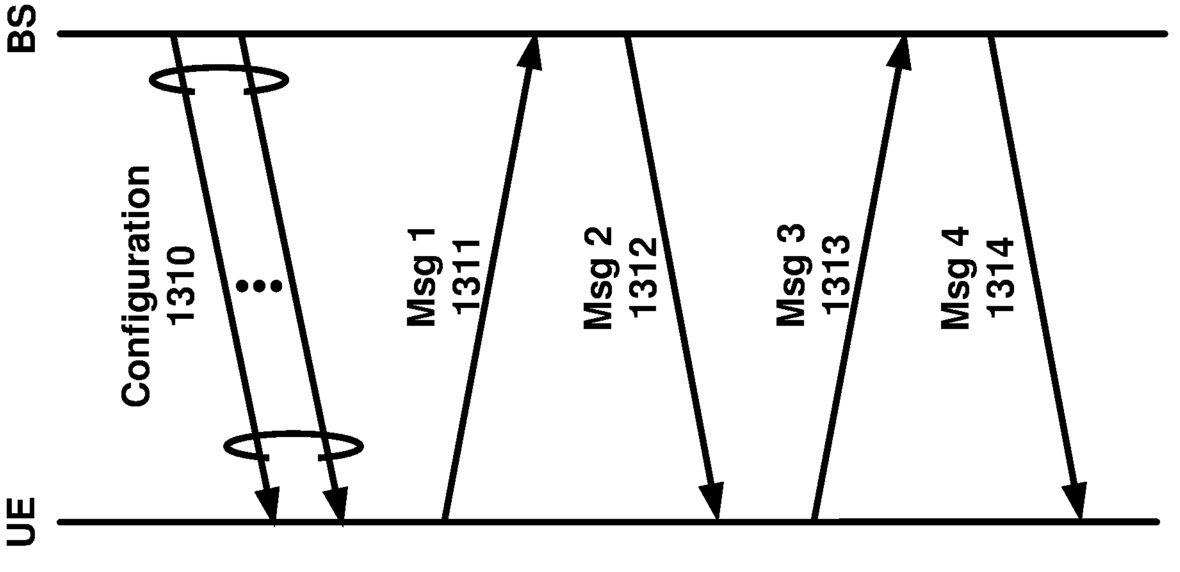

FIG. 13A

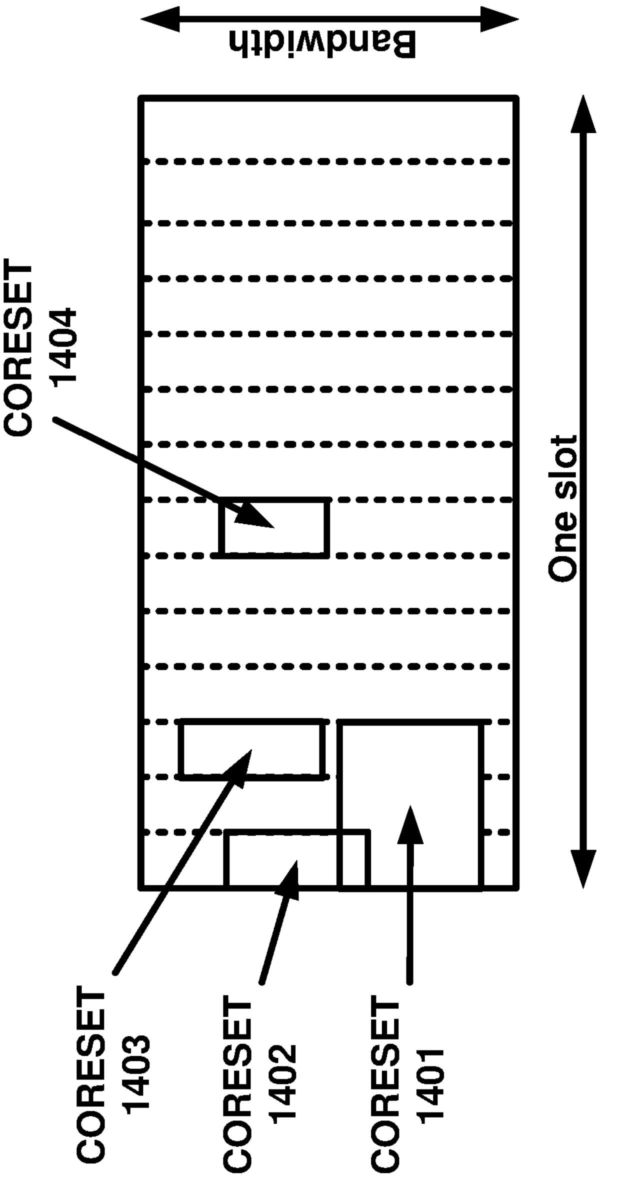

FIG. 14A

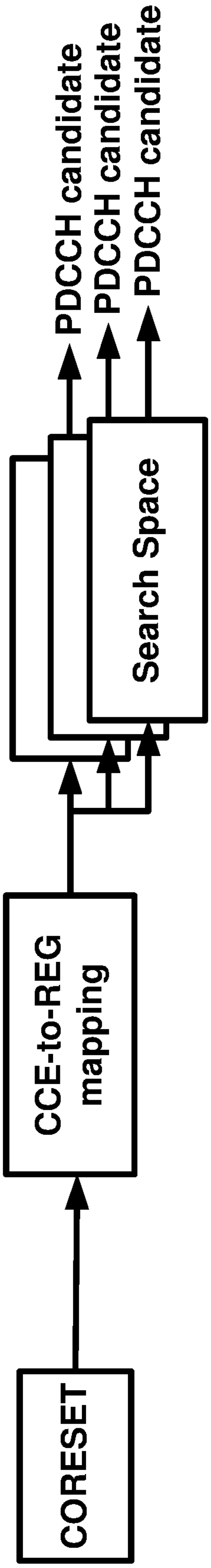

FIG. 14B

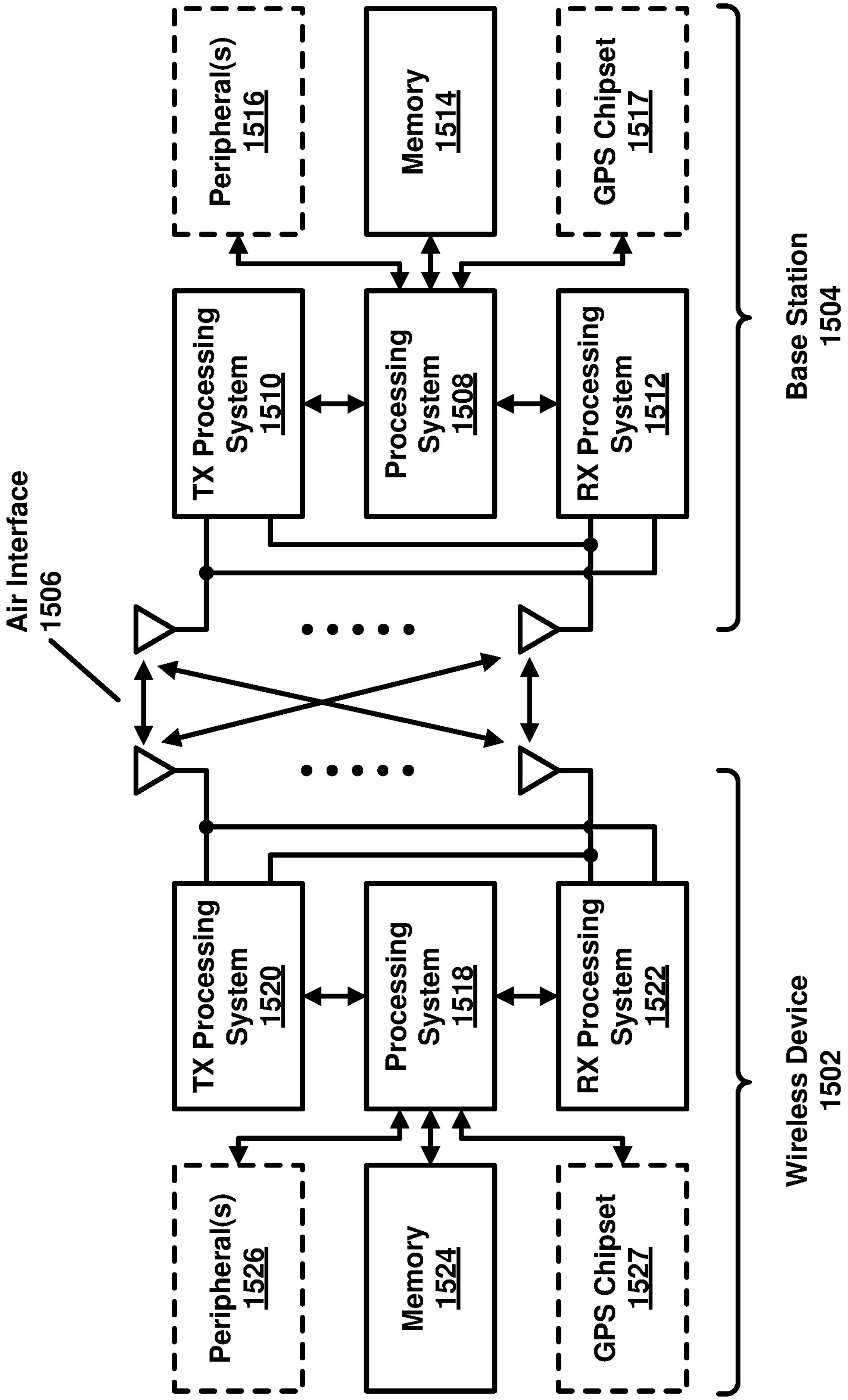
Peripheral(s) 1516
Memory 1514
GPS Chipset 1517
TX Processing System 1510
Processing System 1508
RX Processing System 1512
Base Station 1504
Air Interface 1506
TX Processing System 1520
Processing System 1518
RX Processing System 1522
Wireless Device 1502
Peripheral(s) 1526
Memory 1524
GPS Chipset 1527

