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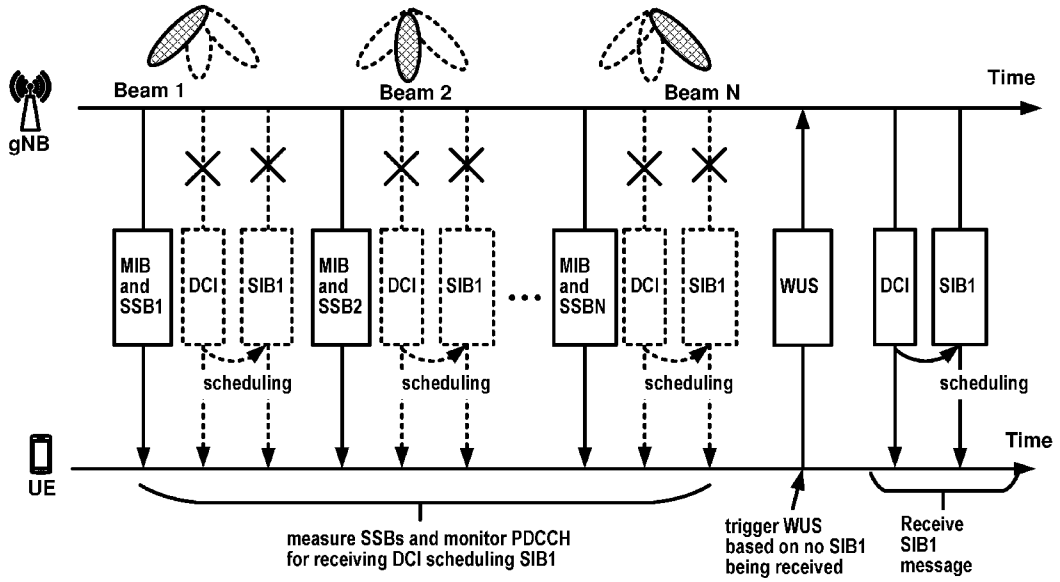


FIG. 38

(57) Abstract: A method can include receiving, by a wireless device, one or more radio resource control (RRC) messages that include parameters of an uplink signal requesting system information block 1 (SIB1) of a cell. Time division duplex (TDD) configuration of the cell can be determined based on the one or more RRC messages. For example, the parameters themselves can indicate the TDD configuration. The method can also include transmitting the uplink signal requesting the SIB1 of the cell. The uplink signal can be transmitted via one or more uplink symbols according to the TDD configuration of the cell.

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[Continued on next page]

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TITLE

WAKE-UP SIGNAL FOR ON-DEMAND SYSTEM INFORMATION BLOCK TRANSMISSION OF A CELL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/600,324, filed November 17, 2023, 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, FIG. 17B and FIG. 17C show examples of MAC subheaders.

[0024] FIG. 18A shows an example of a DL MAC PDU.

[0025] FIG. 18B shows an example of an UL MAC PDU.

[0026] FIG. 19 shows an example of multiple LCIDs of downlink.

[0027] FIG. 20 shows an example of multiple LCIDs of uplink.

[0028] FIG. 21A and FIG. 21B show examples of SCell activation/deactivation MAC CE formats.

[0029] FIG. 22 shows an example of BWP activation/deactivation on a cell.

[0030] FIG. 23 shows examples of a variety of DCI formats.

[0031] FIG. 24A shows an example of MIB message.

[0032] FIG. 24B shows an example of configuration of CORESET 0.

[0033] FIG. 24C shows an example of configuration of search space 0.

[0034] FIG. 25 shows an example of SIB1 message.

[0035] FIG. 26 shows an example of SIB1 message.

[0036] FIG. 27 shows an example of RRC configurations of a BWP, PDCCH and a CORESET.

[0037] FIG. 28 shows an example of RRC configuration of a search space.

[0038] FIG. 29 shows an example of cell dormancy for power saving of a wireless device.

[0039] FIG. 30 shows an example of a DRX configuration for a wireless device.

[0040] FIG. 31 shows an example of a DRX operation for a wireless device.

[0041] FIG. 32A and FIG. 32B show examples of wake-up signal and go-to-sleep signal for power saving of a wireless device.

[0042] FIG. 33 shows an example of activation and deactivation of a cell DTX configuration for network energy saving.

[0043] FIG. 34 shows an example of the minimum time gap for applying a cell DTX configuration for a serving cell.

[0044] FIG. 35 shows an example of SSB configuration for a cell.

[0045] FIG. 36 shows an example of SSB transmission via a cell.

[0046] FIG. 37 shows an example of access control of a wireless device on a cell.

[0047] FIG. 38 shows an example of on-demand triggered *SIB1* transmission via cell for network energy saving.

[0048] FIG. 39 shows an example of existing RA procedures.

[0049] FIG. 40 shows an example embodiment of a wake-up signal triggering on-demand SIB in a cell.

[0050] FIG. 41A and FIG. 41B show example embodiments of uplink resource configurations for wake-up signals in different cells.

DETAILED DESCRIPTION

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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.

[0055] 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.

[0056] 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 affect or influence 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.

[0057] 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.

[0058] 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.

[0059] 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.

[0060] 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.

[0061] 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.

[0062] 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.

[0063] 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 roadside 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.

[0064] 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, Wi-Fi 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).

[0065] 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.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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.

[0070] 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).

[0071] 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.

[0072] 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.

[0073] 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).

[0074] 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.

[0075] 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.

[0076] 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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.

[0082] 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.

[0083] 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.

[0084] 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.

[0085] 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.

[0086] 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.

[0087] 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.

[0088] 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.

[0089] 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.

[0090] 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.

[0091] 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.

[0092] 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.

[0093] 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.

[0094] 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:

[0095] -- 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;

[0096] -- 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;

[0097] -- a common control channel (CCCH) for carrying control messages together with random access;

[0098] -- a dedicated control channel (DCCH) for carrying control messages to/from a specific the UE to configure the UE; and

[0099] -- a dedicated traffic channel (DTCH) for carrying user data to/from a specific the UE.

[0100] 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:

[0101] -- a paging channel (PCH) for carrying paging messages that originated from the PCCH;

[0102] -- a broadcast channel (BCH) for carrying the MIB from the BCCH;

[0103] -- a downlink shared channel (DL-SCH) for carrying downlink data and signaling messages, including the SIBs from the BCCH;

[0104] -- an uplink shared channel (UL-SCH) for carrying uplink data and signaling messages; and

[0105] -- a random access channel (RACH) for allowing a UE to contact the network without any prior scheduling.

[0106] 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:

[0107] -- a physical broadcast channel (PBCH) for carrying the MIB from the BCH;

[0108] -- 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;

[0109] -- 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;

[0110] -- 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;

[0111] -- 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

[0112] -- a physical random access channel (PRACH) for random access.

[0113] 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.

[0114] 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.

[0115] 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.

[0116] 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.

[0117] 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).

[0118] 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.

[0119] 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.

[0120] 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.

[0121] 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).

[0122] 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.

[0123] 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.

[0124] 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.

[0125] A gNB, such as gNBs 160 in FIG. 1B, may be split into 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.

[0126] 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.

[0127] 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.

[0128] 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.

[0129] 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.

[0130] 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.

[0131] 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.

[0132] 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.

[0133] 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.

[0134] 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.

[0135] 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.

[0136] 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).

[0137] 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.

[0138] 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.

[0139] 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.

[0140] 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).

[0141] 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.

[0142] 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 to 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 to 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 to receiving a DCI indicating BWP 902 as the active BWP.

[0143] 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.

[0144] 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.

[0145] 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).

[0146] 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.

[0147] 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).

[0148] 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).

[0149] 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.

[0150] 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.

[0151] 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.

[0152] 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.

[0153] 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.

[0154] 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.

[0155] 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.

[0156] 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.

[0157] 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.

[0158] 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.

[0159] 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.

[0160] 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.

[0161] 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.

[0162] 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.

[0163] 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.

[0164] 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.

[0165] 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.

[0166] 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.

[0167] 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).

[0168] 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.

[0169] 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.

[0170] 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.

[0171] 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.

[0172] 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.

[0173] 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 an 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.

[0174] 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.

[0175] 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.

[0176] 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.

[0177] 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.

[0178] 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.

[0179] 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.

[0180] 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).

[0181] 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 counterclockwise 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 counterclockwise 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.

[0182] 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 counterclockwise 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.

[0183] 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).

[0184] 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.

[0185] 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.

[0186] 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).

[0187] 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.

[0188] 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.

[0189] 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).

[0190] 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.

[0191] 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.

[0192] 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*).

[0193] 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:

[0194] RA-RNTI= 1 + s_id + 14 × t_id + 14 × 80 × f_id + 14 × 80 × 8 × 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).

[0195] 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).

[0196] 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.

[0197] 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).

[0198] 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.

[0199] 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*).

[0200] 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.

[0201] 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.

[0202] 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.

[0203] 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.

[0204] 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.

[0205] 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).

[0206] 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.

[0207] 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.

[0208] 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).

[0209] 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.

[0210] 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.

[0211] 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).

[0212] 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.

[0213] 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.

[0214] 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).

[0215] 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).

[0216] 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.

[0217] 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.

[0218] 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".

[0219] 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.

[0220] 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.

[0221] 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.

[0222] 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.

[0223] 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.

[0224] 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.

[0225] 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.

[0226] 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.

[0227] 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.

[0228] 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.

[0229] 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, a 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.

[0230] 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.

[0231] 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.

[0232] 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.

[0233] 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.

[0234] 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.

[0235] A base station may transmit one or more MAC PDUs to a wireless device. In an example, a MAC PDU may be a bit string that is byte aligned (e.g., aligned to a multiple of eight bits) in length. In an example, bit strings may be represented by tables in which the most significant bit is the leftmost bit of the first line of the table, and the least significant bit is the rightmost bit on the last line of the table. More generally, the bit string may be read from left to right and then in the reading order of the lines. In an example, the bit order of a parameter field within a MAC PDU is represented with the first and most significant bit in the leftmost bit and the last and least significant bit in the rightmost bit.

[0236] In an example, a MAC SDU may be a bit string that is byte aligned (e.g., aligned to a multiple of eight bits) in length. In an example, a MAC SDU may be included in a MAC PDU from the first bit onward. A MAC CE may be a bit string that is byte aligned (e.g., aligned to a multiple of eight bits) in length. A MAC subheader may be a bit string that is byte aligned (e.g., aligned to a multiple of eight bits) in length. In an example, a MAC subheader may be placed immediately in front of a corresponding MAC SDU, MAC CE, or padding. A MAC entity may ignore the value of reserved bits in a DL MAC PDU.

[0237] In an example, a MAC PDU may comprise one or more MAC subPDUs. A MAC subPDU of the one or more MAC subPDUs may comprise: a MAC subheader only (including padding); a MAC subheader and a MAC SDU; a MAC subheader and a MAC CE; a MAC subheader and padding, or a combination thereof. The MAC SDU may be of variable size. A MAC subheader may correspond to a MAC SDU, a MAC CE, or padding.

[0238] In an example, when a MAC subheader corresponds to a MAC SDU, a variable-sized MAC CE, or padding, the MAC subheader may comprise: an R field with a one-bit length; an F field with a one-bit length; an LCID field with a multi-bit length; an L field with a multi-bit length, or a combination thereof.

[0239] FIG. 17A shows an example of a MAC subheader with an R field, an F field, an LCID field, and an L field. In the example MAC subheader of FIG. 17A, the LCID field may be six bits in length, and the L field may be eight bits in length. FIG. 17B shows example of a MAC subheader with an R field, an F field, an LCID field, and an L field. In the example MAC subheader shown in FIG. 17B, the LCID field may be six bits in length, and the L field may be sixteen bits in length. When a MAC subheader corresponds to a fixed sized MAC CE or padding, the MAC subheader may comprise: an R field with a two-bit length and an LCID field with a multi-bit length. FIG. 17C shows an example of a MAC subheader with an R field and an LCID field. In the example MAC subheader shown in FIG. 17C, the LCID field may be six bits in length, and the R field may be two bits in length.

[0240] FIG. 18A shows an example of a DL MAC PDU. Multiple MAC CEs, such as MAC CE 1 and 2, may be placed together. A MAC subPDU, comprising a MAC CE, may be placed before: a MAC subPDU comprising a MAC SDU, or a MAC subPDU comprising padding. FIG. 18B shows an example of a UL MAC PDU. Multiple MAC CEs, such as MAC CE 1 and 2, may be placed together. In an embodiment, a MAC subPDU comprising a MAC CE may be placed after all MAC subPDUs comprising a MAC SDU. In addition, the MAC subPDU may be placed before a MAC subPDU comprising padding.

[0241] In an example, a MAC entity of a base station may transmit one or more MAC CEs to a MAC entity of a wireless device. FIG. 19 shows an example of multiple LCIDs that may be associated with the one or more MAC CEs. The one or more MAC CEs comprise at least one of: a SP ZP CSI-RS Resource Set Activation/Deactivation MAC CE, a PUCCH spatial relation Activation/Deactivation MAC CE, a SP SRS Activation/Deactivation MAC CE, a SP CSI reporting on PUCCH Activation/Deactivation MAC CE, a TCI State Indication for UE-specific PDCCH MAC CE, a TCI State Indication for UE-specific PDSCH MAC CE, an Aperiodic CSI Trigger State Subselection MAC CE, a SP CSI-RS/CSI-IM Resource Set Activation/Deactivation MAC CE, a wireless device contention resolution identity MAC CE, a timing advance command MAC CE, a DRX command MAC CE, a Long DRX command MAC CE, an SCell activation/deactivation MAC CE (1 Octet), an SCell activation/deactivation MAC CE (4 Octet), and/or a duplication activation/deactivation MAC CE. In an example, a MAC CE, such as a MAC CE transmitted by a MAC entity of a base station to a MAC entity of a wireless device, may have an LCID in the MAC subheader corresponding to the MAC CE. Different MAC CE may have different LCID in the MAC subheader corresponding to

the MAC CE. For example, an LCID given by 111011 in a MAC subheader may indicate that a MAC CE associated with the MAC subheader is a long DRX command MAC CE.

[0242] In an example, the MAC entity of the wireless device may transmit to the MAC entity of the base station one or more MAC CEs. FIG. 20 shows an example of the one or more MAC CEs. The one or more MAC CEs may comprise at least one of: a short buffer status report (BSR) MAC CE, a beam failure recovery (BFR) MAC CE, a truncated BFR MAC CE, a truncated enhanced BFR MAC CE, a long BSR MAC CE, a C-RNTI MAC CE, a configured grant confirmation MAC CE, a single entry PHR MAC CE, a multiple entry PHR MAC CE, a short truncated BSR, and/or a long truncated BSR etc. In an example, a MAC CE may have an LCID in the MAC subheader corresponding to the MAC CE. Different MAC CE may have different LCID in the MAC subheader corresponding to the MAC CE. For example, an LCID given by 43 in a MAC subheader may indicate that a MAC CE associated with the MAC subheader is a truncated enhanced BFR MAC CE.

[0243] In carrier aggregation (CA), two or more component carriers (CCs) may be aggregated. A wireless device may simultaneously receive or transmit on one or more CCs, depending on capabilities of the wireless device, using the technique of CA. In an embodiment, a wireless device may support CA for contiguous CCs and/or for non-contiguous CCs. CCs may be organized into cells. For example, CCs may be organized into one primary cell (PCell) and one or more secondary cells (SCells). When configured with CA, a wireless device may have one RRC connection with a network. During an RRC connection establishment/re-establishment/handover, a cell providing NAS mobility information may be a serving cell. During an RRC connection re-establishment/handover procedure, a cell providing a security input may be a serving cell. In an example, the serving cell may denote a PCell. In an example, a base station may transmit, to a wireless device, one or more messages comprising configuration parameters of a plurality of one or more SCells, depending on capabilities of the wireless device.

[0244] When configured with CA, a base station and/or a wireless device may employ an activation/deactivation mechanism of an SCell to improve battery or power consumption of the wireless device. When a wireless device is configured with one or more SCells, a base station may activate or deactivate at least one of the one or more SCells. Upon configuration of an SCell, the SCell may be deactivated unless an SCell state associated with the SCell is set to “activated” or “dormant”.

[0245] A wireless device may activate/deactivate an SCell in response to receiving an SCell Activation/Deactivation MAC CE. In an example, a base station may transmit, to a wireless device, one or more messages comprising an SCell timer (e.g., *sCellDeactivationTimer*). In an example, a wireless device may deactivate an SCell in response to an expiry of the SCell timer.

[0246] When a wireless device receives an SCell Activation/Deactivation MAC CE activating an SCell, the wireless device may activate the SCell. In response to the activating the SCell, the wireless device may perform operations comprising SRS transmissions on the SCell; CQI/PMI/RI/CRI reporting for the SCell; PDCCH monitoring on the SCell; PDCCH monitoring for the SCell; and/or PUCCH transmissions on the SCell. In response to the activating of

the SCell, the wireless device may start or restart a first SCell timer (e.g., *sCellDeactivationTimer*) associated with the SCell. The wireless device may start or restart the first SCell timer in the slot when the SCell Activation/Deactivation MAC CE activating the SCell has been received. In an example, in response to the activating the SCell, the wireless device may (re-)initialize one or more suspended configured uplink grants of a configured grant Type 1 associated with the SCell according to a stored configuration. In an example, in response to activating the SCell, the wireless device may trigger PHR.

[0247] When a wireless device receives an SCell Activation/Deactivation MAC CE deactivating an activated SCell, the wireless device may deactivate the activated SCell. In an example, when a first SCell timer (e.g., *sCellDeactivationTimer*) associated with an activated SCell expires, the wireless device may deactivate the activated SCell. In response to the deactivating the activated SCell, the wireless device may stop the first SCell timer associated with the activated SCell. In an example, in response to the deactivating the activated SCell, the wireless device may clear one or more configured downlink assignments and/or one or more configured uplink grants of a configured uplink grant Type 2 associated with the activated SCell. In an example, in response to the deactivating the activated SCell, the wireless device may: suspend one or more configured uplink grants of a configured uplink grant Type 1 associated with the activated SCell; and/or flush HARQ buffers associated with the activated SCell.

[0248] When an SCell is deactivated, a wireless device may not perform operations comprising: transmitting SRS on the SCell; reporting CQI/PMI/RI/CRI for the SCell; transmitting on UL-SCH on the SCell; transmitting on RACH on the SCell; monitoring at least one first PDCCH on the SCell; monitoring at least one second PDCCH for the SCell; and/or transmitting a PUCCH on the SCell. When at least one first PDCCH on an activated SCell indicates an uplink grant or a downlink assignment, a wireless device may restart a first SCell timer (e.g., *sCellDeactivationTimer*) associated with the activated SCell. In an example, when at least one second PDCCH on a serving cell (e.g., a PCell or an SCell configured with PUCCH, i.e., PUCCH SCell) scheduling the activated SCell indicates an uplink grant or a downlink assignment for the activated SCell, a wireless device may restart the first SCell timer (e.g., *sCellDeactivationTimer*) associated with the activated SCell. In an example, when an SCell is deactivated, if there is an ongoing random access procedure on the SCell, a wireless device may abort the ongoing random access procedure on the SCell.

[0249] FIG. 21A shows an example of an SCell Activation/Deactivation MAC CE of one octet. A first MAC PDU subheader with a first LCID (e.g., '111010' as shown in FIG. 19) may identify the SCell Activation/Deactivation MAC CE of one octet. The SCell Activation/Deactivation MAC CE of one octet may have a fixed size. The SCell Activation/Deactivation MAC CE of one octet may comprise a single octet. The single octet may comprise a first number of C-fields (e.g., seven) and a second number of R-fields (e.g., one).

[0250] FIG. 21B shows an example of an SCell Activation/Deactivation MAC CE of four octets. A second MAC PDU subheader with a second LCID (e.g., '111001' as shown in FIG. 19) may identify the SCell Activation/Deactivation

MAC CE of four octets. The SCell Activation/Deactivation MAC CE of four octets may have a fixed size. The SCell Activation/Deactivation MAC CE of four octets may comprise four octets. The four octets may comprise a third number of C-fields (e.g., 31) and a fourth number of R-fields (e.g., 1).

[0251] In FIG. 21A and/or FIG. 21B, a C_i field may indicate an activation/deactivation status of an SCell with an SCell index i if an SCell with SCell index i is configured. In an example, when the C_i field is set to one, an SCell with an SCell index i may be activated. In an example, when the C_i field is set to zero, an SCell with an SCell index i may be deactivated. In an example, if there is no SCell configured with SCell index i, the wireless device may ignore the C_i field. In FIG. 21A and FIG. 21B, an R field may indicate a reserved bit. The R field may be set to zero.

[0252] A base station may configure a wireless device with uplink (UL) bandwidth parts (BWPs) and downlink (DL) BWPs to enable bandwidth adaptation (BA) on a PCell. If carrier aggregation is configured, the base station may further configure the wireless device with at least DL BWP(s) (i.e., there may be no UL BWPs in the UL) to enable BA on an SCell. For the PCell, an initial active BWP may be a first BWP used for initial access. For the SCell, a first active BWP may be a second BWP configured for the wireless device to operate on the SCell upon the SCell being activated. In paired spectrum (e.g., FDD), a base station and/or a wireless device may independently switch a DL BWP and an UL BWP. In unpaired spectrum (e.g., TDD), a base station and/or a wireless device may simultaneously switch a DL BWP and an UL BWP.

[0253] In an example, a base station and/or a wireless device may switch a BWP between configured BWPs by means of a DCI or a BWP inactivity timer. When the BWP inactivity timer is configured for a serving cell, the base station and/or the wireless device may switch an active BWP to a default BWP in response to an expiry of the BWP inactivity timer associated with the serving cell. The default BWP may be configured by the network. In an example, for FDD systems, when configured with BA, one UL BWP for each uplink carrier and one DL BWP may be active at a time in an active serving cell. In an example, for TDD systems, one DL/UL BWP pair may be active at a time in an active serving cell. Operating on the one UL BWP and the one DL BWP (or the one DL/UL pair) may improve wireless device battery consumption. BWPs other than the one active UL BWP and the one active DL BWP that the wireless device may work on may be deactivated. On deactivated BWPs, the wireless device may: not monitor PDCCH; and/or not transmit on PUCCH, PRACH, and UL-SCH.

[0254] In an example, a serving cell may be configured with at most a first number (e.g., four) of BWPs. In an example, for an activated serving cell, there may be one active BWP at any point in time. In an example, a BWP switching for a serving cell may be used to activate an inactive BWP and deactivate an active BWP at a time. In an example, the BWP switching may be controlled by a PDCCH indicating a downlink assignment or an uplink grant. In an example, the BWP switching may be controlled by a BWP inactivity timer (e.g., *bwp-InactivityTimer*). In an example, the BWP switching may be controlled by a MAC entity in response to initiating a Random Access procedure. Upon addition of an SpCell or activation of an SCell, one BWP may be initially active without receiving a PDCCH indicating a downlink assignment or an uplink grant. The active BWP for a serving cell may be indicated by

RRC and/or PDCCH. In an example, for unpaired spectrum, a DL BWP may be paired with a UL BWP, and BWP switching may be common for both UL and DL.

[0255] FIG. 22 shows an example of BWP switching on a cell (e.g., PCell or SCell). In an example, a wireless device may receive, from a base station, at least one RRC message comprising parameters of a cell and one or more BWPs associated with the cell. The RRC message may comprise: RRC connection reconfiguration message (e.g., *RRCReconfiguration*); RRC connection reestablishment message (e.g., *RRCReestablishment*); and/or RRC connection setup message (e.g., *RRCSetup*). Among the one or more BWPs, at least one BWP may be configured as the first active BWP (e.g., BWP 1), one BWP as the default BWP (e.g., BWP 0). The wireless device may receive a command (e.g., RRC message, MAC CE or DCI) to activate the cell at an nth slot. In case the cell is a PCell, the wireless device may not receive the command activating the cell, for example, the wireless device may activate the PCell once the wireless device receives RRC message comprising configuration parameters of the PCell. The wireless device may start monitoring a PDCCH on BWP 1 in response to activating the cell.

[0256] In an example, the wireless device may start (or restart) a BWP inactivity timer (e.g., *bwp-InactivityTimer*) at an m^{th} slot in response to receiving a DCI indicating DL assignment on BWP 1. The wireless device may switch back to the default BWP (e.g., BWP 0) as an active BWP when the BWP inactivity timer expires, at s^{th} slot. The wireless device may deactivate the cell and/or stop the BWP inactivity timer when the *sCellDeactivationTimer* expires (e.g., if the cell is a SCell). In response to the cell being a PCell, the wireless device may not deactivate the cell and may not apply the *sCellDeactivationTimer* on the PCell.

[0257] In an example, a MAC entity may apply normal operations on an active BWP for an activated serving cell configured with a BWP comprising: transmitting on UL-SCH; transmitting on RACH; monitoring a PDCCH; transmitting PUCCH; receiving DL-SCH; and/or (re-) initializing any suspended configured uplink grants of configured grant Type 1 according to a stored configuration, if any.

[0258] In an example, on an inactive BWP for each activated serving cell configured with a BWP, a MAC entity may: not transmit on UL-SCH; not transmit on RACH; not monitor a PDCCH; not transmit PUCCH; not transmit SRS, not receive DL-SCH; clear any configured downlink assignment and configured uplink grant of configured grant Type 2; and/or suspend any configured uplink grant of configured Type 1.

[0259] In an example, if a MAC entity receives a PDCCH for a BWP switching of a serving cell while a Random Access procedure associated with this serving cell is not ongoing, a wireless device may perform the BWP switching to a BWP indicated by the PDCCH. In an example, if a bandwidth part indicator field is configured in DCI format 1_1, the bandwidth part indicator field value may indicate the active DL BWP, from the configured DL BWP set, for DL receptions. In an example, if a bandwidth part indicator field is configured in DCI format 0_1, the bandwidth part indicator field value may indicate the active UL BWP, from the configured UL BWP set, for UL transmissions.

[0260] In an example, for a primary cell, a wireless device may be provided by a higher layer parameter Default-DL-BWP a default DL BWP among the configured DL BWPs. If a wireless device is not provided a default DL BWP by the higher layer parameter Default-DL-BWP, the default DL BWP is the initial active DL BWP. In an example, a wireless device may be provided by higher layer parameter *bwp-InactivityTimer*, a timer value for the primary cell. If configured, the wireless device may increment the timer, if running, every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the wireless device may not detect a DCI format 1_1 for paired spectrum operation or if the wireless device may not detect a DCI format 1_1 or DCI format 0_1 for unpaired spectrum operation during the interval.

[0261] In an example, if a wireless device is configured for a secondary cell with higher layer parameter *Default-DL-BWP* indicating a default DL BWP among the configured DL BWPs and the wireless device is configured with higher layer parameter *bwp-InactivityTimer* indicating a timer value, the wireless device procedures on the secondary cell may be same as on the primary cell using the timer value for the secondary cell and the default DL BWP for the secondary cell.

[0262] In an example, if a wireless device is configured by higher layer parameter *Active-BWP-DL-SCell* a first active DL BWP and by higher layer parameter *Active-BWP-UL-SCell* a first active UL BWP on a secondary cell or carrier, the wireless device may use the indicated DL BWP and the indicated UL BWP on the secondary cell as the respective first active DL BWP and first active UL BWP on the secondary cell or carrier.

[0263] In an example, a set of PDCCH candidates for a wireless device to monitor is defined in terms of PDCCH search space sets. A search space set comprises a CSS set or a USS set. A wireless device monitors PDCCH candidates in one or more of the following search spaces sets: a Type0-PDCCH CSS set configured by *pdcch-ConfigSIB1* in *MIB* or by *searchSpaceSIB1* in *PDCCH-ConfigCommon* or by *searchSpaceZero* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG, a Type0A-PDCCH CSS set configured by searchSpaceOtherSystemInformation in PDCCH-ConfigCommon for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG, a Type1-PDCCH CSS set configured by *ra-SearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by an RA-RNTI, a MsgB-RNTI, or a TC-RNTI on the primary cell, a Type2-PDCCH CSS set configured by *pagingSearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a P-RNTI on the primary cell of the MCG, a Type3-PDCCH CSS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType* = *common* for DCI formats with CRC scrambled by INT-RNTI, SFI-RNTI, TPC-PUSCH-RNTI, TPC-PUCCH-RNTI, TPC-SRS-RNTI, CI-RNTI, or PS-RNTI and, only for the primary cell, C-RNTI, MCS-C-RNTI, or CS-RNTI(s), and a USS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType* = *ue-Specific* for DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, CS-RNTI(s), SL-RNTI, SL-CS-RNTI, or SL-L-CS-RNTI.

[0264] In an example, a wireless device determines a PDCCH monitoring occasion on an active DL BWP based on one or more PDCCH configuration parameters (e.g., based on example embodiment of FIG. 27 which will be

described later) comprising: a PDCCH monitoring periodicity, a PDCCH monitoring offset, and a PDCCH monitoring pattern within a slot. For a search space set (SS s), the wireless device determines that a PDCCH monitoring occasion(s) exists in a slot with number $n_{s,f}^{\mu}$ in a frame with number n_f if $\left(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - o_s\right) mod\ k_s = 0$. $N_{\text{slot}}^{\text{frame},\mu}$ is a number of slots in a frame when numerology μ is configured. o_s is a slot offset indicated in the PDCCH configuration parameters (e.g., based on example embodiment of FIG. 27). k_s is a PDCCH monitoring periodicity indicated in the PDCCH configuration parameters (e.g., based on example embodiment of FIG. 27). The wireless device monitors PDCCH candidates for the search space set for T_s consecutive slots, starting from slot $n_{s,f}^{\mu}$, and does not monitor PDCCH candidates for search space set s for the next $k_s - T_s$ consecutive slots. In an example, a USS at CCE aggregation level $L \in \{1,\ 2,\ 4,\ 8,\ 16\}$ is defined by a set of PDCCH candidates for CCE aggregation level L.

[0265] In an example, a wireless device decides, for a search space set s associated with CORESET p, CCE indexes for aggregation level L corresponding to PDCCH candidate $m_{s,n_{CI}}$ of the search space set in slot $n_{s,f}^{\mu}$ for an active DL BWP of a serving cell corresponding to carrier indicator field value n_{CI} as $L \cdot \left\{\left(Y_{p,n_{s,f}^{\mu}} + \left\lfloor \frac{m_{s,n_{CI}} \cdot N_{\text{CCE},p}}{L \cdot M_{s,\max}^{(L)}} \right\rfloor + n_{CI}\right) mod \left\lfloor N_{\text{CCE},p}/L \right\rfloor\right\} + i$, where, $Y_{p,n_{s,f}^{\mu}} = 0$ for any CSS; $Y_{p,n_{s,f}^{\mu}} = \left(A_p \cdot Y_{p,n_{s,f}^{\mu}-1}\right) mod\ D$ for a USS, $Y_{p,-1} = n_{\text{RNTI}} \neq 0$, $A_p = 39827$ for $p\ mod\ 3 = 0$, $A_p = 39829$ for $p\ mod\ 3 = 1$, $A_p = 39839$ for $p\ mod\ 3 = 2$, and $D = 65537$; $i = 0, \cdots, L-1$; $N_{\text{CCE},p}$ is the number of CCEs, numbered from 0 to $N_{\text{CCE},p} - 1$, in CORESET p; n_{CI} is the carrier indicator field value if the wireless device is configured with a carrier indicator field by *CrossCarrierSchedulingConfig* for the serving cell on which PDCCH is monitored; otherwise, including for any CSS, $n_{CI} = 0$; $m_{s,n_{CI}} = 0, \ldots, M_{s,n_{CI}}^{(L)} - 1$, where $M_{s,n_{CI}}^{(L)}$ is the number of PDCCH candidates the wireless device is configured to monitor for aggregation level L of a search space set s for a serving cell corresponding to n_{CI}; for any CSS, $M_{s,\max}^{(L)} = M_{s,0}^{(L)}$; for a USS, $M_{s,\max}^{(L)}$ is the maximum of $M_{s,n_{CI}}^{(L)}$ over all configured n_{CI} values for a CCE aggregation level L of search space set s; and the RNTI value used for n_{RNTI} is the C-RNTI.

[0266] In an example, a wireless device may monitor a set of PDCCH candidates according to configuration parameters of a search space set comprising a plurality of search spaces (SSs). The wireless device may monitor a set of PDCCH candidates in one or more CORESETs for detecting one or more DCIs. A CORESET may be configured based on the example embodiment of FIG. 26 which will be described later. 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 SSs, and/or number of PDCCH candidates in the UE-specific SSs) and possible (or configured) DCI formats. The decoding may be referred to as blind decoding. The possible DCI formats may be based on example embodiments of FIG. 23.

[0267] FIG. 23 shows examples of DCI formats which may be used by a base station for transmitting control information to a wireless device or used by the wireless device for PDCCH monitoring. *Different* DCI formats may comprise different DCI fields and/or have different DCI payload sizes. Different DCI formats may have different signaling purposes. In an example, DCI format 0_0 may be used to schedule PUSCH in one cell. DCI format 0_1 may be used to schedule one or multiple PUSCH in one cell or indicate CG-DFI (configured grant-Downlink Feedback Information) for configured grant PUSCH, etc. The DCI format(s) which the wireless device may monitor in a SS may be configured.

[0268] FIG. 24A shows an example of configuration parameters of a master information block (MIB) of a cell (e.g., PCell). In an example, a wireless device, based on receiving primary synchronization signal (PSS) and/or secondary synchronization signal (SSS), may receive a MIB via a PBCH. The configuration parameters of a MIB may comprise six bits (*systemFrameNumber*) of system frame number (SFN), subcarrier spacing indication (*subCarrierSpacingCommon*), a frequency domain offset (*ssb-SubcarrierOffset*) between SSB and overall resource block grid in number of subcarriers, an indication (*cellBarred*) indicating whether the cell is bared, a DMRS position indication (*dmrs-TypeA-Position*) indicating position of DMRS, parameters of CORESET and SS of a PDCCH (*pdcch-ConfigSIB1)* comprising a common CORESET, a common search space and necessary PDCCH parameters, etc.

[0269] In an example, a *pdcch-ConfigSIB1* may comprise a first parameter (e.g., *controlResourceSetZero*) indicating a common ControlResourceSet (CORESET) with ID #0 (e.g., CORESET#0) of an initial BWP of the cell. *controlResourceSetZero* may be an integer between 0 and 15. Each integer between 0 and 15 may identify a configuration of CORESET#0.

[0270] FIG. 24B shows an example of a configuration of CORESET#0. As shown in FIG. 24B, based on a value of the integer of *controlResourceSetZero*, a wireless device may determine a SSB and CORESET#0 multiplexing pattern, a number of RBs for CORESET#0, a number of symbols for CORESET#0, an RB offset for CORESET#0.

[0271] In an example, a *pdcch-ConfigSIB1* may comprise a second parameter (e.g., *searchSpaceZero*) indicating a common search space with ID #0 (e.g., SS#0) of the initial BWP of the cell. *searchSpaceZero* may be an integer between 0 and 15. Each integer between 0 and 15 may identify a configuration of SS#0.

[0272] FIG. 24C shows an example of a configuration of SS#0. As shown in FIG. 24C, based on a value of the integer of *searchSpaceZero*, a wireless device may determine one or more parameters (e.g., *O, M*) for slot determination of PDCCH monitoring, a first symbol index for PDCCH monitoring and/or a number of search spaces per slot.

[0273] In an example, based on receiving a MIB, a wireless device may monitor PDCCH via SS#0 of CORESET#0 for receiving a DCI scheduling a system information block 1 (SIB1). A SIB1 message may be implemented based on the example embodiment of FIG. 25. The wireless device may receive the DCI with CRC scrambled with a system information radio network temporary identifier (SI-RNTI) dedicated for receiving the SIB1.

[0274] FIG. 25 and FIG. 26 show examples of RRC configuration parameters of system information block (SIB). A SIB (e.g., *SIB1*) may be transmitted to all wireless devices in a broadcast way. The SIB may contain information relevant when evaluating if a wireless device is allowed to access a cell, information of paging configuration and/or scheduling configuration of other system information. A SIB may contain radio resource configuration information that is common for all wireless devices and barring information applied to a unified access control. In an example, a base station may transmit to a wireless device (or a plurality of wireless devices) one or more SIB information.

[0275] As shown in FIG. 25, parameters of the one or more SIB information may comprise: one or more parameters (e.g., *cellSelectionInfo*) for cell selection related to a serving cell, one or more configuration parameters of a serving cell (e.g., in *ServingCellConfigCommonSIB* IE), and one or more other parameters. The *ServingCellConfigCommonSIB* IE may comprise at least one of: common downlink parameters (e.g., in *DownlinkConfigCommonSIB* IE) of the serving cell, common uplink parameters (e.g., in *UplinkConfigCommonSIB* IE) of the serving cell, and other parameters.

[0276] As shown in FIG. 26, a SIB1 message may comprise scheduling information for other SIBs (e.g., *SIB2, SIB3, SIB4, ...*), e.g., by *SI-SchedulingInfo* IE. *A SI-SchedulingInfo* IE may comprise a *SI-RequestConfig* IE for a normal uplink carrier (NUL) of a cell and a *SI-RequestConfigSUL* IE for a supplementary uplink carrier of the cell. A *SI-RequestConfig* IE or a *SI-RequestConfigSUL* IE may indicate a RACH configuration (e.g., *rach-OccasionsSI* IE) for a corresponding SI request.