FIG. 15

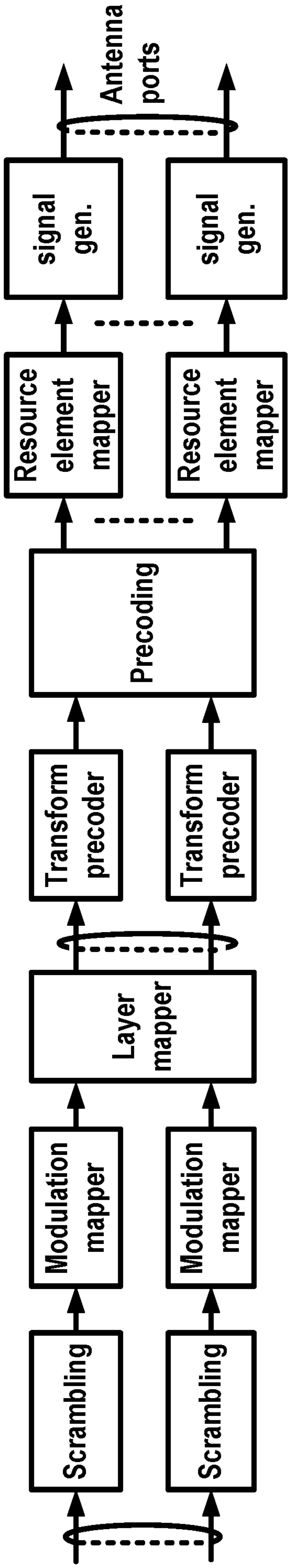

FIG. 16A

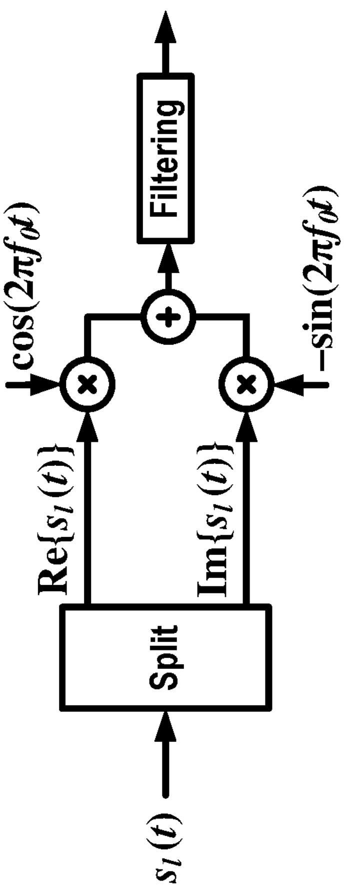

FIG. 16B

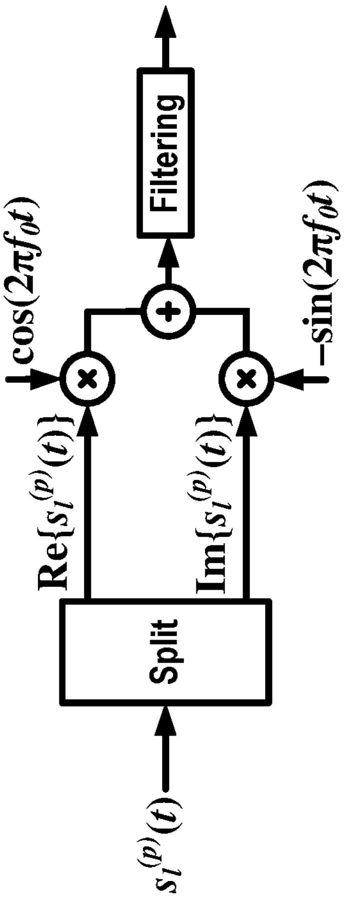

FIG. 16D

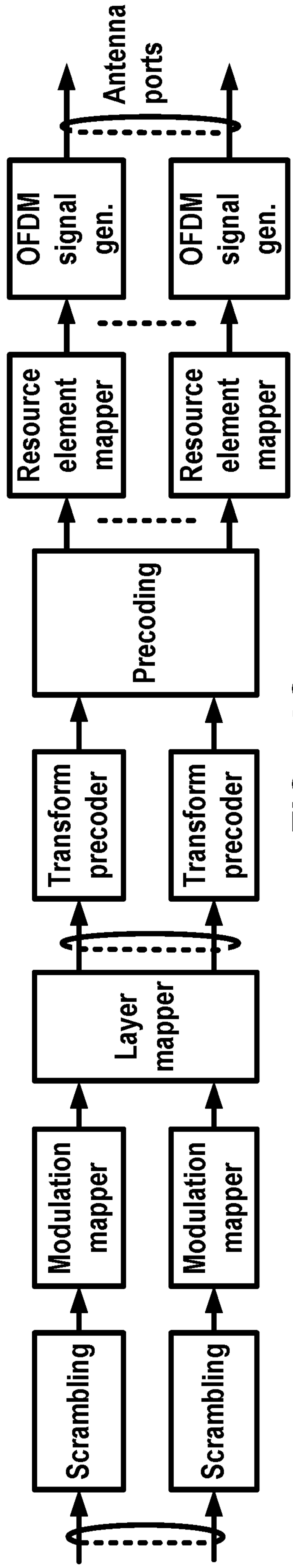

FIG. 16C

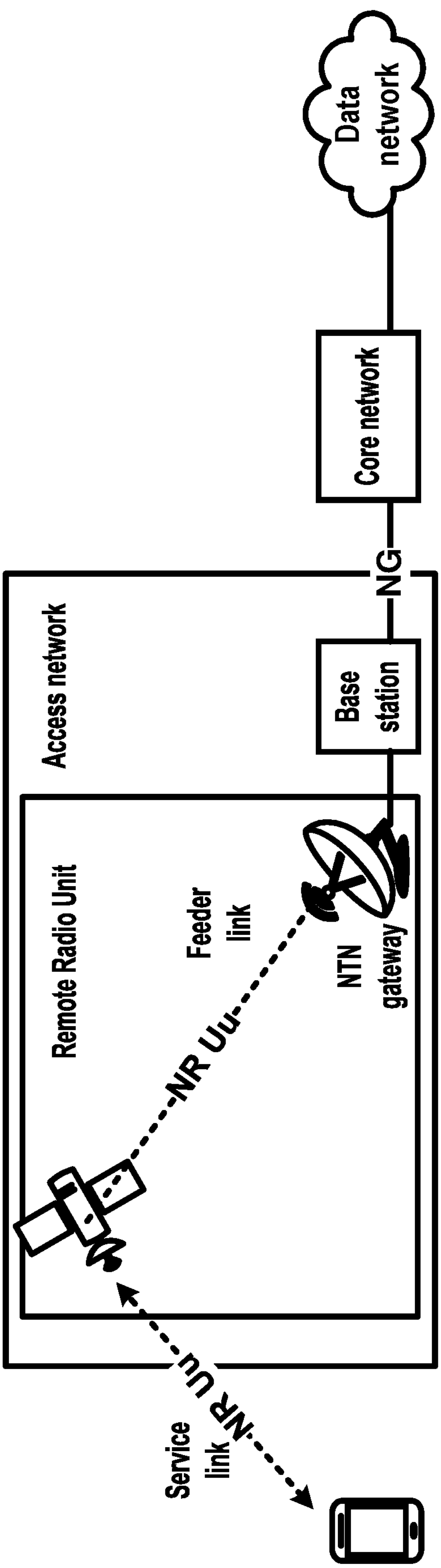

FIG. 17A

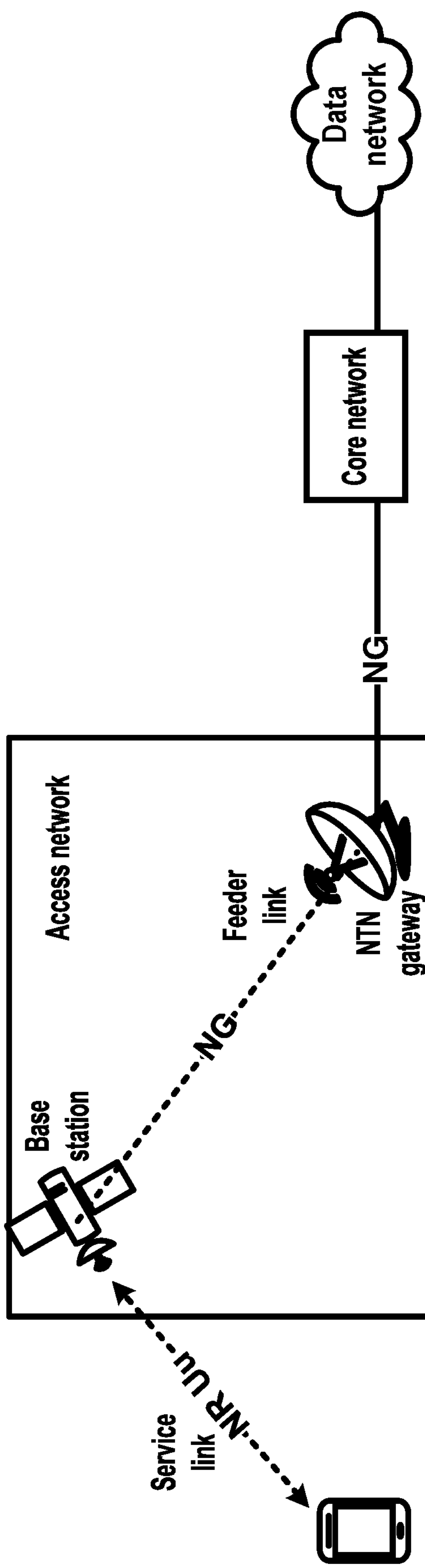

FIG. 17B

RAT type/ Platform type	Altitude range	Orbit	Typical beam footprint size
LEO satellite	250 – 1500 km	Circular around the earth	100 – 500 km
MEO satellite	5000 – 25000 km		100 – 500 km
GEO satellite	35,786 km	Notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point	200 – 1000 km
UAS platform	8-50 km (20km for HAPS)		5 – 200 km
HEO platform	400 – 50000km	Elliptical around the earth	200 – 1000km

FIG. 18

Class of Orbit	Elevation angle (degrees)		
Altitude (km)	0	10	90
LEO satellite	Propagation delay – satellite to UE (millisec)		
800	11.0	7.9	2.7
1400	14.8	11.6	4.7
MEO satellite	Propagation delay – satellite to UE (millisec)		
8000	43.0	39.4	26.7
GEO satellite	Propagation delay – satellite to UE (millisec)		
35,786	138.9	135.3	119.3