[0277] In an example, a *DownlinkConfigCommonSIB* IE may comprise parameters of an initial downlink BWP (*initialDownlinkBWP* IE) of the serving cell (e.g., SpCell). The parameters of the initial downlink BWP may be comprised in a *BWP-DownlinkCommon* IE (as shown in FIG. 27). The *BWP-DownlinkCommon* IE may be used to configure common parameters of a downlink BWP of the serving cell. The base station may configure the *locationAndBandwidth* so that the initial downlink BWP contains the entire CORESET#0 of this serving cell in the frequency domain. The wireless device may apply the *locationAndBandwidth* upon reception of this field (e.g., to determine the frequency position of signals described in relation to this *locationAndBandwidth*) but it keeps CORESET#0 until after reception of *RRCSetup/RRCResume/RRCReestablishment*.

[0278] In an example, the *DownlinkConfigCommonSIB* IE may comprise parameters of a paging channel configuration. The parameters may comprise a paging cycle value (*T*, by *defaultPagingCycle* IE), a parameter (*nAndPagingFrameOffset* IE) indicating total number *N*) of paging frames (PFs) and paging frame offset (*PF_offset*) in a paging DRX cycle, a number (*Ns*) for total paging occasions (POs) per PF, a first PDCCH monitoring occasion indication parameter (*firstPDCCH-MonitoringOccasionofPO* IE) indicating a first PDCCH monitoring occasion for

paging of each PO of a PF. The wireless device, based on parameters of a PCCH configuration, may monitor PDCCH for receiving paging message.

[0279] In an example, the parameter *first-PDCCH-MonitoringOccasionOfPO* may be signaled in *SIB1* for paging in initial DL BWP. For paging in a DL BWP other than the initial DL BWP, the parameter *first-PDCCH-MonitoringOccasionOfPO* may be signaled in the corresponding BWP configuration.

[0280] FIG. 27 shows an example of RRC configuration parameters (e.g., *BWP-DownlinkCommon* IE) in a downlink BWP of a serving cell. A base station may transmit to a wireless device (or a plurality of wireless devices) one or more configuration parameters of a downlink BWP (e.g., initial downlink BWP) of a serving cell. As shown in FIG. 27, the one or more configuration parameters of the downlink BWP may comprise: one or more generic BWP parameters of the downlink BWP, one or more cell specific parameters for PDCCH of the downlink BWP (e.g., in *pdcch-ConfigCommon* IE), one or more cell specific parameters for the PDSCH of this BWP (e.g., in *pdsch-ConfigCommon* IE), and one or mor other parameters. A *pdcch-ConfigCommon* IE may comprise parameters of COESET #0 (e.g., *controlResourceSetZero*) which may be used in any common or UE-specific search spaces. A value of the *controlResourceSetZero* may be interpreted like the corresponding bits in *MIB pdcch-ConfigSIB1*. A *pdcch-ConfigCommon* IE may comprise parameters (e.g., in *commonControlResourceSet*) of an additional common control resource set which may be configured and used for any common or UE-specific search space. If the network configures this field, it uses a *ControlResourceSetId* other than 0 for this *ControlResourceSet*. The network configures the *commonControlResourceSet* in *SIB1* so that it is contained in the bandwidth of CORESET#0. A *pdcch-ConfigCommon* IE may comprise parameters (e.g., in *commonSearchSpaceList*) of a list of additional common search spaces. Parameters of a search space may be implemented based on the example of FIG. 28 which will be described later. A *pdcch-ConfigCommon* IE may indicate, from a list of search spaces, a search space for paging (e.g., *pagingSearchSpace*), a search space for random access procedure (e.g., *ra-SearchSpace*), a search space for SIB1 message (e.g., *searchSpaceSIB1*), a common search space#0 (e.g., *searchSpaceZero*), and one or more other search spaces.

[0281] As shown in FIG. 27, a control resource set (CORESET) may be associated with a CORESET index (e.g., *ControlResourceSetId*). A CORESET may be implemented based on example embodiments described above with respect to FIG. 14A and/or FIG. 14B. The CORESET index with a value of 0 may identify a common CORESET configured in *MIB* and in *ServingCellConfigCommon* (*controlResourceSetZero*) and may not be used in the *ControlResourceSet* IE. The CORESET index with other values may identify CORESETs configured by dedicated signaling or in *SIB1*. The *controlResourceSetId* is unique among the BWPs of a serving cell. A CORESET may be associated with *coresetPoolIndex* indicating an index of a CORESET pool for the CORESET. A CORESET may be associated with a time duration parameter (e.g., *duration*) indicating contiguous time duration of the CORESET in number of symbols. In an example, as shown in FIG. 27, configuration parameters of a CORESET may comprise at least one of: frequency resource indication (e.g., *frequencyDomainResources*), a CCE-REG mapping type indicator

(e.g., *cce-REG-MappingType*), a plurality of TCI states, an indicator indicating whether a TCI is present in a DCI, and the like.

[0282] FIG. 28 shows an example of configuration of a search space (e.g., *SearchSpace* IE). In an example, one or more search space configuration parameters of a search space may comprise at least one of: a search space ID (*searchSpaceId*), a control resource set ID (*controlResourceSetId*), a monitoring slot periodicity and offset parameter (*monitoringSlotPeriodicityAndOffset*), a search space time duration value (*duration*), a monitoring symbol indication (*monitoringSymbolsWithinSlot*), a number of candidates for an aggregation level (*nrofCandidates*), and/or a SS type indicating a common SS type or a UE-specific SS type (*searchSpaceType*). The monitoring slot periodicity and offset parameter may indicate slots (e.g., in a radio frame) and slot offset (e.g., relative to a starting of a radio frame) for PDCCH monitoring. The monitoring symbol indication may indicate on which symbol(s) of a slot a wireless device may monitor PDCCH on the SS. The control resource set ID may identify a control resource set on which a SS may be located.

[0283] In an example, a wireless device, in RRC_IDLE or RRC_INACTIVE state, may periodically monitor paging occasions (POs) for receiving paging message for the wireless device. Before monitoring the POs, the wireless device, in RRC_IDLE or RRC_INACTIVE state, may wake up at a time before each PO for preparation and/or turn all components in preparation of data reception (warm up). The gap between the waking-up and the PO may be long enough to accommodate all the processing requirements. The wireless device may perform, after the warming up, timing acquisition from SSB and coarse synchronization, frequency and time tracking, time and frequency offset compensation, and/or calibration of local oscillator. After that, the wireless device may monitor a PDCCH for a paging DCI in one or more PDCCH monitoring occasions based on configuration parameters of the PCCH configuration configured in SIB1. The configuration parameters of the PCCH configuration may be implemented based on example embodiments described above with respect to FIG. 25.

[0284] FIG. 29 shows an example of transitioning between a dormant state and a non-dormant state on a SCell. In an example, a base station may transmit to a wireless device one or more RRC messages comprising configuration parameters of a SCell, wherein the SCell comprises a plurality of BWPs. Among the plurality of BWPs, a first BWP (e.g., BWP 3 in FIG. 29) may be configured as a non-dormant BWP, and/or a second BWP (e.g., BWP 1 in FIG. 29) may be configured as a dormant BWP. In an example, a default BWP (e.g., BWP 0 in FIG. 29) may be configured in the plurality of BWPs. In an example, the non-dormant BWP may be a BWP which the wireless device may activate in response to transitioning the SCell from a dormant state to a non-dormant state. In an example, the dormant BWP may be a BWP which the wireless device may switch to in response to transitioning the SCell from a non-dormant state to a dormant state. In an example, the configuration parameters may indicate one or more search spaces and/or CORESETs configured on the non-dormant BWP. The configuration parameters may indicate no search spaces or no CORESETs configured on the dormant BWP. The configuration parameter may indicate CSI reporting configuration parameters for the dormant BWP.

[0285] In an example, a default BWP may be different from a dormant BWP. The configuration parameters may indicate one or more search spaces or one or more CORESETs configured on the default BWP. When a BWP inactivity timer expires or receiving a DCI indicating switching to the default BWP, a wireless device may switch to the default BWP as an active BWP. The wireless device, when the default BWP is in active, may perform at least one of: monitoring PDCCH on the default BWP of the SCell, receiving PDSCH on the default BWP of the SCell, transmitting PUSCH on the default BWP of the SCell, transmitting SRS on the default BWP of the SCell, and/or transmitting CSI report (e.g., periodic, aperiodic, and/or semi-persistent) for the default BWP of the SCell. In an example, when receiving a dormancy/non-dormancy indication indicating a dormant state for a SCell, the wireless device may switch to the dormant BWP as an active BWP of the SCell. In response to switching to the dormant BWP, the wireless device may perform at least one of: refraining from monitoring PDCCH on the dormant BWP of the SCell (or for the SCell if the SCell is cross-carrier scheduled by another cell), refraining from receiving PDSCH on the dormant BWP of the SCell, refraining from transmitting PUSCH on the dormant BWP of the SCell, refraining from transmitting SRS on the dormant BWP of the SCell, and/or transmitting CSI report (e.g., periodic, aperiodic, and/or semi-persistent) for the dormant BWP of the SCell.

[0286] As shown in FIG. 29, a base station may transmit to a wireless device a DCI via a PDCCH resource, the DCI comprising a dormancy/non-dormancy indication indicating whether a dormant state or a non-dormant state for the SCell. In response to the dormancy/non-dormancy indication indicating a dormant state for the SCell, the wireless device may: transition the SCell to the dormant state if the SCell is in a non-dormant state before receiving the DCI or maintain the SCell in the dormant state if the SCell is in the dormant state before receiving the DCI. Transitioning the SCell to the dormant state may comprise switching to the dormant BWP (e.g., configured by the base station) of the SCell. In response to the dormancy/non-dormant indication indicating a non-dormant state for the SCell, the wireless device may: transition the SCell to the non-dormant state if the SCell is in a dormant state before receiving the DCI or maintain the SCell in the non-dormant state if the SCell is in the non-dormant state before receiving the DCI. Transitioning the SCell to the non-dormant state may comprise switching to a non-dormant BWP (e.g., configured by the base station) of the SCell.

[0287] As shown in FIG. 29, in response to transitioning the SCell from a dormant state to a non-dormant state, the wireless device may switch to the non-dormant BWP (e.g., BWP 3 as shown in FIG. 29), configured by the base station, as an active BWP of the SCell. Based on the switching to the non-dormant BWP as the active BWP of the SCell, the wireless device may perform at least one of: monitoring PDCCH on the active BWP of the SCell (or monitoring PDCCH for the SCell when the SCell is configured to be cross-carrier scheduled by another cell), receiving PDSCH on the active BWP of the SCell, and/or transmitting PUCCH/PUSCH/RACH/SRS on the active BWP (e.g., if the active BWP is an uplink BWP).

[0288] As shown in FIG. 29, in response to transitioning the SCell from a non-dormant state to a dormant state, the wireless device may switch to the dormant BWP (e.g., BWP 1 of the SCell as shown in FIG. 29), configured by the

base station. Based on the switching to the dormant BWP of the SCell, the wireless device may perform at least one of: refraining from monitoring PDCCH on the dormant BWP of the SCell (or refraining from monitoring PDCCH for the SCell when the SCell is configured to be cross-carrier scheduled by another cell), refraining from receiving PDSCH on the dormant BWP of the SCell, refraining from transmitting PUCCH/PUSCH/RACH/SRS on the dormant BWP (e.g., if the dormant BWP is an uplink BWP), and/or transmitting CSI report for the dormant BWP of the SCell based on the CSI reporting configuration parameters configured on the dormant BWP of the SCell.

[0289] In an example embodiment, DRX operation may be used by a wireless device to improve the wireless device battery lifetime. With DRX configured, the wireless device may discontinuously monitor downlink control channel, e.g., PDCCH or EPDCCH. A base station may configure DRX operation with a set of DRX parameters, e.g., using RRC configuration. The set of DRX parameters may be selected based on the application type such that the wireless device may reduce power and resource consumption. In response to DRX being configured/activated, the wireless device may receive data packets with an extended delay, since the wireless device may be in DRX Sleep/Off state at the time of data arrival at the wireless device and the base station may wait until the wireless device transitions to the DRX ON state.

[0290] In an example embodiment, during a DRX mode, the wireless device may power down most of its circuitry when there are no packets to be received. The wireless device may monitor PDCCH discontinuously in the DRX mode. The wireless device may monitor the PDCCH continuously when a DRX operation is not configured. During this time the wireless device listens to the downlink (DL) (or monitors PDCCHs) which is called DRX Active state. In DRX mode, a time during which the wireless device doesn't listen/monitor PDCCH is called DRX Sleep state.

[0291] FIG. 30 shows an example of DRX operation. A base station may transmit an RRC message comprising one or more DRX parameters of a DRX cycle. The one or more parameters may comprise a first parameter and/or a second parameter. The first parameter may indicate a first time/window value of the DRX Active state (e.g., DRX On duration) of the DRX cycle. The second parameter may indicate a second time of the DRX Sleep state (e.g., DRX Off duration) of the DRX cycle. The one or more parameters may further comprise a time duration of the DRX cycle. During the DRX Active state, the wireless device may monitor PDCCHs for detecting one or more DCIs on a serving cell. During the DRX Sleep state, the wireless device may stop monitoring PDCCHs on the serving cell. When multiple cells are in active state, the wireless device may monitor all PDCCHs on (or for) the multiple cells during the DRX Active state. During the DRX off duration, the wireless device may stop monitoring all PDCCH on (or for) the multiple cells. The wireless device may repeat the DRX operations according to one or more DRX parameters.

[0292] In an example embodiment, DRX may be beneficial to the base station. In an example, if DRX is not configured, the wireless device may be transmitting periodic CSI and/or SRS frequently (e.g., based on the configuration). With DRX, during DRX OFF periods, the wireless device may not transmit periodic CSI and/or SRS. The base station may assign these resources to the other UEs to improve resource utilization efficiency.

[0293] In an example embodiment, the MAC entity may be configured by RRC with a DRX functionality that controls the wireless device's downlink control channel (e.g., PDCCH) monitoring activity for a plurality of RNTIs for the MAC entity. The plurality of RNTIs may comprise at least one of: C-RNTI; CS-RNTI; INT-RNTI; SP-CSI-RNTI; SFI-RNTI; TPC-PUCCH-RNTI; TPC-PUSCH-RNTI; Semi-Persistent Scheduling C-RNTI; eIMTA-RNTI; SL-RNTI; SL-V-RNTI; CC-RNTI; or SRS-TPC-RNTI. In an example, in response to being in RRC_CONNECTED, if DRX is configured, the MAC entity may monitor the PDCCH discontinuously using the DRX operation; otherwise, the MAC entity may monitor the PDCCH continuously.

[0294] In an example embodiment, RRC may control DRX operation by configuring a plurality of timers. The plurality of timers may comprise: a DRX On duration timer (e.g., *drx-onDurationTimer*); a DRX inactivity timer (e.g., *drx-InactivityTimer*); a downlink DRX HARQ round trip time (RTT) timer (e.g., *drx-HARQ-RTT-TimerDL*); an uplink DRX HARQ RTT Timer (e.g., *drx-HARQ-RTT-TimerUL*); a downlink retransmission timer (e.g., *drx-RetransmissionTimerDL*); an uplink retransmission timer (e.g., *drx-RetransmissionTimerUL*); one or more parameters of a short DRX configuration (e.g., *drx-ShortCycle* and/or *drx-ShortCycleTimer*)) and one or more parameters of a long DRX configuration (e.g., *drx-LongCycle*). In an example, time granularity for DRX timers may be in terms of PDCCH subframes (e.g., indicated as psf in the DRX configurations), or in terms of milliseconds.

[0295] In an example embodiment, in response to a DRX cycle being configured, the Active Time of the DRX operation may include the time while at least one timer is running. The at least one timer may comprise *drx-onDurationTimer*, *drx-InactivityTimer*, *drx-RetransmissionTimerDL*, *drx-RetransmissionTimerUL*, or *mac-ContentionResolutionTimer*. During the Active time of the DRX operation, the wireless device may monitor PDCCH with RNTI(s) impacted by the DRX operation. The RNTIs may comprise C-RNTI, CI-RNTI, CS-RNTI, INT-RNTI, SFI-RNTI, SP-CSI-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, TPC-SRS-RNTI, and/or AI-RNTI.

[0296] In an example embodiment, *drx-Inactivity-Timer* may specify a time duration for which the wireless device may be active after successfully decoding a PDCCH indicating a new transmission (UL or DL or SL). This timer may be restarted upon receiving PDCCH for a new transmission (UL or DL or SL). The wireless device may transition to a DRX mode (e.g., using a short DRX cycle or a long DRX cycle) in response to the expiry of this timer. In an example, *drx-ShortCycle* may be a first type of DRX cycle (e.g., if configured) that needs to be followed when the wireless device enters DRX mode. In an example, *DRX-Config* IE indicates the length of the short cycle. *drx-ShortCycleTimer* may be expressed as multiples of *shortDRX-Cycle*. The timer may indicate the number of initial DRX cycles to follow the short DRX cycle before entering the long DRX cycle. *drx-onDurationTimer* may specify the time duration at the beginning of a DRX Cycle (e.g., DRX ON). *drx-onDurationTimer* may indicate the time duration before entering the sleep mode (DRX OFF). *drx-HARQ-RTT-TimerDL* may specify a minimum duration from the time new transmission is received and before the wireless device may expect a retransmission of a same packet. This timer may be fixed and may not be configured by RRC. *drx-RetransmissionTimerDL* may indicate a maximum

duration for which the wireless device may be monitoring PDCCH when a retransmission from the base station is expected by the wireless device.

[0297] In response to a DRX cycle being configured, the Active Time may comprise the time while a Scheduling Request is sent on PUCCH and is pending. In an example, in response to a DRX cycle being configured, the Active Time may comprise the time while an uplink grant for a pending HARQ retransmission can occur and there is data in the corresponding HARQ buffer for synchronous HARQ process. In response to a DRX cycle being configured, the Active Time may comprise the time while a PDCCH indicating a new transmission addressed to the C-RNTI of the MAC entity has not been received after successful reception of a Random Access Response for the preamble not selected by the MAC entity.

[0298] In an example embodiment, a DL HARQ RTT Timer (e.g., *drx-HARQ-RTT-TimerDL*) may expire in a subframe and the data of the corresponding HARQ process may not be successfully decoded. The MAC entity may start the *drx-RetransmissionTimerDL* for the corresponding HARQ process. An UL HARQ RTT Timer (e.g., *drx-HARQ-RTT-TimerUL*) may expire in a subframe. The MAC entity may start the *drx-RetransmissionTimerUL* for the corresponding HARQ process.

[0299] In an example, a wireless device may receive a DRX Command MAC CE or a Long DRX Command MAC CE (e.g., based on example embodiments described above with respect to FIG. 19). The MAC entity of the wireless device may stop *drx-onDurationTimer* and/or stop *drx-InactivityTimer* in response to receiving the DRX Command MAC CE and/or the long DRX Command MAC CE. In an example, if *drx-InactivityTimer* expires and if Short DRX cycle being configured, the MAC entity may start or restart *drx-ShortCycleTimer* and may use Short DRX Cycle. Otherwise, the MAC entity may use the Long DRX cycle.

[0300] In an example, *drx-ShortCycleTimer* may expire in a subframe. The MAC entity may use the Long DRX cycle. In an example, a Long DRX Command MAC control element may be received. The MAC entity may stop *drx-ShortCycleTimer* and may use the Long DRX cycle.

[0301] In an example embodiment, if the Short DRX Cycle is used and [(SFN * 10) + subframe number] modulo (*drx-ShortCycle*) = (*drxStartOffset*) modulo (*drx-ShortCycle*), the wireless device may start *drx-onDurationTimer* after *drx-SlotOffset* from the beginning of the subframe, wherein *drx-SlotOffset* may be a value (configured in the DRX configuration parameters) indicating a delay before starting the *drx-onDurationTimer*. In an example, if the Long DRX Cycle is used and [(SFN * 10) + subframe number] modulo (*drx-longCycle*) = *drxStartOffset*, the wireless device may start *drx-onDurationTimer* after *drx-SlotOffset* from the beginning of the subframe, wherein *drx-SlotOffset* may be a value (configured in the DRX configuration parameters) indicating a delay before starting the *drx-onDurationTimer*.

[0302] FIG. 31 shows an example of DRX operation. A base station may transmit an RRC message comprising configuration parameters of DRX operation. The configuration parameters may comprise a first timer value for a DRX inactivity timer (e.g., *drx-InactivityTimer*), a second timer value for a HARQ RTT timer (e.g., *drx-HARQ-RTT-*

TimerDL, drx-HARQ-RTT-TimerUL), a third timer value for a HARQ retransmission timer (e.g., *drx-RetransmissionTimerDL* or *drx-RetransmissionTimerUL*).

[0303] As shown in FIG. 31, a base station may transmit, via a PDCCH, a DCI (e.g., 1st DCI) comprising downlink assignment for a TB, to a wireless device. In response to receiving the DCI, the wireless device may start the *drx-InactivityTimer*. While the *drx-InactivityTimer* is running, the wireless device may monitor the PDCCH. The wireless device may receive the TB based on receiving the DCI. The wireless device may transmit a NACK to the base station upon unsuccessful decoding the TB. In the first symbol after the end of transmitting the NACK, the wireless device may start a HARQ RTT Timer (e.g., *drx-HARQ-RTT-TimerDL*). The wireless device may stop the *drx-RetransmissionTimerDL* for a HARQ process corresponding to the TB (not shown in FIG. 30). While the HARQ RTT Timer is running, the wireless device may stop monitoring the PDCCH for one or more RNTI(s) impacted by the DRX operation. The one or more RNTI(s) may comprise C-RNTI, CI-RNTI, CS-RNTI, INT-RNTI, SFI-RNTI, SP-CSI-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, TPC-SRS-RNTI, and/or AI-RNTI.

[0304] As shown in FIG. 31, when the HARQ RTT Timer expires, the wireless device may monitor the PDCCH and start a HARQ retransmission timer (e.g., *drx-RetransmissionTimerDL*). When the HARQ retransmission timer is running, the wireless device, during the monitoring of the PDCCH, may receive a second DCI (e.g., 2nd DCI in FIG 30) scheduling retransmission of the TB. If not receiving the second DCI before the HARQ retransmission timer expires, the wireless device may stop monitoring the PDCCH.

[0305] FIG. 32A shows an example of a power saving mechanism based on wake-up indication. A base station may transmit one or more messages comprising parameters of a wake-up duration (e.g., a power saving duration, or a Power Saving Channel (PSCH) occasion), to a wireless device. The wake-up duration may be located at a number of slots (or symbols) before a DRX On duration of a DRX cycle. A DRX cycle may be implemented based on example embodiments described above with respect to FIG. 30. The number of slots (or symbols), or, referred to as a gap between a wakeup duration and a DRX on duration, may be configured in the one or more RRC messages or predefined as a fixed value. The gap may be used for at least one of: synchronization with the base station; measuring reference signals; and/or retuning RF parameters. The gap may be determined based on the capability of the wireless device and/or the base station. In an example, the parameters of the wake-up duration may be pre-defined without RRC configuration. In an example, the wake-up mechanism may be based on a wake-up indication via a PSCH. The parameters of the wake-up duration may comprise at least one of: a PSCH channel format (e.g., numerology, DCI format, PDCCH format); a periodicity of the PSCH; a control resource set and/or a search space of the PSCH. When configured with the parameters of the wake-up duration, the wireless device may monitor the wake-up signal or the PSCH during the wake-up duration. When configured with the parameters of the PSCH occasion, the wireless device may monitor the PSCH for detecting a wake-up indication during the PSCH occasion. In response to receiving the wake-up signal/channel (or a wake-up indication via the PSCH), the wireless device may wake-up to monitor PDCCHs in a DRX active time of a next DRX cycle according to the DRX configuration. In

an example, in response to receiving the wake-up indication via the PSCH, the wireless device may monitor PDCCHs in the DRX active time (e.g., when *drx-onDurationTimer* is running). The wireless device may go back to sleep if not receiving PDCCHs in the DRX active time. The wireless device may keep in sleep during the DRX off duration of the DRX cycle. In an example, if the wireless device doesn't receive the wake-up signal/channel (or a wake-up indication via the PSCH) during the wake-up duration (or the PSCH occasion), the wireless device may skip monitoring PDCCHs in the DRX active time. In an example, if the wireless device receives an indication indicating skipping PDCCH monitoring during the wake-up duration (or the PSCH occasion), the wireless device may skip monitoring PDCCHs in the DRX active time.

[0306] In an example, a power saving mechanism may be based on a go-to-sleep indication via a PSCH. FIG. 32B shows an example of a power saving based on go-to-sleep indication. In response to receiving a go-to-sleep indication via the PSCH, the wireless device may go back to sleep and skip monitoring PDCCHs during the DRX active time (e.g., next DRX on duration of a DRX cycle). In an example, if the wireless device doesn't receive the go-to-sleep indication via the PSCH during the wake-up duration, the wireless device monitors PDCCHs during the DRX active time, according to the configuration parameters of the DRX operation. This mechanism may reduce power consumption for PDCCH monitoring during the DRX active time.

[0307] In an example, a power saving mechanism may be implemented by combining FIG. 32A and FIG. 32B. A base station may transmit a power saving indication, in a DCI via a PSCH, indicating whether the wireless device wakes up for next DRX on duration or skip next DRX on duration. The wireless device may receive the DCI via the PSCH. In response to the power saving indication indicating the wireless device wake up for next DRX on duration, the wireless device may wake up for next DRX on duration. The wireless device monitors PDCCH in the next DRX on duration in response to the waking up. In response to the power saving indication indicating the wireless device skips (or go to sleep) for next DRX on duration, the wireless device goes to sleep or skips for next DRX on duration. The wireless device skips monitoring PDCCH in the next DRX on duration in response to the power saving indication indicating the wireless device may go to sleep for next DRX on duration.

[0308] In an example, one or more embodiments of FIG. 31, FIG. 32A, and/or FIG. 32B may be extended or combined to further improve power consumption of a wireless device, and/or signaling overhead of a base station.

[0309] In an example, network energy saving operation may comprise a cell DTX/DRX configuration/mode/state/operation, (e.g., similar to UE DRX configuration, where a UE DRX configuration is described above with respect to FIG. 31, FIG. 32A and/or FIG. 32B). Different from the UE DRX configuration, the cell DTX/DRX configuration is applied for all UEs in the cell. During a cell DTX operation, the base station may (periodically) power-on a cell (or a plurality of cells) for a first time duration and then power-off the cell for a second time duration. In this specification, a UE DRX configuration, specifically configured for a wireless device, may be referred to as a C-DRX configuration, or simply a DRX configuration which is different from a cell DRX configuration applied for all wireless devices in a cell.

[0310] When a cell DTX configuration is configured (and activated if an explicit activation command is needed) for a cell, in a first time duration of the cell DTX configuration (e.g., in a first power state/mode, in a cell DTX Active Time, in a cell DTX on duration, etc.), the base station may transmit periodic downlink signals (e.g., SIBs/SSBs/CSI-RSs/TRSs), downlink control channels (PDCCH), downlink shared channels (PDSCH), etc., as it does in normal state for the cell (e.g., when the Cell DTX configuration is not configured as in legacy system). In a second time duration of the cell DTX configuration (e.g., in a second power state/mode, in a cell DTX inactive/non-active time, in a cell DTX off duration, etc.), the base station may reduce transmission power/bandwidth/beam of the periodic downlink signals (e.g., CSI-RSs), stop transmission of the periodic downlink signals (e.g., CSI-RSs), keep transmitting SSBs, and/or stop transmission of PDCCHs/PDSCHs (e.g., SPS PDSCHs and/or dynamic scheduled PDSCHs) via the cell. The wireless device may stop receiving the periodic downlink signals and the PDCCHs/PDSCHs via the cell. The base station may perform the cell DTX operation (for each DTX cycle) on the cell periodically, e.g., by configuring a periodicity of a DTX cycle comprising the first time duration and/or the second time duration.

[0311] When a cell DRX configuration is configured for a cell (and activated if an explicit activation command is needed), in a first time duration of the cell DRX configuration (e.g., in a first power state/mode, in a cell DRX Active Time, in a cell DRX on duration, etc.), the base station may receive, and/or the wireless device may transmit, PUSCH/PUCCH/SRS via the cell, as it does in normal state of the cell (e.g., when the Cell DRX configuration is not configured as in legacy system). In a second time duration of the cell DRX configuration (e.g., in a second power state/mode, in a cell DRX inactive/non-active time, in a cell DRX off duration, etc.), the base station may stop receiving, and/or the wireless device may stop transmitting PUSCHs (e.g., dynamical scheduled PUSCH and/or configured grant PUSCH), PUCCHs (e.g., SR/CSI/HARQ-ACK) and/or SRSs via the cell. The base station may perform the cell DRX operation for each DRX cycle periodically, e.g., by configuring a periodicity of a DRX cycle comprising the first time duration and/or the second time duration.

[0312] In an example, a cell DTX configuration and a cell DRX configuration may be separately configured/activated/deactivated or jointly configured/activated/deactivated. In this specification, one or more embodiments described for a cell DTX configuration may be applied for a cell DRX configuration if applicable, where the cell DTX configuration is exchangeable with the cell DRX configuration.

[0313] FIG. 33 shows an example of cell DTX (which is similarly applied for cell DRX) for network energy saving. In an example, at a first time (e.g., T0), a wireless device (UE) may receive, and/or a base station (gNB) may transmit, one or more RRC messages comprising configuration parameters of a cell (or a plurality of cells). A cell may be implemented based on example embodiments described above with respect to FIG. 10A and/or FIG. 10B. The cell may be a PCell/PSCell. In an example, the cell may be a SCell.

[0314] In an example, the one or more RRC messages may comprise configuration parameters (first parameters) of a DRX configuration specifically for the wireless device. The DRX configuration may be referred to as a UE specific

DRX configuration (UE DRX configuration, C-DRX configuration, or DRX configuration). Different wireless devices may receive different configuration parameters of DRX configurations. The configuration parameters of the DRX configuration are specifically for a wireless device who receives the UE specific RRC message. A DRX configuration may be implemented based on example embodiments described above with respect to FIG. 30 and/or FIG. 31. In an example, the configuration parameters of a DRX configuration for the wireless device may comprise: a value of a DRX cycle (short cycle or long cycle) of the DRX configuration, a time offset value (*drx_StartOffset*) of a starting point of the DRX cycle, relative to a reference subframe (e.g., subframe 0 of a radio frame), a first timer value (*drx-onDurationTimer*) of a DRX on duration timer, a slot offset value (*drx_SlotOffset*) for a delay (e.g., a number of slots) before starting the DRX on duration timer at the beginning of a subframe, a second timer value (*drx-InactivityTimer*) of a DRX inactivity timer, a third timer value (*drx-RetransmissionTimerDL* or *drx-RetransmissionTimerUL*) of a DRX retransmission timer and/or a fourth timer value (*drx-HARQ-RTT-TimerDL* or *drx-HARQ-RTT-TimerUL*) of a DRX HARQ RTT timer.

[0315] In an example, the one or more RRC messages may comprise configuration parameters (second parameters) of a cell DTX configuration. The one or more RRC messages may comprise a cell common RRC message (e.g., *MIB, SIB1/SIB2/SIB3/...,* etc.). The cell DTX configuration may be referred to as a cell level DTX configuration (or cell DTX configuration, DTX configuration, cell common DTX configuration, etc.), which is applied for all wireless devices in the cell. The configuration parameters of the cell DTX configuration may comprise a periodicity value of a cell DTX cycle of the cell DTX configuration, and a time offset value of a starting point of the cell DTX cycle. In an example, the configuration parameters of the cell DTX configuration may comprise at least one of: a first length indication of a first time period of a cell DTX Active Time (or a cell DTX on duration) of the cell DTX cycle and/or a second length indication of a second time period of a cell DTX inactive/non-active time (or a cell DTX off duration) of the DTX cycle.

[0316] In an example, the cell DTX/DRX configuration may be per cell configured (by the one or more RRC messages) in which case, each cell of a plurality of cells configured for the wireless device may be associated with one or more cell DTX/DRX configuration parameters specifically applied on the corresponding cell.

[0317] In an example, the wireless device may receive a SCell activation/deactivation MAC CE indicating an activation of the cell, e.g., if the cell is a SCell. Based on receiving the SCell activation/deactivation MAC CE, the wireless device may activate the SCell, e.g., based on example embodiments described above with respect to FIG. 21A, FIG. 21B and/or FIG. 22. The wireless device may perform downlink receptions and/or uplink transmissions via the activated SCell based on example embodiments described above with respect to FIG. 22.

[0318] In the example of FIG. 33, the wireless device may receive, at a second time (e.g., T1), a first message comprising parameters indicating an enabling (or triggering, activating, initiating, etc.) of the cell DTX configuration. The wireless device may receive the first message after the cell is activated (e.g., based on receiving a SCell activation/deactivation MAC CE indicating the activation of the cell) if the cell is an SCell.

[0319] In an example, the first message may comprise at least one of: an RRC message (which may be different from the one or more RRC messages, received in T0, configuring the UE DRX configuration and/or the cell DTX configuration), a MAC CE, a DCI, or any combination thereof. The MAC CE enabling the cell DTX configuration may be different from existing MAC CEs (e.g., as shown in FIG.19). The DCI enabling/activating the cell DTX configuration may be different from existing DCI formats (e.g., as shown in FIG. 23). The DCI may be a group common DCI transmitted to a plurality of wireless devices in the cell.

[0320] In the example of FIG. 33, the first message is a first DCI with DCI format 2_9 with CRC being scrambled by NES-RNTI or CDTRX-RNTI) used for activating or de-activating the cell DTX/DRX configuration of one or multiple serving cells for one or more UEs. The first DCI may comprise a plurality of information blocks, wherein each of the plurality of information blocks corresponds to a respective cell of a plurality of serving cells. The starting position of an information block is determined by the parameter *positionInDCI-cellDTRX* provided by higher layers for the wireless device. Each information block may comprise a cell DTX/DRX indication which may be 2 bits with the MSB corresponding to cell DTX configuration and the LSB corresponding to cell DRX configuration; otherwise, 1 bit. The wireless device may receive the first DCI via a first serving cell from a plurality of serving cells.

[0321] In an example, in response to receiving, at T1 (e.g., slot *m*), the first message indicating an enabling (or triggering, activating, initiating, etc.) of the cell DTX configuration corresponding to the first cell, the wireless device may operate on the first cell according to the cell DTX configuration of the first cell from T1.

[0322] In the example of FIG. 33, in response to receiving, at T1 (e.g., slot *m*), the first message indicating an enabling (or triggering, activating, initiating, etc.) of the cell DTX configuration corresponding to a second cell (different from the first cell where the wireless device receives the first message), the wireless device may operate on the second cell according to the cell DTX configuration corresponding to the second cell starting from a slot on the active BWP of the first cell, that is not before the beginning of the slot $m + d$ on the active DL BWP of the first cell where d is a number of slots for the SCS of the active DL BWP of the first cell as shown in FIG. 34.

[0323] In the example of FIG. 33, the wireless device operates on the second cell, from T2, according to the cell DTX configuration corresponding to the second cell, after receiving the first DCI at T1, wherein the time gap between T1 and T2 is equal to or greater than d.

[0324] In an example, the wireless device, when operating on the cell (e.g., the first cell, the second cell, etc.) according to the cell DTX configuration if the cell DTX configuration is activated, may perform the UE DRX operation (if configured) according to both the first parameters of the UE DRX configuration and the second parameters of the cell DTX configuration.

[0325] In an example, the wireless device, when operating on the cell according to the cell DTX configuration if the cell DTX configuration is activated, may perform the cell DTX according to the second parameters of the cell DTX configuration if the UE DRX is not configured.

[0326] In an example, when (or after) the cell DTX configuration is enabled/activated, in a first time duration of the cell DTX Active Time of a DTX cycle for the cell DTX configuration, the base station may transmit periodic downlink signals (e.g., SIBs/SSBs/CSI-RSs/TRSs), PDCCH/PDSCH, etc., as it does in the normal state of the cell. When (or after) the cell DTX configuration is enabled/activated, in a second time duration of the cell DTX inactive/non-active time of the DTX cycle for the cell DTX configuration, the base station may reduce transmission power/bandwidth/beam of the CSI-RSs, stop transmission of the CSI-RSs, and/or stop transmission of PDCCHs/PDSCHs, while the base station may keep transmitting MIB/SSBs/SIBs (which can be used for synchronization for legacy wireless devices or wireless devices in RRC_IDLE state or RRC_INACTIVE state).

[0327] In an example, if UE DRX configuration is configured, the wireless device may perform the UE DRX operation comprising discontinuously monitoring PDCCH (for one or more RNTIs associated with UE DRX configuration as shown above with respect to FIG. 30) in the UE DRX Active Time (indicated by the first parameters) within the first time duration (indicated by the second parameters) of the cell DTX Active Time according to example embodiments of FIG. 30. The wireless device may skip PDCCH monitoring for the one or more RNTIs associated with the UE DRX operation in the UE DRX inactive time, which may be within the first time duration of the cell DTX Active Time or the second time duration of the cell DTX inactive time, according to example embodiments of FIG. 30.