FIG. 19

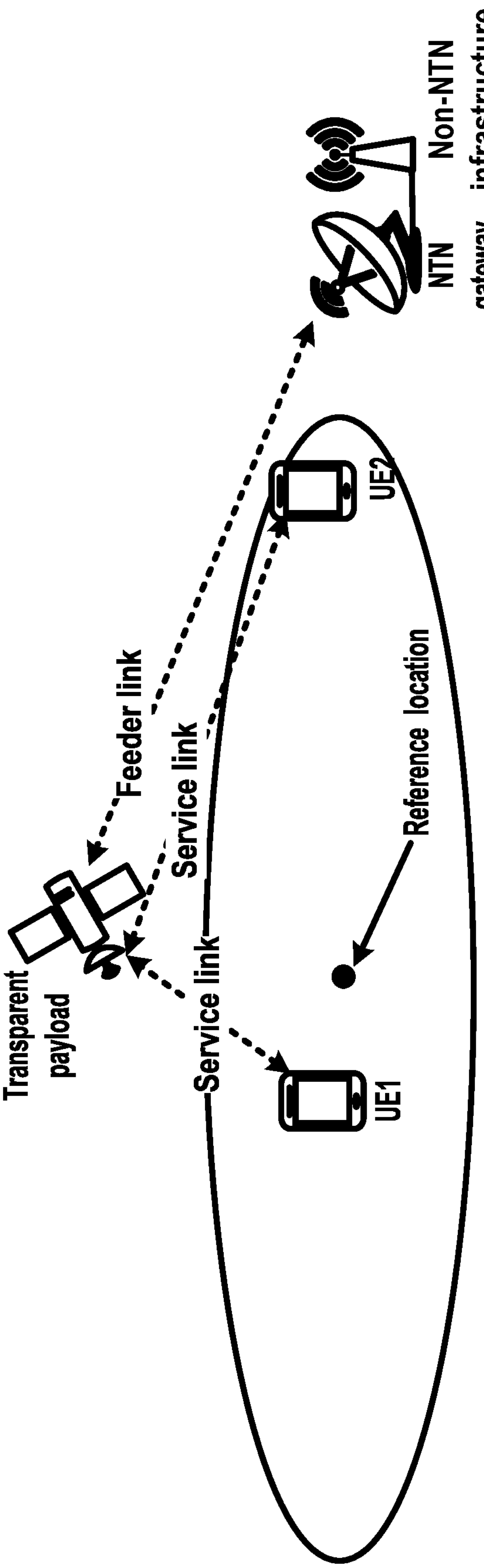

FIG. 20A

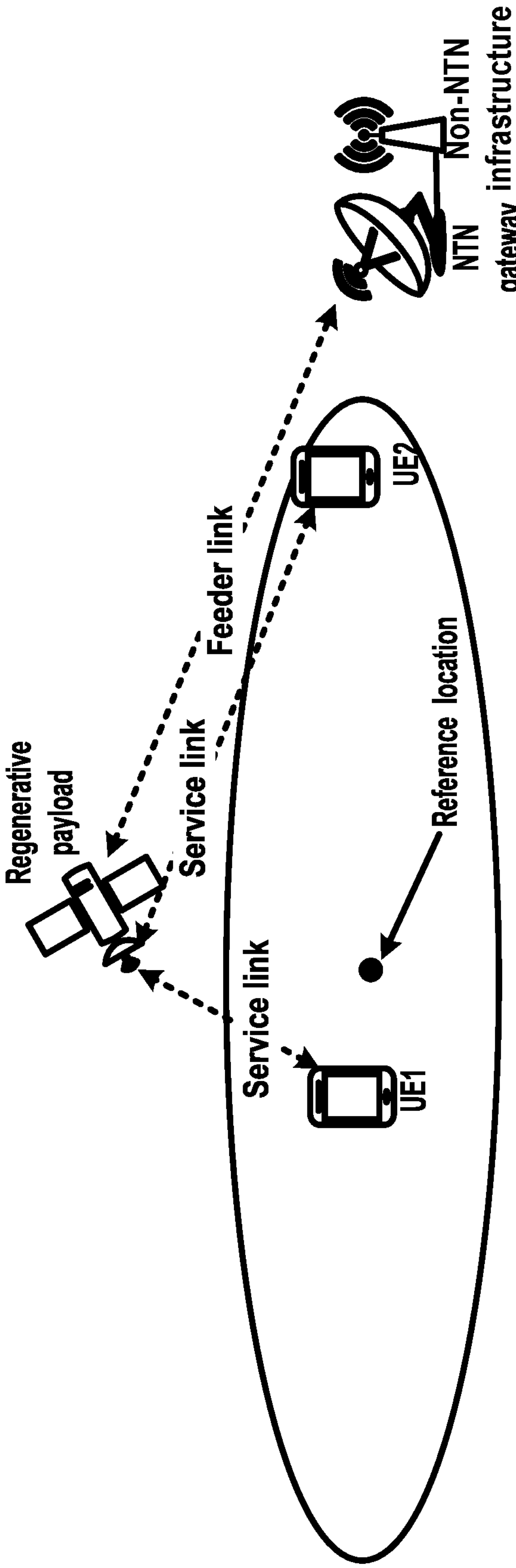

FIG. 20B

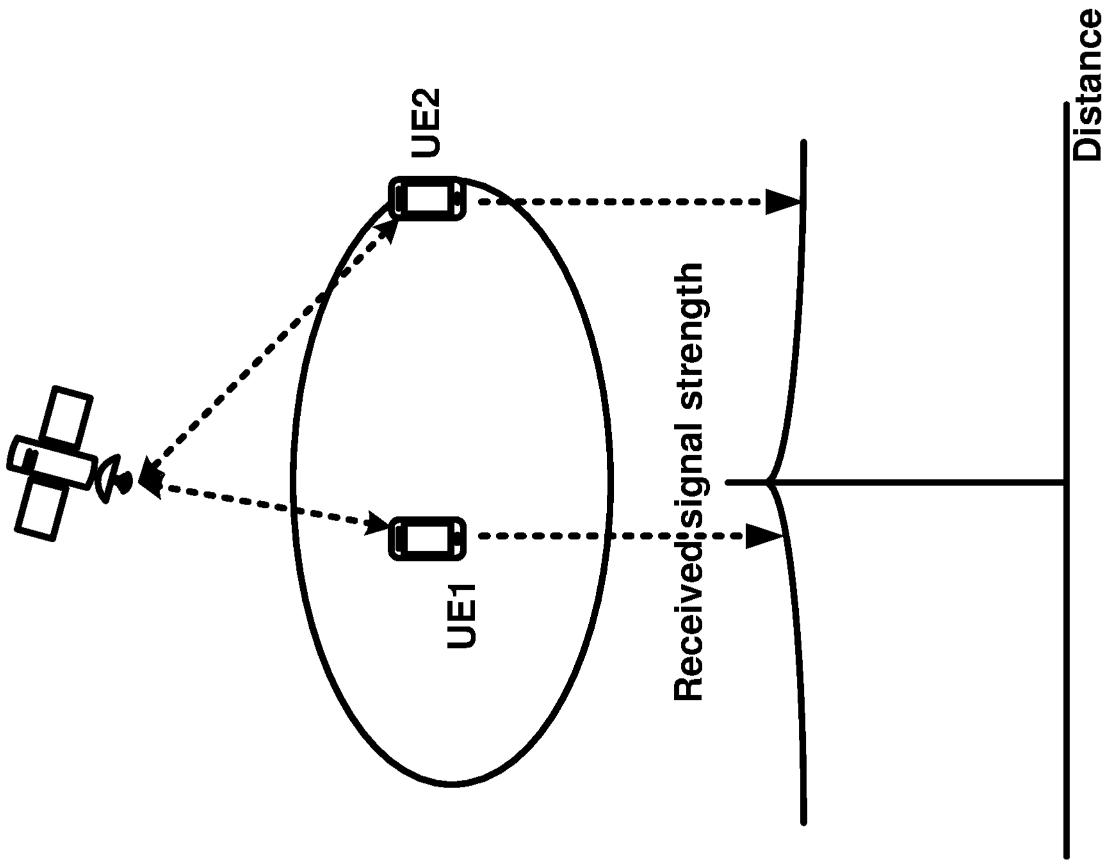

FIG. 21B

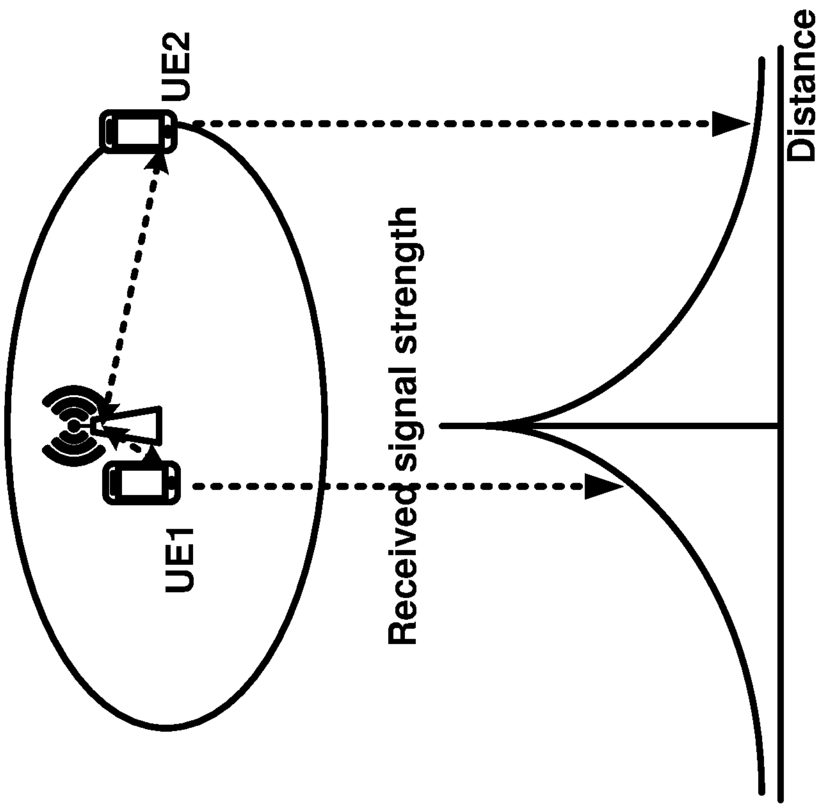

FIG. 21A

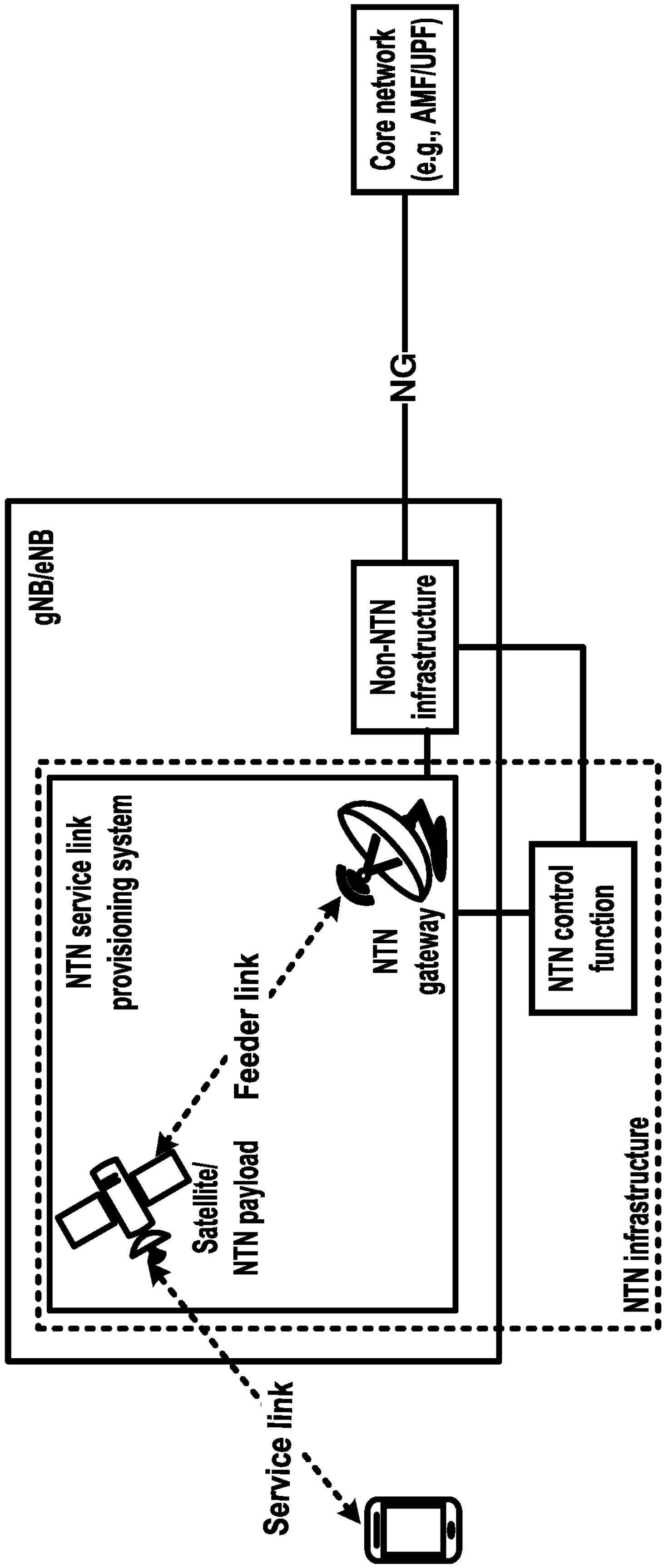
Core network
(e.g., AMF/UPF)
NG
gNB/eNB
Non-NTN
infrastructure
NTN service link
provisioning system
Feeder link
NTN
gateway
NTN control
function
Satellite/
NTN payload
NTN infrastructure
Service link

FIG. 22

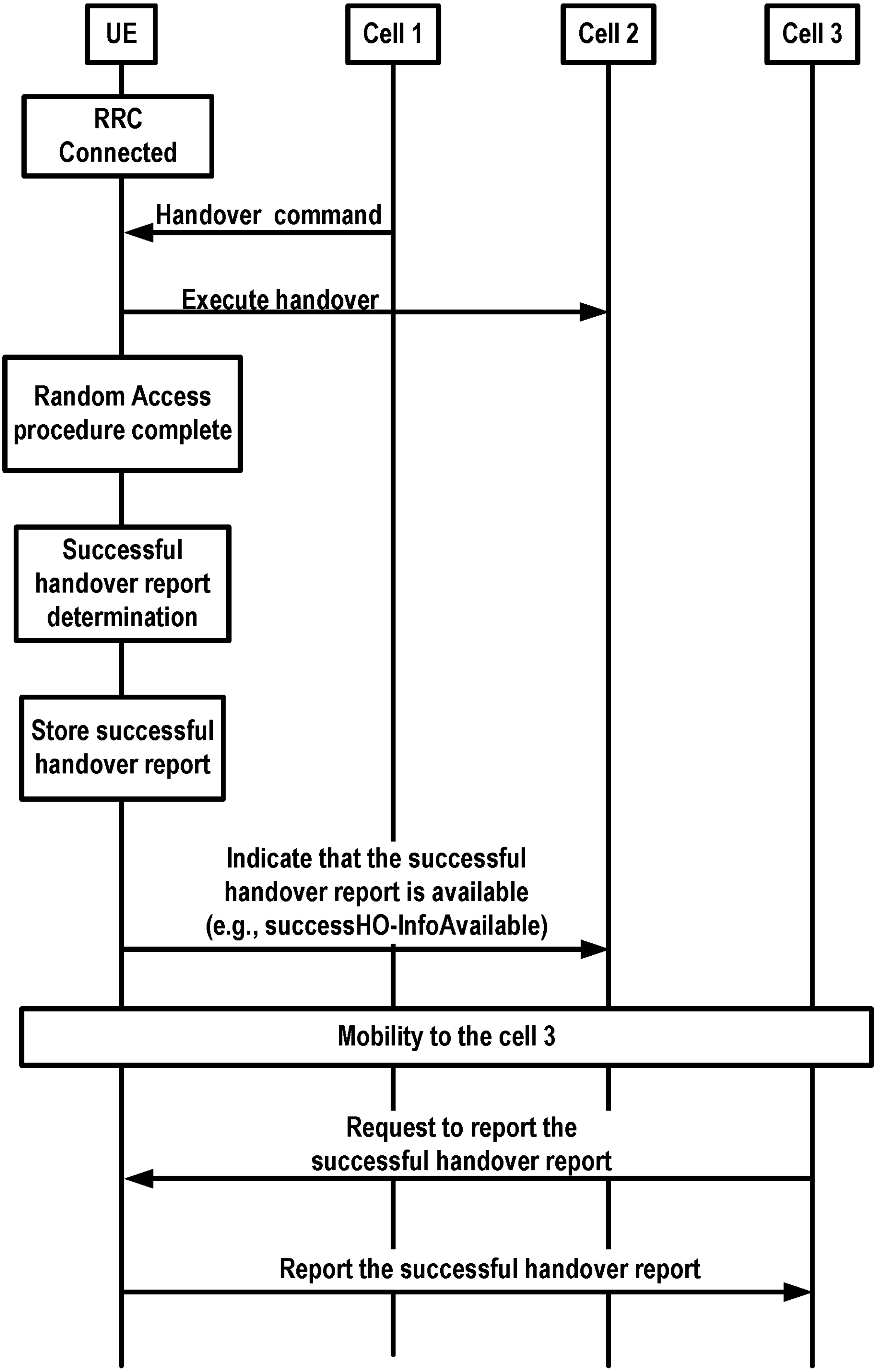
UE
Cell 1
Cell 2
Cell 3
RRC Connected
Handover command
Execute handover
Random Access procedure complete
Successful handover report determination
Store successful handover report
Indicate that the successful handover report is available (e.g., successHO-InfoAvailable)
Mobility to the cell 3
Request to report the successful handover report
Report the successful handover report

FIG. 23

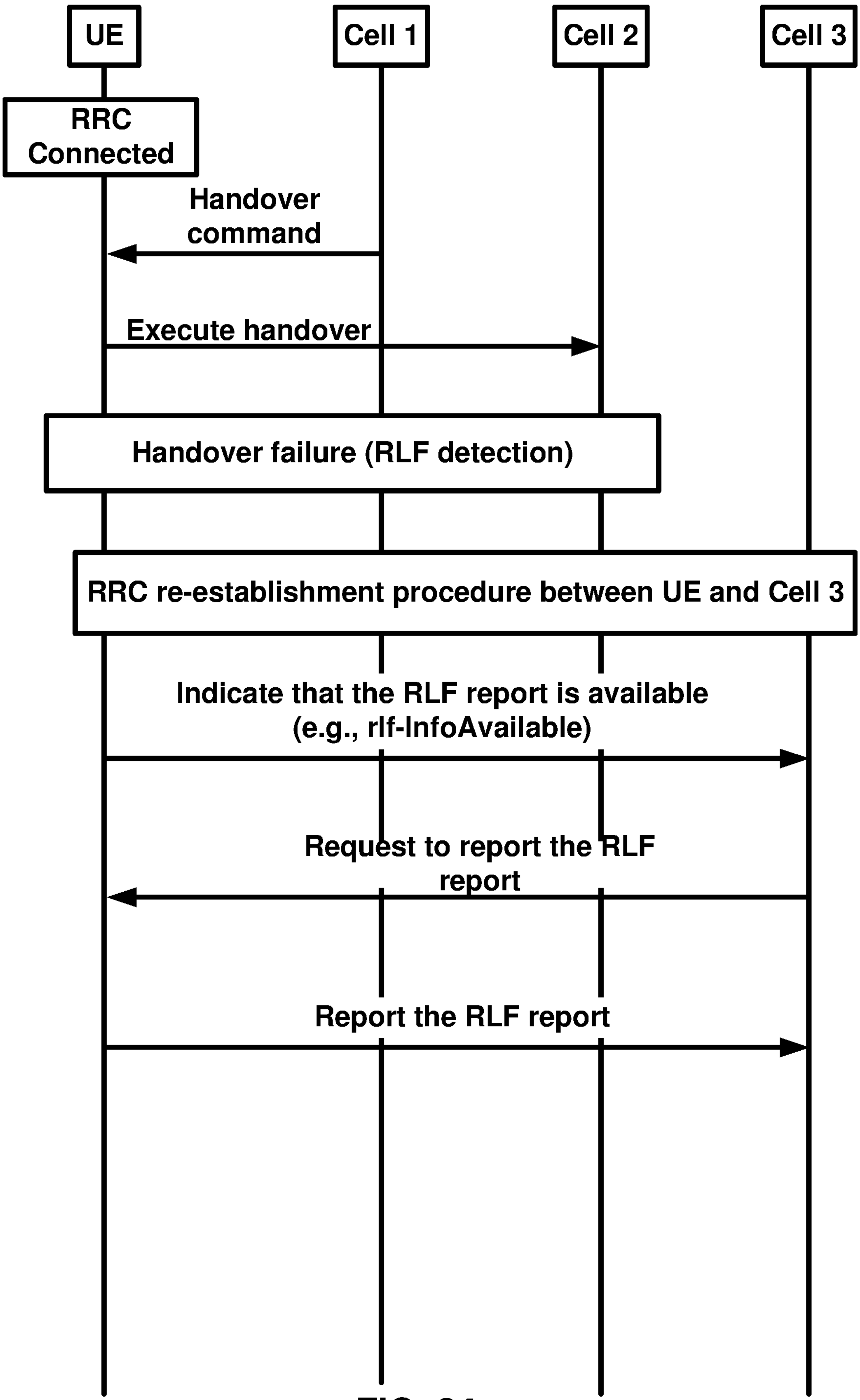
UE
Cell 1
Cell 2
Cell 3
RRC Connected
Handover command
Execute handover
Handover failure (RLF detection)
RRC re-establishment procedure between UE and Cell 3
Indicate that the RLF report is available (e.g., rlf-InfoAvailable)
Request to report the RLF report
Report the RLF report

FIG. 24

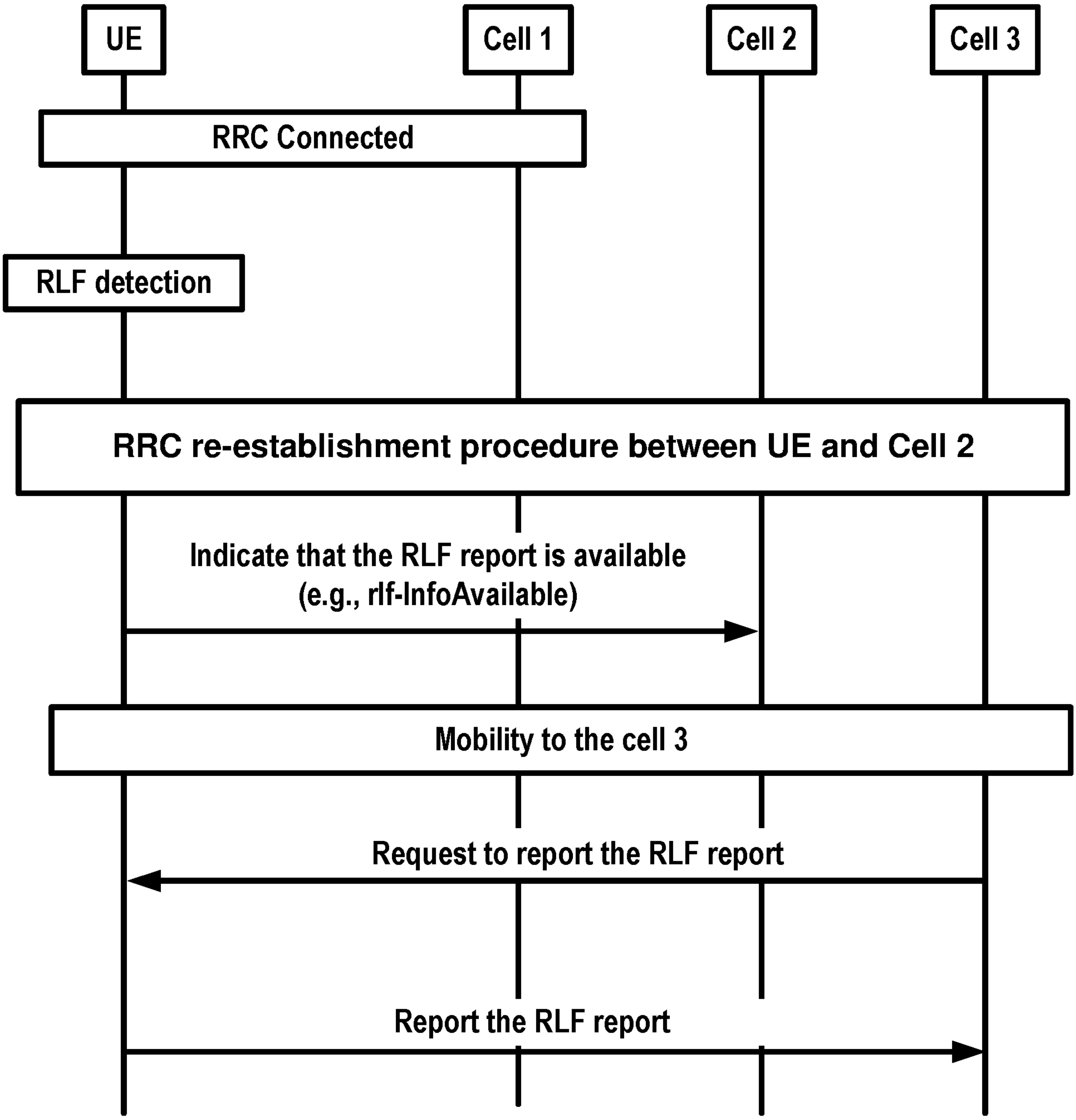
UE
Cell 1
Cell 2
Cell 3
RRC Connected
RLF detection
RRC re-establishment procedure between UE and Cell 2
Indicate that the RLF report is available
(e.g., rlf-InfoAvailable)
Mobility to the cell 3
Request to report the RLF report
Report the RLF report