[0328] In an example, the wireless device may not be configured with a UE DRX configuration, in which case, the wireless device may monitor/receive MIB/SSBs/SIBs/CSI-RSs/PDSCHs/PDCCHs in the first time of the cell DTX Active Time of a cell DTX cycle of a cell DTX configuration and stop monitoring/receiving CSI-RSs/PDSCHs/PDCCHs in the second time of the cell DTX inactive time of the cell DTX cycle after the Cell DTX configuration is activated.

[0329] In the example of FIG. 33, the base station may determine to disable (or release, deactivate, clear, etc.) the cell DTX configuration, e.g., when there are more and more active wireless devices entering in the cell or moving into the cell, and/or when there are more and more (urgent) downlink/uplink data pending for transmissions. Staying (always) in the cell level DTX configuration (comprising periodic transitioning between cell DTX Active Time and cell DTX inactive time) may not ensure data transmission latency for these cases when there are more and more active wireless devices entering in the cell or moving into the cell, and/or when there are more and more (urgent) downlink/uplink data pending for transmissions. To improve the transmission latency, the base station may transmit, e.g., at T3, a second message indicating a disabling (or releasing, deactivating, clearing, etc.) of the cell DTX configuration. In response to deactivating the cell DTX configuration, the base station may resume the transmission of CSI-RSs/TRSs/PDCCHs/PDSCHs via the cell according to the configuration parameters of the downlink signals, in addition to keeping the transmissions of MIB/SSBs/SIBs via the cell.

[0330] In an example, the second message may comprise at least one of: an RRC message (which may be different from the first message, received in T1, enabling/activating the cell DTX configurations, each cell DTX configuration

being associated with a respective cell), a MAC CE, a DCI, or any combination thereof. In the example of FIG. 33, the second message is a DCI with the same DCI format as the first DCI.

[0331] In an example, in response to receiving, at T3 (e.g., slot *n*), the second message indicating a disabling (or releasing, deactivating, clearing, etc.) of the cell DTX configuration corresponding to the first cell, the wireless device may operate on the first cell without applying the cell DTX configuration of the first cell from T3.

[0332] In the example of FIG. 33, in response to receiving, at T3 (e.g., slot *n*), the second message indicating a disabling (or releasing, deactivating, clearing, etc.) of the cell DTX configuration corresponding to a second cell (different from the first cell where the wireless device receives the second message), the wireless device may operate on the second cell without applying the cell DTX configuration corresponding to the second cell (or may resume the normal (non-NES) operation on the second cell) starting from a slot on the active BWP of the first cell, that is not before the beginning of the slot $n + d$ on the active DL BWP of the first cell where d is a number of slots for the SCS of the active DL BWP of the first cell as shown in FIG. 34.

[0333] In the example of FIG. 33, the wireless device, based on disabling/deactivating the cell DTX configuration of the cell (the first cell or the second cell), may assume/determine that the cell is (always) in the power-on state (or the first power state/mode or the normal power state). Based on the disabling/deactivating of the cell DTX operation and the determining that the cell is in the power-on state (or the first power state/mode or the normal power state), the wireless device may perform the UE specific DRX operation (if configured), e.g., by ignoring the second parameters of the cell DTX configuration. The wireless device may perform the UE specific DRX operation based on example embodiments described above with respect to FIG. 30 and/or FIG. 31 if the UE specific DRX is configured for the wireless device.

[0334] In an example, if a base station needs to reduce periodicity of the always-on downlink signal transmission for network energy saving, the base station may transmit an RRC message (e.g., *SIB1*) indicating a longer periodicity for the always-on downlink signal transmission.

[0335] In an example, a base station, before determining to totally power off (e.g., both RF modules and base band units (BBUs)) for network energy saving (e.g., not just reducing periodicity of the always-on downlink signal transmission or perform cell DTX/DRX configuration as shown in FIG. 33), may transmit RRC reconfiguration messages to each wireless device in a source cell to indicate a handover to a neighbor cell.

[0336] In this specification, a cell which is in a network energy saving state may be referred to as a network-energy-saving (NES) cell. A base station may transmit less power, less bandwidth, less antenna ports/TRPs, less PDSCH/PDCCH via a NES cell. A non-NES cell may be a cell which is not operating in a NES state. A base station may transmit full power, full bandwidth, and more channels via a non-NES cell.

[0337] In an example, a base station may transmit one or more SSBs periodically to a wireless device, or a plurality of wireless devices. The wireless device (in RRC_IDLE state, RRC_INACTIVE state, or RRC_CONNECTED state) may use the one or more SSBs for time and frequency synchronization with a cell of the base station. An SSB,

comprising a primary synchronization signal (PSS), a secondary synchronization signal (SSS), a physical broadcast channel (PBCH), and a PBCH DM-RS, may be transmitted based on example embodiments described above with respect to FIG. 11A. An SSB may occupy a number (e.g., 4) of OFDM symbols as shown in FIG. 11A. The base station may transmit one or more SSBs in a SSB burst, e.g., to enable beam-sweeping for PSS/SSS and PBCH. An SSB burst comprises a set of SSBs, each SSB potentially transmitted on a different beam. SSBs in the SSB burst may be transmitted in time-division multiplexing fashion. In an example, an SSB burst may always be confined to a 5ms window and is either located in first-half or in the second half of a 10ms radio frame. In this specification, an SSB burst may be equivalently referred to as a transmission window (e.g., 5ms) in which the set of SSBs are transmitted.

[0338] In an example, the base station may indicate a transmission periodicity of SSB via RRC message (e.g., *ssb-PeriodicityServingCell* in *ServingCellConfigCommonSIB* of *SIB1* message, or *ServingCellConfigCommon* of a serving cell). A candidate value of the transmission periodicity may be in a range of {5ms, 10ms, 20ms, 40ms, 80ms, 160ms}. The maximum number of candidate SSBs (L_{max}) within an SSB burst depends upon a carrier frequency/band of the cell. In an example, L_{max}=4 if f_c<=3GHz, wherein f_c is the carrier frequency of the cell. L_{max}=8 if 3GHz<f_c<=6GHz. L_{max}=64 if f_c>=6GHz, etc.

[0339] In an example, a starting OFDM symbol index of a candidate SSB (occupying 4 OFDM symbols) within a SSB burst (5ms) may depend on a subcarrier spacing (SCS) and a carrier frequency band of the cell.

[0340] FIG. 35 shows an example of starting OFDM symbol index determination of an SSB. As shown in FIG. 35, starting OFDM symbol indexes of SSBs in a SSB burst, for a cell configured with 15 kHz and carrier frequency fc<3GHz (L_{max}=4), are 2, 8, 16, and 22. OFDM symbols in a half-frame are indexed with the first symbol of the first slot being indexed as 0. Starting OFDM symbol indexes of SSBs in a SSB burst, for a cell configured with 15 kHz and carrier frequency 3GHz<fc<6GHz (L_{max}=8), are 2, 8, 16, 22, 30, 36, 44 and 50, etc. In an example, when the base station is not transmitting the SSBs with beam forming, the base station may transmit only one SSB by using the first SSB starting position.

[0341] FIG. 36 shows an example of SSB transmission of a cell by a base station. In the example of FIG. 36, a SCS of the cell is 15 kHz, and the cell is configured with 3GHz<fc<=6GHz. Based on example embodiment of FIG. 36, maximum number of candidate SSBs in a SSB burst is 8 (Lmax=8). As shown in FIG. 36, SSB#1 starts at symbol#2 of 70 symbols in 5ms, SSB#2 starts at symbol#8, SSB#3 starts at symbol#16, SSB#4 starts at symbol#22, SSB#5 starts at symbol#30, SSB#6 starts at symbol#36, SSB#7 starts at symbol#44, and SSB#8 starts at symbol 50. The SSB burst is transmitted in the first half (not the second half as shown in FIG. 36) of a radio frame with 10 ms.

[0342] In an example, the SSB burst (also for each SSB of the SSB burst) may be transmitted in a periodicity. In the example of FIG. 36, a default periodicity of a SSB burst is 20 ms, e.g., before a wireless device receives a *SIB1* message for initial access of the cell. The base station, with 20 ms transmission periodicity of SSB (or SSB burst),

may transmit the SSB burst in the first 5 ms of each 20 ms. The base station does not transmit the SSB burst in the rest 15 ms of the each 20 ms.

[0343] In an example, a base station may transmit RRC messages (e.g., *SIB1* and/or *ServingCellConfigCommon* IE) indicating cell specific configuration parameters of SSB transmission of a serving cell (e.g., a PCell or a SCell). The cell specific configuration parameters may comprise a value for a transmission periodicity (*ssb-PeriodicityServingCell*) of a SSB burst, locations of a number of SSBs (e.g., active SSBs), of a plurality of candidate SSBs, comprised in the SSB burst. The plurality of candidate SSBs may be implemented based on example embodiments described above with respect to FIG. 36. The cell specific configuration parameters may comprise position indication of a SSB in a SSB burst (e.g., *ssb-PositionsInBurst*). The position indication may comprise a first bitmap (e.g., *groupPresence*) and a second bitmap (e.g., *inOneGroup*) indicating locations of a number of SSBs comprised in a SSB burst.

[0344] In an example, a base station may transmit a Master Information Block (*MIB* or MIB in this specification) on PBCH, to indicate configuration parameters (e.g., *PDCCH-ConfigSIB1* as shown in FIG. 24A) for a wireless device monitoring PDCCH for receiving a *SIB1* message. The *PDCCH-ConfigSIB1* IE may indicate a resource configuration index (*ControlResourceSetZero* indicating SSB and CORESET multiplex pattern, number of RBs for the CORESET, number of symbols of the CORESET and frequency offset of the CORESET relative to a reference point of the cell, as shown in FIG. 24B) for CORESET#0 (corresponding to the CORESET for Type0-PDCCH CSS set) for the *SIB1* message. The *PDCCH-ConfigSIB1* IE may indicate a resource configuration index (*SearchSpaceZero* indicating, a time offset, number of search space sets in a slot, first symbol index, etc., as shown in FIG. 24C) for search space #0 for the *SIB1* message. The base station may transmit a *MIB* message with a transmission periodicity of 80 millisecond (ms). The same *MIB* message may be repeated (according to SSB periodicity) within the 80 ms. Contents of a *MIB* message are same over 80 ms period. The same *MIB* is transmitted over all SSBs within a SS burst. In an example, PBCH may indicate that there is no associated *SIB1*, in which case a wireless device may be pointed to another frequency from where to search for an SSB that is associated with a *SIB1* as well as a frequency range where the wireless device may assume no SSB associated with *SIB1* is present. The indicated frequency range may be confined within a contiguous spectrum allocation of the same operator in which SSB is detected.

[0345] In an example, as a first option, a base station may transmit SSB and CORESET#0 multiplexed in time domain, wherein the symbols used for SSB transmissions and the symbols used for CORESET#0 are not overlapping in time domain, in which case, the transmission of SSB and CORESET#0 may be referred to as SSB and CORESET#0 multiplexing pattern 1. Different from the SSB and CORESET#0 multiplexing pattern 1, as a second option, the base station may transmit the SSB and CORESET#0 in different symbols (or time domain multiplexed) while the PDSCH (containing *SIB1* message) scheduled by a DCI via CORESET#0 are frequency domain multiplexed with the SSB, in which case, the transmission of SSB and CORESET#0 may be referred to as

SSB and CORESET#0 multiplexing pattern 2. As a third option, the base station may transmit SSB and CORESET#0 and the PDSCH multiplexed in frequency domain, wherein the symbols used for SSB transmissions and the symbols used for CORESET#0/PDSCH are overlapping in time domain, in which case, the transmission of SSB and CORESET#0 may be referred to as SSB and CORESET#0 multiplexing pattern 3.

[0346] In an example, the base station may transmit a DCI (or a group common DCI), scheduling the *SIB1* message, via a PDCCH with SI-RNTI according to configuration parameters of search space #0 and control resource set #0 indicated by the *MIB* messages. The base station may transmit a *SIB1* message with a periodicity of 160 ms. The base station may transmit the same *SIB1* message with variable transmission repetition periodicity within 160 ms. The default transmission repetition periodicity of *SIB1* is 20 ms. The base station may determine an actual transmission repetition periodicity based on network implementation. In an example, for SSB and CORESET multiplexing pattern 1, *SIB1* repetition transmission period is 20 ms. For SSB and CORESET multiplexing pattern 2/3, *SIB1* transmission repetition period is the same as the SSB period. *SIB1* may comprise information regarding the availability and scheduling (e.g., mapping of SIBs to SI message, periodicity, SI-window size) of other SIBs, an indication whether one or more SIBs are only provided on-demand and in which case, configuration parameters needed by a wireless device to perform an SI request.

[0347] In an example, a base station may transmit SSBs/*SIB1* over each serving cell (e.g., a PCell or an SCell) of multiple serving cells configured for a wireless device. The base station may transmit SSBs/*SIB1* over some serving cells of the multiple serving cells and may not transmit SSBs/*SIB1* over other serving cells of the multiple serving cells. A serving cell without SSBs/*SIB1* may be referred to as an SSB/*SIB1*-less serving cell. A serving cell with SSBs/*SIB1*always transmitted by the base station may be referred to as an always-on- SSBs/*SIB1* serving cell.

[0348] In an example, the *MIB* message may comprise a *ssb-SubcarrierOffset* (as shown in FIG. 24A) indicating a frequency domain offset (corresponding to k_{SSB}) between SSB and the overall resource block grid in number of subcarriers. The *ssb-SubcarrierOffset* field may indicate that the cell does not provide *SIB1* and that there is hence no CORESET#0 configured in *MIB*. The wireless device may determine, from *MIB*, upon detection of a SSB, that a CORESET for Type0-PDCCH CSS set (corresponding to CORESET#0), is present if $k_{SSB} \leq 23$ for FR1 or if $k_{SSB} \leq 11$ for FR2. The wireless device may determine, from *MIB*, that CORESET#0 is not present if $k_{SSB} > 23$ for FR1 or if $k_{SSB} > 11$ for FR2. In this case, the field *pdcch-ConfigSIB1* of the MIB message may indicate the frequency positions where the wireless device may (not) find a SSB with CORESET#0 and search space#0 for *SIB1*. If the field *ssb-SubcarrierOffset* indicates that *SIB1* is absent, the field *pdcch-ConfigSIB1* of the MIB message may indicate the frequency positions where the wireless device may find SSB with *SIB1* or the frequency range where the network does not provide SSB with *SIB1*, e.g., according to 3GPP standard specification TS 38.213, clause 13.

[0349] In an example, a wireless device, for operation without shared spectrum channel access and for the SSB and CORESET multiplexing pattern 1, may monitor PDCCH in the Type0-PDCCH CSS set (corresponding to search

space #0) over two slots. For a SSB with index i, the wireless device may determine an index of slot n_0 as $n_0 = (O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor) \mathrm{mod} N_{\mathrm{slot}}^{\mathrm{frame},\mu}$ that is in a frame with system frame number (SFN) $\mathrm{SFN_C}$ satisfying $\mathrm{SFN_c mod} 2 = 0$ if $\lfloor (O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor) / N_{\mathrm{slot}}^{\mathrm{frame},\mu} \rfloor \mathrm{mod} 2 = 0$, or in a frame with SFN satisfying $\mathrm{SFN_c mod} 2 = 1$ if $\lfloor (O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor) / N_{\mathrm{slot}}^{\mathrm{frame},\mu} \rfloor \mathrm{mod} 2 = 1$ where $\mu \in \{0,1,2,3,5,6\}$ based on the SCS for PDCCH receptions in the CORESET. In an example, M, O, and the index of the first symbol of the CORESET may be indicated by *SearchSpaceZero*, e.g., as shown in FIG. 24C. For $\mu \in \{0, 1, 2, 3\}$ and for a SSB index i, the two slots including the associated Type0-PDCCH monitoring occasions are slots n_0 and $n_0 + 1$. For $\mu = 5$ and for a SSB index i, the two slots including the associated Type0-PDCCH monitoring occasions are slots n_0 and $n_0 + 4$. For $\mu = 6$ and for a SSB index i, the two slots including the associated Type0-PDCCH monitoring occasions are slots n_0 and $n_0 + 8$, etc.

[0350] In an example, a wireless device, for operation without shared spectrum channel access and for the SSB and CORESET multiplexing pattern 2 and/or 3, may monitor PDCCH in the Type0-PDCCH CSS set over one slot with Type0-PDCCH CSS set periodicity equal to the periodicity of SSB. For a SSB with index i, the UE determines, based on *SearchSpaceZero*, the slot index n_c and $\mathrm{SFN_c}$ based on parameters provided by Tables 13-13 through 13-15A of 3GPP TS 38.213 clause 13.

[0351] In an example, a wireless device, for the SSB and CORESET multiplexing patterns 2 and 3, if the active DL BWP is the initial DL BWP, may be expected to be able to perform radio link monitoring (RLM) and measurements for radio resource management (RRM) using a SSB that provides a CORESET for Type0-PDCCH CSS set.

[0352] In an example, if a wireless device detects a first SSB and determines that a CORESET for Type0-PDCCH CSS set is not present, and for $24 \le k_{\mathrm{SSB}} \le 29$ for FR1 or for $12 \le k_{\mathrm{SSB}} \le 13$ for FR2, the wireless device may determine the nearest (in the corresponding frequency direction) global synchronization channel number (GSCN) of a second SSB having a CORESET for an associated Type0-PDCCH CSS set as $N_{\mathrm{GSCN}}^{\mathrm{Reference}} + N_{\mathrm{GSCN}}^{\mathrm{Offset}}$. $N_{\mathrm{GSCN}}^{\mathrm{Reference}}$ is the GSCN of the first SSB and $N_{\mathrm{GSCN}}^{\mathrm{Offset}}$ is a GSCN offset (e.g., provided by Table 13-16 for FR1 and Table 13-17 for FR2 in TS 38.213, clause 13). If the wireless device detects the second SSB and the second SSB does not provide a CORESET for Type0-PDCCH CSS set, the wireless device may ignore the information related to GSCN of SSB locations for performing cell search.

[0353] In an example, if a wireless device detects a SSB and determines that a CORESET for Type0-PDCCH CSS set is not present, and for $k_{\mathrm{SSB}} = 31$ for FR1 or for $k_{\mathrm{SSB}} = 15$ for FR2, the wireless device determines that there is no SSB having an associated Type0-PDCCH CSS set within a GSCN range $[N_{\mathrm{GSCN}}^{\mathrm{Reference}} - N_{\mathrm{GSCN}}^{\mathrm{Start}}, N_{\mathrm{GSCN}}^{\mathrm{Reference}} + N_{\mathrm{GSCN}}^{\mathrm{End}}]$. $N_{\mathrm{GSCN}}^{\mathrm{Start}}$ and $N_{\mathrm{GSCN}}^{\mathrm{End}}$ are respectively determined by *controlResourceSetZero* and *searchSpaceZero* in *pdcch-ConfigSIB1*. If the GSCN range is $[N_{\mathrm{GSCN}}^{\mathrm{Reference}}, N_{\mathrm{GSCN}}^{\mathrm{Reference}}]$, the wireless device determines that there is no information for a second SSB with a CORESET for an associated Type0-PDCCH CSS set on the detected SSB.

[0354] In an example, if a wireless device does not detect any SSB providing a CORESET for Type0-PDCCH CSS set, within a time period determined by the wireless device, the wireless device may ignore the information related to GSCN of SSBs in performing cell search.

[0355] For a serving cell without transmission of SSBs, the wireless device may acquire time and frequency synchronization with the serving cell based on receptions of SSBs on the PCell, or on the PSCell, of the cell group for the serving cell.

[0356] In an example, the base station may transmit a *SIB1* message of a cell via RRC Reconfiguration message (e.g., comprising *dedicatedSIB1-Delivery* IE), different from the broadcasted *SIB1* message scheduled by DCI with SI-RNTI in search space#0 and CORESET#0.

[0357] In addition to always-on SSBs/*SIB1*and SSBs/*SIB1*-less, a base station may transmit SSBs/*SIB1* over a cell based on indication from a wireless device, or from another base station, and/or triggered by the base station itself (e.g., by transmitting a SCell activation/deactivation MAC CE). When there is no indication from the wireless device or from another base station or there is no trigger from the base station, the base station may stop/skip transmitting the SSBs/*SIB1*. The SSBs/*SIB1* transmitted/stopped upon a request may be referred to as on-demand SSBs/*SIB1*.

[0358] In an example, a wireless device may acquire essential system information (e.g., *MIB* or *SIB1*) as described above, e.g., when performing camping a cell in RRC_IDLE state or performing handover to a neighbor cell in RRC_CONNECTED state. The wireless device, if *ssb-SubcarrierOffset* indicates *SIB1* is transmitted in the cell and if *SIB1* acquisition is required for the wireless device, may acquire the *SIB1,* which is scheduled by a DCI with SI-RNTI via PDCCH occasions according to search space#0 and CORESET#0 of the cell. The wireless device may not be able to acquire the SIB message. When the wireless device is unable to acquire the *SIB1* message, the wireless device may consider the cell is barred and may perform a cell re-selection to another cell in the same frequency.

[0359] FIG. 37 shows an example of an essential system information reception procedure. In an example, a wireless device receives, and/or a base station transmits, a *MIB* message comprising configuration and/or scheduling information of a *SIB1* message of a cell. The configuration and/or the scheduling information may be implemented based on examples above and/or FIG. 24A. The wireless device, based on the *MIB* message, may detect/receive SSBs of the cell. A SSB may be implemented based on examples of FIG. 35 and/or FIG. 36. The transmissions of MIB and SSBs illustrated in FIG. 37 are only for reference. Note that MIB and SSBs are transmitted in the same slot as shown in FIG. 36.

[0360] In an example, as shown in FIG. 37, the wireless device may measure the SSBs and monitor PDCCH via search space#0 of CORESET#0 of the cell based on the *MIB* message. In response to receiving a DCI scheduling *SIB1* message based on monitoring the PDCCH via search space#0 of CORESET#0 of the cell, the wireless device may obtain the cell common configuration parameters (e.g., based on example of FIG. 25 and/or FIG. 26) of the cell and acquire other system information (e.g., SIB2, SIB3, etc.) based on the cell common configuration parameters of

the cell, wherein the other system information may be on-demand triggered by a RA procedure as shown in FIG. 37 based on RRC configuration of FIG. 26, or may be periodical transmitted if it is configured as broadcast transmissions. After obtaining the system information, the wireless device may perform an initial access procedure (e.g., based on examples of FIG. 13A, FIG. 13B and/or FIG. 13C) via the cell, based on the cell common configuration parameters of the cell.

[0361] In an example, the wireless device may not receive/decode the DCI scheduling the *SIB1* message according to the configuration of search space#0 and CORESET#0 of the cell based on the *MIB* message. In an example, the wireless device may not receive/decode the DCI due to bad channel quality of the PDCCH carrying the DCI. The wireless device may not decode the *SIB1* message carried in a PDSCH transmission scheduled by the DCI with CRC scrambled by SI-RNTI. In an example, the wireless device may not decode the *SIB1* message due to bad channel quality of the PDSCH carrying the *SIB1* message. In response to the *MIB* being acquired and the *SIB1* not being acquired (e.g., due to not decoding the DCI and/or the PDSCH carrying the *SIB1* message), the wireless device may determine/consider the cell as barred (even if the cell is not indicated as barred in the *MIB* message). The wireless device, if it is a RedCap wireless device, may perform barring (as shown below) as if *intraFreqReselectionRedCap* of a *SIB1* message is set to *allowed*. The wireless device, if it is not a RedCap wireless device, may perform a cell re-selection to other cells on the same frequency as the barred cell.

[0362] In an example, allowing the wireless device to select, for camping, another cell (for example, any other cell than a selected cell) in response to not acquiring *SIB1* message from a selected cell, may reduce power consumption of the wireless device for finding a suitable cell for camping. Otherwise, the wireless device may keep trying to decode the *SIB1* message in vain when the channel quality of the PDCCH/PDSCH is not good enough on the selected cell.

[0363] In the example of FIG. 37, in response to receiving/acquiring the SIB1 message, the wireless device may determine whether other SIBs (e.g., *SIB2, SIB3, SIB4*, etc.), other than SIB1, are periodically transmitted or on-demand requested, based on scheduling configuration parameters (e.g., *SI-SchedulingInfo* IE as shown in FIG. 25 and/or FIG. 26), of system information, comprised in the SIB1 message. The wireless device may request on-demand SIs according to following procedure(s):

1> if *SIB1* includes *si-SchedulingInfo* containing *si-RequestConfigSUL* and criteria to select supplementary uplink is met:

2> trigger the lower layer to initiate the Random Access procedure on supplementary uplink using the PRACH preamble(s) and PRACH resource(s) in *si-RequestConfigSUL* corresponding to the SI message(s) that the UE requires to operate within the cell, and for which *si-BroadcastStatus* is set to *notBroadcasting*;

2> if acknowledgement for SI request is received from lower layers:

3> acquire the requested SI message(s) immediately;

1> else if the UE is a RedCap UE and if *initialUplinkBWP-RedCap* is configured in *UplinkConfigCommonSIB* and if *SIB1* includes *si-SchedulingInfo* containing *si-RequestConfigRedCap* and criteria to select normal uplink is met:

2> trigger the lower layer to initiate the Random Access procedure on normal uplink using the PRACH preamble(s) and PRACH resource(s) in *si-RequestConfigRedcap* corresponding to the SI message(s) that the UE requires to operate within the cell, and for which *si-BroadcastStatus* is set to *notBroadcasting*;

2> if acknowledgement for SI request is received from lower layers:

3> acquire the requested SI message(s) immediately;

1> else:

2> if the UE is not a RedCap UE and if *SIB1* includes *si-SchedulingInfo* containing *si-RequestConfig* and criteria to select normal uplink is met; or

2> if the UE is a RedCap UE and if *initialUplinkBWP-RedCap* is not configured in *UplinkConfigCommonSIB* and if *SIB1* includes *si-SchedulingInfo* containing *si-RequestConfig* and criteria to select normal uplink is met:

3> trigger the lower layer to initiate the Random Access procedure on normal uplink using the PRACH preamble(s) and PRACH resource(s) in *si-RequestConfig* corresponding to the SI message(s) that the UE requires to operate within the cell, and for which *si-BroadcastStatus* is set to *notBroadcasting*;

3> if acknowledgement for SI request is received from lower layers:

4> acquire the requested SI message(s) immediately;

2> else:

3> apply the default L1 parameter values as specified in corresponding physical layer specifications except for the parameters for which values are provided in *SIB1*;

3> apply the default MAC Cell Group configuration;

3> apply the *timeAlignmentTimerCommon* included in *SIB1*;

3> apply the CCCH configuration;

3> initiate transmission of the *RRCSystemInfoRequest* message with *rrcSystemInfoRequest*;

3> if acknowledgement for *RRCSystemInfoRequest* message with *rrcSystemInfoRequest* is received from lower layers:

4> acquire the requested SI message(s) immediately;

1> if cell reselection occurs while waiting for the acknowledgment for SI request from lower layers:

2> reset MAC;

2> if SI request is based on *RRCSystemInfoRequest* message with *rrcSystemInfoRequest*:

3> release RLC entity for SRB0.

[0364] In existing technologies for network energy saving, different from periodical transmissions of *SIB1* message (e.g., wherein the configuration parameters of the periodical transmissions of the *SIB1* message may be implemented based on examples of FIG. 24A, FIG. 24B, FIG. 24C, FIG. 25 and/or FIG. 26), a base station may

transmit *SIB1* message on-demand, e.g., triggered by a reception of an uplink signal from a wireless device. The base station may skip the periodic transmissions of the *SIB1* message when there is no wireless device selecting the cell or camping on the cell.

[0365] FIG. 38 shows an example of on-demand *SIB1* transmission based on a wake-up signal (WUS). A wireless device (e.g., in an RRC_IDLE state) may receive a *MIB* message from a cell. The *MIB* message may be implemented based on examples of FIG. 24A, FIG. 24B and/or FIG. 24C. The *MIB* message may indicate whether SSB and/or *SIB1* message are transmitted via the cell, based on examples of FIG. 24A, FIG. 24B and/or FIG. 24C and/or descriptions as above.

[0366] In the example of FIG. 38, the *SIB1* message may be on-demand transmitted or may not be always transmitted via the cell. The SSBs (e.g., SSB1, SSB2, ..., SSBN) may be periodically transmitted via the cell based on example of FIG. 38. Different SSBs may be transmitted with different beams, e.g., SSB1 with Beam 1, SSB2 with Beam 2, ..., SSBN with Beam N. The (time domain and/or frequency domain) multiplexing between a SSB and a type0 CSS for a DCI scheduling the *SIB1* message (and the PDSCH carrying the *SIB1* message) may be implemented based on examples above.

[0367] In the example of FIG. 38, the wireless device may measure the SSBs (e.g., by detecting the PCI of the cell) and monitor PDCCH (via the type0 CSS of the CORESET#0 of the cell) for receiving the DCI (with CRC bits being scrambled by SI-RNTI) scheduling the *SIB1* message. One or more PDCCH monitoring occasions of the PDCCH may be determined based on a corresponding SSB, based on the multiplexing pattern of the SSB and the type0 CSS as described above. Different SSBs may be associated with different PDCCH monitoring occasions. The wireless device may use the same receiving beam (or spatial domain filter) to receive a SSB and monitor one or more PDCCH monitoring occasions, corresponding to the SSB, of the type0 CSS. The DCIs, scheduling *SIB1* message, transmitted via different PDCCH occasions corresponding to different SSBs may have the same contents and the *SIB1* messages received according to the DCIs may have the same contents, e.g., when the *SIB1* message has not been changed.

[0368] In the example of FIG. 38, the wireless device may receive one or more SSBs of the SSBs in a period of the transmission of the SSBs. The wireless device may not detect the DCI scheduling the *SIB1* message or may not decode the *SIB1* message in a transmission period of the *SIB1* message. The periodicity of the SSBs and the periodicity of the *SIB1* message/type0 CSS may be implemented based on the examples set forth above. In response to receiving at least one SSB and not receiving the *SIB1* message, the wireless device may trigger the WUS transmission. A WUS may be a signal sequence similar to a preamble for an RA procedure, or similar to a sounding reference signal (SRS), or a new signal sequence specifically configured or preconfigured for requesting the *SIB1* message.

[0369] Afte the wireless device transmits the WUS, the wireless device may monitor PDCCH occasions for receiving the DCI scheduling the *SIB1* message. The base station, in response to receiving the WUS in uplink of the cell, may transmit the *SIB1* message.

[0370] In this specification, the *SIB1* message triggered by a WUS may be referred to an on-demand *SIB1* message, which is different from always-on *SIB1* message in a legacy system not implementing network energy saving operation. The base station, by not always transmitting the *SIB1* message and/or by triggering the transmission of the *SIB1* message upon receiving a WUS, may reduce power consumption of the transmission of the common message/signaling, e.g., when there is no active wireless device in the cell (or no wireless device selecting the cell or camping on the cell).

[0371] In existing technologies, it is proposed to reuse the legacy preamble/RA procedure for a WUS requesting/triggering on-demand SIB1 message for a network energy saving operation. A procedure for the WUS requesting/triggering on-demand SIB1 message for a network energy saving operation may be implemented based on examples illustrated by FIG. 38. The legacy preamble/procedure may be implemented based on examples of FIG. 13A, FIG. 13B and/or FIG. 13C. The legacy RA procedure may be used by a wireless device for uplink time/frequency synchronization, beam failure recovery, handover to a neighbor cell, etc.

[0372] FIG. 39 shows an example of an existing RA procedure.

[0373] In an example, to ensure a base station correctly receive a preamble from a wireless device, the goal of existing RACH (e.g., CBRA) procedure being designed is to avoid/reduce uplink interference for preamble transmissions from different wireless devices, (in the same cell or different cells), e.g., by reducing the possibility of selecting the same preamble, the same RACH occasion from the same pool of preambles/occasions by multiple wireless devices.

[0374] In existing technologies, if there is a collision among wireless devices, the wireless devices may apply a collision resolution mechanism (e.g., comprising reselection of preamble/RACH occasion and/or applying a time backoff and/or power ramping up for retransmission, as shown in FIG. 13A).

[0375] In existing technologies, to avoid/reduce uplink interference among multiple wireless devices for preambles transmissions for an RA procedure, the base station may configure multiple preambles available for a wireless device to select (e.g., the total number of preambles in the preamble pool is 64 in 3GPP standards). A preamble is generated as a Zadoff-Chu sequence. The 64 preambles may be enumerated in increasing order of first increasing cyclic shift C_v of a logical root sequence, and then in increasing order of a logical root sequence index, starting with the index obtained from the higher-layer parameter *prach-RootSequenceIndex* (indicated for the logical root sequence). In an example of FIG. 39, Cell 0 may be associated with or configured with a first group of preambles, while Cell 1 may be associated with or configured with a second group of preambles, wherein the first group of preambles may be different from the second group of preambles.

[0376] In existing technologies, to further reduce collision, the base station may configure the RACH resources per cell as follows: different RACH occasions are configured to be associated with different SSBs; PRACH configuration index may be configured to be different for different cells, preamble root sequence index (*prach-RootSequenceIndex*) may be configured to be different for different cells; and/or frequency start point of the preamble may be configured to be different for different cells, etc.

[0377] In existing technologies, to ensure the base station receives the preamble, the base station may configure a dedicated search space (e.g., a search space for an RAR reception, *ra-SearchSpace* which is a type1-PDCCH CSS, or a search space for a BFR response reception, *recoverySearchSpaceId, etc.)* for a wireless device to monitor for an RA response upon the wireless device transmits the preamble. If the wireless device does not receive the RA response (due to the base station miss-detecting the preamble caused by uplink collision or uplink channel quality not good enough, or due to downlink channel quality not good for the RA response transmission), the wireless device may retransmit the preamble or select another preamble to continue the RA procedure. In the example of FIG. 39, UE1, in Cell 0, may transmit preamble1 to Cell 0 and then monitor a dedicated search space of Cell 0 for receiving an RAR corresponding to the preamble1, while UE2, in Cell 0, may transmit preamble2 to Cell 0 and then monitor a dedicated search space of Cell 0 for receiving an RAR corresponding to the preamble2. The RAR for preamble1 may comprise a parameter indicating a received preamble1 by the base station, while the RAR for preamble2 may comprise a parameter indicating a received preamble2 by the base station, so that UE1 and/or UE2 understand/determine whether the base station receives the preambles. The RARs for different UEs may be different. A similar RAR transmission may be applied for Cell 1.

[0378] However, reusing existing/legacy (on-demand SI information request, initial access, random access procedure, beam failure recovery, handover, etc.) RA procedure or preamble for the WUS triggering on-demand *SIB1* may not be efficient in terms of implementation complexity, power consumption, resource consumption, and/or latency for a base station for transmitting the on-demand *SIB1* and/or a wireless device for triggering/acquiring the on-demand *SIB1*. There is a need to improve implementation complexity, power consumption, resource consumption and/or latency for a transmission of a WUS requesting/triggering the SIB1 for network energy saving.

[0379] One or more example embodiments comprise a wireless device, in an RRC_IDLE state or an RRC_INACTIVE state, receiving from a base station a *MIB* message, of a cell. The *MIB* message can include a first indication indicating that a *SIB1* is on-demand transmitted via the cell; a second indication indicating an uplink radio resource for a wake-up signal (WUS) triggering the *SIB1*; and configuration parameters of SSBs of the cell. The wireless device determines a PCI of the cell based on receiving at least one of the SSBs of the cell. The wireless device generates a signal (or a signal sequence) of the WUS based on the PCI of the cell, in response to the determining the PCI of the cell and the first indication indicating that *SIB1* is on-demand transmitted via the cell. The wireless device transmits, via the uplink radio resource, the signal of the WUS triggering/requesting a broadcast transmission

of the *SIB1*. The base station, in response to receiving the WUS generated based on the PCI of the cell, starts to broadcast the *SIB1* on the cell.

[0380] One or more example embodiments comprise a wireless device receiving from a base station a *MIB* message, of a cell. The *MIB* message includes an indication indicating that a *SIB1* is on-demand (and broadcast) transmitted via the cell. The wireless device, in response to the indication indicating that *SIB1* is on-demand transmitted via the cell, transmits a signal triggering/requesting a broadcast transmission of the *SIB1* and generated based on a PCI of the cell. The base station, in response to receiving the WUS generated based on the PCI of the cell, starts to broadcast the *SIB1* on the cell.

[0381] One or more example embodiments comprise a wireless device transmitting to a base station and via a cell, an uplink signal (or signal sequence): triggering (or requesting or demanding) a broadcast transmission of a *SIB1* message via the cell; and generated based on a PCI of the cell. The base station, in response to receiving the uplink signal, starts to broadcast the *SIB1* on the cell.

[0382] One or more example embodiments comprise transmitting (or starting to transmit), by a base station, a broadcast SIB1 message in a cell, in response to receiving a WUS, of a wireless device, triggering an on-demand transmission of the SIB1 message in the cell.