FIG. 25

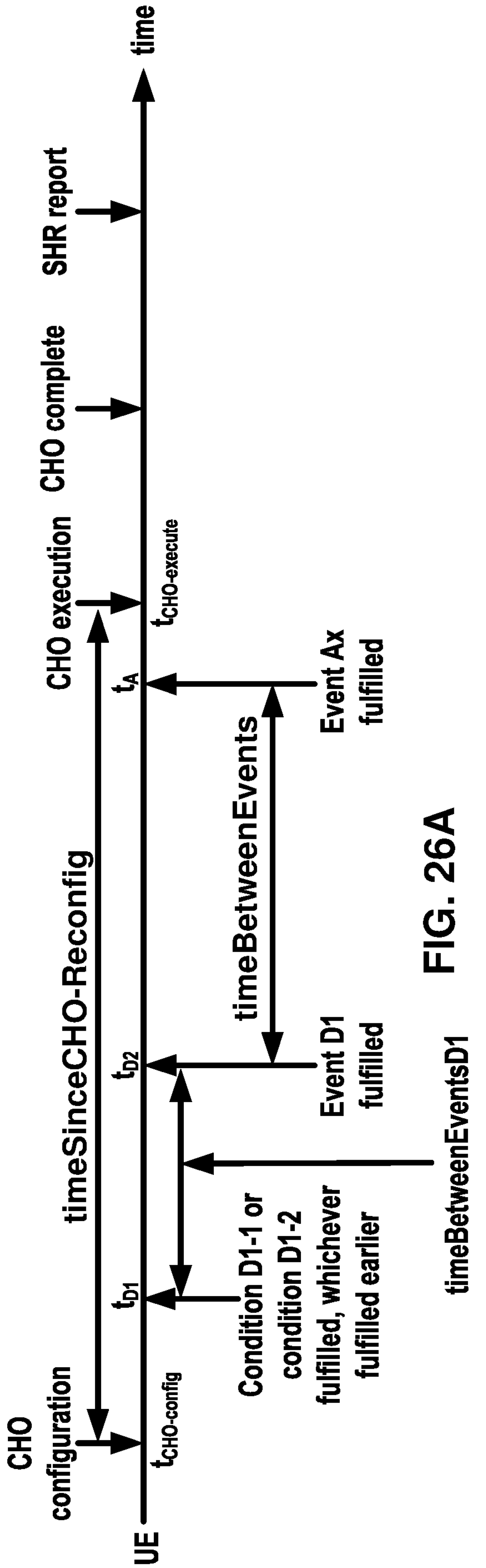

FIG. 26A

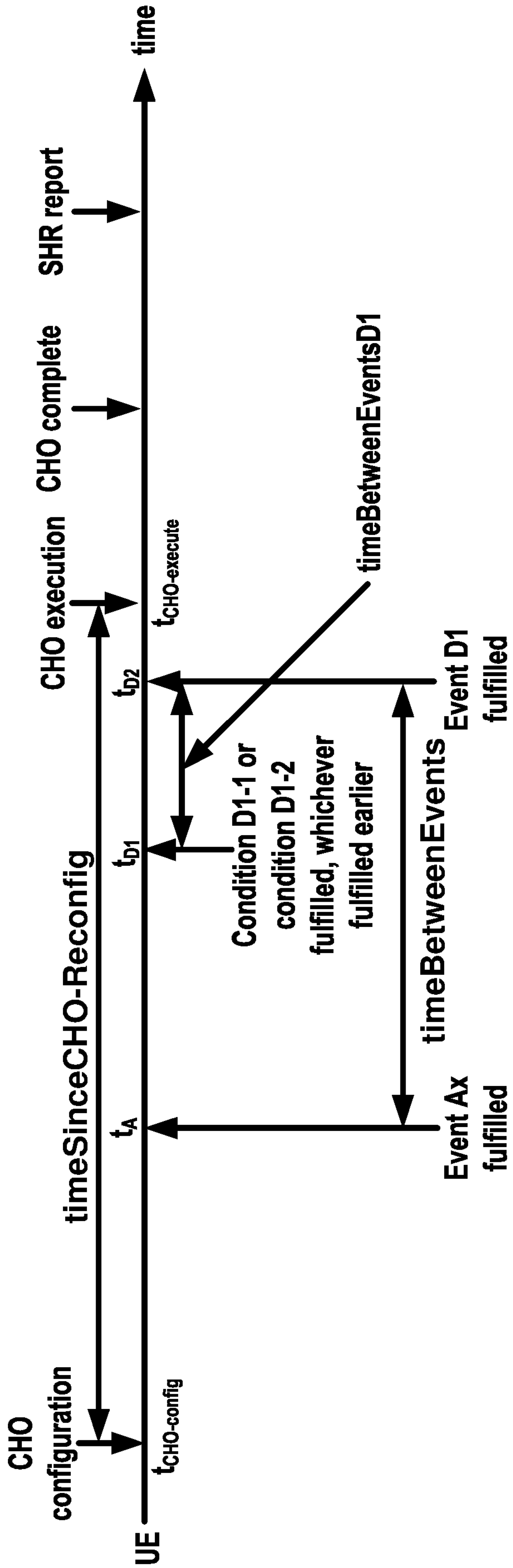

FIG. 26B

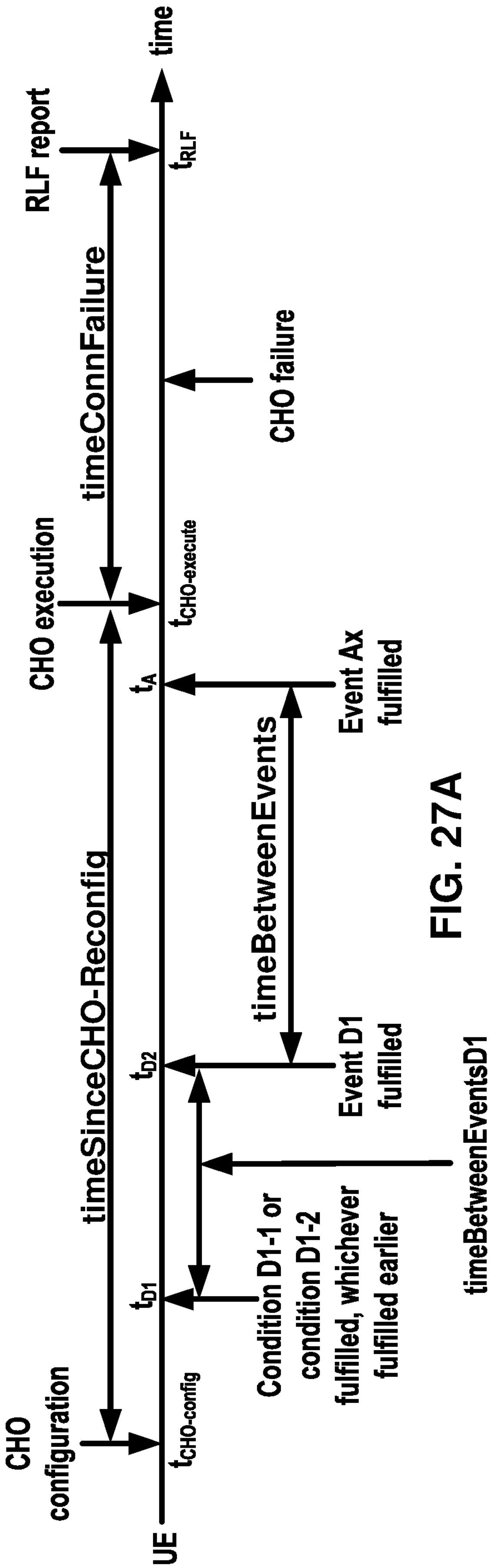

FIG. 27A

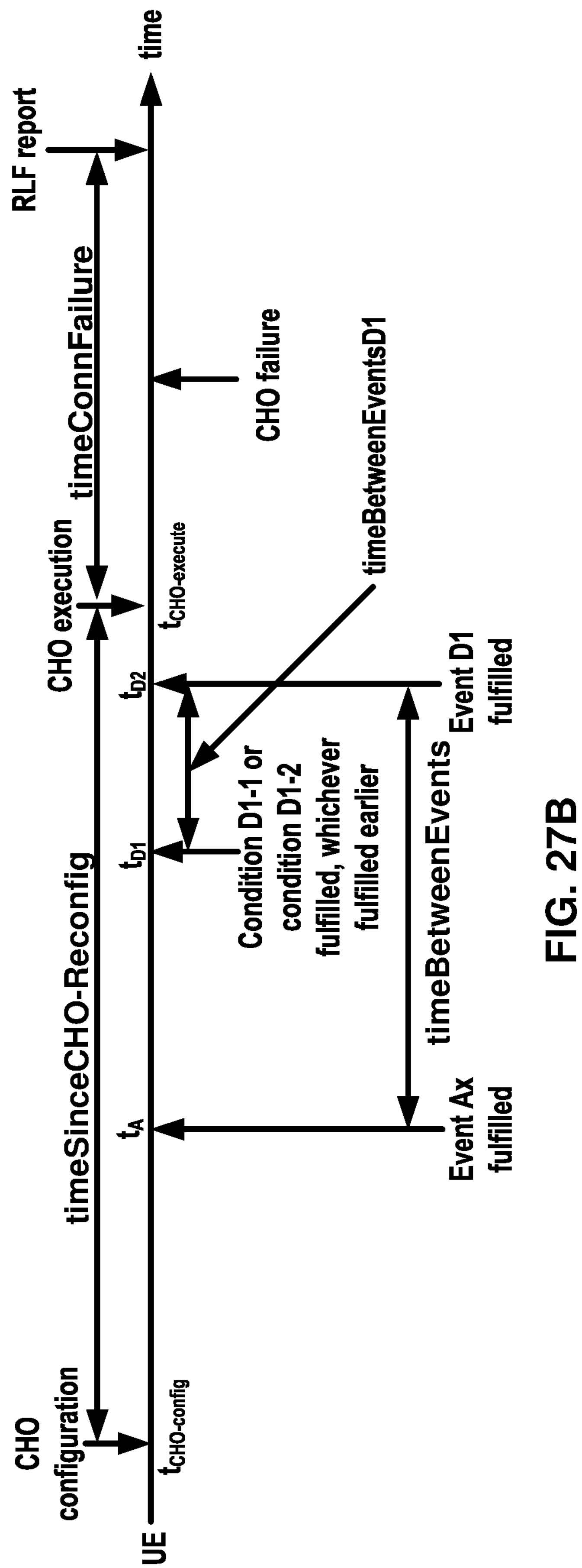

FIG. 27B

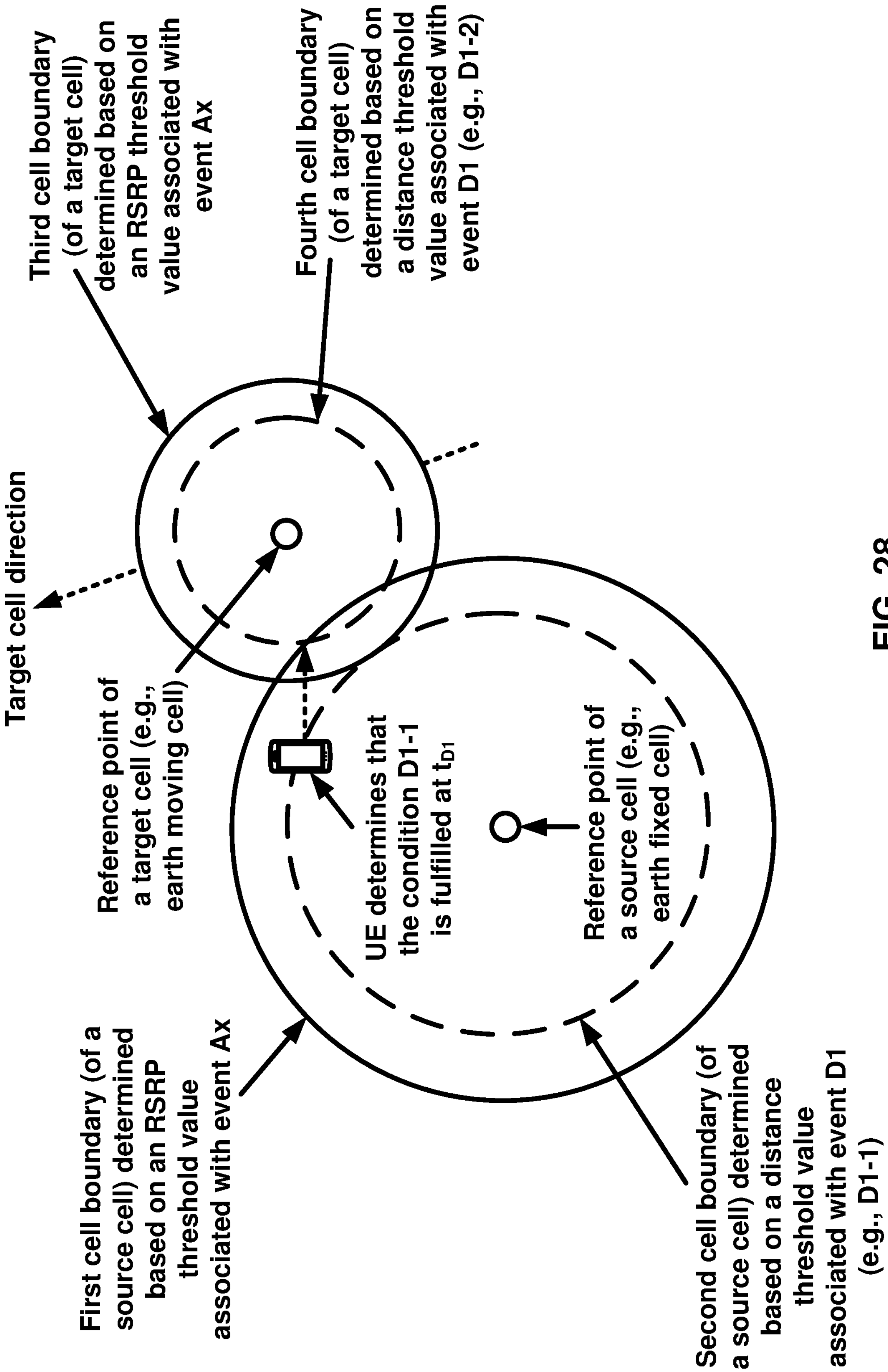
Target cell direction
Third cell boundary (of a target cell) determined based on an RSRP threshold value associated with event Ax
Fourth cell boundary (of a target cell) determined based on a distance threshold value associated with event D1 (e.g., D1-2)
Reference point of a target cell (e.g., earth moving cell)
UE determines that the condition D1-1 is fulfilled at t_{D1}
Reference point of a source cell (e.g., earth fixed cell)
First cell boundary (of a source cell) determined based on an RSRP threshold value associated with event Ax
Second cell boundary (of a source cell) determined based on a distance threshold value associated with event D1 (e.g., D1-1)