[0383] One or more example embodiments comprise a wireless device receiving, in an RRC_CONNECTED state, an RRC release message comprising first configuration parameters of SSBs of a cell, a parameter indicating that a *SIB1* is on-demand triggered on the cell, and/or second configuration parameters of uplink radio resources of a wake-up signal triggering the *SIB1* of the cell. The wireless device transitions, based on the RRC release message, from the RRC_CONNECTED state to an RRC IDLE state or an RRC_INACTIVE state. The wireless device, via the uplink radio resources, the wake-up signal triggering/requesting/demanding the *SIB1*, wherein the wake-up signal is a signal (or a signal sequence) generated based on a PCI of the cell, in response to the wireless device transitioning to the RRC_IDLE state or the RRC_INACTIVE state; receiving at least one SSB of the SSBs of the cell; not receiving the *SIB1* in *SIB1* occasions; and/or the *SIB1* not being available after the RRC release message is received.

[0384] One or more example embodiments comprise receiving, by a wireless device, an RRC release message comprising a first parameter indicating a signal sequence of a wake-up signal and a second parameter indicating that *SIB1* message is on-demand triggered, by the wake-up signal, on the cell. The wireless device transitions from an RRC_CONNECTED state to an RRC_IDLE state (or an RRC_INACTIVE state). The wireless device transmits, based on the signal sequence, the wake-up signal triggering/requesting the *SIB1* message, in response to the wireless device transitioning to the RRC_IDLE state (or the RRC_INACTIVE state) and the second parameter indicating that the *SIB1* message is on-demand triggered.

[0385] One or more example embodiments comprise receiving, by a wireless device, an RRC release message comprising configuration parameters of uplink radio resources of a wake-up signal, a first parameter indicating a

signal sequence of the wake-up signal and a second parameter indicating that a *SIB1* message is on-demand triggered, by the wake-up signal on the cell. The wireless device transitions from an RRC_CONNECTED state to an RRC_IDLE state (or an RRC_INACTIVE state). The wireless device transmits, via the uplink radio resources based on the signal sequence, the wake-up signal triggering/requesting the *SIB1* message, in response to the wireless device transitioning to the RRC_IDLE state (or the RRC_INACTIVE state) and the second parameter indicating that the *SIB1* message is on-demand triggered.

[0386] One or more example embodiments comprise transmitting a wake-up signal, triggering an on-demand *SIB1* message of a cell, with a subcarrier spacing based on an indication of a *MIB* message of the cell. The indication indicates a common subcarrier spacing used for at least one of: a reception of the *SIB1*, a transmission of a message 2 and/or 4 for initial access, a reception of a message B for initial access, a reception of a paging message, and/or a reception of broadcast SI message. The subcarrier spacing, used for the wake-up signal triggering the on-demand *SIB1* message of the cell, is independently and/or separately configured from a second subcarrier spacing for a preamble for a random access procedure, wherein the second subcarrier spacing is configured in the on-demand *SIB1* message.

[0387] One or more example embodiments comprise determining, by a wireless device, a signal (or a signal sequence), for a wake-up signal triggering an on-demand *SIB1* message of a cell, based on at least one of: a PCI value of the cell, an SSB index of a detected SSB of the cell, an indicated offset by the *MIB* of the cell and/or a combination thereof.

[0388] One or more example embodiments comprise determining, by a wireless device, for a transmission of a wake-up signal triggering an on-demand *SIB1* message of a cell, a (default or predefined) TDD pattern of the cell based on at least one of: a parameter of the *MIB* message, a frequency band of the cell, a pre-stored configuration of the cell, an RRC release message for the cell, etc. The wireless device transmits the wake-up signal in an uplink symbol/slot based on the determined TDD pattern of the cell and/or a system frame number indicated by the *MIB* message of the cell.

[0389] FIG. 40 shows an example embodiment of wake-up signal transmission triggering on-demand *SIB1* message of a cell, based on examples of FIG. 38. As shown in FIG. 40, a wireless device (e.g., UE1, UE2, UE3, UE4) may select a cell (e.g., Cell 0, Cell 1) for camping on in an RRC_IDLE state (or an RRC_INACTIVE state), e.g., based on a cell (re-)selection procedure. In the example of FIG. 40, UE1 and UE2 may select Cell 0, e.g., based on an RSRP measurement of SSBs of Cell 0 being good to meet a cell selection criteria. UE3 and UE4 may select Cell 1, e.g., based on a RSRP measurement of SSBs of Cell 1 being good to meet a cell selection criteria.

[0390] In an example, a wireless device (UE1, UE2, UE3, UE4, etc.) in an RRC_IDLE state or an RRC_INACTIVE state, receives a *MIB* message, of a cell (Cell 0, Cell 1), comprising a first indication indicating that a *SIB1* (or a *SIB1* message) is on-demand transmitted via the cell; a second indication indicating an uplink radio resource for a wake-up signal (WUS) (or an uplink signal, a signal sequence, etc.) triggering the *SIB1*; and configuration

parameters of SSBs of the cell. The wireless device determines a PCI of the cell based on receiving at least one of the SSBs of the cell. The uplink radio resource for the WUS may be implemented based on examples of FIG. 41A and/or FIG. 41B which will be described later.

[0391] In an example, the wireless device generates a signal (or a signal sequence) of the WUS based on the PCI of the cell, in response to the determining the PCI of the cell and the first indication indicating that *SIB1* is on-demand transmitted via the cell. The wireless device transmits, via the uplink radio resource, the signal of the WUS triggering/requesting a broadcast transmission of the *SIB1*. In the example of FIG. 40, UE1 and UE2 in Cell 0 may generate a first signal (WUS1) based on PCI1 of Cell 0, while UE3 and UE4 in Cell 1 may generate a second signal (WUS2) based on PCI1 of Cell 1.

[0392] In the example of FIG. 40, in response to receiving WUS1 from UE1 and/or UE2, the base station may start to broadcast (a cell specific) *SIB1* of Cell 0 via Cell 0. In response to receiving WUS2 from UE3 and/or UE4, the base station may start to broadcast (a cell specific) *SIB1* of Cell 1 via Cell 1.

[0393] Based on the example embodiment, different from a legacy RA procedure used for uplink synchronization, beam failure recovery, or handover to a neighbor cell, upon receiving a WUS requesting on-demand *SIB1* from a wireless device, a base station starts to broadcast the *SIB1*. Although in this case the *SIB1* is on-demand triggered by a specific wireless device (e.g., UE1 and/or UE2 in Cell 0, UE3 and/or UE4 in Cell1) transmitting the WUS, the on-demand triggered/requested (and broadcasted) *SIB1* may not be a dedicated message for that wireless device only, or may be a broadcasted message for any wireless device in the cell, which is different from a wireless device dedicated RA response (transmitted by the base station) corresponding to a preamble transmission from a wireless device for the legacy RA procedure as shown in FIG. 13A, FIG. 13B and/or FIG. 13C. The legacy RA procedure may also be used for on-demand requested *SIB2/SIB3/SIB4/*... as shown in FIG. 26.

[0394] In an example embodiment, upon triggered by the WUS from the wireless device in a cell, broadcasting the *SIB1* via the cell, by the base station, may comprise scheduling the *SIB1*, in predefined/periodical SIB1 transmission occasions based on examples above with respect to FIG. 36, with a group common DCI with CRC being scrambled by a predefined RNTI (SI-RNTI) so that any wireless device (e.g., UE1 and/or UE2 in Cell 0 if the received WUS by the base station is WUS1, or UE3 and/or UE4 in Cell 1 if the received WUS by the base station is WUS2) in the cell may receive the *SIB1*. The broadcast *SIB1*, as shown in FIG. 25 and/or FIG. 26, may contain information relevant when evaluating if a wireless device is allowed to access a cell and/or may indicate scheduling information of other system information (e.g., SIB2, SIB3, etc.). The *SIB1* may also contain radio resource configuration information that is common for all wireless devices and barring information applied to the unified access control.

[0395] By implementing the example embodiment of FIG. 40, it is beneficial for any wireless device camped in the cell, by broadcasting, by a base station, the *SIB1* upon receiving a WUS from a specific wireless device. Otherwise, if implementing existing technologies for on-demand SI (*SIB2, SIB3*, etc.) transmission or RAR transmission (which is dedicated for a specific wireless device whoever transmits a preamble), by transmitting a wireless device specific

SIB1 upon receiving a WUS from the wireless device, the base station may retransmit the same SIB1 for different wireless devices in different radio resources, wherein each *SIB1* is transmitted in a radio resource corresponding to a respective wireless device) upon receiving WUSs from the wireless devices, which may increase power consumption of the base station and therefore reduce network energy saving gain associated with the on-demand *SIB1* transmission.

[0396] By implementing the example embodiments, it is also beneficial for the base station, in terms of energy saving and/or resource utilization efficiency, when broadcasting the *SIB1* upon receiving a WUS from a wireless device, without transmitting a wireless device specific response upon receiving a WUS from a wireless device. Otherwise, if implementing existing technologies for on-demand SI (*SIB2, SIB3*, etc.) transmission or RAR transmission (which is dedicated for a specific wireless device whoever transmits a preamble), by transmitting a wireless device specific response upon receiving a WUS from the wireless device, the base station may transmit multiple responses for different wireless devices in different radio resources, wherein each response is transmitted in a radio resource corresponding to a respective wireless device) upon receiving WUSs from the wireless devices. However, the on-demand *SIB1* is triggered by a wireless device in an RRC_IDLE state or an RRC_INACTIVE state in which case, the wireless device has no wireless device dedicated RRC configurations or even no cell common RRC configurations for a cell (in contrast, in existing technologies, the wireless device has already obtained cell common RRC configurations, e.g., by SIB1 message as shown in FIG. 25 and/or FIG. 26, for the cell when requesting on-demand *SIB2, SIB3,* etc., or when initiating an RA procedure). Given the situation, reusing existing technologies may make it difficult for the base station to identify which wireless device transmits the WUS, if there are multiple wireless devices transmitting WUSs requesting the on-demand *SIB1*, and/or to transmit a wireless device dedicated response corresponding to a WUS from a wireless device. To reuse the existing technologies, the base station may need to pre-configure (since when a wireless device is in RRC_IDLE state, there is no wireless device dedicated RRC message configured for the wireless device before the wireless device receives the *SIB1*) a wireless device specific WUS for each wireless device and/or pre-configure a wireless device specific search space for receiving a response corresponding to the WUS for each wireless device. In addition, it is more difficult to pre-configure the wireless device specific WUS and resources for the response when the base station has no prior information regarding which wireless devices are camped on (or select) the cell since the wireless devices are in the RRC_IDLE state. Therefore, not using the example embodiment may increase implementation complexity, power consumption of the base station and therefore reduce network energy saving gain associated with the on-demand *SIB1* transmission.

[0397] By implementing the example embodiments, it is beneficial for the base station, in terms of energy saving and/or resource utilization efficiency, when broadcasting the SIB1 upon receiving a WUS from a wireless device, without transmitting a wireless device specific response upon receiving a WUS from a wireless device. By implementing example embodiments, the base station may not need to know which wireless device is requesting

the SIB1 message and/or may not need to know which wireless device will receive the SIB1 message, therefore, simplifying the implementation complexity for the on-demand SIB1 transmission.

[0398] Example embodiments, based on determining that the on-demand triggered *SIB1* is broadcasted, or is not unicast transmitted to a specific wireless device who transmits a WUS and/or based on determining that no wireless device specific response, other than the broadcasted *SIB1*, is required to be transmitted from the base station in response to receiving a WUS from a wireless device, may comprise configuring/determining/preconfiguring a cell common signal sequence used (by all wireless devices in the cell) for a WUS triggering on-demand *SIB1* transmission. The cell common signal sequence may be used for any wireless device, in the cell, whoever requests the on-demand *SIB1* transmission. Different cells may be configured/preconfigured with different cell common signal sequences for WUSs requesting on-demand SIB1 transmissions in different cells. All wireless devices in the same cell may use the same cell common signal sequence for the WUS transmission in the cell.

[0399] Different from existing technologies for RA procedure, the cell common signal sequence for the WUS is not specifically configured for (and/or used by) a wireless device or a group of wireless devices in the cell. Any wireless device in the cell may transmit the same cell common signal sequence as the WUS for requesting the *SIB1*. In case multiple wireless devices transmit the same cell common signal sequence requesting the on-demand *SIB1*, the base station may trigger the on-demand *SIB1* without the necessity to know who is requesting the on-demand *SIB1* and/or who will receive the on-demand *SIB1*.

[0400] Example embodiments may increase reliability of a reception of the WUS by the base station, e.g., when there are multiple wireless devices requesting the on-demand *SIB1* by transmitting the same cell common signal sequence. In this case, the base station may receive, with a higher success possibility, the cell common signal sequence with reception power accumulated, by the same cell common signal sequence being transmitted by the multiple wireless devices. Example embodiments may increase resource utilization efficiency for the WUS triggering the on-demand *SIB1*, by configuring a cell common signal sequence for the WUS. In contrast, in legacy RA procedure, the base station may configure multiple signal sequences for preambles in a cell, each signal sequence being used for a preamble transmission for a specific wireless device or a specific group of wireless devices of a plurality of wireless devices in a cell.

[0401] In one or more example embodiments, the cell common signal sequence, of a cell, for the WUS transmission may be a pseudo-random sequence based on a Gold sequence generated based on a PCI value (e.g., $N_{\mathrm{ID}}^{\mathrm{cell}}$) of the cell, or $N_{\mathrm{ID}}^{(1)}$ and $N_{\mathrm{ID}}^{(2)}$ of the cell, wherein $N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$. The cell common signal sequence $c(n)$ of length M_{PN}, where $n = 0,1,\ldots,M_{\mathrm{PN}} - 1$, may be defined by:

$$c(n) = \left(x_1(n+N_C) + x_2(n+N_C)\right) \bmod 2$$
$$x_1(n+31) = \left(x_1(n+3) + x_1(n)\right) \bmod 2$$
$$x_2(n+31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right) \bmod 2$$

where N_C is a predefined value (e.g., 1600), and M_{PN} may be predefined as a fixed value. The first m-sequence $x_1(n)$ may be initialized with $x_1(0) = 1, x_1(n) = 0, n = 1,2,\ldots,30$. The initialization of the second m-sequence, $x_2(n)$, may be denoted by with c_{init} based on a PCI value (e.g., N_{ID}^{cell}) of the cell at the beginning of each radio frame.

[0402] In one or more example embodiments, $c_{init} = 2^x * N_{ID}^{cell}$, or generally $c_{init} = function\ (N_{ID}^{cell})$, wherein *x* (could be zero, or any number greater than zero) may be determined based on a (bit) length of the cell common signal sequence and/or a (bit) length of the PCI value of the cell. $function$ may be predefined based on the (bit) length of the cell common signal sequence, M_{PN}, etc.

[0403] In one or more example embodiments, $c_{init} = 2^x * N_{ID}^{(1)}$, or generally $c_{init} = function\ (N_{ID}^{(1)})$. wherein *x* (could be zero, or any number greater than zero) may be determined based on a length of the cell signal sequence and/or a (bit) length of $N_{ID}^{(1)}$of the cell. $function$ may be predefined based on the length of the cell common signal sequence, M_{PN}, etc.

[0404] In one or more example embodiments, $c_{init} = 2^x * N_{ID}^{(1)} + 2^y * N_{ID}^{(2)}$, where *x* and/or *y* may be determined based on a length of the cell common signal sequence and/or the (bit) length of $N_{ID}^{(1)}$ and/or $N_{ID}^{(2)}$, or generally $c_{init} = function\ (N_{ID}^{(1)}, N_{ID}^{(2)})$. $function$ may be predefined based on the length of the cell common signal sequence, M_{PN}, etc.

[0405] In one or more example embodiments, $c_{init} = 2^x * N_{ID}^{cell} + 2^y * SSB_{index}$, or generally $c_{init} = function\ (N_{ID}^{cell}, SSB_{index})$, wherein *x* and *y* may be determined based on the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, the (bit) length of SSB_{index}. $function$ may be predefined based on the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, the length of SSB_{index}, etc. The wireless device may detect SSB_{index} of a received SSB based on receiving the SSB of the SSBs and receiving the *MIB* message.

[0406] In one or more example embodiments, $c_{init} = 2^x * N_{ID}^{cell} + 2^y * C_{offset}$, or generally $c_{init} = function\ (N_{ID}^{cell}, C_{offset})$, wherein *x* and *y* may be determined based on the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, the (bit) length of C_{offset}. $function$ may be predefined based on the length of the cell common signal sequence and/or M_{PN}, the length of N_{ID}^{cell}, the length of C_{offset}, etc. The wireless device may obtain a value C_{offset} based on an indication of the *MIB* message. The indication of the *MIB* message may indicate the value of C_{offset}.

[0407] In one or more example embodiments based on one or more combination of above embodiments, $c_{init} = 2^x * N_{ID}^{cell} + 2^y * C_{offset} + 2^z * SSB_{index}$, or generally $c_{init} = function\ (N_{ID}^{cell}, C_{offset}, SSB_{index})$, wherein *x*, *y* and *z* may be determined based on the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, the

length of C_{offset}, the length of SSB_{index}, etc. $function$ may be predefined based on the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, the length of C_{offset}, the length of SSB_{index}, etc.

[0408] In one or more example embodiments based on one or more combination of above embodiments, $c_{init} = 2^x * N_{ID}^{(1)} + 2^y * N_{ID}^{(2)} + 2^z * C_{offset} + 2^m * SSB_{index}$, or generally $c_{init} = function\ (N_{ID}^{(1)}, N_{ID}^{(2)}, C_{offset}, SSB_{index})$, wherein x, y, z and m may be determined based on the length of the cell common signal sequence, M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of C_{offset}, the length of SSB_{index}, etc. $function$ may be predefined based on the length of the cell common signal sequence, M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of C_{offset}, the length of SSB_{index}, etc.

[0409] In an example, the wireless device may detect/determine the PCI value of the cell based on receiving/detecting at least one of SSBs of the cell.

[0410] By implementing the example embodiment, the wireless device may determine the cell common signal sequence (a Gold sequence) based on the PCI value (and/or a SSB index of a detected SSB, an offset value indicated by the *MIB* message, etc.) of the cell, which is different from existing uplink signal (e.g., SRS, DM-RS for PUCCH/PUSCH, etc.) where the Gold sequence is initialized by an identifier indicated by the base station in a wireless device dedicated RRC message.

[0411] In an example embodiment, the wireless device may determine the PCI value (e.g., N_{ID}^{cell}) of the cell based on detecting the at least one of SSBs of the cell. There may be 1008 PCI values. In an example, $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$, where $N_{ID}^{(1)} \in \{0,1,\ldots,335\}$ and $N_{ID}^{(2)} \in \{0,1,2\}$.

[0412] In an example, a first sequence for a PSS of a SSB may be generated as

$$d_{\mathrm{PSS}}(n) = 1 - 2x(m)$$
$$m = \left(n + 43N_{\mathrm{ID}}^{(2)}\right) \bmod 127$$
$$0 \le n < 127$$

where

$$x(i+7) = \left(x(i+4) + x(i)\right) mod\ 2$$

and

$$[x(6)\quad x(5)\quad x(4)\quad x(3)\quad x(2)\quad x(1)\quad x(0)] = [1\quad 1\quad 1\quad 0\quad 1\quad 1\quad 0].$$

In an example, a second sequence for a SSS of the SSB may be generated as

$$d_{\mathrm{SSS}}(n) = \left[1 - 2x_0\left((n + m_0) \bmod 127\right)\right]\left[1 - 2x_1\left((n + m_1) \bmod 127\right)\right]$$
$$m_0 = 15\left\lfloor \frac{N_{\mathrm{ID}}^{(1)}}{112} \right\rfloor + 5N_{\mathrm{ID}}^{(2)}$$
$$m_1 = N_{\mathrm{ID}}^{(1)} \bmod 112$$
$$0 \le n < 127$$

where

$$x_0(i+7)=(x_0(i+4)+x_0(i))\bmod 2$$
$$x_1(i+7)=(x_1(i+1)+x_1(i))\bmod 2$$

and

$$[x_0(6)\ \ x_0(5)\ \ x_0(4)\ \ x_0(3)\ \ x_0(2)\ \ x_0(1)\ \ x_0(0)]=[0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1]$$
$$[x_1(6)\ \ x_1(5)\ \ x_1(4)\ \ x_1(3)\ \ x_1(2)\ \ x_1(1)\ \ x_1(0)]=[0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1]$$

[0413] In an example embodiment, the wireless device may detect the first sequence for the PSS and the second sequence for the SSS based on receiving/detecting at least one SSB of the SSBs of the cell according to configuration parameters of the SSBs of the cell. Based on detecting the first sequence and the second sequence, the wireless device may detect $N_{\mathrm{ID}}^{(1)}$ and $N_{\mathrm{ID}}^{(2)}$, which may be used to determine $N_{\mathrm{ID}}^{\mathrm{cell}}$ of the cell by the wireless device.

[0414] In one or more example embodiments, the cell common signal sequence of a cell, for the WUS transmission may be a pseudo-random sequence based on a Zadoff-Chu sequence generated based on a PCI value of the cell. A Zadoff-Chu sequence $x_{u,v}(n)$ may be generated as:

$$x_{u,v}(n)=x_u((n+C_v)\bmod L_{\mathrm{RA}})$$
$$x_u(i)=e^{-j\frac{\pi ui(i+1)}{L_{\mathrm{RA}}}},\ i=0,1,\ldots,L_{\mathrm{RA}}-1$$

from which the frequency-domain representation may be generated according to

$$y_{u,v}(n)=\sum_{m=0}^{L_{\mathrm{RA}}-1}x_{u,v}(m)\cdot e^{-j\frac{2\pi mn}{L_{\mathrm{RA}}}}$$

where L_{RA} may be a predefined value.

[0415] In an example embodiment, the sequence number *u* may be obtained from a logical root sequence index. In an example, the logical root sequence index may be equal to the PCI value (e.g., $N_{\mathrm{ID}}^{\mathrm{cell}}$) (or $N_{\mathrm{ID}}^{(1)}$ and/or $N_{\mathrm{ID}}^{(2)}$) of the cell. In general, the logic root sequence index may be generated based on the PCI value (or $N_{\mathrm{ID}}^{(1)}$ and/or $N_{\mathrm{ID}}^{(2)}$) of the cell. By implementing example embodiment, the wireless device may determine the cell common signal sequence (a Zadoff-Chu sequence) based on the PCI value of the cell, where different cells may be associated with different cell common signal sequences due to different cell having different PCI values. The example embodiments are different from existing RA procedure where the logic root sequence index, used to generate the preamble for the RA procedure, is indicated by the base station in a wireless device dedicated RRC message.

[0416] In an example embodiment, the sequence number *u* may be same for different cells, e.g., as a predefined/preconfigure value. A cyclic shift value (e.g., C_v) may be determined (e.g., $C_v=2^x*N_{\mathrm{ID}}^{\mathrm{cell}}$, or $C_v=function(N_{\mathrm{ID}}^{\mathrm{cell}})$) (or e.g., $C_v=N_{\mathrm{ID}}^{(1)}$, or $C_v=function(N_{\mathrm{ID}}^{(1)})$) (or e.g., $C_v=N_{\mathrm{ID}}^{(2)}$, or $C_v=function(N_{\mathrm{ID}}^{(2)})$) (or e.g., $C_v=2^x*N_{\mathrm{ID}}^{(1)}+2^y*N_{\mathrm{ID}}^{(2)}$, or $C_v=function(N_{\mathrm{ID}}^{(1)},N_{\mathrm{ID}}^{(2)})$) based on a PCI value of a cell, where different cells may be associated with different cyclic shift values, wherein *x* and/or *y* may be determined based on

the length of the cell common signal sequence, M_{PN}, the length of N_{ID}^{cell}, $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, etc. By implementing example embodiment, the wireless device may determine the cell common signal sequence (a Zadoff-Chu sequence) based on the PCI value of the cell, where different cells may be associated with different cell common signal sequences due to different cell having different PCI values. The example embodiments are different from existing RA procedure where the cyclic shift value, used to generate the preamble for the RA procedure, is indicated by the base station in a wireless device dedicated RRC message.

[0417] In an example embodiment based on one or more combination of above embodiments, the logical root sequence index and/or the cyclic shift value of the Zadoff-Chu sequence, used for generating the cell common signal sequence for the WUS triggering the on-demand SIB1, may be obtained/determined based on at least one of: a PCI value of the cell, a SSB index of a detected SSB of the cell, a value of offset indicated by the MIB message, etc. The value of offset indicated by the MIB message may be implemented based on example embodiments described above.

[0418] In an example embodiment, logic root sequence index (u) may be equal to $2^x * N_{ID}^{(1)} + 2^y * N_{ID}^{(2)} + 2^z * C_{offset} + 2^m * SSB_{index}$, or $2^x * N_{ID}^{cell} + 2^y * C_{offset} + 2^z * SSB_{index}$, or generally, $function\ (N_{ID}^{(1)}, N_{ID}^{(2)}, C_{offset}, SSB_{index})$, wherein x, y, z and m may be determined based on the length of the cell common signal sequence, M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of N_{ID}^{cell}, the length of C_{offset}, the length of SSB_{index}, etc. $function$ may be predefined based on the length of the cell common signal sequence and/or M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of N_{ID}^{cell}, the length of C_{offset}, the length of SSB_{index}, etc.

[0419] In an example embodiment, the cyclic shift value (e.g., C_v) may be equal to $2^x * N_{ID}^{(1)} + 2^y * N_{ID}^{(2)} + 2^z * C_{offset} + 2^m * SSB_{index}$, or $2^x * N_{ID}^{cell} + 2^y * C_{offset} + 2^z * SSB_{index}$, or generally, $function\ (N_{ID}^{(1)}, N_{ID}^{(2)}, C_{offset}, SSB_{index})$, wherein x, y, z and m may be determined based on the length of the cell common signal sequence and/or M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of N_{ID}^{cell}, the length of C_{offset}, the length of SSB_{index}, etc. $function$ may be predefined based on the length of the cell common signal sequence and/or M_{PN}, the length of $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the length of N_{ID}^{cell}, the length of C_{offset}, the length of SSB_{index}, etc.

[0420] In an example embodiment, a combination of a logic root sequence index (u) and a cyclic shift value (e.g., C_v) may be determined as a function of $2^x * N_{ID}^{(1)} + 2^y * N_{ID}^{(2)} + 2^z * C_{offset} + 2^m * SSB_{index}$.

[0421] By implementing the example embodiments, the wireless device may determine the cell common signal sequence (a Gold sequence and/or a Zadoff-Chu sequence) based on the PCI value of the cell, the SSB index of a detected SSB of the cell and/or an indicated offset by the *MIB* of the cell. The example embodiments are different from existing RA procedure where the logic root sequence index and/or the cyclic shift value, used to generate the preamble for the RA procedure, is indicated by the base station in a wireless device dedicated RRC message.

[0422] In an example embodiment, the wireless device, for a transmission of a wake-up signal triggering an on-demand SIB1 message of a cell, a (default or predefined) TDD pattern of the cell based on at least one of: a parameter of the *MIB* message, a frequency band of the cell, a pre-stored configuration of the cell, an RRC release message for the cell, etc. The wireless device transmits the wake-up signal in an uplink symbol/slot based on the determined TDD pattern of the cell and/or a system frame number indicated by the *MIB* message of the cell.

[0423] FIG. 41A and/or FIG. 41B show example embodiments of uplink radio resource configuration for a WUS triggering on-demand *SIB1* in a cell.

[0424] In the example of FIG. 41A, uplink radio resources for WUSs (or WUS occasions) from different cells (e.g., Cell 1, Cell 2) may be allocated/indicated/configured so that different uplink radio resources of the WUSs via different cells are not overlapping in time domain, while a single uplink radio resource is used for all UEs in the same cell.

[0425] Based on the example embodiment, by configuring uplink radio resources for WUSs from different cells in a way of time domain multiplexing, uplink transmission collision of WUSs for different cells may be reduced.

[0426] Based on the example embodiment, by configuring uplink radio resources for WUSs from different cells in a way of time domain multiplexing, frequency resources allocated/reserved for the WUSs in a cell may be reduced since all WUSs from different cells are allocated with the same frequency resource.

[0427] Based on the example embodiment, by configuring a single uplink resource for all UEs in the same cell may further reduce resource allocation for the WUS, and/or reduce power consumption of the base station so that the base station does not need to monitor different uplink resources for receiving the WUSs from different UEs in the cell.

[0428] In the example of FIG. 41B, uplink radio resources for WUSs (or WUS occasions) from different cells (e.g., Cell 1, Cell 2) may be allocated/indicated/configured so that different uplink radio resources of the WUSs via different cells are not overlapping in frequency domain, while a single uplink radio resource is used for all UEs in the same cell.

[0429] Based on the example embodiment, by configuring uplink radio resources for WUSs from different cells in a way of frequency domain multiplexing, uplink transmission collision of WUSs for different cells may be reduced.

[0430] Based on the example embodiment, by configuring uplink radio resources for WUSs from different cells in a way of frequency domain multiplexing, latency of transmission of the WUSs in different cells may be reduced since all WUSs from different cells may be transmitted in the same symbol/slot.

[0431] In the examples of FIG. 41A and/or FIG. 41B, the uplink radio resources for the WUSs may be indicated by the MIB message, e.g., WUS occasion for Cell 0 may be indicated in the MIB message of Cell 0, WUS occasion for Cell 1 may be indicated in the *MIB* message of Cell 1, etc.

[0432] Based on example embodiments of FIG. 40, FIG. 41A, FIG. 41B, a wireless device in an RRC_IDLE state or an RRC_INACTIVE state, receives a MIB message, of a cell, comprising a first indication indicating that a SIB1 is

on-demand transmitted via the cell; a second indication indicating an uplink radio resource for a wake-up signal (WUS) triggering the SIB1; and configuration parameters of SSBs of the cell. The wireless device determines a PCI of the cell based on receiving at least one of the SSBs of the cell. The wireless device generates a signal (or a signal sequence) of the WUS based on the PCI of the cell, in response to the determining the PCI of the cell and the first indication indicating that SIB1 is on-demand transmitted via the cell. The wireless device transmits, via the uplink radio resource, the signal of the WUS triggering/requesting a broadcast transmission of the SIB1.

[0433] In an example embodiment, a wireless device receives a MIB message, of a cell, comprising an indication indicating that a SIB1 is on-demand (and broadcast) transmitted via the cell. The wireless device, in response to the indication indicating that SIB1 is on-demand transmitted via the cell, transmits a signal triggering/requesting a broadcast transmission of the SIB1 and generated based on a PCI of the cell.

[0434] In an example embodiment, a wireless device transmits to a base station and via a cell, an uplink signal (or signal sequence): triggering (or requesting or demanding) a broadcast transmission of a SIB1 message via the cell; and generated based on a PCI of the cell.

[0435] According to an example embodiment, the signal is based on an SSB index of a SSB of the cell.

[0436] According to an example embodiment, the wireless device detects the PCI of the cell based on the SSB index of the SSB of the cell.

[0437] According to an example embodiment, the wireless device transmits the signal triggering/requesting the SIB1 of the cell, in response to the wireless device being capable of transmitting the signal in an RRC_IDLE state or in an RRC_INACTIVE state.

[0438] According to an example embodiment, the wireless device receives a MIB message, of the cell, comprising a first indication indicating that the SIB1 is on-demand transmitted via the cell, a second indication indicating an uplink radio resource for a wake-up signal (WUS) triggering the SIB1, and/or configuration parameters of SSBs of the cell.

[0439] According to an example embodiment, the wireless device transmits the signal triggering/requesting the SIB1 of the cell based on the first indication indicating that SIB1 is on-demand transmitted via the cell.

[0440] According to an example embodiment, the wireless device transmits the signal via the uplink radio resource of the cell, indicated by the second indication of the MIB message.

[0441] According to an example embodiment, the wireless device discards the uplink radio resource of the cell associated with the signal, in response to transmitting the signal via the uplink radio resource.

[0442] According to an example embodiment, the second indication indicates the uplink radio resource, from a plurality of uplink radio resources (pre-)configured on the cell for the transmitting the WUS triggering/requesting the SIB1.

[0443] According to an example embodiment, the wireless device detects the PCI of the cell based on receiving at least one SSB of the SSBs of the cell, wherein the PCI is generated based on a first identity and a second identity.

[0444] According to an example embodiment, the signal, triggering/requesting the SIB1 of the cell, is generated based on the first identity of the PCI of the cell.

[0445] According to an example embodiment, the signal, triggering/requesting the SIB1 of the cell, is generated based on the second identity of the PCI of the cell.

[0446] According to an example embodiment, the signal, triggering/requesting the SIB1 of the cell, is generated based on both the first identity and the second identity.

[0447] According to an example embodiment, each SSB of the SSBs comprises at least one of: a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and a physical broadcast channel (PBCH) carrying the MIB message.

[0448] According to an example embodiment, the PSS is a second signal sequence generated based on the first identity of the PCI of the cell.

[0449] According to an example embodiment, the SSS is a third signal sequence generated based on the first identity of the PCI and the second identity of the PCI.

[0450] According to an example embodiment, the signal is a Zadoff-Chu sequence with a cyclic shift determined based on the PCI of the cell.

[0451] According to an example embodiment, the signal is a pseudo-random sequence generated/initialized by the PCI of the cell.

[0452] According to an example embodiment, the signal is a low peak-to-average-power ratio (PAPR) sequence generated/initialized by the PCI of the cell.

[0453] According to an example embodiment, the wireless device is in an RRC_IDLE state or an RRC_INACTIVE state. For example, the transmitting the uplink signal can be performed in the RRC_IDLE state or RRC_INACTIVE state.

[0454] According to an example embodiment, the wireless device receives the SIB1 based on the transmitting the signal. The wireless device receives the SIB1 broadcasted and scheduled by a group common DCI with CRC scrambled by SI-RNTI. The wireless device receives the group common DCI via a cell common search space, of the cell, indicated by the MIB message.

[0455] According to an example embodiment, the wireless device monitors PDCCH of the cell for receiving a DCI scheduling the SIB1 message. The wireless device transmits the WUS based on SIB1 not being received during monitoring the PDCCH and after receiving the MIB message.

[0456] According to an example embodiment, the wireless device transmits the signal based on at least one of SSBs, of the cell, being received. The wireless device determines the at least one of the SSBs is received based on detecting a PCI of the cell.

[0457] According to an example embodiment, the wireless device receives a MIB message, of the cell, comprising an indication indicating a value of an offset or a cyclic shift for the signal. The signal is generated based on the value and the PCI of the cell.

[0458] According to an example embodiment, the wireless device transmits the signal, with a subcarrier spacing based on an indication of the MIB.

[0459] According to an example embodiment, the indication indicates a common subcarrier spacing used for at least one of: a reception of the SIB1, a transmission of a message 2 and/or 4 for initial access, a reception of a message B for initial access, a reception of a paging message, and/or a reception of broadcast SI messages.

[0460] According to an example embodiment, the subcarrier spacing is independently and/or separately configured from a second subcarrier spacing for a preamble for a random access procedure, wherein the second subcarrier spacing is configured in the SIB1.

[0461] In an example embodiment, a wireless device receives, in an RRC_CONNECTED state, an RRC release message comprising first configuration parameters of SSBs of a cell, a parameter indicating that a SIB1 is on-demand triggered on the cell, and/or second configuration parameters of uplink radio resources of a wake-up signal triggering the SIB1 of the cell. The wireless device transitions, based on the RRC release message, from the RRC_CONNECTED state to an RRC IDLE state or an RRC_INACTIVE state. The wireless device, via the uplink radio resources, the wake-up signal triggering/requesting/demanding the SIB1, wherein the wake-up signal is a signal (or a signal sequence) generated based on a PCI of the cell, in response to the wireless device transitioning to the RRC_IDLE state or the RRC_INACTIVE state; receiving at least one SSB of the SSBs of the cell; not receiving the SIB1 in SIB1 occasions; and/or the SIB1 not being available after the RRC release message is received.

[0462] In an example embodiment, a wireless device receives an RRC release message comprising a first parameter indicating a signal sequence of a wake-up signal and a second parameter indicating that SIB1 message is on-demand triggered, by the wake-up signal, on the cell. The wireless device transitions from an RRC_CONNECTED state to an RRC_IDLE state (or an RRC_INACTIVE state). The wireless device transmits, based on the signal sequence, the wake-up signal triggering/requesting the SIB1 message, in response to the wireless device transitioning to the RRC_IDLE state (or the RRC_INACTIVE state) and the second parameter indicating that the SIB1 message is on-demand triggered.

[0463] In an example embodiment, a wireless device receives an RRC release message comprising configuration parameters of uplink radio resources of a wake-up signal, a first parameter indicating a signal sequence of the wake-up signal and a second parameter indicating that a SIB1 message is on-demand triggered, by the wake-up signal on the cell. The wireless device transitions from an RRC_CONNECTED state to an RRC_IDLE state (or an RRC_INACTIVE state). The wireless device transmits, via the uplink radio resources based on the signal sequence, the wake-up signal triggering/requesting the SIB1 message, in response to the wireless device transitioning to the

RRC_IDLE state (or the RRC_INACTIVE state) and the second parameter indicating that the SIB1 message is on-demand triggered.

[0464] According to an example embodiment, the first parameter indicates that the signal sequence is generated based on a PCI of the cell.

[0465] According to an example embodiment, the first parameter comprises a signal sequence index for the signal sequence.

[0466] According to an example embodiment, the RRC release message comprises a third parameter comprising an index offset for the signal sequence.

[0467] Clause 1. A method comprising: receiving, by a wireless device, one or more radio resource control (RRC) messages comprising configuration parameters of an uplink signal, of a cell, requesting system information block 1 (SIB1) of the cell, wherein: the configuration parameters indicate that the SIB1 of the cell is on-demand requested; and time division duplex (TDD) configuration of the cell is determined based on the one or more RRC messages; transmitting, in an RRC idle state, the uplink signal requesting the SIB1 of the cell, wherein the uplink signal is transmitted via one or more uplink symbols according to the TDD configuration of the cell; and camping on the cell after receiving the SIB1 of the cell.

[0468] Clause 2. A method comprising: receiving, by a wireless device, one or more radio resource control (RRC) messages comprising parameters of uplink signal configuration of a preamble, of a cell, requesting system information block 1 (SIB1) of the cell, wherein the parameters indicate: that the SIB1 is on-demand requested on the cell; and time division duplex (TDD) configuration of the cell; transmitting, in an RRC idle state, the preamble requesting the SIB1 of the cell, wherein the preamble is transmitted via one or more uplink symbols according to the TDD configuration of the cell; and camping on the cell after receiving the SIB1 of the cell.

[0469] Clause 3. A method comprising: receiving, by a wireless device, one or more radio resource control (RRC) messages comprising configuration parameters of wake-up signal (WUS) configuration of a WUS requesting system information block 1 (SIB1) of the cell, wherein the configuration parameters indicate a time division duplex (TDD) configuration of the cell; transmitting, via one or more uplink symbols of the cell, the WUS requesting the SIB1 of the cell, wherein the one or more uplink symbols are determined based on: the TDD configuration of the cell; and a system frame number of a system frame of the cell; and camping on the cell after receiving the SIB1 of the cell.

[0470] Clause 4. A method comprising: receiving, by a wireless device, one or more radio resource control (RRC) messages comprising configuration parameters of a wake-up signal (WUS), of a cell, requesting system information block 1 (SIB1) of the cell, wherein the parameters indicate: that the SIB1 is on-demand requested on the cell; the WUS being associated with a physical cell identity (PCI) of the cell; and time division duplex (TDD) configuration of the cell; transmitting the WUS requesting the SIB1 of the cell: via one or more uplink symbols according to the TDD configuration of the cell; in an RRC idle state; and before receiving the SIB1 of the cell; and camping on the cell after receiving the SIB1.

[0471] Clause 5. A method comprising: receiving, by a wireless device, one or more radio resource control (RRC) messages comprising configuration parameters of a wake-up signal (WUS) configuration of a WUS requesting system information block 1 (SIB1) of the cell, wherein the configuration parameters indicate a first uplink subcarrier spacing for the WUS; transmitting, in an RRC idle state and before receiving the SIB1 of the cell, the WUS with the first uplink subcarrier spacing and requesting the SIB1 of the cell; receiving, based on the transmitting the WUS, the SIB1 of the cell, wherein the SIB1 indicates a second uplink subcarrier spacing for one or more preambles for initial access procedure of the cell; and transmitting, via the cell, a first preamble, of the one or more preambles, with the second subcarrier spacing and for the initial access procedure.

[0472] Clause 6. The method of any of clauses 1 to 5, wherein the wireless device transmits the uplink signal requesting the SIB1 of the cell based on the uplink signal being associated with the PCI of the cell.

[0473] Clause 7. The method of any of clauses 1 to 6, wherein the wireless device transmits the uplink signal requesting the SIB1 of the cell based on the one or more RRC messages indicating that the SIB1 is on-demand requested on the cell.

[0474] Clause 8. The method of any of clauses 1 to 7, wherein the wireless device receives the one or more RRC messages before the wireless device receives the SIB1 of the cell.

[0475] Clause 9. The method of any of clauses 1 to 8, wherein the uplink signal is a WUS.

[0476] Clause 10. The method of any of clauses 1 to 9, wherein the uplink signal is a preamble.

[0477] Clause 11. The method of any of clauses 1 to 10, wherein the wireless device transmits the WUS before receiving the SIB1 of the cell.

[0478] Clause 12. The method of any of clauses 1 to 11, wherein the wireless device transmits the WUS based on not receiving the SIB1 of the cell.

[0479] Clause 13. The method of any of clauses 1 to 12, wherein the wireless device transmits the WUS requesting the SIB1 of the cell, in response to the wireless device being capable of transmitting the WUS, requesting on-demand SIB1 of a cell, in the RRC idle state or in an RRC inactive state.

[0480] Clause 14. The method of any of clauses 1 to 13, wherein the wireless device transmits the uplink signals in the one or more uplink symbols based on a system frame number indicated by a master information block (MIB), of the cell, comprised in the one or more RRC messages.

[0481] Clause 15. The method of any of clauses 1 to 14, wherein the wireless device transmits the WUS in the uplink symbols with a first subcarrier spacing value, wherein the first subcarrier spacing value is indicated by the one or more RRC messages.

[0482] Clause 16. The method of any of clauses 1 to 15, wherein the first subcarrier spacing value is separately configured from a second subcarrier spacing value.

[0483] Clause 17. The method of any of clauses 1 to 16, wherein the second subcarrier spacing value is used for at least one of: a reception of the SIB1; a transmission of a message 2 and/or 4 for initial access; a reception of a message B for initial access; a reception of a paging message; and a reception of broadcast SI-messages.

[0484] Clause 18. The method of any of clauses 1 to 17, wherein the second subcarrier spacing value is comprised in the MIB of the cell.

[0485] Clause 19. The method of any of clauses 1 to 18, wherein the first subcarrier spacing value is independently and/or separately configured from a third subcarrier spacing value for transmission of a first preamble for an initial access procedure, wherein the third subcarrier spacing value is comprised in the SIB1 of the cell.

[0486] Clause 20. The method of any of clauses 1 to 19, wherein the one or more RRC messages comprise second configuration parameters of second WUS associated with a second PCI of a second cell.

[0487] Clause 21. The method of any of clauses 1 to 20, wherein the one or more RRC messages indicate that SIB1 of the second cell is on-demand requested.

[0488] Clause 22. The method of any of clauses 1 to 21, wherein the wireless device transmits the second WUS requesting SIB1 of the second cell based on the second WUS being associated with the second PCI of the second cell.

[0489] Clause 23. The method of any of clauses 1 to 22, wherein the wireless device transmits, via first uplink frequency resources of the cell, the WUS requesting the SIB1 of the first cell.

[0490] Clause 24. The method of any of clauses 1 to 23, wherein the wireless device transmits, via second uplink frequency resources of the second cell, the second WUS requesting the SIB1 of the second cell.

[0491] Clause 25. The method of any of clauses 1 to 24, wherein the first uplink frequency resources are different from the second uplink frequency resources.

[0492] Clause 26. The method of any of clauses 1 to 25, wherein the one or more RRC messages comprise: configuration parameters of the first uplink frequency resources of the WUS of the first cell; and configuration parameters of the second uplink frequency resources of the second WUS of the second cell.

[0493] Clause 27. The method of any of clauses 1 to 26, wherein the one or more RRC messages comprise an MIB of the cell.

[0494] Clause 28. The method of any of clauses 1 to 27, wherein the one or more RRC messages comprise an RRC release message.

[0495] Clause 29. The method of any of clauses 1 to 28, wherein the one or more RRC messages do not comprise the SIB1 of the cell.

[0496] Clause 30. The method of any of clauses 1 to 29, wherein the wireless device detects the PCI of the cell based on a synchronization signal block (SSB) index of an SSB of the cell, wherein the wireless device receives the SSB of the cell before transmitting the WUS.

[0497] Clause 31. The method of any of clauses 1 to 30, wherein the wireless device detects the PCI of the cell based on receiving at least one SSB of SSBs of the cell, wherein the PCI is determined based on a first identity and a second identity.

[0498] Clause 32. The method of any of clauses 1 to 31, wherein the WUS, requesting the SIB1 of the cell, is generated based on the first identity of the PCI of the cell.

[0499] Clause 33. The method of any of clauses 1 to 32, wherein the WUS, requesting the SIB1 of the cell, is generated based on the second identity of the PCI of the cell.

[0500] Clause 34. The method of any of clauses 1 to 33, wherein the WUS, requesting the SIB1 of the cell, is generated based on both the first identity and the second identity.

[0501] Clause 35. The method of any of clauses 1 to 34, wherein each SSB of the SSBs of the cell comprises at least one of: a primary synchronization signal (PSS); a secondary synchronization signal (SSS); and a physical broadcast channel (PBCH) carrying the MIB of the cell.

[0502] Clause 36. The method of any of clauses 1 to 35, wherein the PSS is a second signal sequence generated based on the first identity of the PCI of the cell.

[0503] Clause 37. The method of any of clauses 1 to 36, wherein the SSS is a third signal sequence generated based on the first identity of the PCI and the second identity of the PCI.

[0504] Clause 38. The method of any of clauses 1 to 37, wherein the WUS is a pseudo-random sequence generated/initialized by the PCI of the cell.

[0505] Clause 39. The method of any of clauses 1 to 38, wherein the wireless device is in an RRC idle state or an RRC inactive state.

[0506] Clause 40. The method of any of clauses 1 to 39, further comprising receiving the SIB1 of the cell based on the transmitting the WUS.

[0507] Clause 41. The method of any of clauses 1 to 40, wherein the wireless device receives the SIB1 scheduled by a group common downlink control information (DCI) with cyclic redundancy check (CRC) scrambled by system information-radio network temporary identifier (SI-RNTI).

[0508] Clause 42. The method of any of clauses 1 to 41, further comprising receiving the group common DCI via a cell common search space of the cell, wherein the cell common search space is indicated by the one or more messages.

[0509] Clause 43. The method of any of clauses 1 to 42, further comprising monitoring, before transmitting the WUS, a physical downlink control channel (PDCCH) of the cell for receiving a second DCI scheduling the SIB1 of the cell.

[0510] Clause 44. The method of any of clauses 1 to 43, wherein the wireless device transmits the WUS based on no SIB1 being received during monitoring the PDCCH of the cell.

[0511] Clause 45. The method of any of clauses 1 to 44, wherein the wireless device transmits the WUS based on at least one of SSBs, of the cell, being received.

[0512] Clause 46. The method of any of clauses 1 to 45, wherein the wireless device determines the at least one of the SSBs, of the cell, is received based on successfully detecting the PCI of the cell.

[0513] Clause 47. The method of any of clauses 1 to 46, wherein: the WUS, requesting the SIB1 of the cell, is transmitted via first uplink symbols determined based on a first TDD configuration of the cell indicated by the one or more RRC messages; and the first preamble, for the initial access procedure of the cell, is transmitted via second uplink symbols determined based on a second TDD configuration of the cell indicated by the SIB1 received after the transmitting the WUS.

[0514] Clause 48. The method of any of clauses 1 to 47, wherein the wireless device performs the initial access procedure, comprising the transmitting the first preamble, after the wireless device receives the SIB1 of the cell.

[0515] Clause 49. The method of any of clauses 1 to 48, further comprising transitioning to an RRC connected state after the initial access procedure.

[0516] Clause 50. An apparatus comprising one or more processors and memory storing instructions that, when executed by the one or more processors, cause the apparatus at least to perform the method according to any one of clauses 1-49.

[0517] Clause 51. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of a device, cause the device to perform the method according to any one of clauses 1-49.

CLAIMS

What is claimed is:

1. A method comprising:

receiving, by a wireless device, one or more radio resource control (RRC) messages comprising parameters of an uplink signal requesting system information block 1 (SIB1) of a cell, wherein time division duplex (TDD) configuration of the cell is determined based on the one or more RRC messages; and

transmitting the uplink signal requesting the SIB1 of the cell, wherein the uplink signal is transmitted via one or more uplink symbols according to the TDD configuration of the cell.

2. The method of claim 1, wherein the parameters comprise configuration parameters.
3. The method of any one of claims 1 to 2, wherein the uplink signal comprises an uplink signal of the cell.
4. The method of any one of claims 1 to 3, wherein the parameters indicate that the SIB1 of the cell is on-demand requested.
5. The method of any one of claims 1 to 4, wherein the parameters indicate that the SIB1 is on-demand requested on the cell.
6. The method of any one of claims 1 to 5, wherein the parameters indicate the TDD configuration of the cell.
7. The method of any one of claims 1 to 6, wherein the uplink signal comprises a preamble.
8. The method of any one of claims 1 to 7, wherein the uplink signal comprises a wake-up signal (WUS).
9. The method of claim 8, wherein the parameters indicate that the WUS is associated with a physical cell identity (PCI) of the cell.
10. The method of any one of claims 1 to 9, further comprising: camping on the cell after receiving the SIB1 of the cell.
11. The method of any one of claims 1 to 10, wherein the transmitting the uplink signal is performed in at least one of an RRC idle state or an RRC inactive state.
12. The method of any one of claims 1 to 11, wherein the transmitting the uplink signal is performed before receiving the SIB1 of the cell.
13. The method of any one of claims 1 to 12, wherein the one or more uplink symbols are determined based on the TDD configuration of the cell and a system frame number of a system frame of the cell.
14. The method of any one of claims 1 to 13, further comprising:

receiving, based on the transmitting the uplink symbol, the SIB1 of the cell, wherein the SIB1 indicates a second uplink subcarrier spacing for one or more preambles for initial access procedure of the cell; and

transmitting, via the cell, a first preamble, of the one or more preambles, with the second subcarrier spacing and for the initial access procedure.

15. The method of any of claims 1 to 14, wherein the wireless device transmits the uplink signal requesting the SIB1 of the cell based on the uplink signal being associated with a physical cell identity (PCI) of the cell.
16. The method of any of claims 1 to 15, wherein the wireless device transmits the uplink signal requesting the SIB1 of the cell based on the one or more RRC messages indicating that the SIB1 is on-demand requested on the cell.
17. The method of any of claims 1 to 16, wherein the wireless device receives the one or more RRC messages before the wireless device receives the SIB1 of the cell.
18. The method of any of claims 1 to 17, wherein the wireless device transmits the uplink signal based on not receiving the SIB1 of the cell.
19. The method of any of claims 1 to 18, wherein the wireless device transmits the WUS requesting the SIB1 of the cell, in response to the wireless device being capable of transmitting the WUS, requesting on-demand SIB1 of a cell, in the RRC idle state or in an RRC inactive state.
20. The method of any of claims 1 to 19, wherein the wireless device transmits the uplink signal in one or more uplink symbols based on a system frame number indicated by a master information block (MIB), of the cell, comprised in the one or more RRC messages.
21. The method of any of claims 1 to 20, wherein the wireless device transmits the uplink signal in one or more uplink symbols with a first subcarrier spacing value, wherein the first subcarrier spacing value is indicated by the one or more RRC messages.
22. The method of any of claims 1 to 21, wherein the first subcarrier spacing value is separately configured from a second subcarrier spacing value.
23. The method of any of claims 1 to 22, wherein the second subcarrier spacing value is used for at least one of:
    a reception of the SIB1;
    a transmission of a message 2 and/or 4 for initial access;
    a reception of a message B for initial access;
    a reception of a paging message; and
    a reception of broadcast SI-messages.
24. The method of any of claims 1 to 23, wherein the second subcarrier spacing value is comprised in a master information block (MIB) of the cell.
25. The method of any of claims 1 to 24, wherein the first subcarrier spacing value is independently and/or separately configured from a third subcarrier spacing value for transmission of a first preamble for an initial access procedure, wherein the SIB1 of the cell comprises the third subcarrier spacing value.
26. The method of any of claims 1 to 25, wherein the one or more RRC messages comprise second configuration parameters of a second WUS associated with a second PCI of a second cell.
27. The method of any of claims 1 to 26, wherein the one or more RRC messages indicate that SIB1 of the second cell is on-demand requested.

28. The method of any of claims 1 to 27, wherein the wireless device transmits a second WUS requesting SIB1 of the second cell based on the second WUS being associated with the second PCI of the second cell.
29. The method of any of claims 1 to 28, wherein the wireless device transmits, via first uplink frequency resources of the cell, the uplink signal requesting the SIB1 of the first cell.
30. The method of any of claims 1 to 29, wherein the wireless device transmits, via second uplink frequency resources of the second cell, a second uplink signal requesting the SIB1 of the second cell.
31. The method of claim 30, wherein the first uplink frequency resources are different from the second uplink frequency resources.
32. The method of any of claims 1 to 31, wherein the one or more RRC messages comprise:
    configuration parameters of the first uplink frequency resources of the WUS of the first cell; and
    configuration parameters of the second uplink frequency resources of the second WUS of the second cell.
33. The method of any of claims 1 to 32, wherein the one or more RRC messages comprise an MIB of the cell.
34. The method of any of claims 1 to 33, wherein the one or more RRC messages comprise an RRC release message.
35. The method of any of claims 1 to 34, wherein the one or more RRC messages do not comprise the SIB1 of the cell.
36. The method of any of claims 1 to 35, wherein the wireless device detects the PCI of the cell based on a synchronization signal block (SSB) index of an SSB of the cell, wherein the wireless device receives the SSB of the cell before transmitting the WUS.
37. The method of any of claims 1 to 36, wherein the wireless device detects the PCI of the cell based on receiving at least one SSB of SSBs of the cell, wherein the PCI is determined based on a first identity and a second identity.
38. The method of claim 37, wherein the WUS, requesting the SIB1 of the cell, is generated based on the first identity of the PCI of the cell.
39. The method of claim 37, wherein the WUS, requesting the SIB1 of the cell, is generated based on the second identity of the PCI of the cell.
40. The method of claim 37, wherein the WUS, requesting the SIB1 of the cell, is generated based on both the first identity and the second identity.
41. The method of any of claims 1 to 40, wherein each SSB of the SSBs of the cell comprises at least one of:
    a primary synchronization signal (PSS);
    a secondary synchronization signal (SSS); and
    a physical broadcast channel (PBCH) carrying the MIB of the cell.
42. The method of claim 41, wherein the PSS is a second signal sequence generated based on the first identity of the PCI of the cell.

43. The method of any of claims 41 to 42, wherein the SSS is a third signal sequence generated based on the first identity of the PCI and the second identity of the PCI.
44. The method of any of claims 1 to 43, wherein the WUS is a pseudo-random sequence generated/initialized by the PCI of the cell.
45. The method of any of claims 1 to 44, further comprising receiving the SIB1 of the cell based on the transmitting the WUS.
46. The method of any of claims 1 to 45, wherein the wireless device receives the SIB1 scheduled by a group common downlink control information (DCI) with cyclic redundancy check (CRC) scrambled by system information–radio network temporary identifier (SI-RNTI).
47. The method of any of claims 1 to 46, further comprising receiving the group common DCI via a cell common search space of the cell, wherein the cell common search space is indicated by the one or more messages.
48. The method of any of claims 1 to 47, further comprising monitoring, before transmitting the WUS, a physical downlink control channel (PDCCH) of the cell for receiving a second DCI scheduling the SIB1 of the cell.
49. The method of any of claims 1 to 48, wherein the wireless device transmits the WUS based on no SIB1 being received during monitoring the PDCCH of the cell.
50. The method of any of claims 1 to 49, wherein the wireless device transmits the WUS based on at least one of SSBs, of the cell, being received.
51. The method of any of claims 1 to 50, wherein the wireless device determines the at least one of the SSBs, of the cell, is received based on successfully detecting the PCI of the cell.
52. The method of any of claims 1 to 51, wherein:

the WUS, requesting the SIB1 of the cell, is transmitted via first uplink symbols determined based on a first TDD configuration of the cell indicated by the one or more RRC messages; and

the first preamble, for the initial access procedure of the cell, is transmitted via second uplink symbols determined based on a second TDD configuration of the cell indicated by the SIB1 received after the transmitting the WUS.
53. The method of any of claims 1 to 52, wherein the wireless device performs the initial access procedure, comprising the transmitting the first preamble, after the wireless device receives the SIB1 of the cell.
54. The method of any of claims 1 to 53, further comprising transitioning to an RRC connected state after the initial access procedure.
55. An apparatus comprising one or more processors and memory storing instructions that, when executed by the one or more processors, cause the apparatus at least to perform the method according to any one of claims 1-54.
56. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of a device, cause the device to perform the method according to any one of claims 1-54.

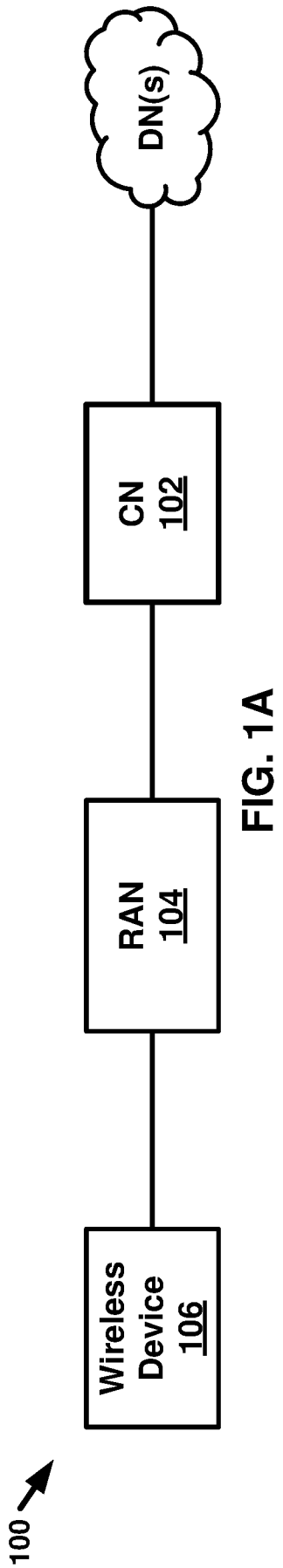

100
Wireless Device 106
RAN 104
CN 102
DN(s)

FIG. 1A

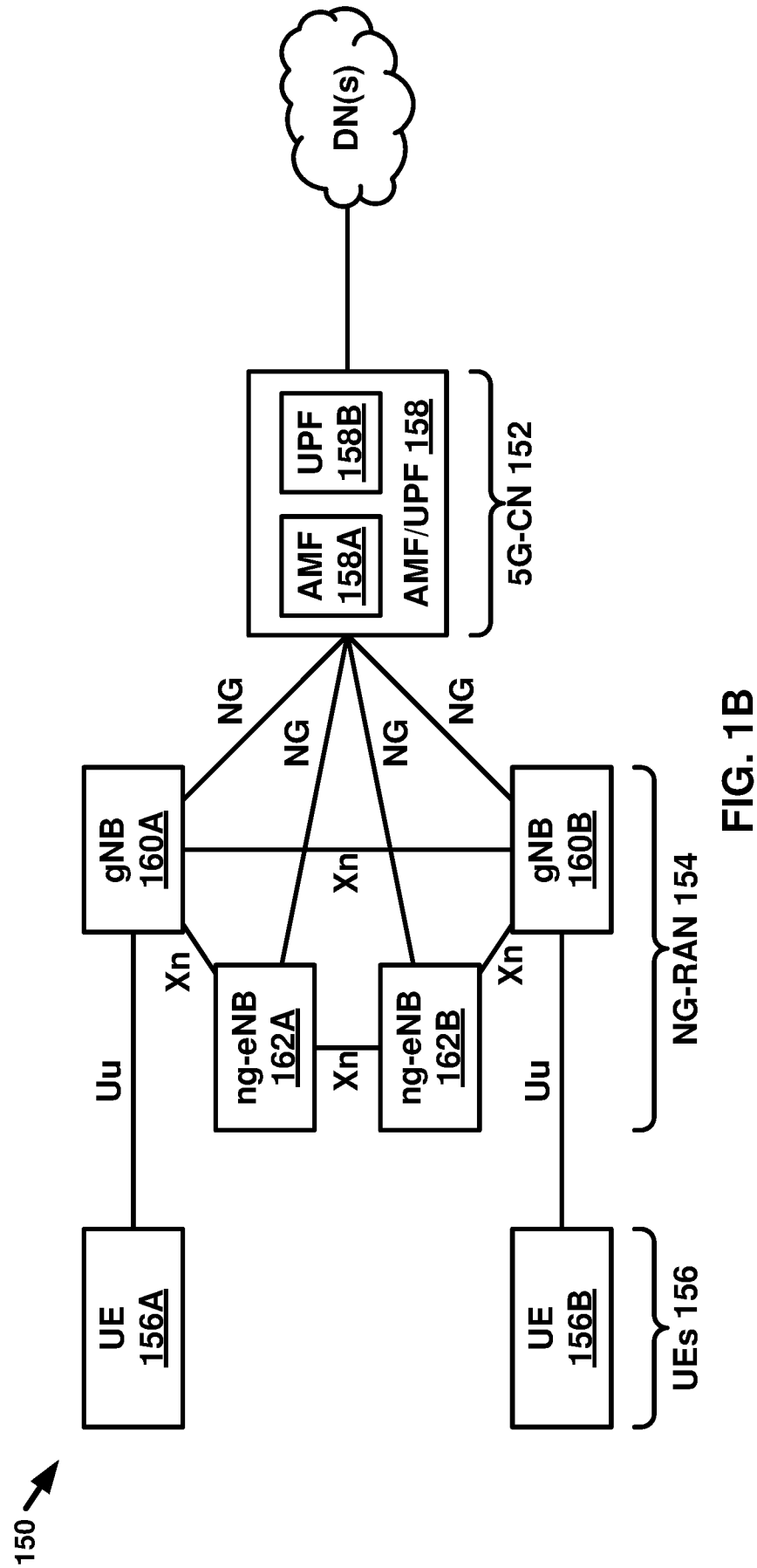

150
UE 156A
UE 156B
UEs 156
gNB 160A
gNB 160B
ng-eNB 162A
ng-eNB 162B
NG-RAN 154
Uu
Xn
NG
AMF/UPF 158
AMF 158A
UPF 158B
5G-CN 152
DN(s)

FIG. 1B

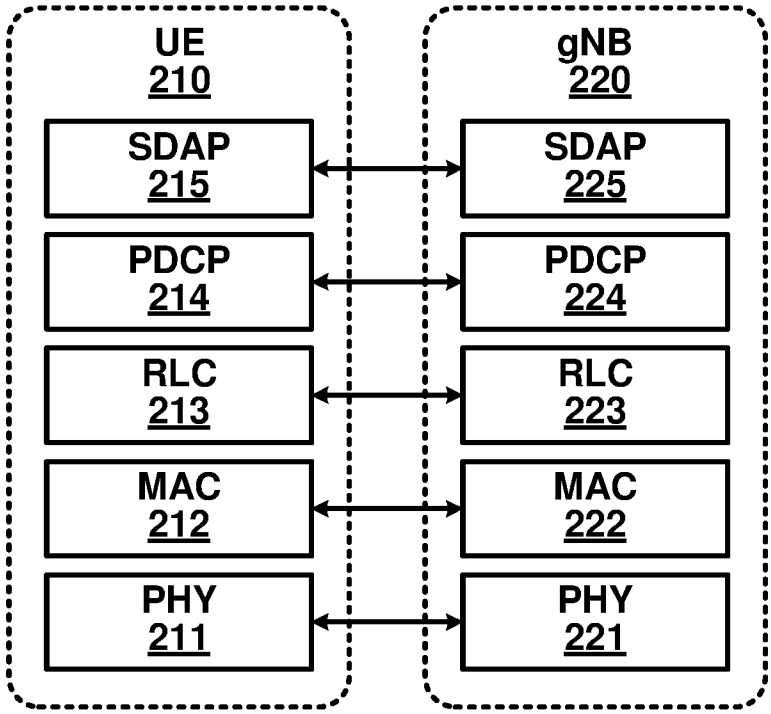

UE
210
gNB
220
SDAP
215
SDAP
225
PDCP
214
PDCP
224
RLC
213
RLC
223
MAC
212
MAC
222
PHY
211
PHY
221

FIG. 2A

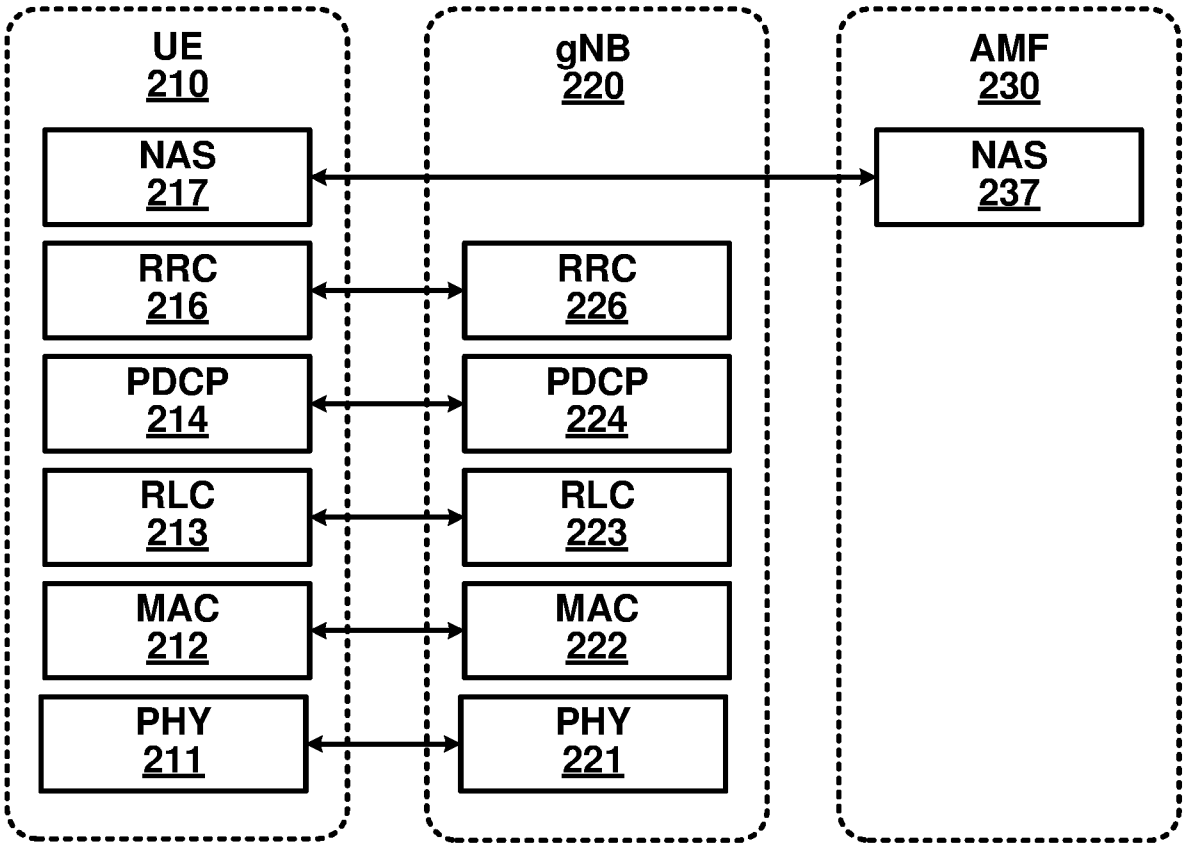

UE
210
gNB
220
AMF
230
NAS
217
NAS
237
RRC
216
RRC
226
PDCP
214
PDCP
224
RLC
213
RLC
223
MAC
212
MAC
222
PHY
211
PHY
221

FIG. 2B

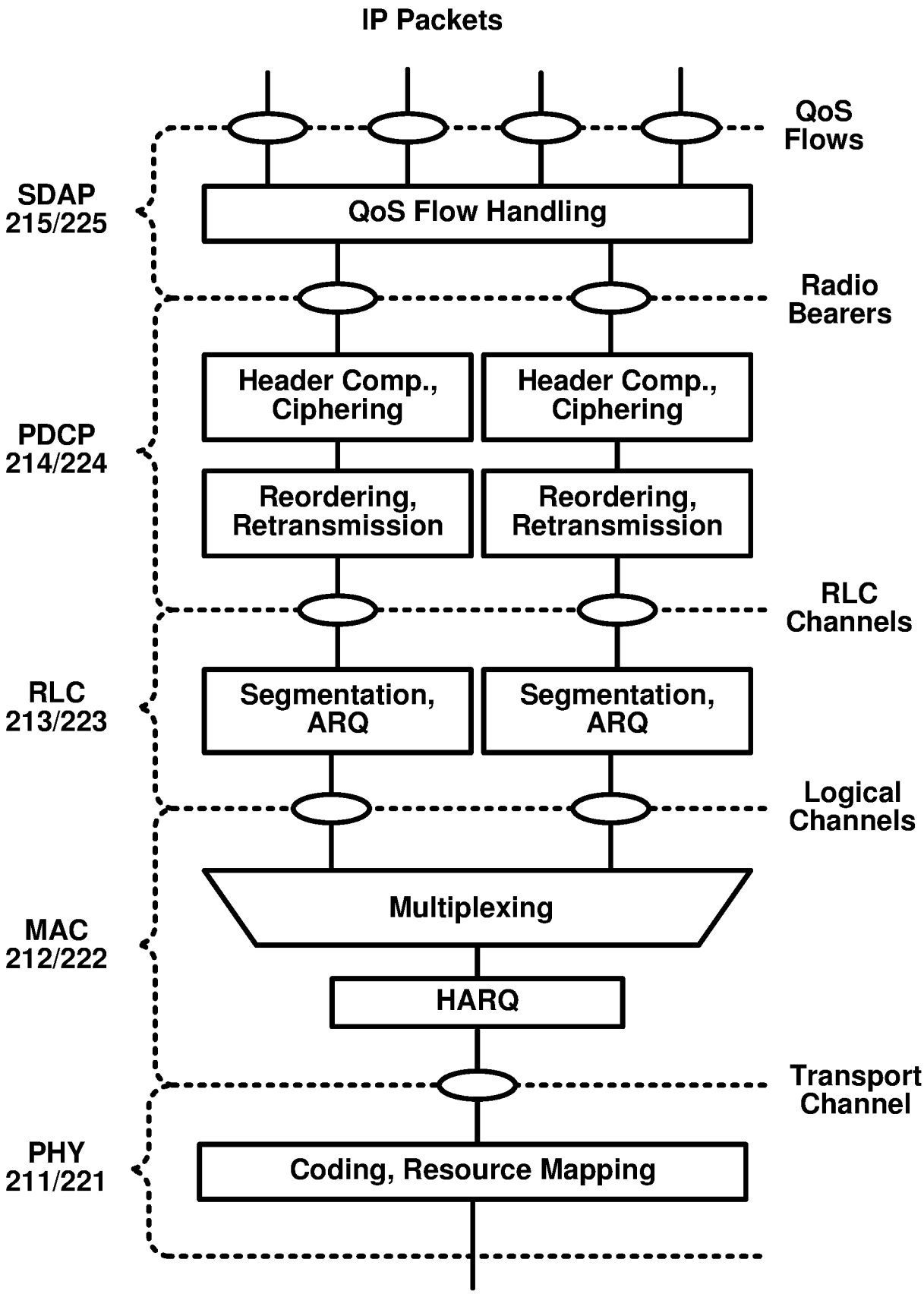

IP Packets
QoS Flows
SDAP 215/225
QoS Flow Handling
Radio Bearers
PDCP 214/224
Header Comp., Ciphering
Header Comp., Ciphering
Reordering, Retransmission
Reordering, Retransmission
RLC Channels
RLC 213/223
Segmentation, ARQ
Segmentation, ARQ
Logical Channels
MAC 212/222
Multiplexing
HARQ
Transport Channel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

FIG. 3

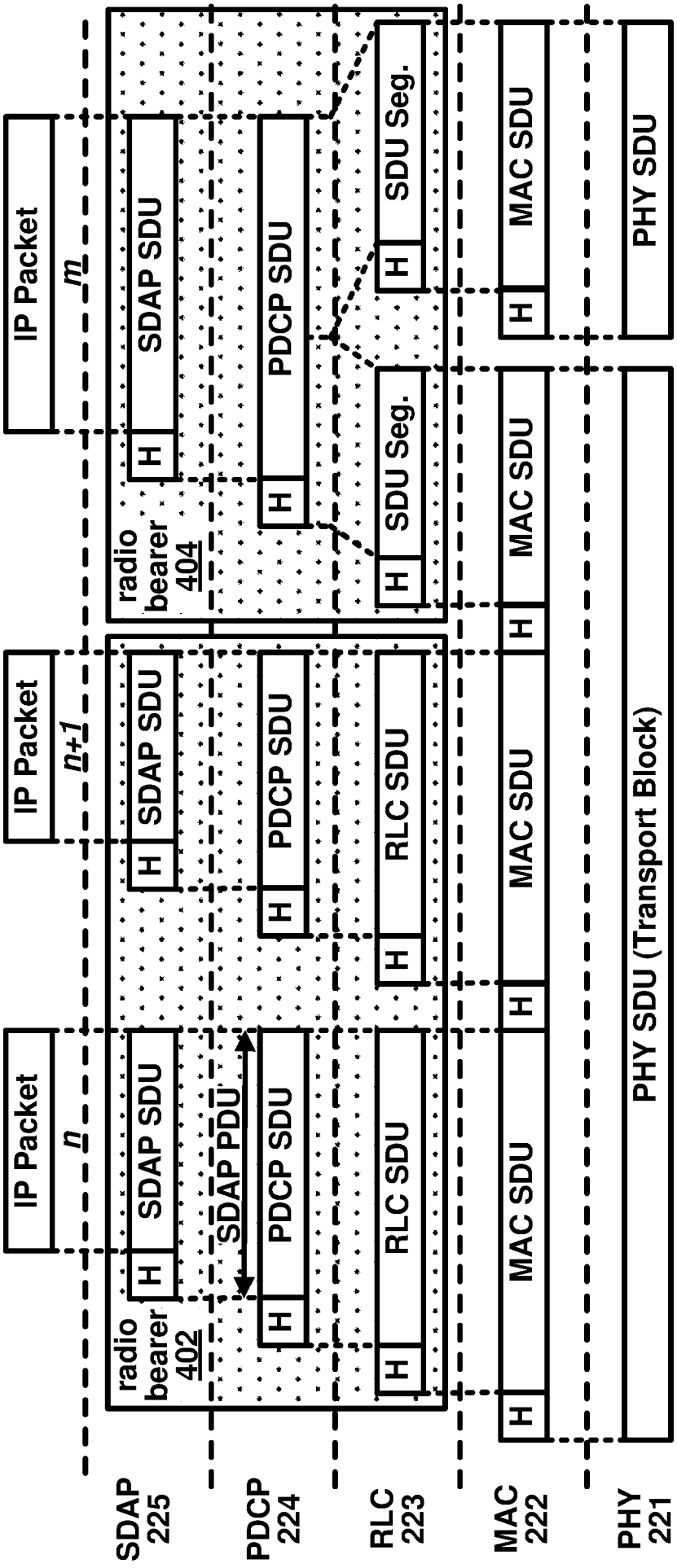

IP Packet
n
IP Packet
n+1
IP Packet
m
radio bearer 402
radio bearer 404
H
SDAP SDU
SDAP PDU
PDCP SDU
RLC SDU
SDU Seg.
MAC SDU
PHY SDU (Transport Block)
PHY SDU
SDAP 225
PDCP 224
RLC 223
MAC 222
PHY 221