FIG. 28

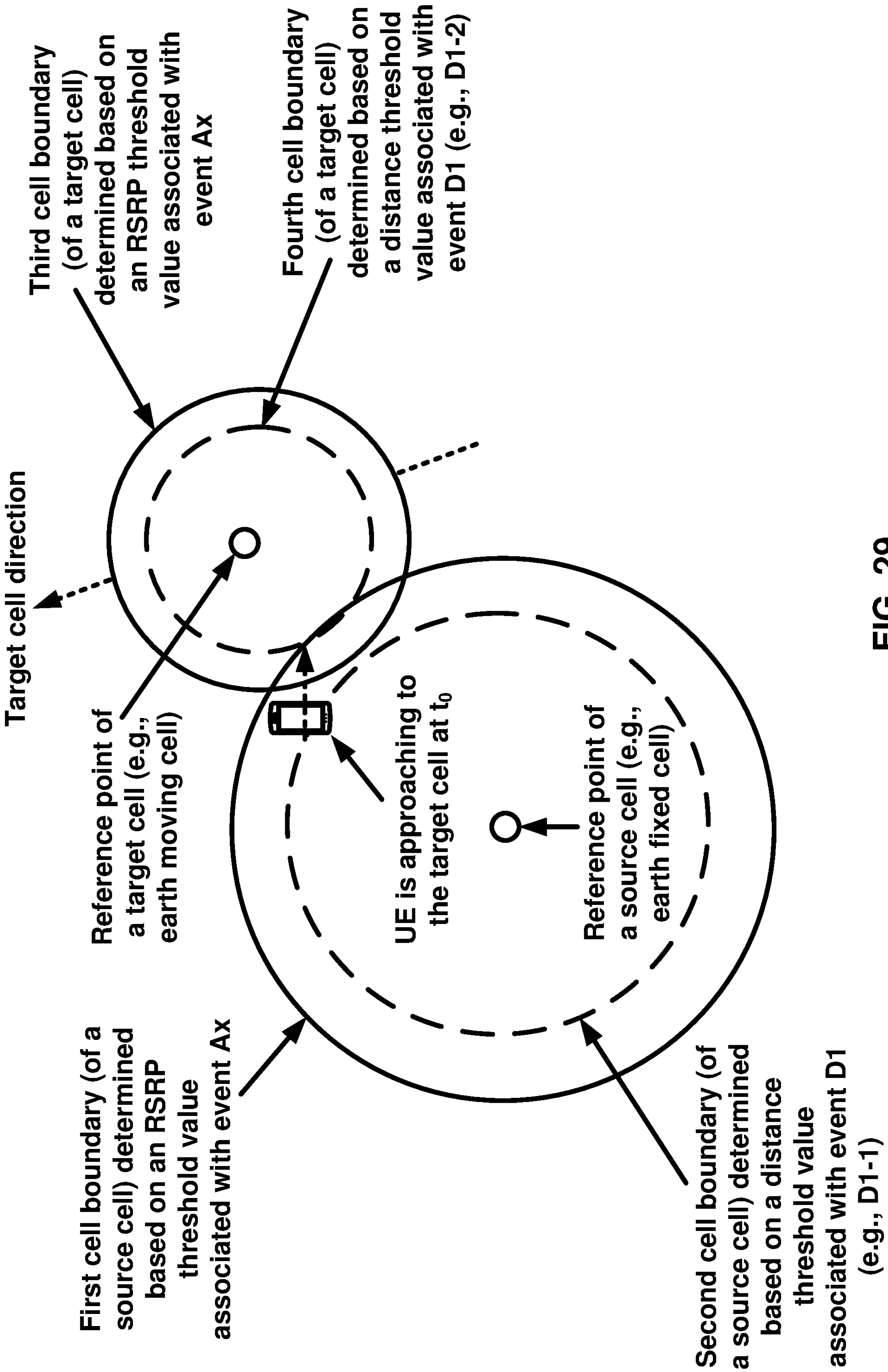
Third cell boundary (of a target cell) determined based on an RSRP threshold value associated with event Ax
Fourth cell boundary (of a target cell) determined based on a distance threshold value associated with event D1 (e.g., D1-2)
Target cell direction
Reference point of a target cell (e.g., earth moving cell)
UE is approaching to the target cell at t_0
Reference point of a source cell (e.g., earth fixed cell)
First cell boundary (of a source cell) determined based on an RSRP threshold value associated with event Ax
Second cell boundary (of a source cell) determined based on a distance threshold value associated with event D1 (e.g., D1-1)

FIG. 29

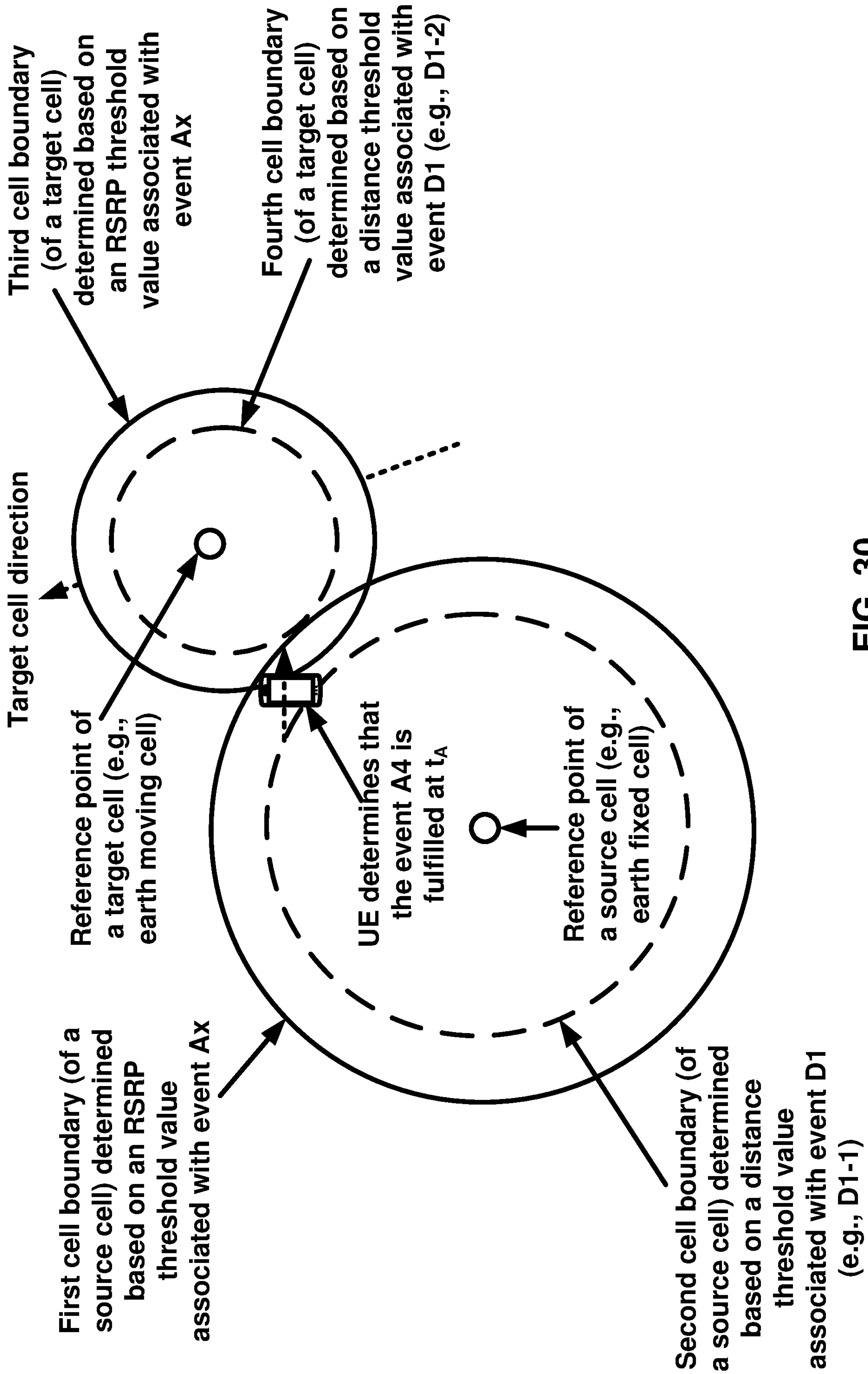
Third cell boundary (of a target cell) determined based on an RSRP threshold value associated with event Ax
Fourth cell boundary (of a target cell) determined based on a distance threshold value associated with event D1 (e.g., D1-2)
Target cell direction
Reference point of a target cell (e.g., earth moving cell)
UE determines that the event A4 is fulfilled at t_A
Reference point of a source cell (e.g., earth fixed cell)
First cell boundary (of a source cell) determined based on an RSRP threshold value associated with event Ax
Second cell boundary (of a source cell) determined based on a distance threshold value associated with event D1 (e.g., D1-1)

FIG. 30

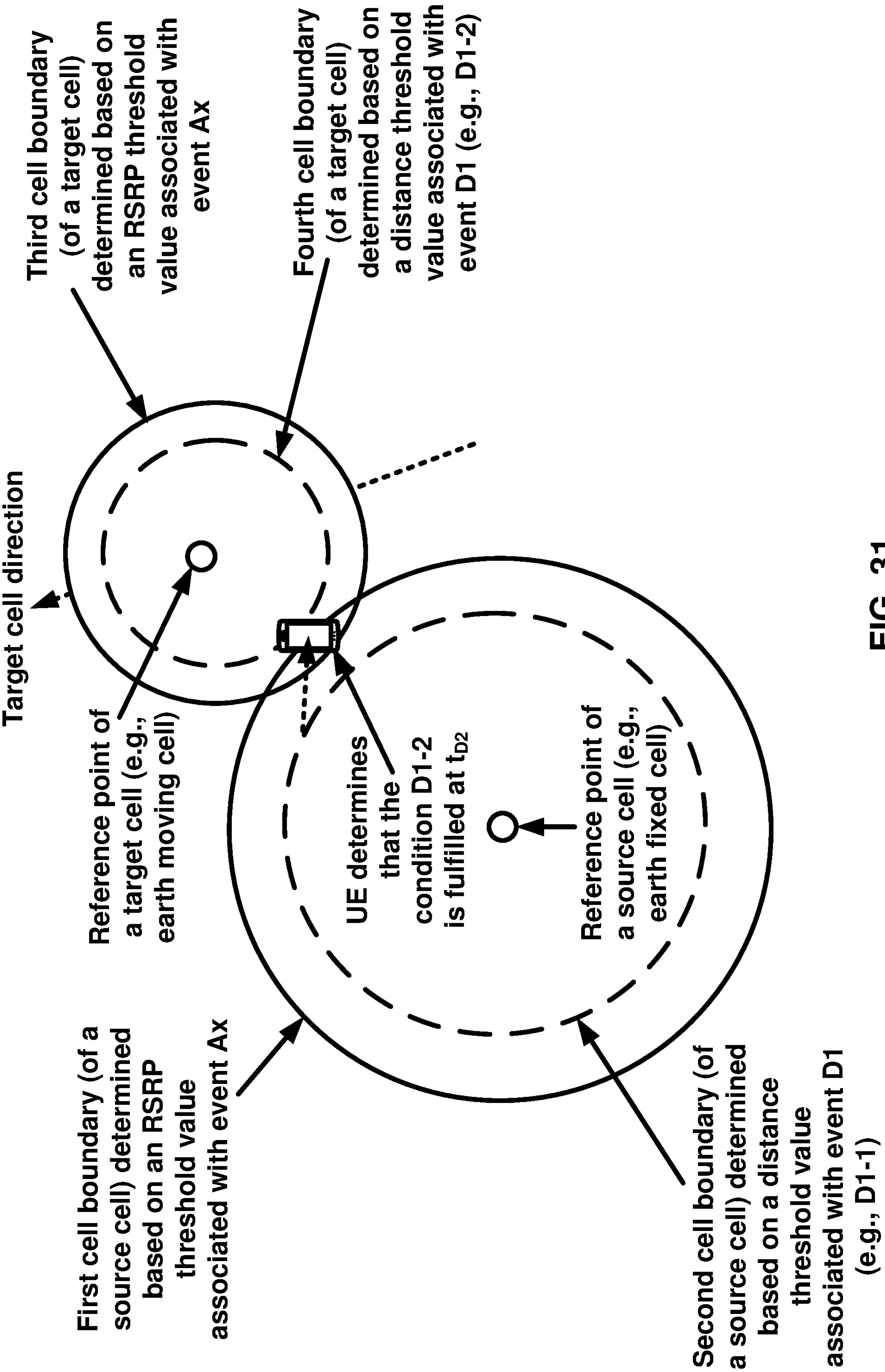
Third cell boundary (of a target cell) determined based on an RSRP threshold value associated with event Ax
Fourth cell boundary (of a target cell) determined based on a distance threshold value associated with event D1 (e.g., D1-2)
Target cell direction
Reference point of a target cell (e.g., earth moving cell)
UE determines that the condition D1-2 is fulfilled at t_{D2}
Reference point of a source cell (e.g., earth fixed cell)
First cell boundary (of a source cell) determined based on an RSRP threshold value associated with event Ax
Second cell boundary (of a source cell) determined based on a distance threshold value associated with event D1 (e.g., D1-1)

FIG. 31

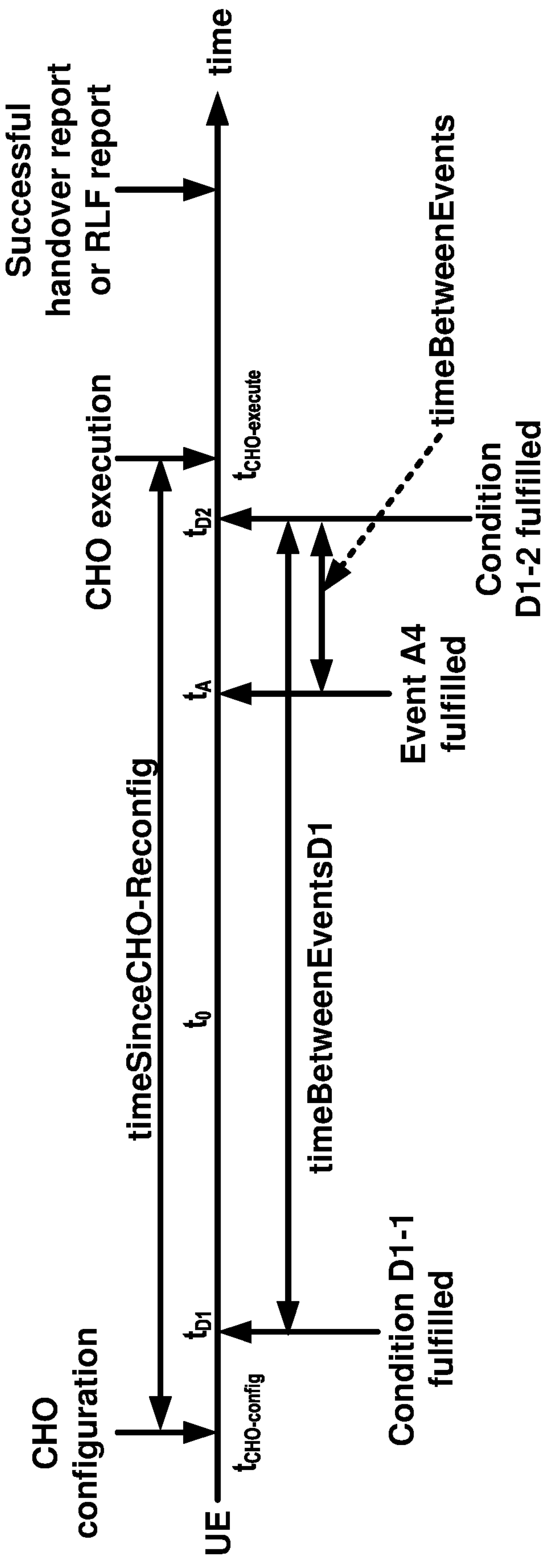
UE
time
CHO configuration
$t_{CHO\text{-}config}$
t_{D1}
Condition D1-1 fulfilled
timeSinceCHO-Reconfig
t_0
timeBetweenEventsD1
t_A
Event A4 fulfilled
t_{D2}
Condition D1-2 fulfilled
timeBetweenEvents
CHO execution
$t_{CHO\text{-}execute}$
Successful handover report or RLF report

FIG. 32

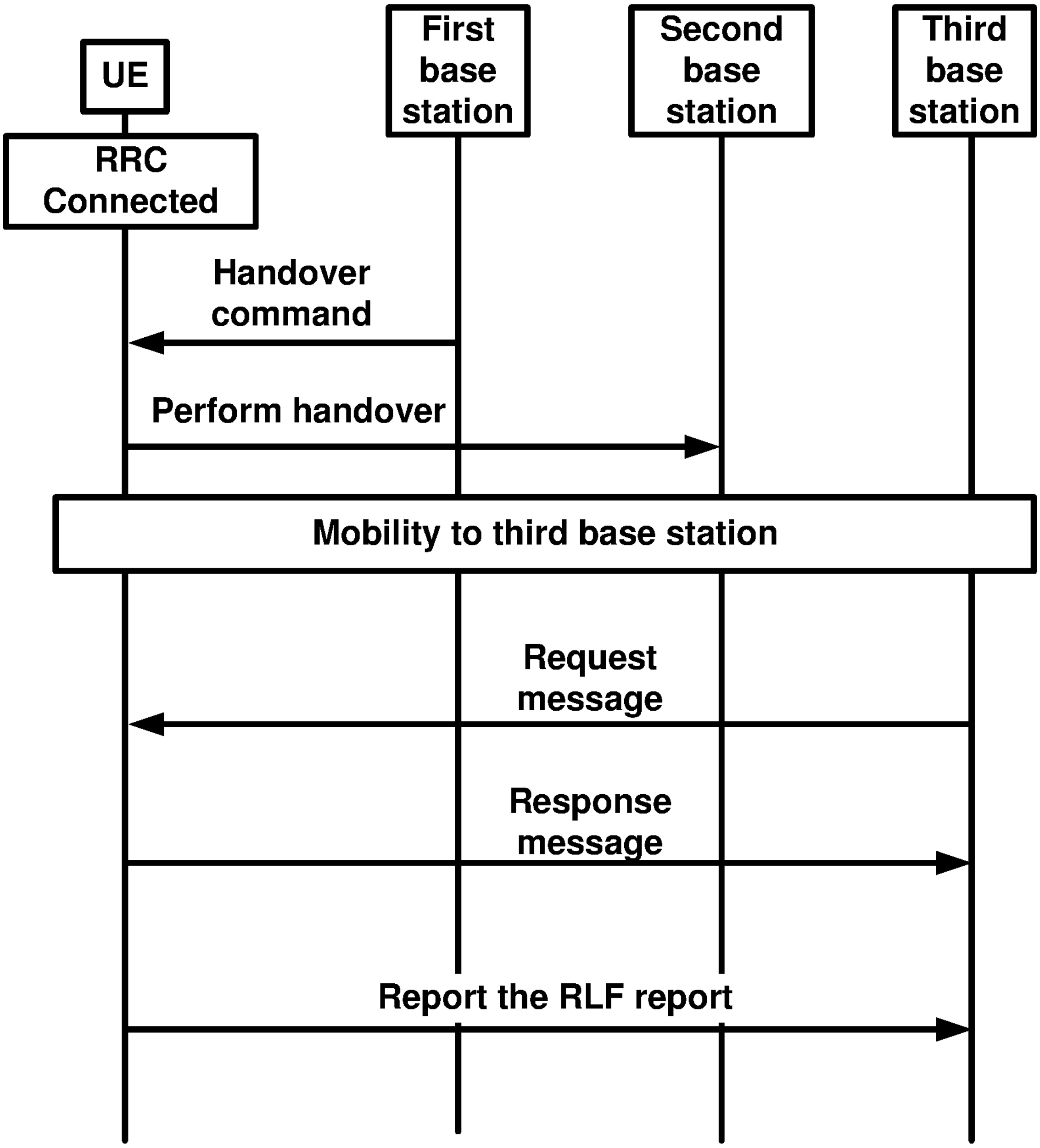
UE
First base station
Second base station
Third base station
RRC Connected
Handover command
Perform handover
Mobility to third base station
Request message
Response message
Report the RLF report

FIG. 33

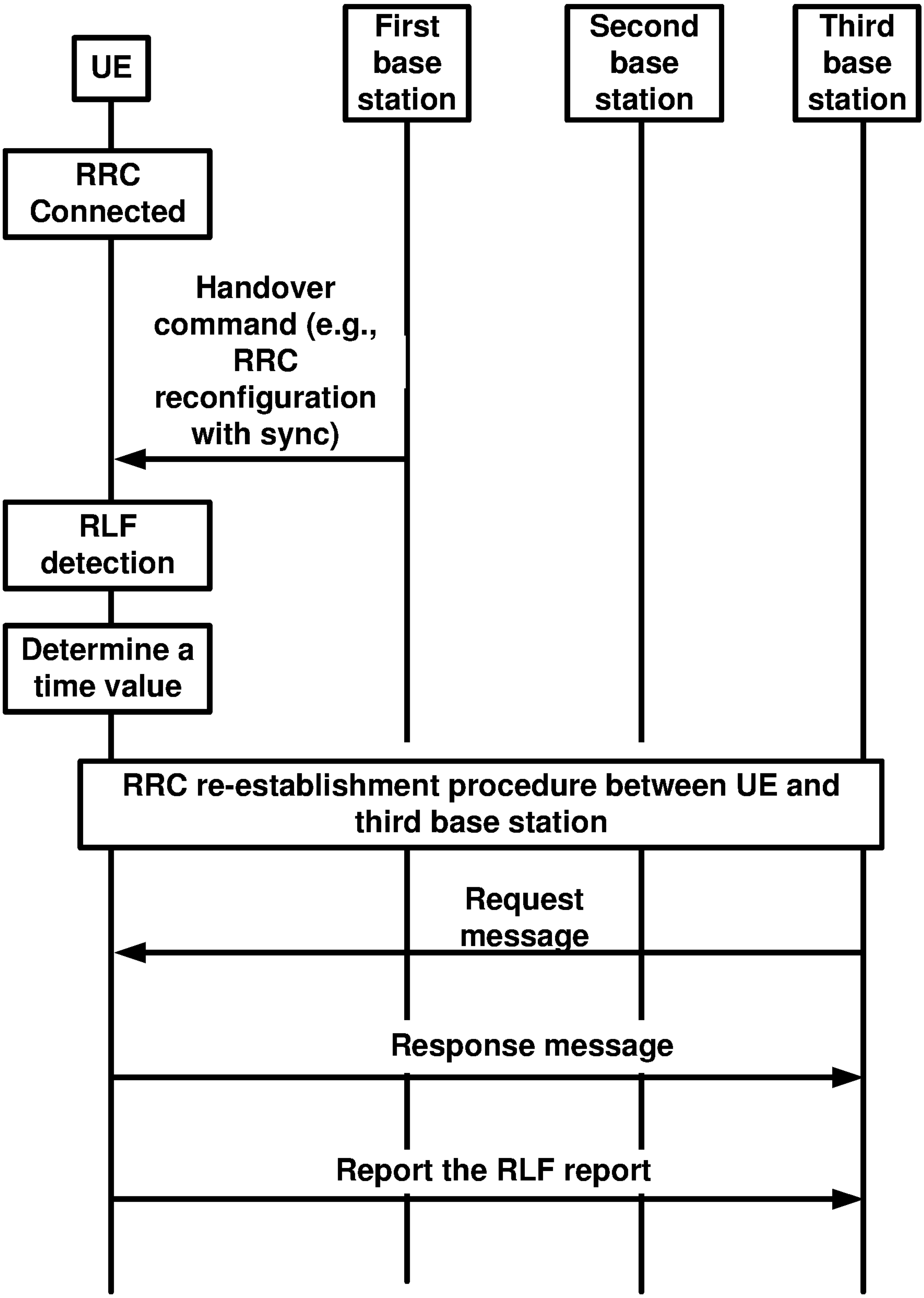
UE
First base station
Second base station
Third base station
RRC Connected
Handover command (e.g., RRC reconfiguration with sync)
RLF detection
Determine a time value
RRC re-establishment procedure between UE and third base station
Request message
Response message
Report the RLF report