FIG. 4A

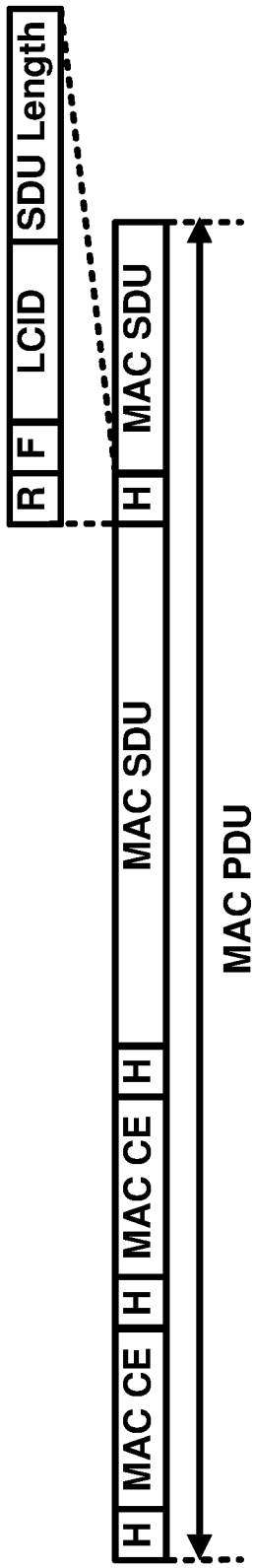

R
F
LCID
SDU Length
H
MAC SDU
MAC CE
MAC PDU

FIG. 4B

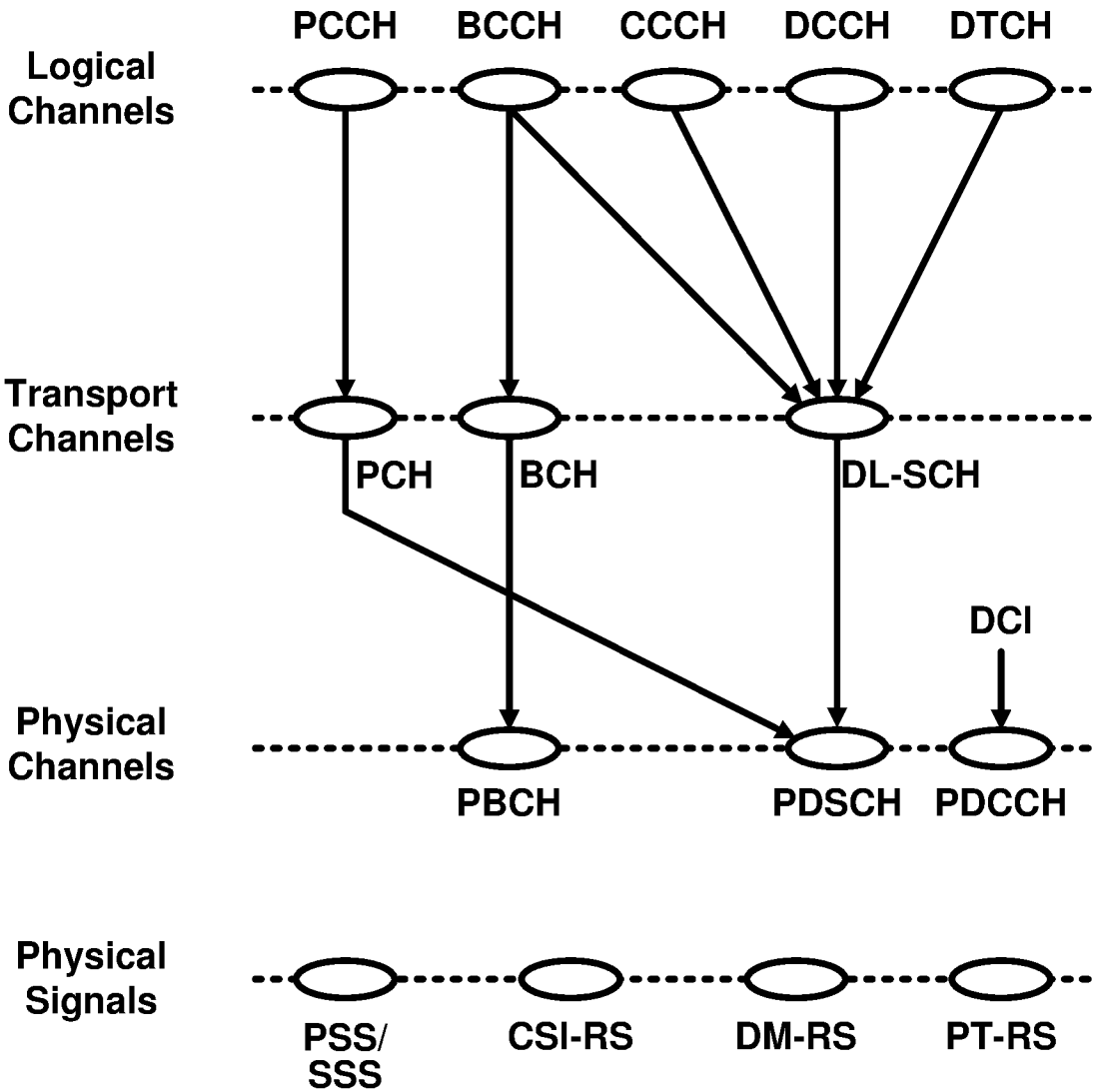


FIG. 5A

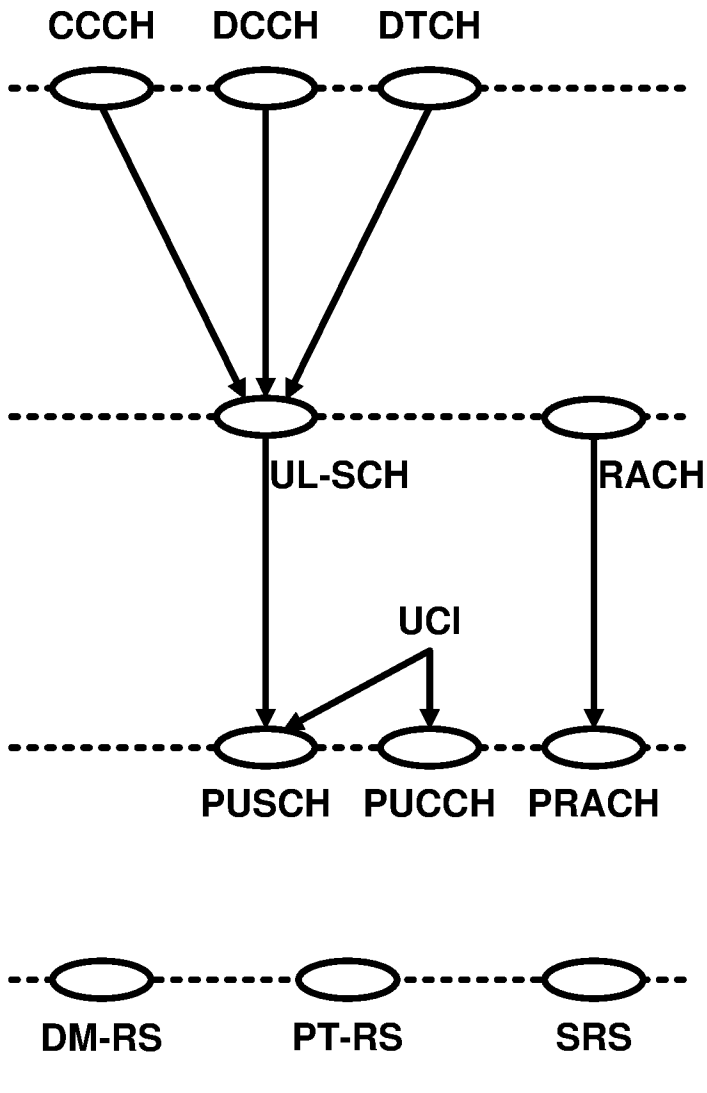


FIG. 5B

WO 2025/106963
PCT/US2024/056368

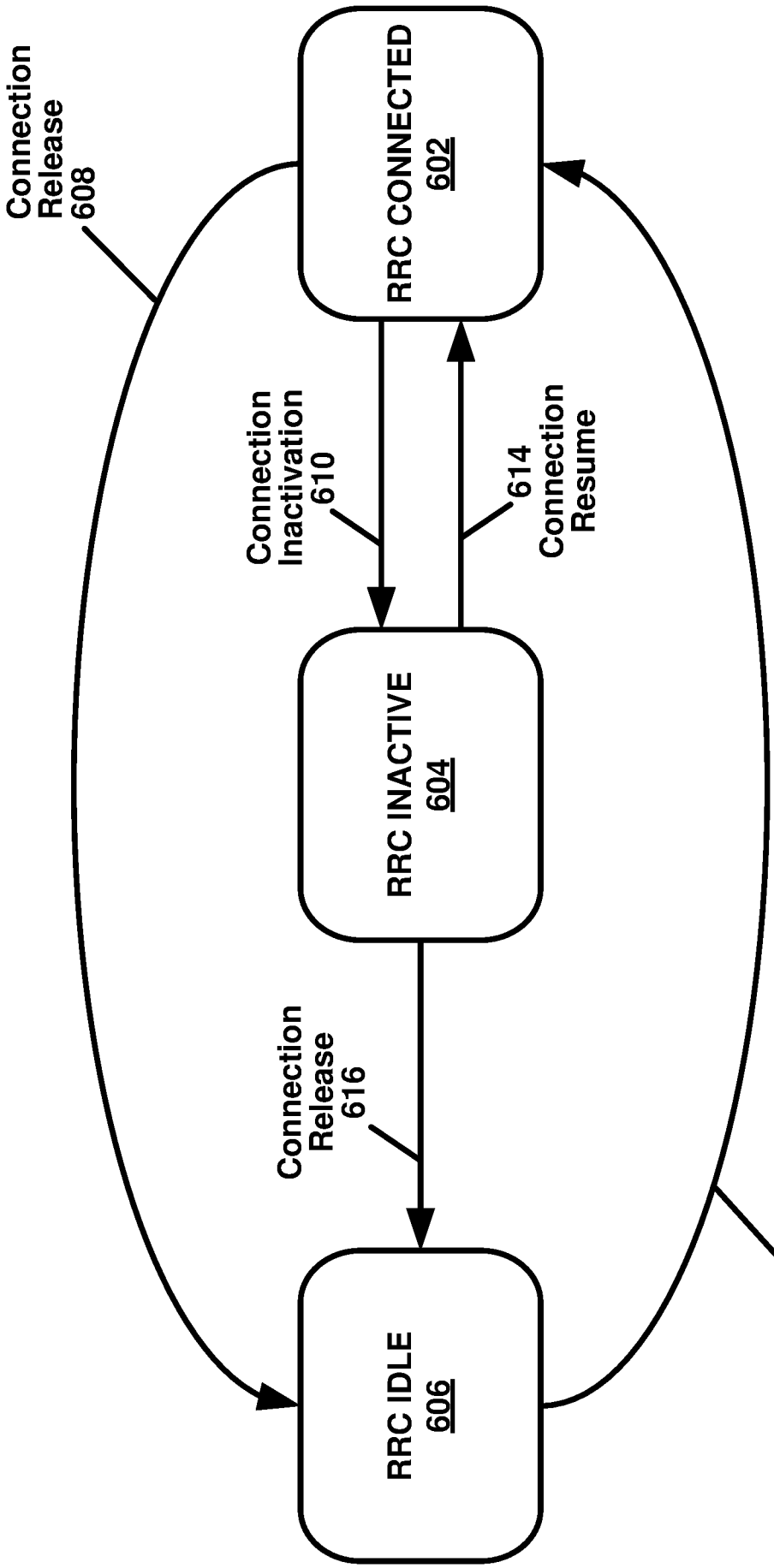

RRC CONNECTED
602
RRC INACTIVE
604
RRC IDLE
606
Connection
Release
608
Connection
Inactivation
610
614
Connection
Resume
Connection
Release
616
612
Connection
Establishment

FIG. 6

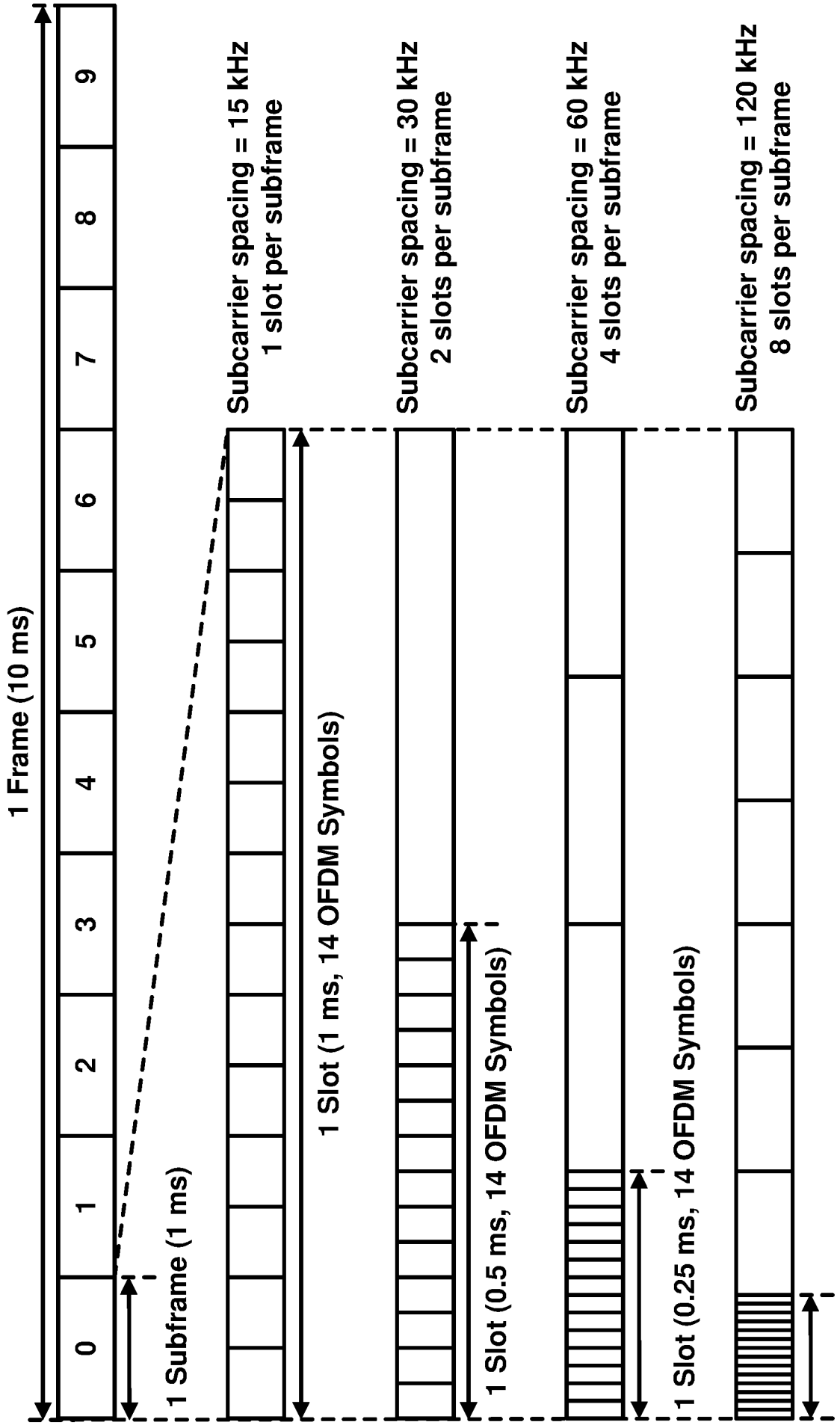

1 Frame (10 ms)
0
1
2
3
4
5
6
7
8
9
1 Subframe (1 ms)
Subcarrier spacing = 15 kHz
1 slot per subframe
1 Slot (1 ms, 14 OFDM Symbols)
Subcarrier spacing = 30 kHz
2 slots per subframe
1 Slot (0.5 ms, 14 OFDM Symbols)
Subcarrier spacing = 60 kHz
4 slots per subframe
1 Slot (0.25 ms, 14 OFDM Symbols)
Subcarrier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

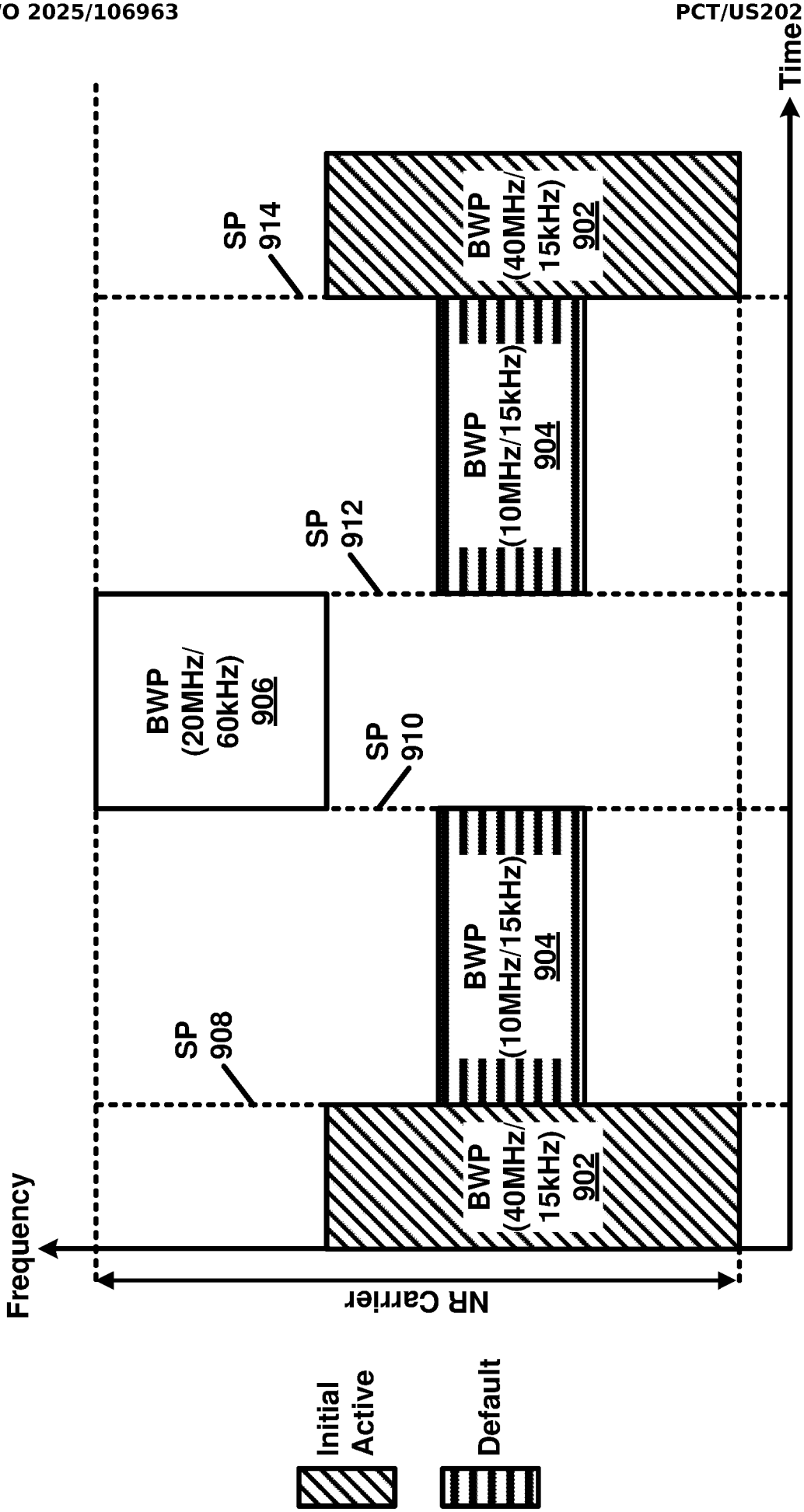

Time
Frequency
NR Carrier
BWP (40MHz/ 15kHz) 902
BWP (10MHz/15kHz) 904
BWP (20MHz/ 60kHz) 906
SP 914
SP 912
SP 910
SP 908
Initial Active
Default