FIG. 34

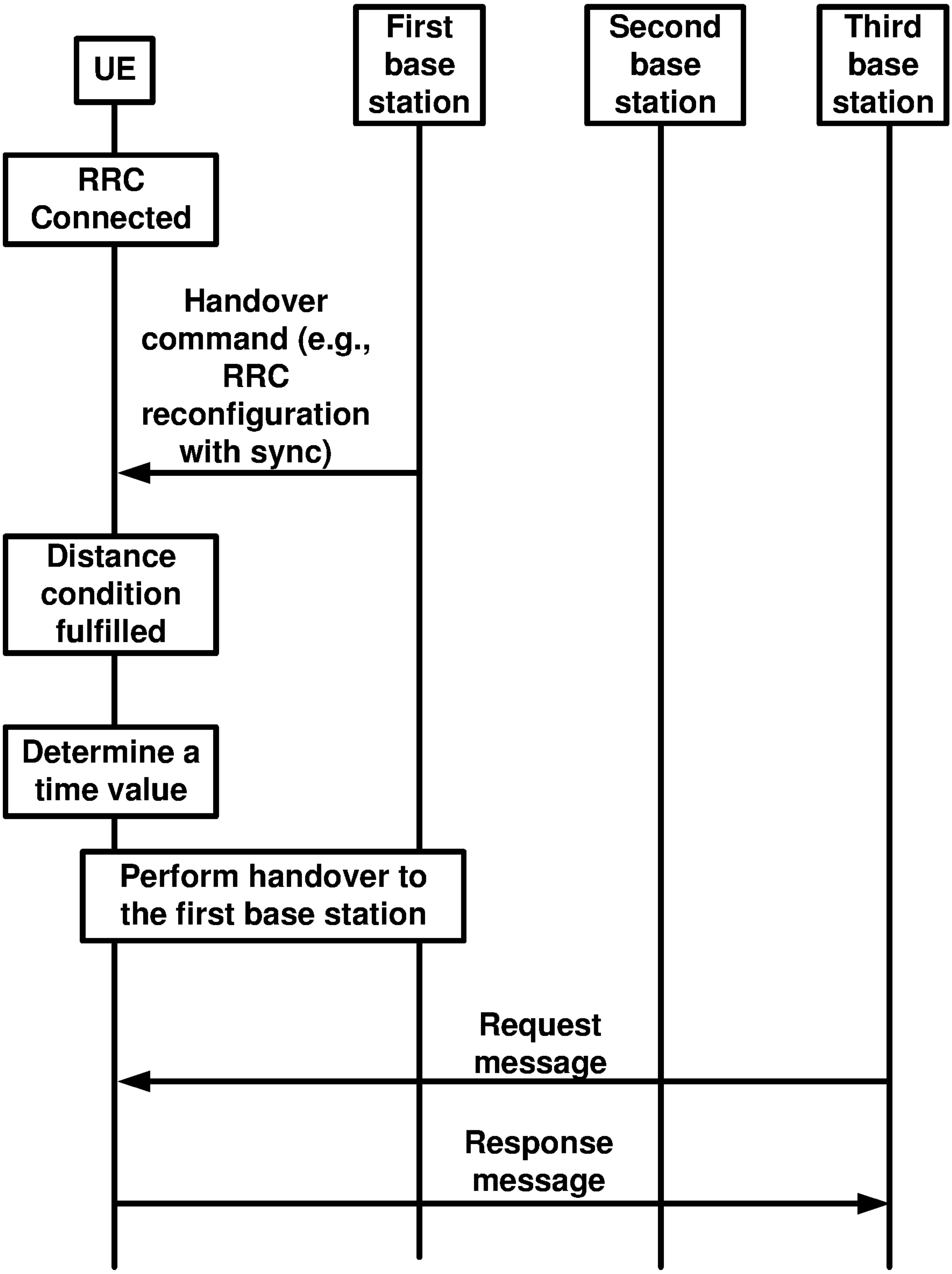
UE
First base station
Second base station
Third base station
RRC Connected
Handover command (e.g., RRC reconfiguration with sync)
Distance condition fulfilled
Determine a time value
Perform handover to the first base station
Request message
Response message

FIG. 35

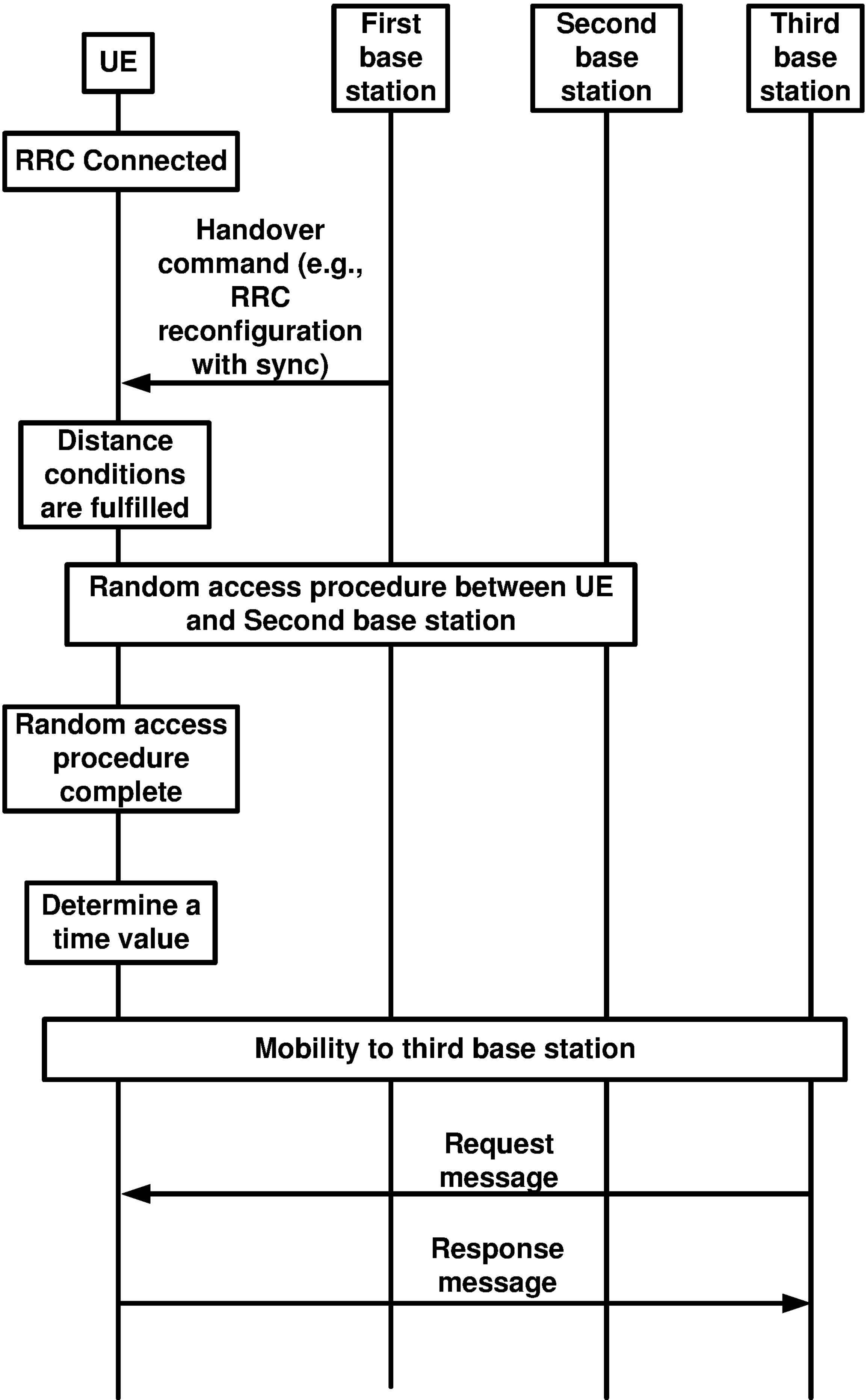
UE
First base station
Second base station
Third base station
RRC Connected
Handover command (e.g., RRC reconfiguration with sync)
Distance conditions are fulfilled
Random access procedure between UE and Second base station
Random access procedure complete
Determine a time value
Mobility to third base station
Request message
Response message

FIG. 36

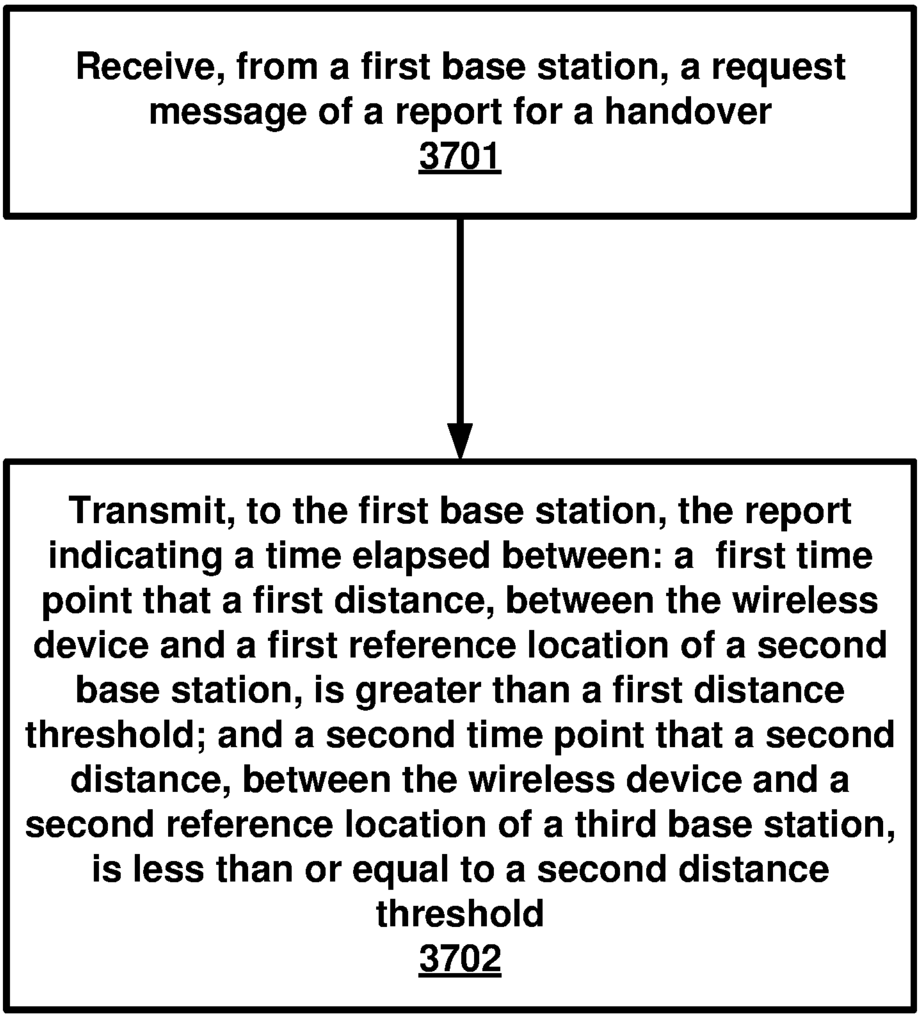
Receive, from a first base station, a request message of a report for a handover
3701
Transmit, to the first base station, the report indicating a time elapsed between: a first time point that a first distance, between the wireless device and a first reference location of a second base station, is greater than a first distance threshold; and a second time point that a second distance, between the wireless device and a second reference location of a third base station, is less than or equal to a second distance threshold
3702

FIG. 37

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/034259

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W36/00 H04W36/32
ADD. H04W36/08 H04W36/24

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[x] Further documents are listed in the continuation of Box C.

[x] 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
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"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
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"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 December 2023	19/01/2024

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	Kahl, Marcus

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/034259

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; NR and NG-RAN Overall Description; Stage 2 (Release 17)", 3GPP DRAFT; DRAFT_38300-H20_V2, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , 28 September 2022 (2022-09-28), XP052211896, Retrieved from the Internet: URL:https://ftp.3gpp.org/tsg_ran/WG2_RL2/Specifications/202209_draft_specs_after_RAN_97/Draft_38300-h20_v2.docx [retrieved on 2022-09-28] chapter 9.2.3.4 chapter 16.14.3.2.2 -----	1-47
A	EP 2 915 359 B1 (ERICSSON TELEFON AB L M [SE]) 17 October 2018 (2018-10-17) paragraphs [0023], [0024]; claims 1,11 -----	1-47

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International application No
PCT/US2023/034259

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