FIG. 9

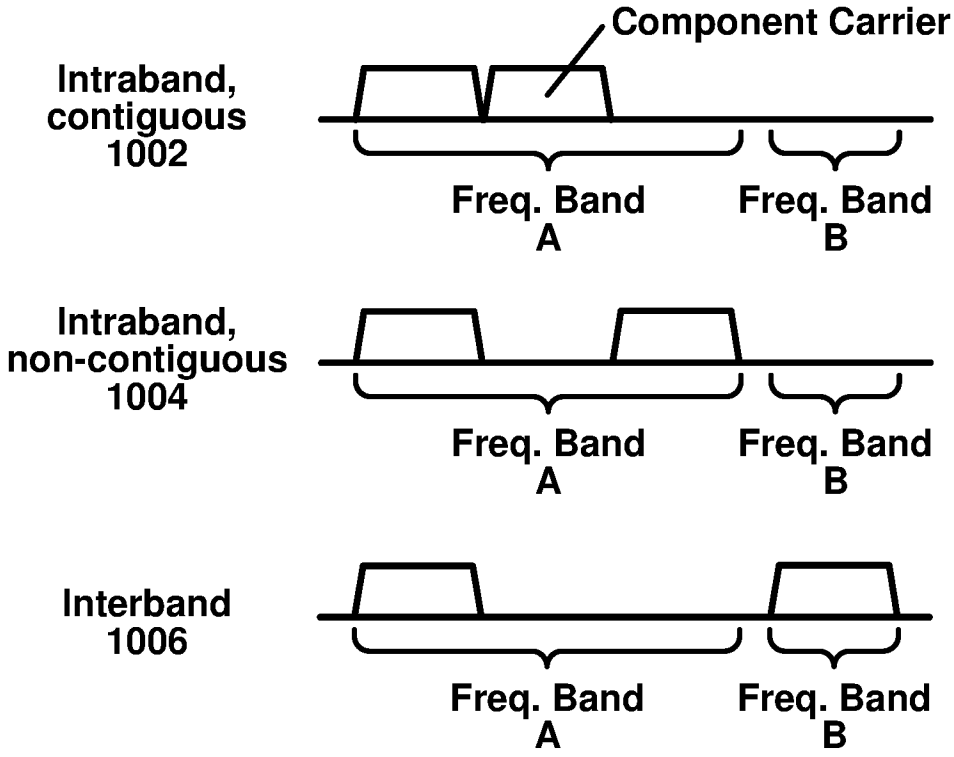


FIG. 10A

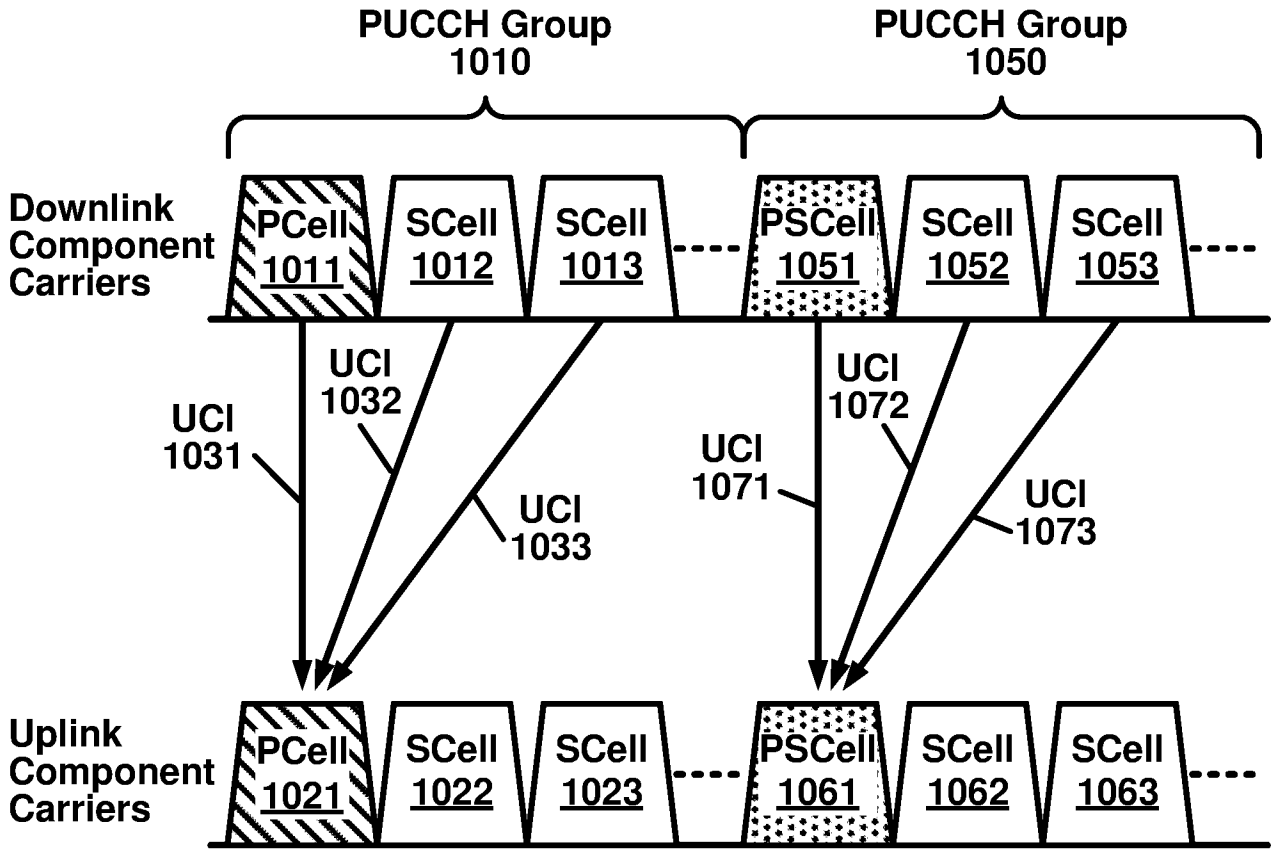


FIG. 10B

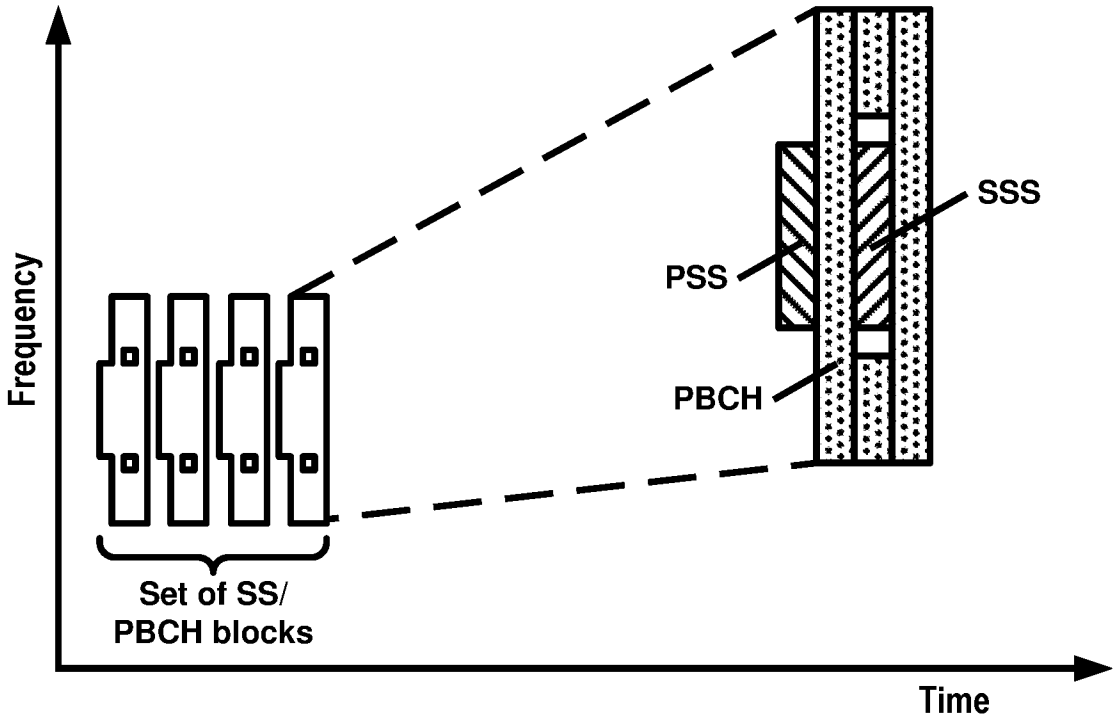


FIG. 11A

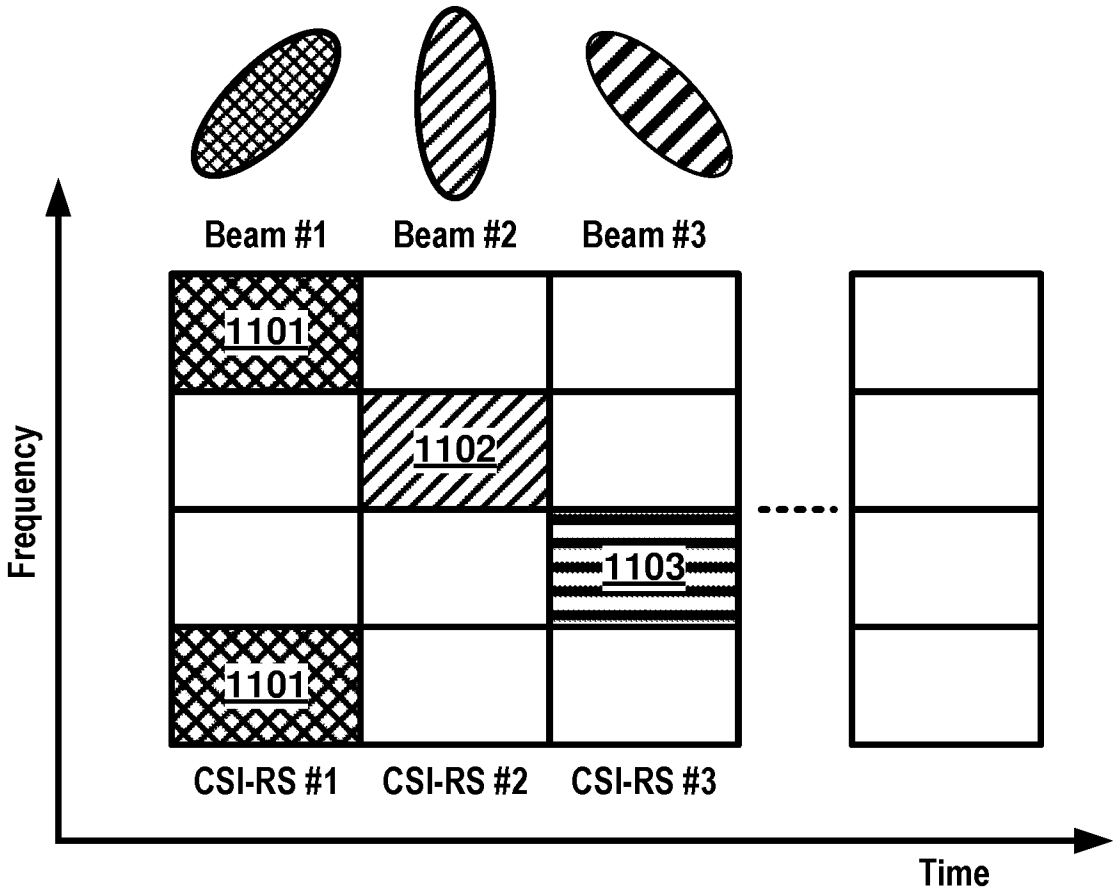


FIG. 11B

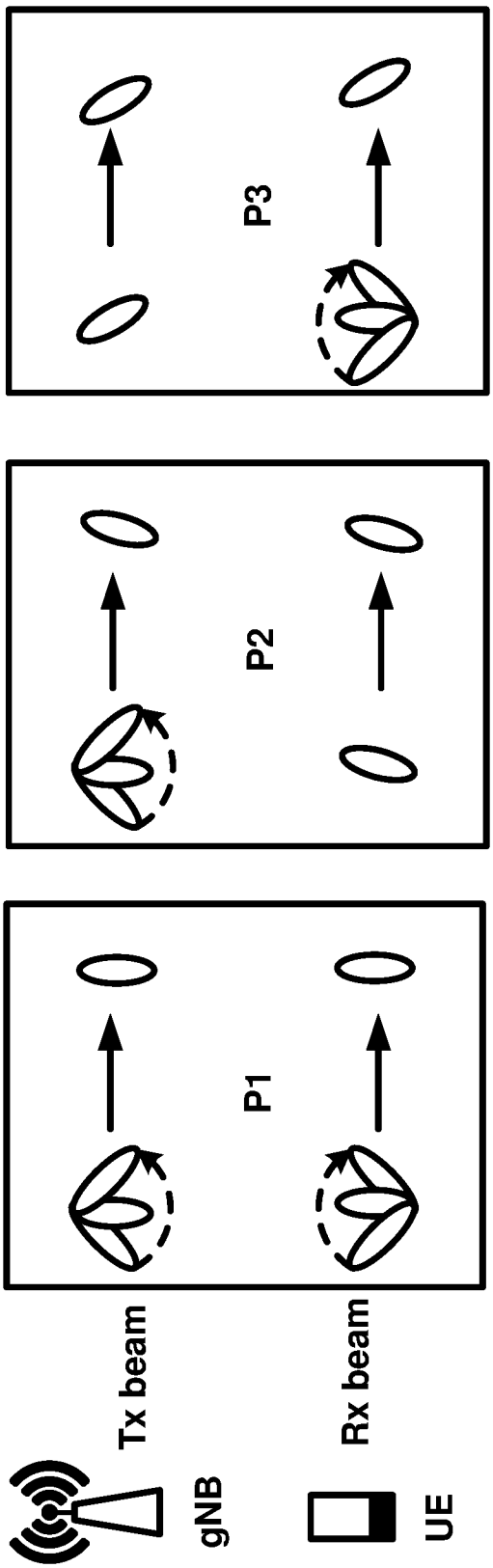


FIG. 12A

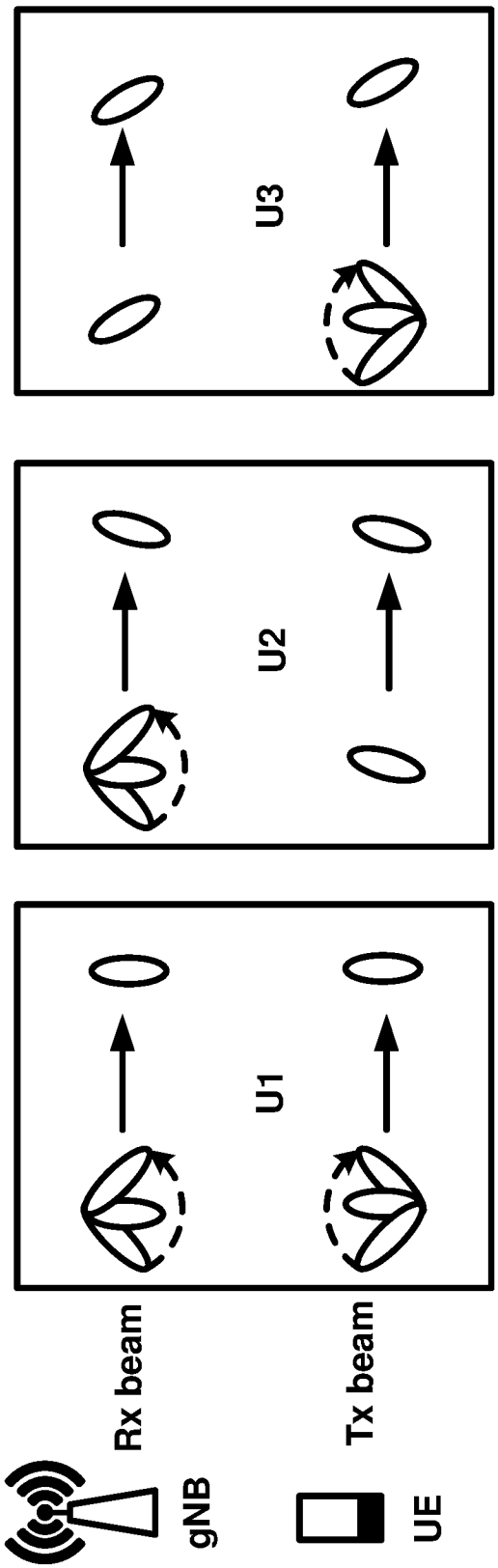


FIG. 12B

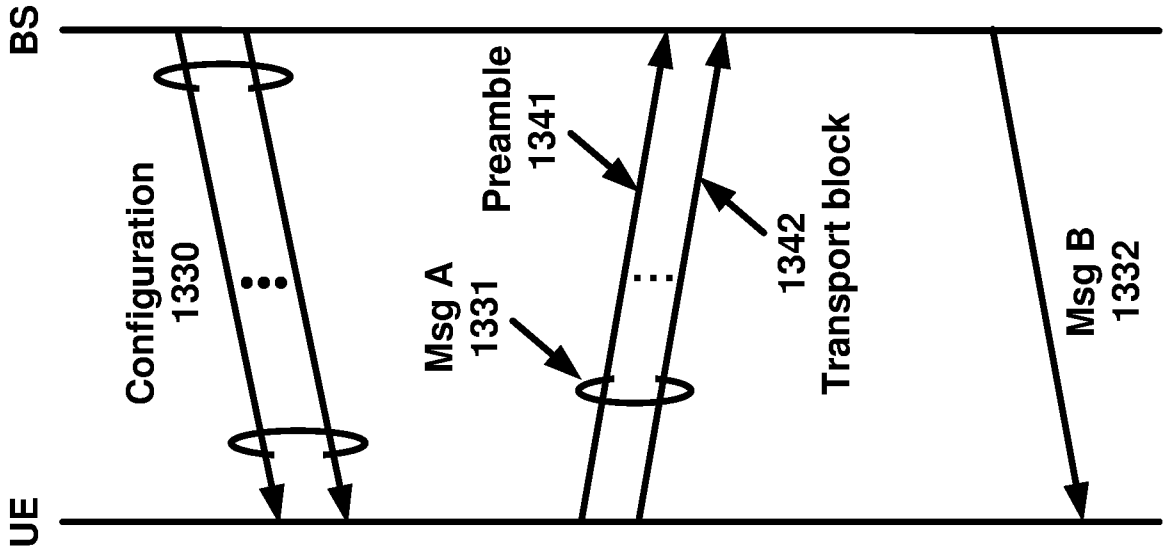


FIG. 13C

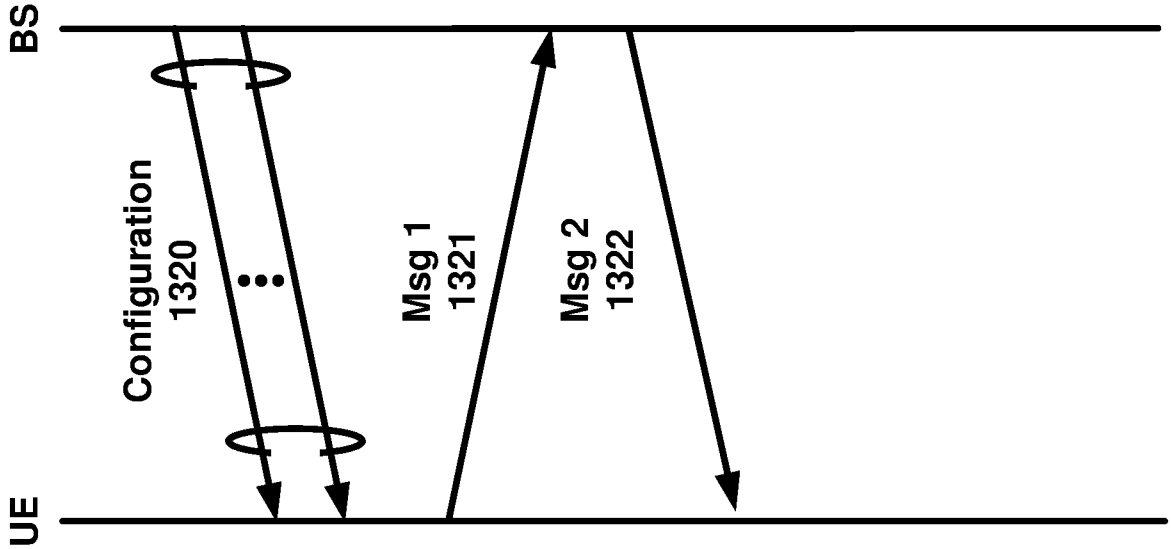


FIG. 13B

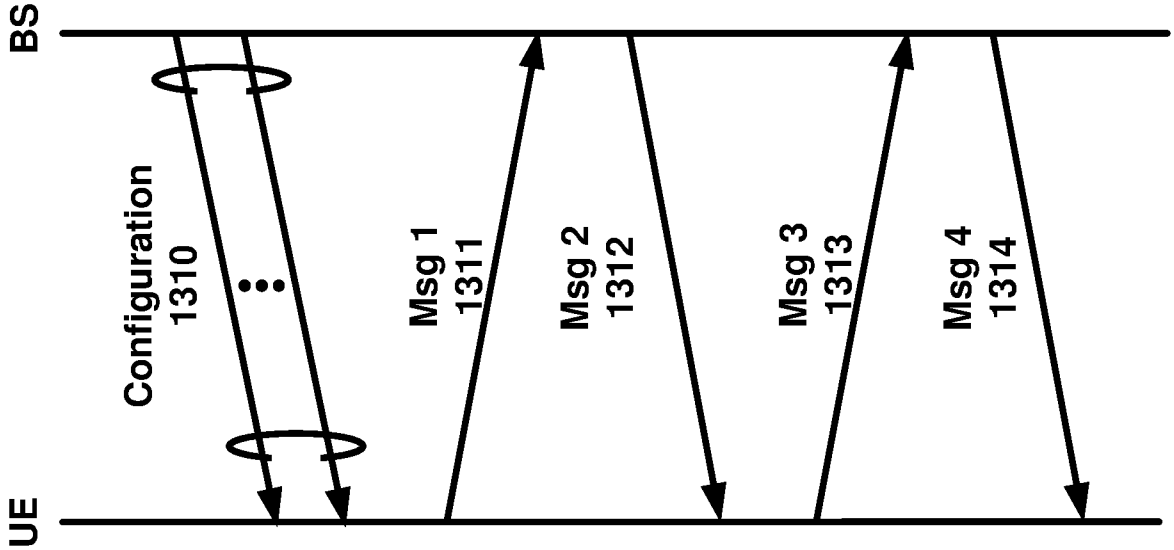


FIG. 13A

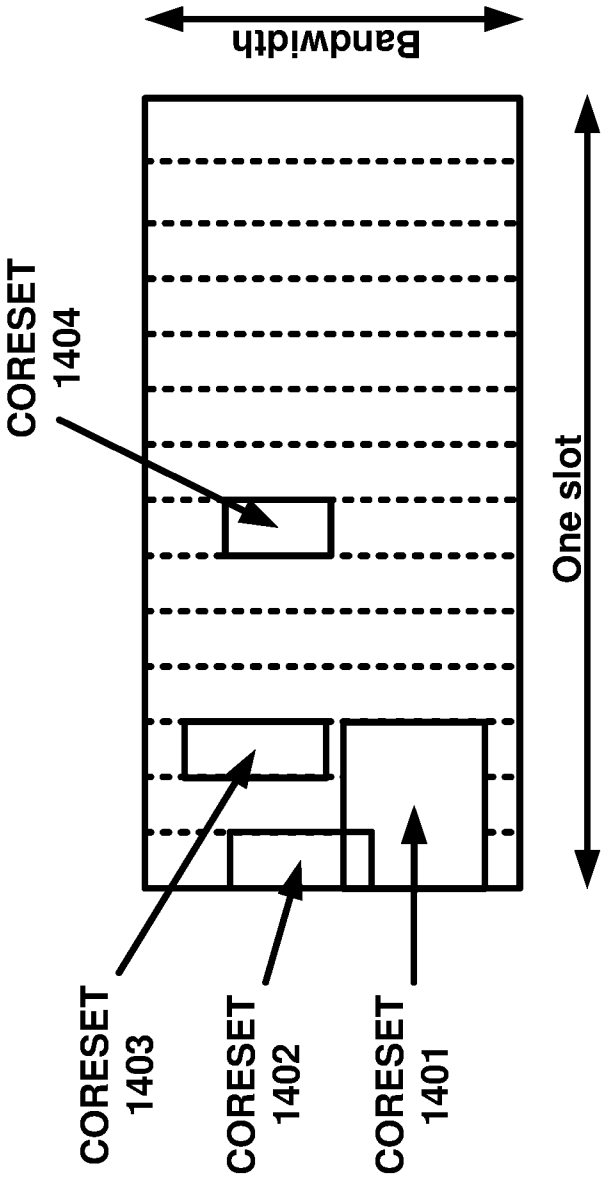


FIG. 14A

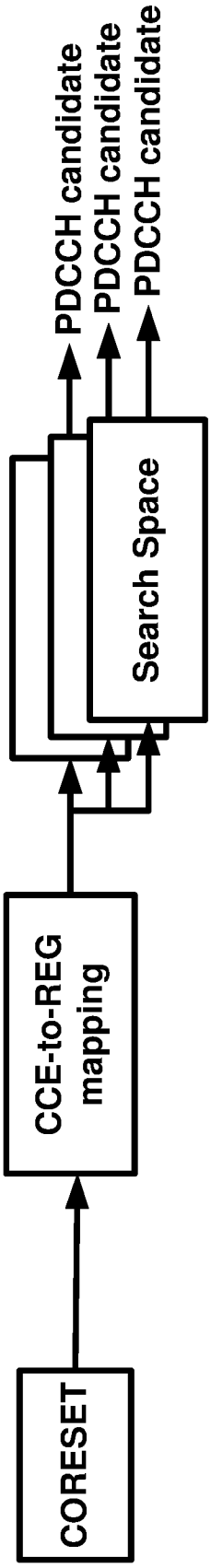


FIG. 14B

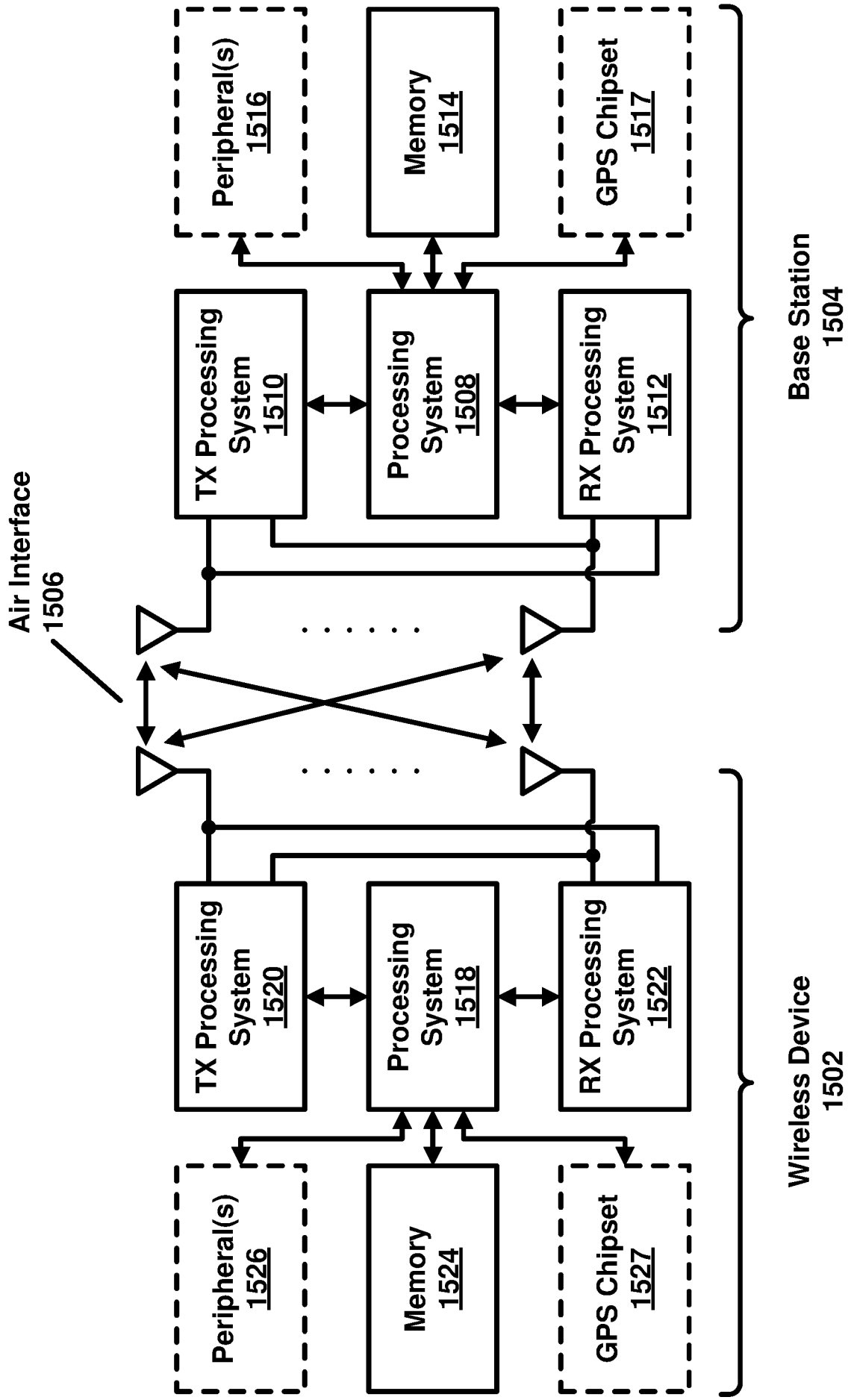

Peripheral(s) 1516
Memory 1514
GPS Chipset 1517
TX Processing System 1510
Processing System 1508
RX Processing System 1512
Base Station 1504
Air Interface 1506
TX Processing System 1520
Processing System 1518
RX Processing System 1522
Peripheral(s) 1526
Memory 1524
GPS Chipset 1527
Wireless Device 1502

FIG. 15

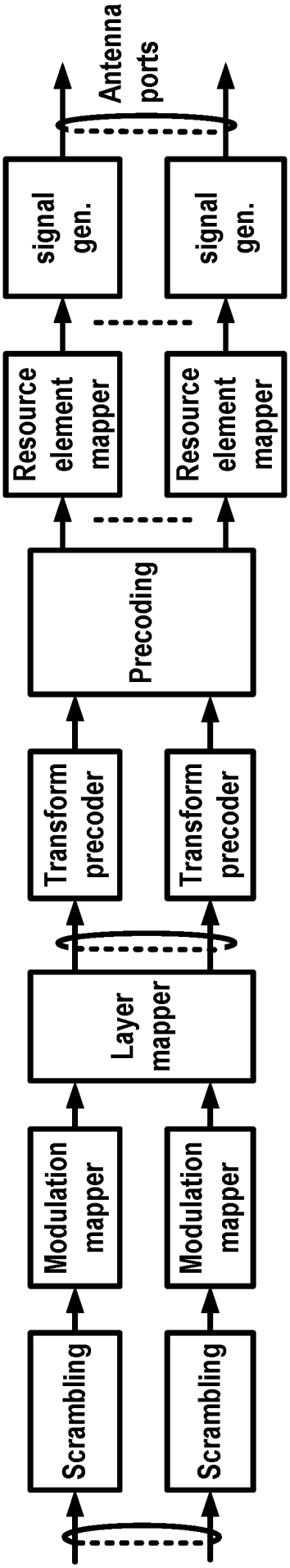


FIG. 16A

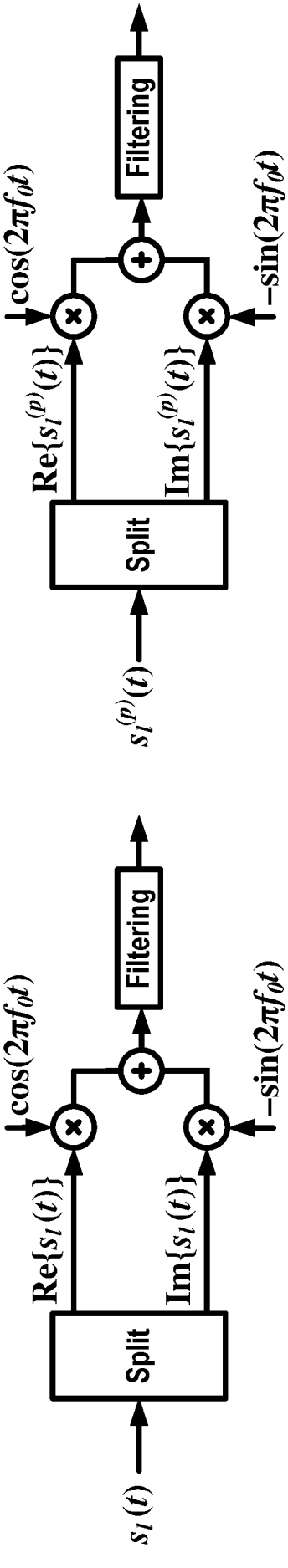


FIG. 16B

FIG. 16D

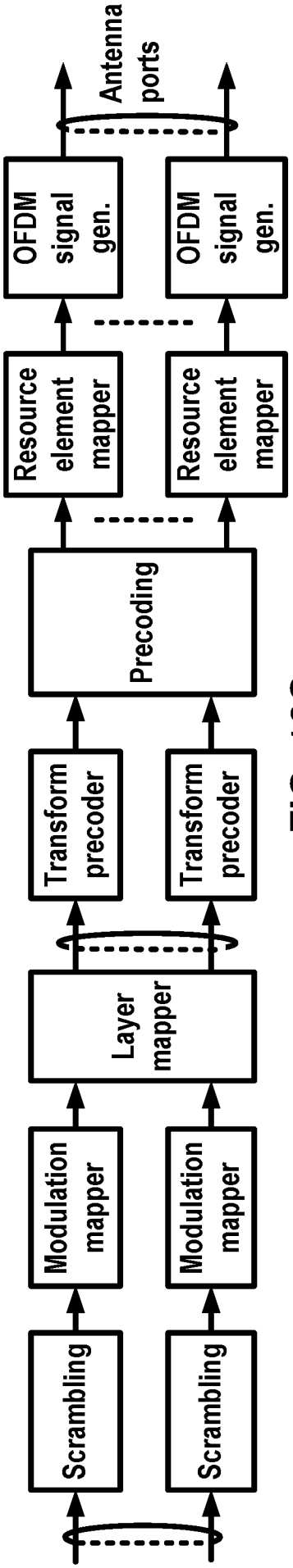


FIG. 16C

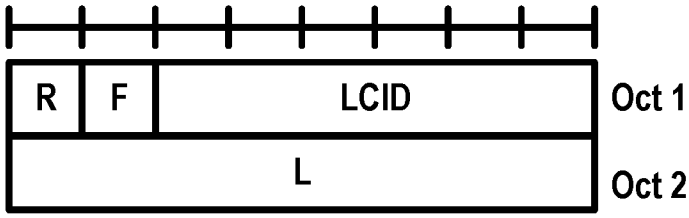


FIG. 17A

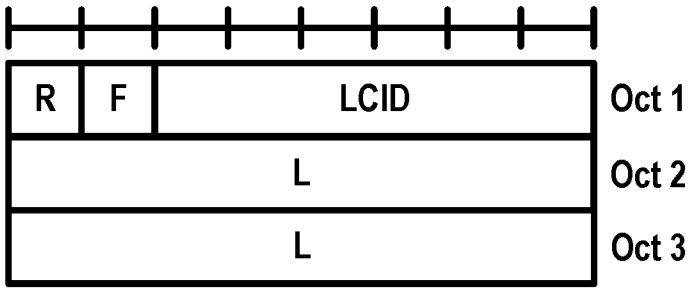


FIG. 17B

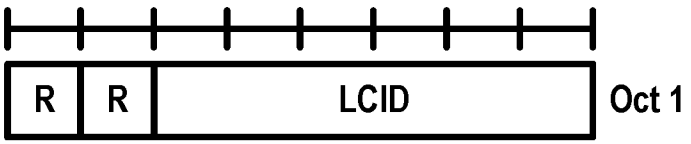


FIG. 17C

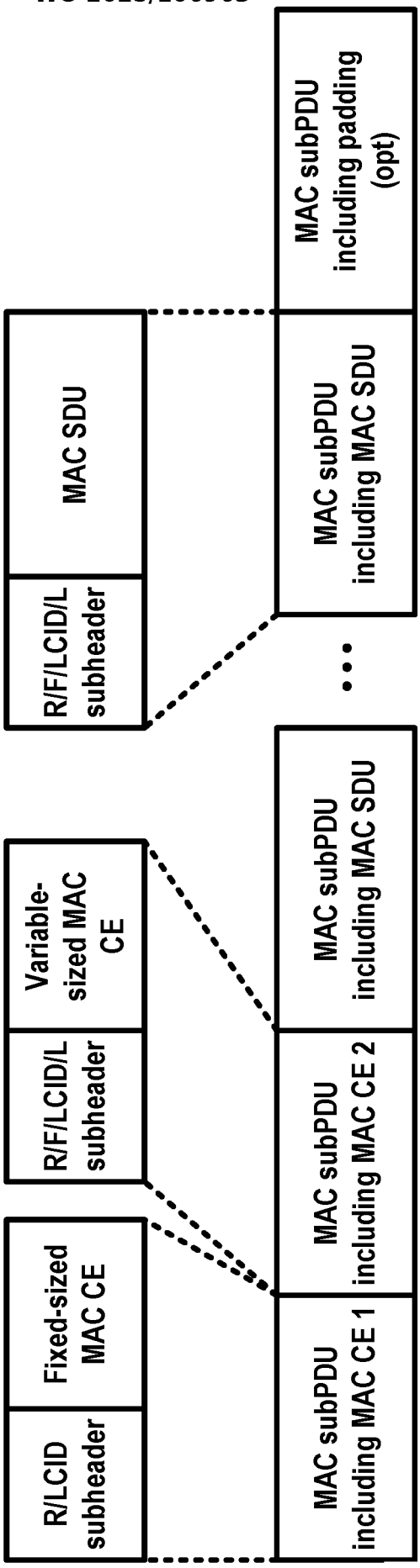


FIG. 18A

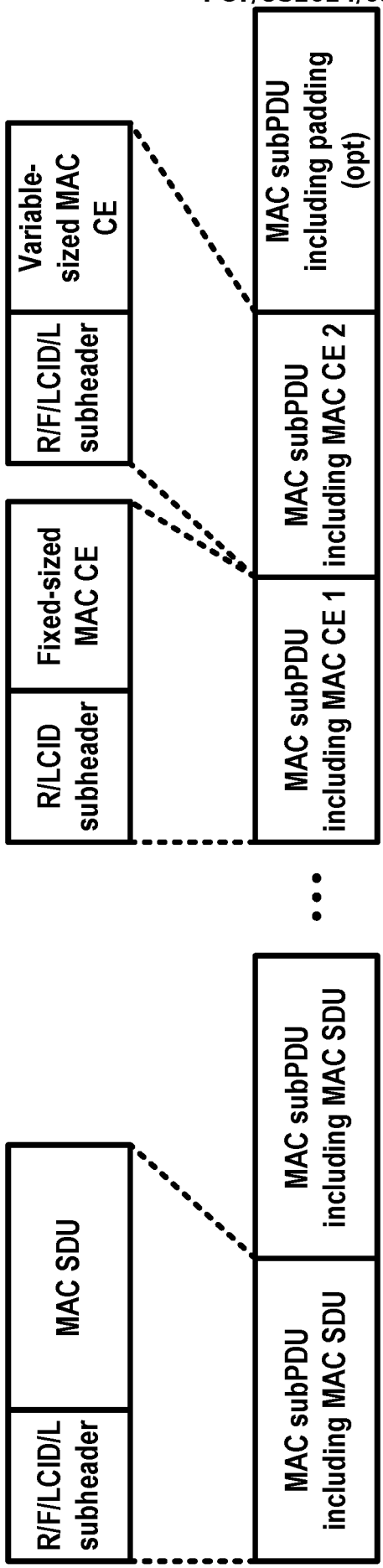


FIG. 18B

Index	LCID values
000000	CCCH
000001-100000	Identity of a logical channel
100001-101111	Reserved
110000	SP ZP CSI-RS Resource Set Act./Deact.
110001	PUCCH spatial relation Act./Deact.
110010	SP SRS Act./Deact.
110011	SP CSI reporting on PUCCH Act./Deact.
110100	TCI State Indication for UE-specific PDCCH
110101	TCI State Indication for UE-specific PDSCH
110110	Aperiodic CSI Trigger State Subselection
110111	SP CSI-RS/CSI-IM Resource Set Act./Deact.
111000	Duplication Activation/deactivation
111001	SCell activation/deactivation (4 Octet)
111010	SCell activation/deactivation (1 Octet)
111011	Long DRX Command
111100	DRX Command
111101	Timing Advance Command
111110	UE Contention Resolution Identity
111111	Padding

FIG. 19

Index	LCID values
000000	CCCH
000001-100000	Identity of a logical channel
100001-110110	Reserved
110111	Configured Grant Confirmation
111000	Multiple Entry PHR
111001	Single Entry PHR
111010	C-RNTI
111011	Short Truncated BSR
111100	Long Truncated BSR
111101	Short BSR
111110	Long BSR
111111	Padding

FIG. 20

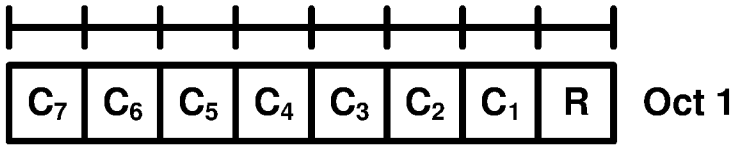


FIG. 21A

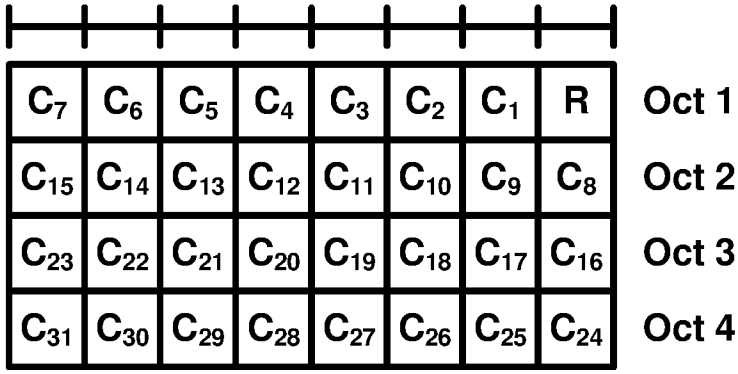


FIG. 21B

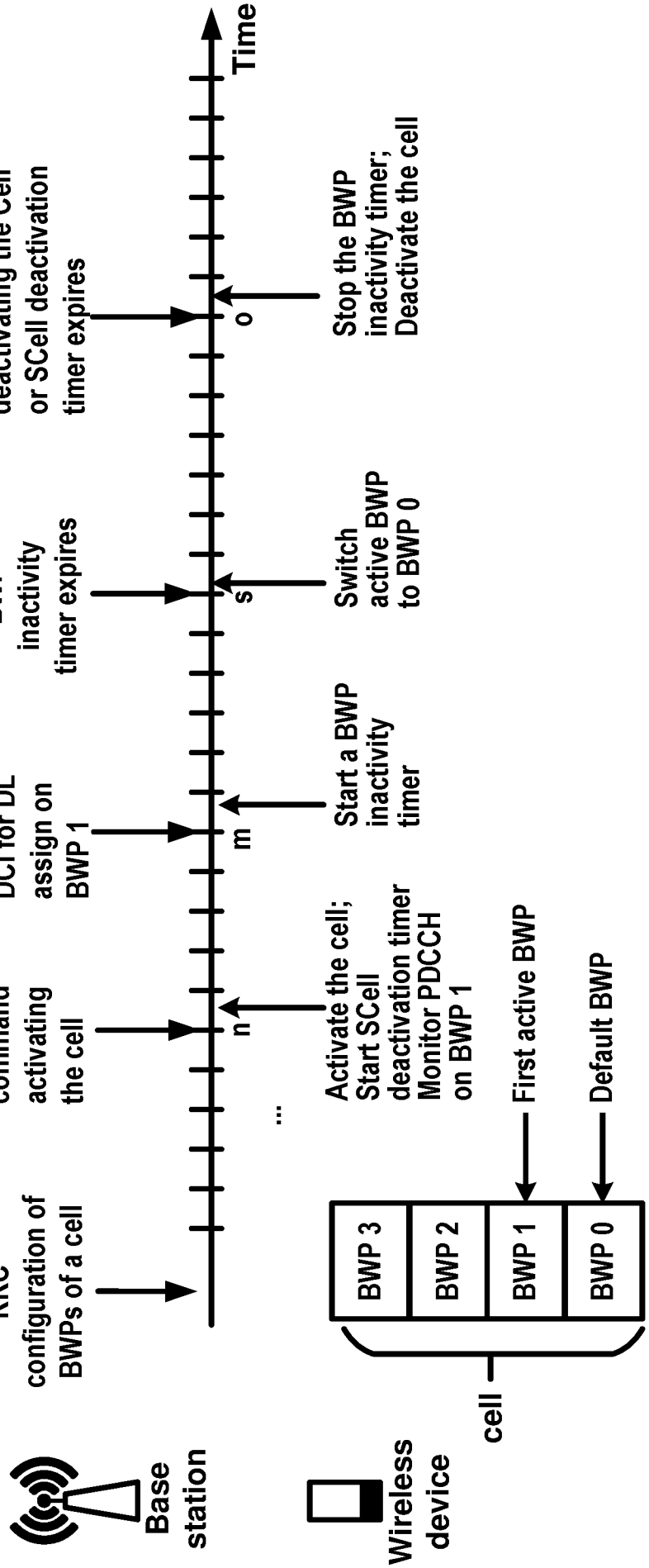

Time
RRC configuration of BWPs of a cell
command activating the cell
DCI for DL assign on BWP 1
BWP inactivity timer expires
command deactivating the Cell or SCell deactivation timer expires
n
m
s
o
...
Activate the cell; Start SCell deactivation timer Monitor PDCCH on BWP 1
Start a BWP inactivity timer
Switch active BWP to BWP 0
Stop the BWP inactivity timer; Deactivate the cell
First active BWP
Default BWP
BWP 3
BWP 2
BWP 1
BWP 0
cell
Base station
Wireless device

FIG. 22

DCI format	Usage
0_0	Scheduling of PUSCH in one cell
0_1	Scheduling of one or multiple PUSCH in one cell, or indicating CG-DFI for configured grant PUSCH
0_2	Scheduling of PUSCH in one cell
1_0	Scheduling of PDSCH in one cell
1_1	Scheduling of PDSCH in one cell, and/or triggering one shot HARQ-ACK codebook feedback
1_2	Scheduling of PDSCH in one cell
2_0	Notifying a group of UEs of the slot format, available RB sets, COT duration and search space set group switching
2_1	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE
2_2	Transmission of TPC commands for PUCCH and PUSCH
2_3	Transmission of a group of TPC commands for SRS transmissions by one or more UEs
2_4	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE cancels the corresponding UL transmission from the UE
2_5	Notifying the availability of soft resources
2_6	Notifying the power saving information outside DRX Active Time for one or more UEs
2_7	Notifying Paging early indication and TRS availability indication for one or more UEs
3_0	Scheduling of NR sidelink in one cell
3_1	Scheduling of LTE sidelink in one cell
4_0	Schedulng of PDSCH with CRC scrambled by MCCH-RNTI/G-RNTI for broadcast
4_1	Schedulng of PDSCH with CRC scrambled by G-RNTI/G-CS-RNTI for multicast
4_2	Schedulng of PDSCH with CRC scrambled by G-RNTI/G-CS-RNTI for multicast

FIG. 23

```
MIB ::=                    SEQUENCE {
   systemFrameNumber            BIT STRING (SIZE (6)),
   subCarrierSpacingCommon        ENUMERATED {scs15or60, scs30or120},
   ssb-SubcarrierOffset         INTEGER (0..15),
   dmrs-TypeA-Position           ENUMERATED {pos2, pos3},
   pdcch-ConfigSIB1             PDCCH-ConfigSIB1,
   cellBarred                 ENUMERATED {barred, notBarred},
   intraFreqReselection         ENUMERATED {allowed, notAllowed},
   spare                    BIT STRING (SIZE (1))}

PDCCH-ConfigSIB1 ::=          SEQUENCE {
   controlResourceSetZero       ControlResourceSetZero,
   searchSpaceZero              SearchSpaceZero}
```

FIG. 24A

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs per coreset	Number of Symbols per coreset	Offset (RBs)
0	1	24	2	0
1	1	24	2	2
2	1	24	2	4
3	1	24	3	0
4	1	24	3	2
5	1	24	3	4
6	1	48	1	12
7	1	48	1	16
...	...	...	...	...

FIG. 24B

Index	*O*	Number of search space sets per slot	*M*	First symbol index
0	0	1	1	0
1	0	2	1/2	{0, if *i* is even}, {*N*, if is odd}
2	2	1	1	0
3	2	2	1/2	{0, if *i* is even}, {*N*, if *i* is odd}
4	5	1	1	0
5	5	2	1/2	{0, if *i* is even}, *N*, if *i* is odd
6	7	1	1	0
7	7	2	1/2	{0, if *i* is even}, {*N*, if *i* is odd}
...	...	...	...	...

FIG. 24C

```
SIB1 ::=        SEQUENCE {
   cellSelectionInfo                SEQUENCE {
      q-RxLevMin                       Q-RxLevMin,
      q-RxLevMinOffset                 INTEGER (1..8) ...}
   cellAccessRelatedInfo            CellAccessRelatedInfo,
   connEstFailureControl            ConnEstFailureControl
   si-SchedulingInfo                SI-SchedulingInfo
   servingCellConfigCommon          ServingCellConfigCommonSIB
   ims-EmergencySupport             ENUMERATED {true}
   eCallOverIMS-Support             ENUMERATED {true}
   ue-TimersAndConstants            UE-TimersAndConstants
   uac-BarringInfo                  SEQUENCE { ...}
   useFullResumeID                  ENUMERATED {true}
   lateNonCriticalExtension         OCTET STRING
   nonCriticalExtension             SIB1-v16xy-IEs  }

ServingCellConfigCommonSIB ::=      SEQUENCE {
   downlinkConfigCommon             DownlinkConfigCommonSIB,
   uplinkConfigCommon               UplinkConfigCommonSIB
   supplementaryUplink              UplinkConfigCommonSIB
   n-TimingAdvanceOffset            ENUMERATED { n0, n25600, n39936 }
   ssb-PositionsInBurst             SEQUENCE {
      inOneGroup                    BIT STRING (SIZE (8)),
      groupPresence                 BIT STRING (SIZE (8)) },
   ssb-PeriodicityServingCell       ENUMERATED {ms5, ms10, ms20, ms40, ms80, ms160},
   tdd-UL-DL-ConfigurationCommon    TDD-UL-DL-ConfigCommon
   ss-PBCH-BlockPower               INTEGER (-60..50),
   ...,}

DownlinkConfigCommonSIB ::=     SEQUENCE {
   frequencyInfoDL                  FrequencyInfoDL-SIB,
   initialDownlinkBWP               BWP-DownlinkCommon,
   bcch-Config                      BCCH-Config,
   pcch-Config                      PCCH-Config,  ...}

PCCH-Config ::=             SEQUENCE {
   defaultPagingCycle               PagingCycle,
   nAndPagingFrameOffset            CHOICE {
      oneT                          NULL,
      halfT                         INTEGER (0..1), ...},
   ns                               ENUMERATED {four, two, one},
   firstPDCCH-MonitoringOccasionOfPO   CHOICE {
      sCS15KHZoneT                  SEQUENCE (SIZE (1..maxPO-perPF)) OF INTEGER (0..139),...}
   ...,
   [[   nrofPDCCH-MonitoringOccasionPerSSB-InPO-r16  INTEGER (2..4)  ]]
}
```

FIG. 25

```
SI-SchedulingInfo ::=              SEQUENCE {
    schedulingInfoList             SEQUENCE (SIZE (1..maxSI-Message)) OF SchedulingInfo,
    si-WindowLength                ENUMERATED {s5, s10, ... },
    si-RequestConfig               SI-RequestConfig                                    OPTIONAL,  -
- Cond MSG-1
    si-RequestConfigSUL            SI-RequestConfig                                    OPTIONAL,  -
- Cond SUL-MSG-1
    systemInformationAreaID            BIT STRING (SIZE (24))
OPTIONAL,  -- Need R
    ...
}

SchedulingInfo ::=                 SEQUENCE {
    si-BroadcastStatus                 ENUMERATED {broadcasting, notBroadcasting},
    si-Periodicity                 ENUMERATED {rf8, rf16, rf32, rf64, rf128, rf256, rf512},
    sib-MappingInfo                    SIB-Mapping
}

SIB-Mapping ::=                    SEQUENCE (SIZE (1..maxSIB)) OF SIB-TypeInfo

SIB-TypeInfo ::=                   SEQUENCE {
    type                           ENUMERATED {sibType2, sibType3, ... },
    valueTag                           INTEGER (0..31)    OPTIONAL, -- Cond SIB-TYPE
    areaScope                          ENUMERATED {true}      OPTIONAL -- Need S
}


SI-RequestConfig ::=               SEQUENCE {
    rach-OccasionsSI                   SEQUENCE {
        rach-ConfigSI                  RACH-ConfigGeneric,
        ssb-perRACH-Occasion               ENUMERATED {oneEighth, oneFourth, oneHalf,
one, two, four, eight, sixteen}
    }                                                                          OPTIONAL,   -- Need R
    si-RequestPeriod               ENUMERATED {one, two, four, six, eight, ten, twelve,
sixteen}      OPTIONAL,   -- Need R
    si-RequestResources                SEQUENCE (SIZE (1..maxSI-Message)) OF SI-
RequestResources
}

SI-RequestResources ::=            SEQUENCE {
    ra-PreambleStartIndex              INTEGER (0..63),
    ra-AssociationPeriodIndex          INTEGER (0..15)
OPTIONAL,   -- Need R
    ra-ssb-OccasionMaskIndex           INTEGER (0..15)
OPTIONAL    -- Need R
}
```

FIG. 26

```
BWP-DownlinkCommon ::=            SEQUENCE {
   genericParameters              BWP,
   pdcch-ConfigCommon             SetupRelease { PDCCH-ConfigCommon }
   pdsch-ConfigCommon             SetupRelease { PDSCH-ConfigCommon }
   ...}

PDCCH-ConfigCommon ::=            SEQUENCE {
   controlResourceSetZero         ControlResourceSetZero
   commonControlResourceSet       ControlResourceSet
   searchSpaceZero                SearchSpaceZero
   commonSearchSpaceList          SEQUENCE (SIZE(1..4)) OF SearchSpace
   searchSpaceSIB1                SearchSpaceId
   searchSpaceOtherSystemInformation  SearchSpaceId
   pagingSearchSpace              SearchSpaceId
   ra-SearchSpace                 SearchSpaceId
    [[
   firstPDCCH-MonitoringOccasionOfPO  CHOICE {
      sCS15KHZoneT   SEQUENCE (SIZE (1..maxPO-perPF)) OF INTEGER (0..139),
      ...
   }OPTIONAL   -- Cond OtherBWP
    ]]
   ...,}

PDCCH-ServingCellConfig ::=       SEQUENCE {
   slotFormatIndicator            SetupRelease { SlotFormatIndicator }...,
   [[
   availabilityIndicator-r16      SetupRelease {AvailabilityIndicator-r16}
   searchSpaceSwitchTimer-r16     INTEGER (1..80)
   ]]
}

SearchSpaceSwitchConfig-r16 ::=   SEQUENCE {
   cellGroupsForSwitchList-r16    SEQUENCE(SIZE (1..4)) OF CellGroupForSwitch-r16
   searchSpaceSwitchDelay-r16     INTEGER (10..52)
}
CellGroupForSwitch-r16 ::= SEQUENCE(SIZE (1..16)) OF ServCellIndex

ControlResourceSet ::=            SEQUENCE {
   controlResourceSetId           ControlResourceSetId,
   frequencyDomainResources       BIT STRING (SIZE (45)),
   duration                       INTEGER (1..maxCoReSetDuration),
   cce-REG-MappingType            CHOICE {
      interleaved                 SEQUENCE {
         reg-BundleSize           ENUMERATED {n2, n3, n6},
         interleaverSize          ENUMERATED {n2, n3, n6},
         shiftIndex               INTEGER(0..maxNrofPhysicalResourceBlocks-1)},
      nonInterleaved              NULL},
   precoderGranularity            ENUMERATED {sameAsREG-bundle, allContiguousRBs},
   pdcch-DMRS-ScramblingID        INTEGER (0..65535)
   ...,   }
```

FIG. 27

```
SearchSpace ::=                    SEQUENCE {
   searchSpaceId                      SearchSpaceId,
   controlResourceSetId               ControlResourceSetId
   monitoringSlotPeriodicityAndOffset     CHOICE {
      sl1                             NULL,
      sl2                             INTEGER (0..1),...}
   duration                           INTEGER (2..2559)
   monitoringSymbolsWithinSlot            BIT STRING (SIZE (14))
   nrofCandidates                     SEQUENCE {
      aggregationLevel1                   ENUMERATED {n0, n1, n2, ... n8},
      aggregationLevel2                   ENUMERATED {n0, n1, n2, ... n8},
      ...}
   searchSpaceType                    CHOICE {
      common                          SEQUENCE {
         dci-Format0-0-AndFormat1-0           SEQUENCE {...}
         dci-Format2-0                  SEQUENCE {
            nrofCandidates-SFI                SEQUENCE {
               aggregationLevel1                 ENUMERATED {n1, n2}
               aggregationLevel2                 ENUMERATED {n1, n2}...},
            ...}
         dci-Format2-1                  SEQUENCE {...}
...
      },
      ue-Specific                     SEQUENCE {
         dci-Formats       ENUMERATED {formats0-0-And-1-0, formats0-1-And-1-1},
         ...,}
   }
}

SearchSpaceExt-r16 ::=             SEQUENCE {
   controlResourceSetId-r16           ControlResourceSetId-r16
   searchSpaceType-r16                SEQUENCE {
      common-r16                      SEQUENCE {
         dci-Format2-4-r16                SEQUENCE {
            nrofCandidates-CI-r16               SEQUENCE {
               aggregationLevel1-r16                ENUMERATED {n1, n2}...},...}
         dci-Format2-5-r16              SEQUENCE {
            nrofCandidates-IAB-r16              SEQUENCE {
               aggregationLevel1-r16                ENUMERATED {n1, n2}...},...}
         dci-Format2-6-r16              SEQUENCE {...}
         ...}
   }
   searchSpaceGroupIdList-r16       SEQUENCE (SIZE (1.. 2)) OF INTEGER (0..1)
   freqMonitorLocations-r16               BIT STRING (SIZE (5))
}

SearchSpaceSwitchTrigger-r16 ::=   SEQUENCE {
   servingCellId-r16               ServCellIndex,
   positionInDCI-r16
INTEGER(0..maxSFI-DCI-PayloadSize-1)
}
```

FIG. 28

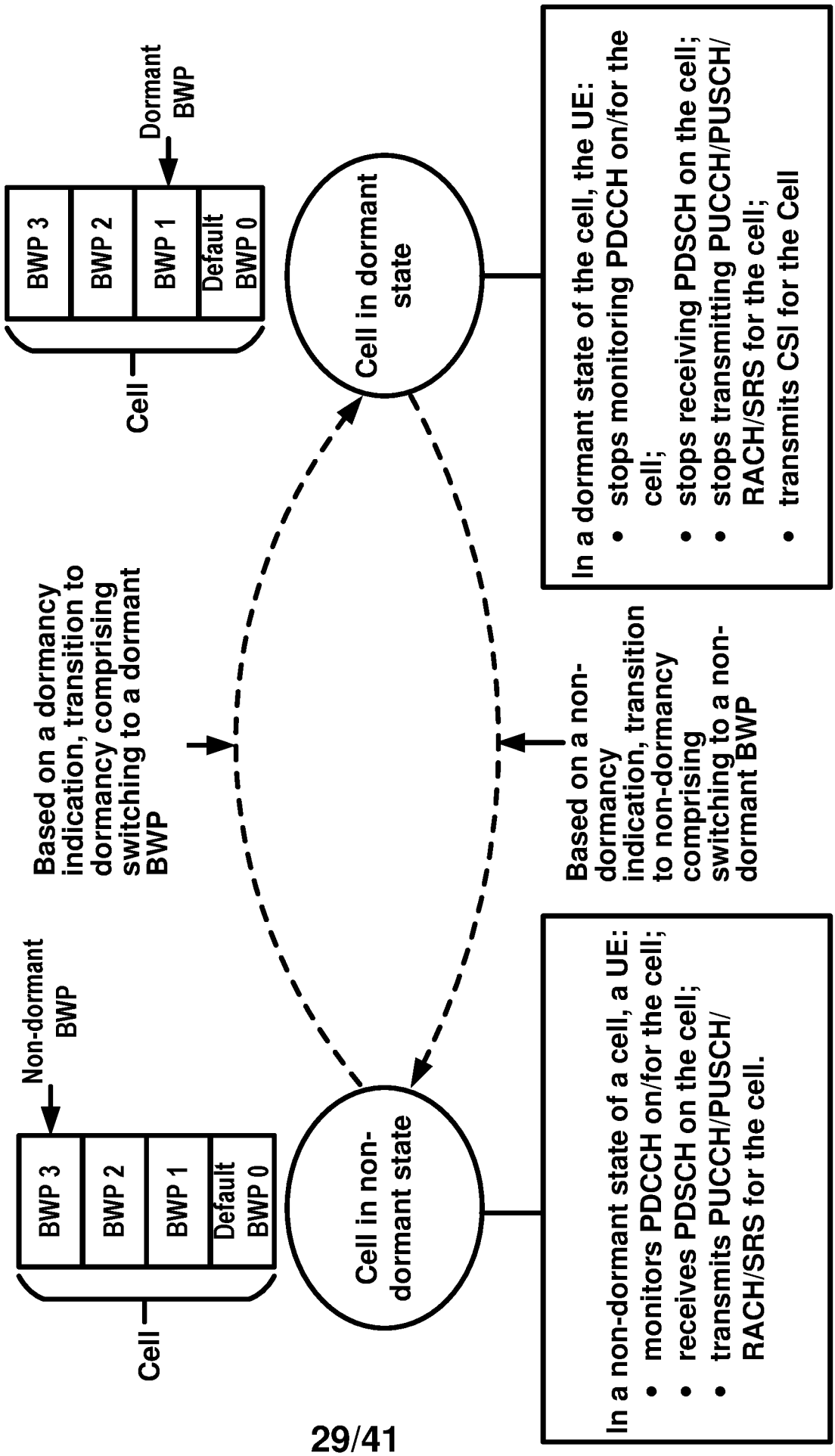

Dormant BWP
BWP 3
BWP 2
BWP 1
Default BWP 0
Cell
Cell in dormant state
In a dormant state of the cell, the UE:
• stops monitoring PDCCH on/for the cell;
• stops receiving PDSCH on the cell;
• stops transmitting PUCCH/PUSCH/ RACH/SRS for the cell;
• transmits CSI for the Cell
Based on a dormancy indication, transition to dormancy comprising switching to a dormant BWP
Based on a non-dormancy indication, transition to non-dormancy comprising switching to a non-dormant BWP
Non-dormant BWP
BWP 3
BWP 2
BWP 1
Default BWP 0
Cell
Cell in non-dormant state
In a non-dormant state of a cell, a UE:
• monitors PDCCH on/for the cell;
• receives PDSCH on the cell;
• transmits PUCCH/PUSCH/ RACH/SRS for the cell.

FIG. 29

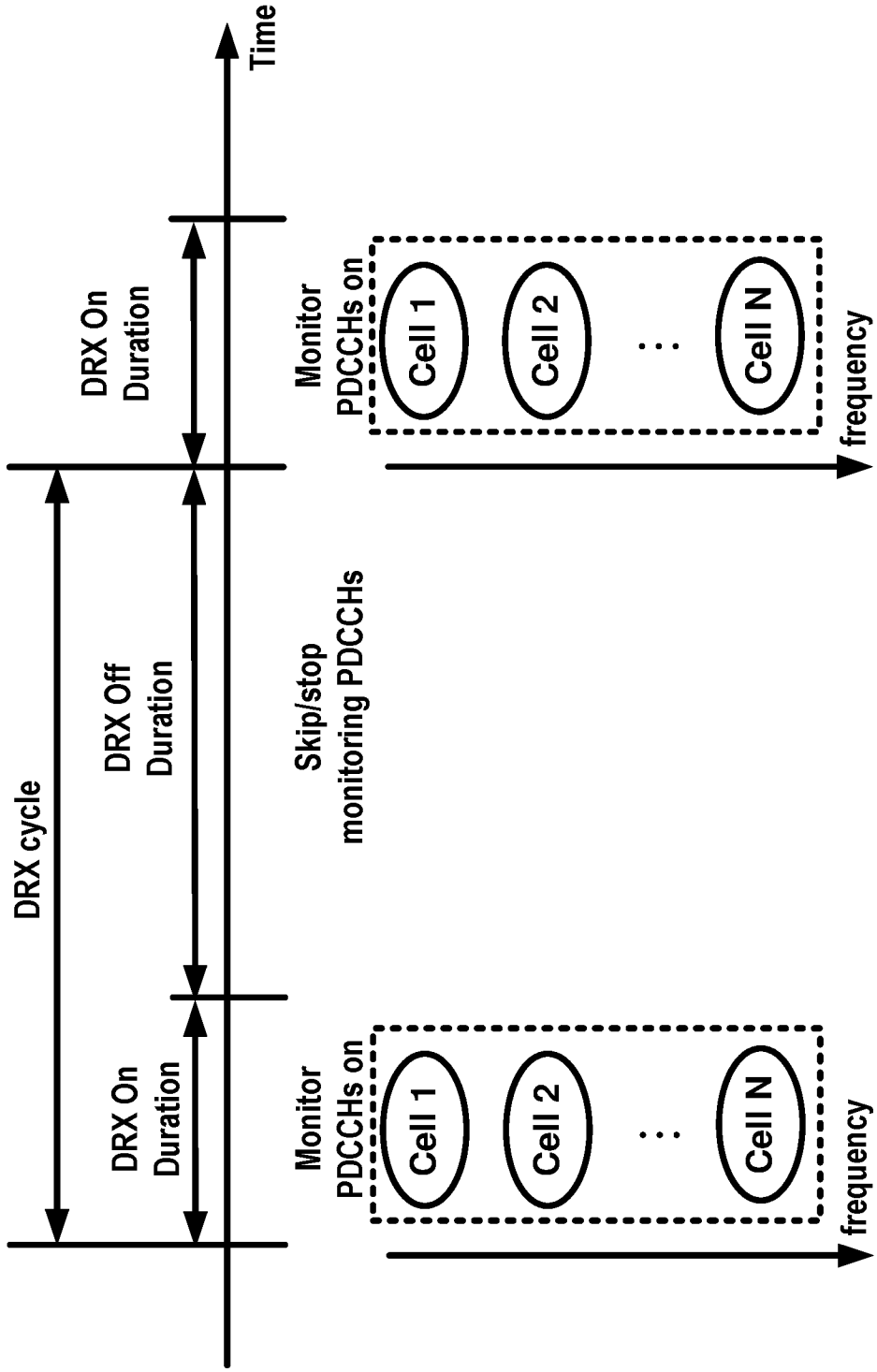

Time
DRX On Duration
Monitor PDCCHs on
Cell 1
Cell 2
...
Cell N
frequency
DRX cycle
DRX Off Duration
Skip/stop monitoring PDCCHs
DRX On Duration
Monitor PDCCHs on
Cell 1
Cell 2
...
Cell N
frequency

FIG. 30

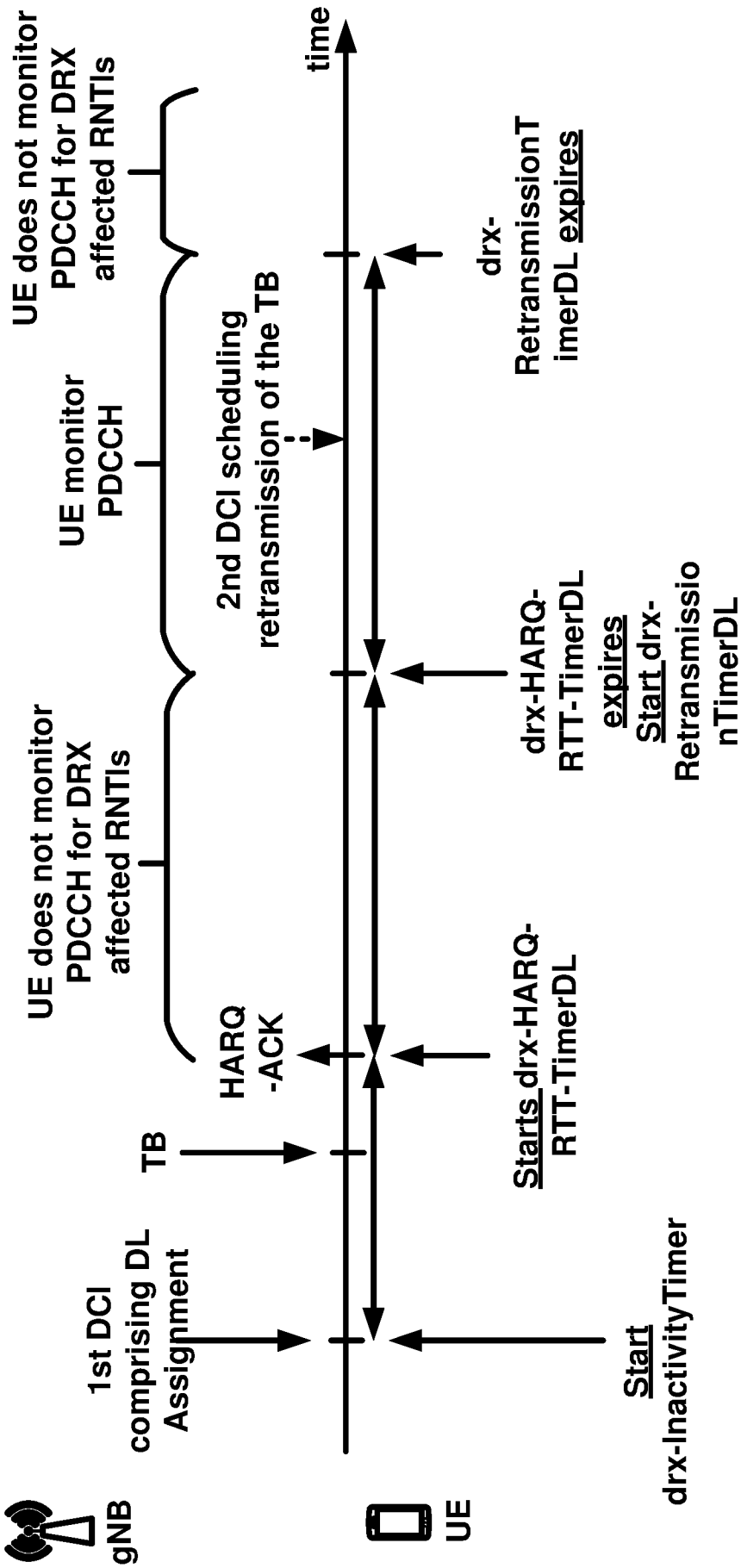

gNB
UE
1st DCI comprising DL Assignment
TB
HARQ -ACK
UE does not monitor PDCCH for DRX affected RNTIs
UE monitor PDCCH
2nd DCI scheduling retransmission of the TB
UE does not monitor PDCCH for DRX affected RNTIs
time
Start drx-InactivityTimer
Starts drx-HARQ-RTT-TimerDL
drx-HARQ-RTT-TimerDL expires
Start drx-RetransmissionTimerDL
drx-RetransmissionTimerDL expires

FIG. 31

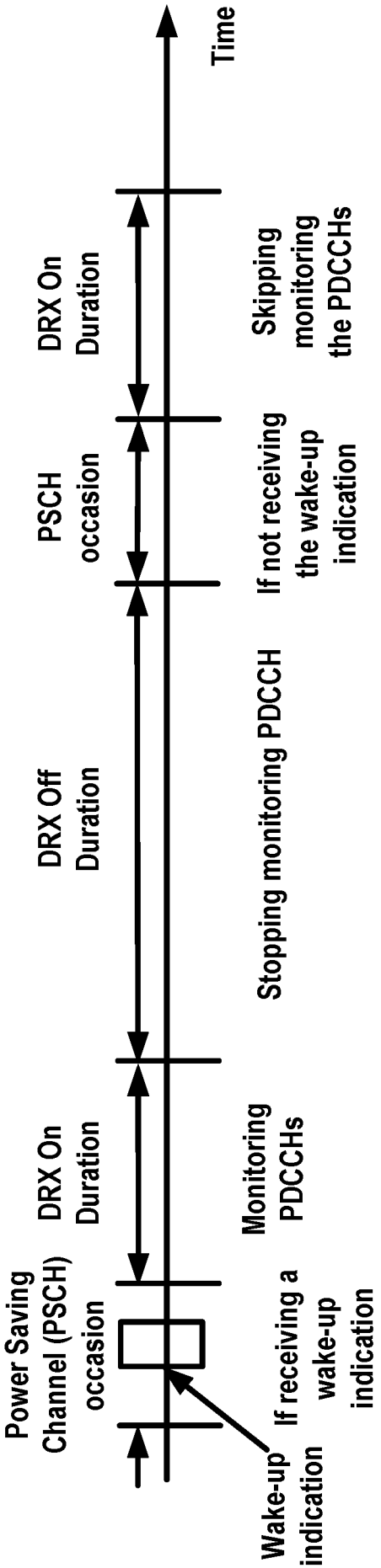


FIG. 32A

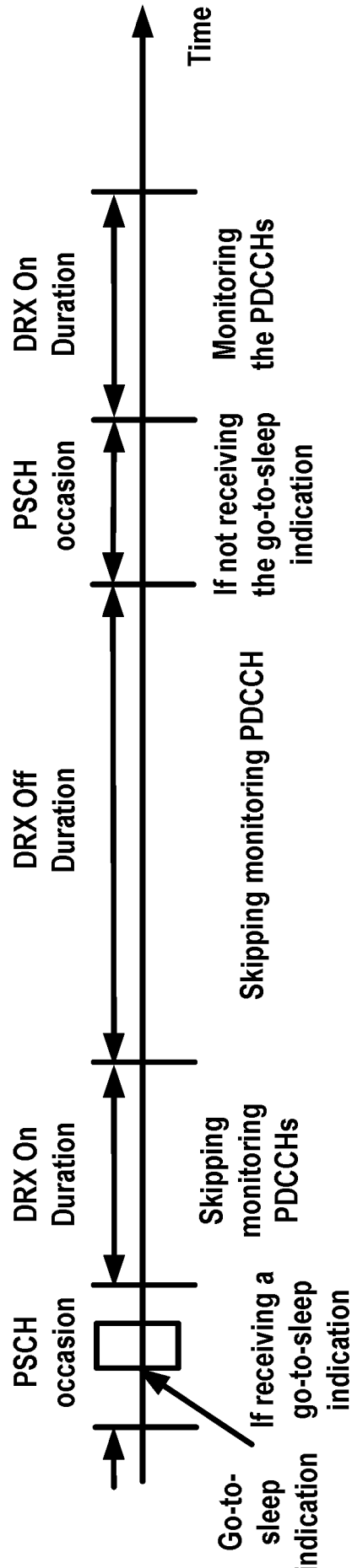


FIG. 32B

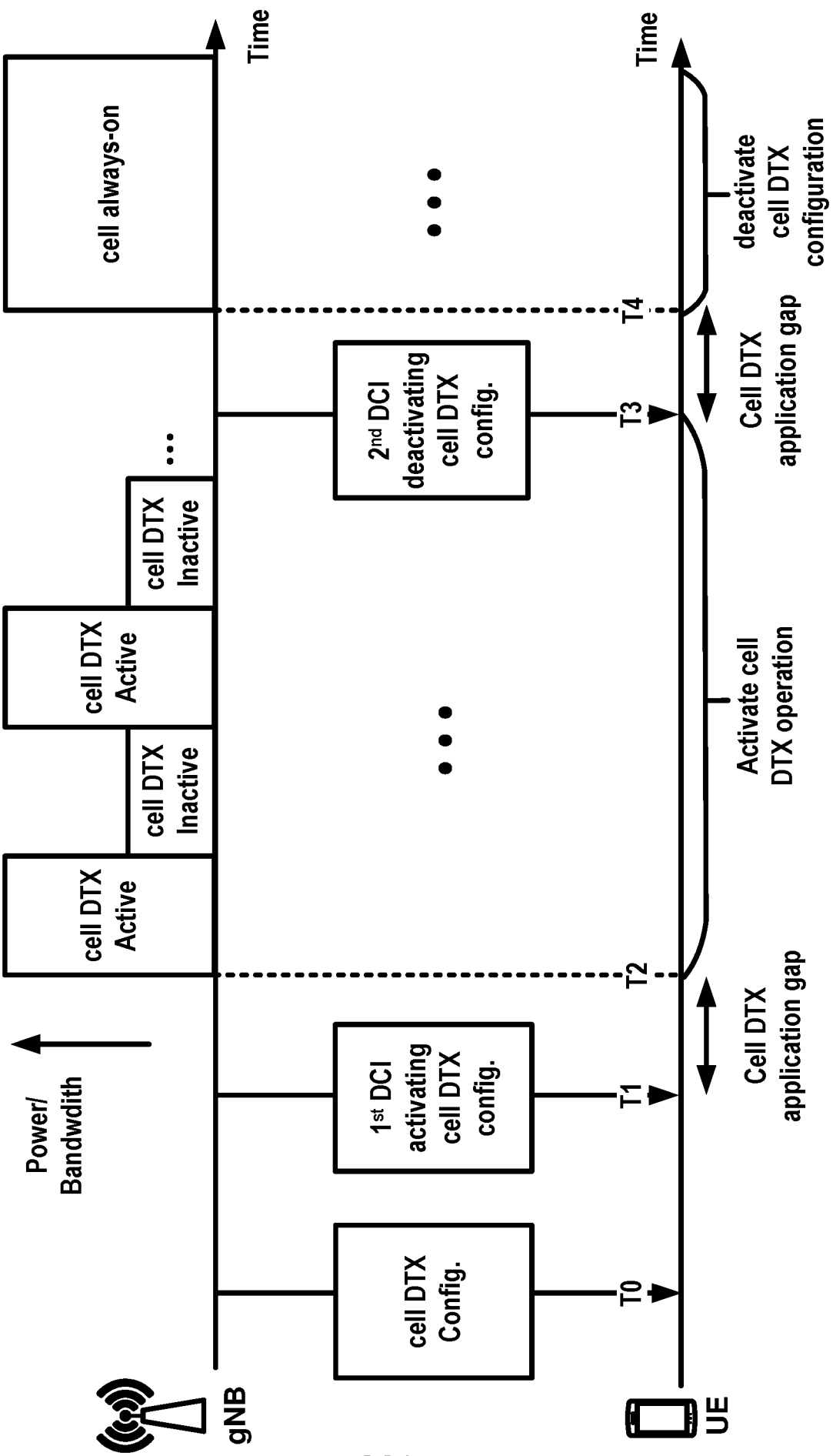

Time
Time
cell always-on
cell DTX Active
cell DTX Inactive
cell DTX Active
cell DTX Inactive
cell DTX Config.
1st DCI activating cell DTX config.
2nd DCI deactivating cell DTX config.
deactivate cell DTX configuration
Cell DTX application gap
Activate cell DTX operation
Cell DTX application gap
T0
T1
T2
T3
T4
Power/ Bandwdith
gNB
UE

FIG. 33

SCS (KHz)	Number of slots
15	3
30	6
60	12
120	24
480	96
960	192

FIG. 34

SCS	OFDM starting Symbols of the candidate SSBs	fc<=3GHz, Lmax=4	3GHz<fc<=6GHz, Lmax=8	fc>6GHz, Lmax=64
CaseA: 15 KHz	{2,8}+14n	n=0,1	n=0,1,2,3	Not Applicable (NA)
CaseB: 30 KHz	{4,8,16,20}+28n	n=0	n=0,1	NA
CaseC: 30 KHz	{2,8}+14n	n=0,1	n=0,1,2,3	NA
CaseD: 120 KHz	{4,8,16,20}+28n	NA	NA	n=0,1,2,3,5,6,7,8,10,11,12,13,15,16,17,18
CaseE: 240 KHz	{8,12,16,20,32,36,40,44} + 56n	NA	NA	n=0,1,2,3,5,6,7,8

FIG. 35

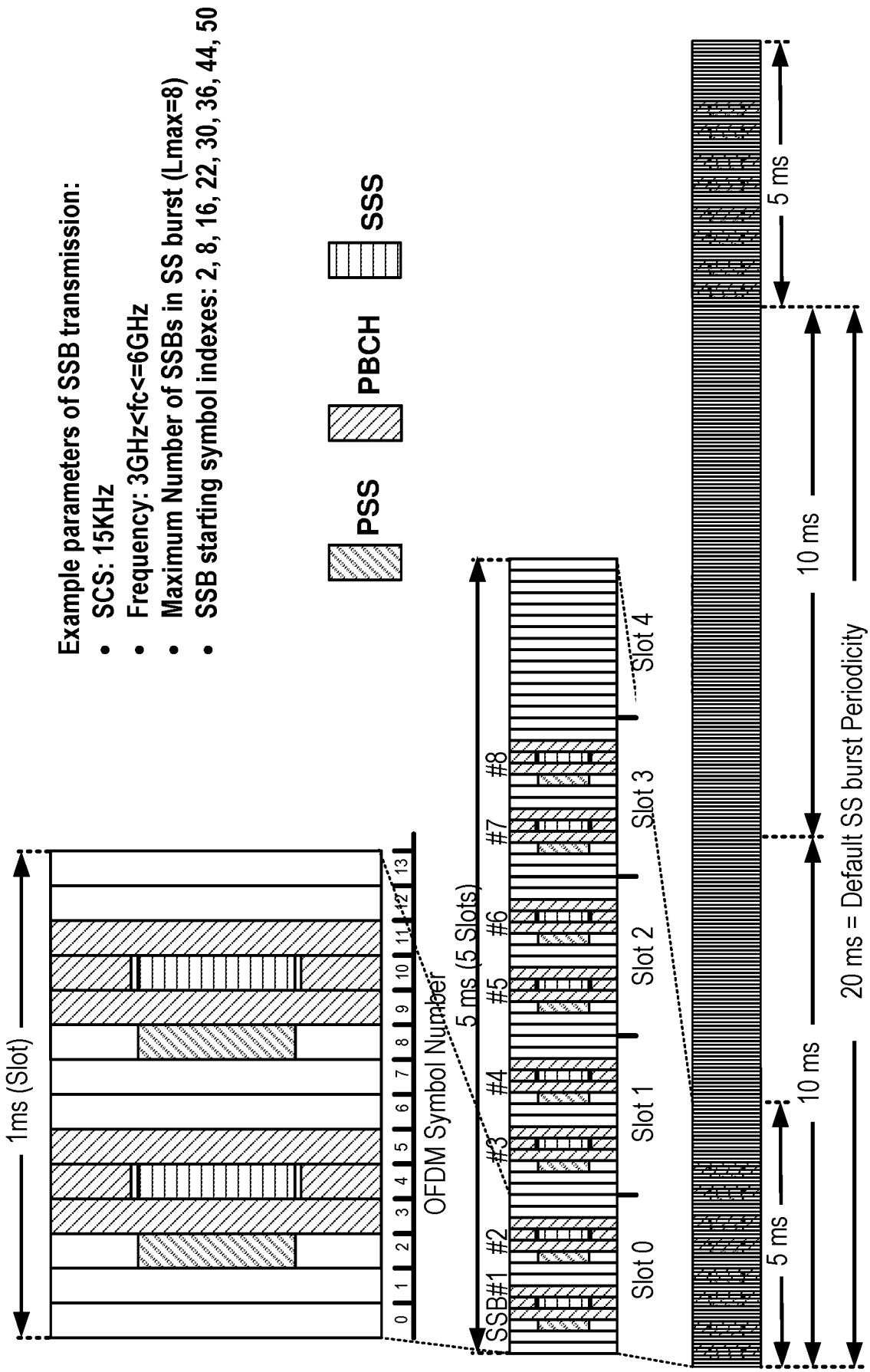

Example parameters of SSB transmission:
SCS: 15KHz
Frequency: 3GHz<fc<=6GHz
Maximum Number of SSBs in SS burst (Lmax=8)
SSB starting symbol indexes: 2, 8, 16, 22, 30, 36, 44, 50
PSS
PBCH
SSS
1ms (Slot)
OFDM Symbol Number
5 ms (5 Slots)
SSB#1
#2
#3
#4
#5
#6
#7
#8
Slot 0
Slot 1
Slot 2
Slot 3
Slot 4
5 ms
10 ms
10 ms
5 ms
20 ms = Default SS burst Periodicity

FIG. 36

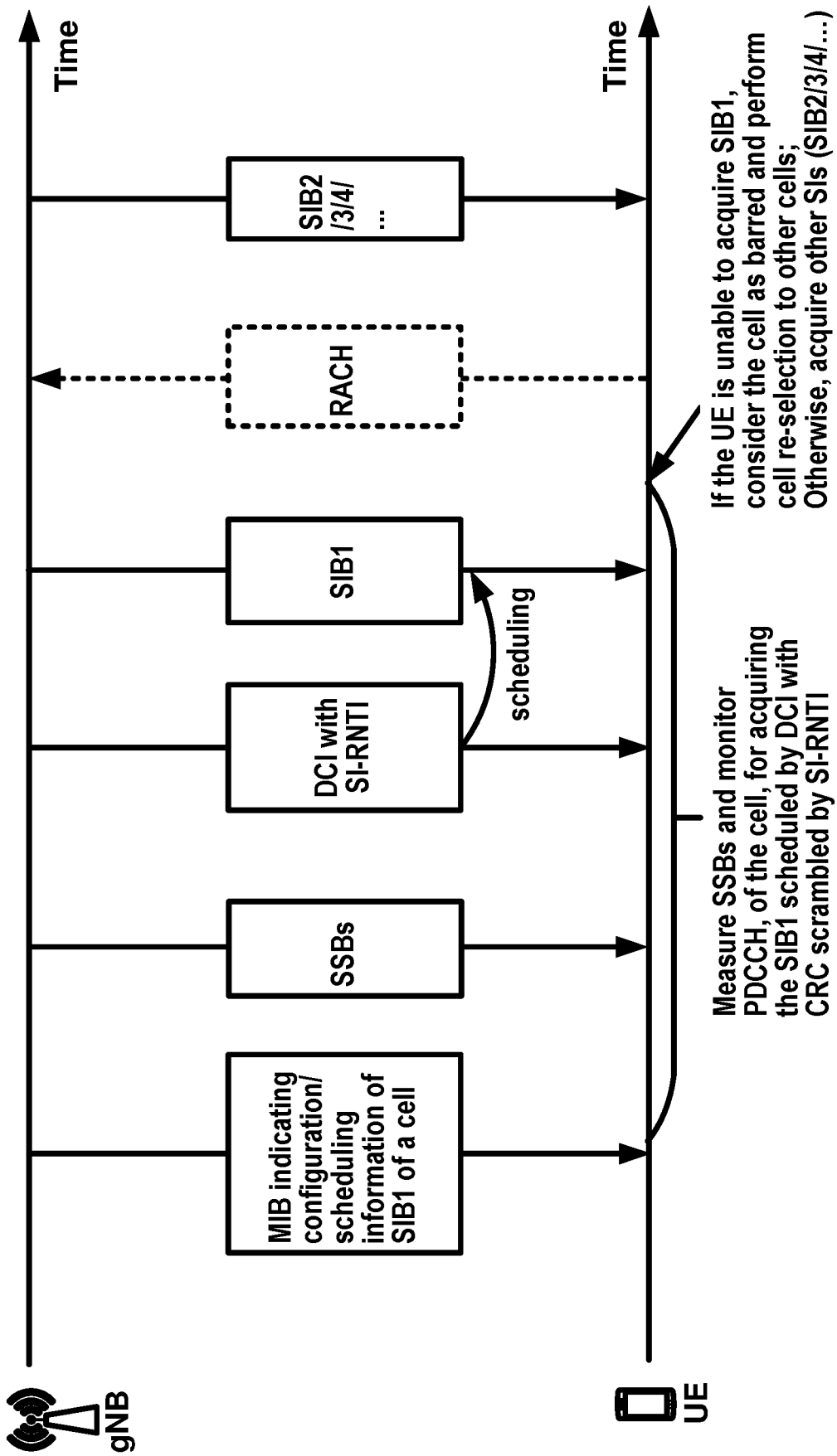

Time
Time
gNB
UE
MIB indicating configuration/ scheduling information of SIB1 of a cell
SSBs
DCI with SI-RNTI
SIB1
RACH
SIB2 /3/4/ ...
scheduling
Measure SSBs and monitor PDCCH, of the cell, for acquiring the SIB1 scheduled by DCI with CRC scrambled by SI-RNTI
If the UE is unable to acquire SIB1, consider the cell as barred and perform cell re-selection to other cells; Otherwise, acquire other SIs (SIB2/3/4/...)

FIG. 37

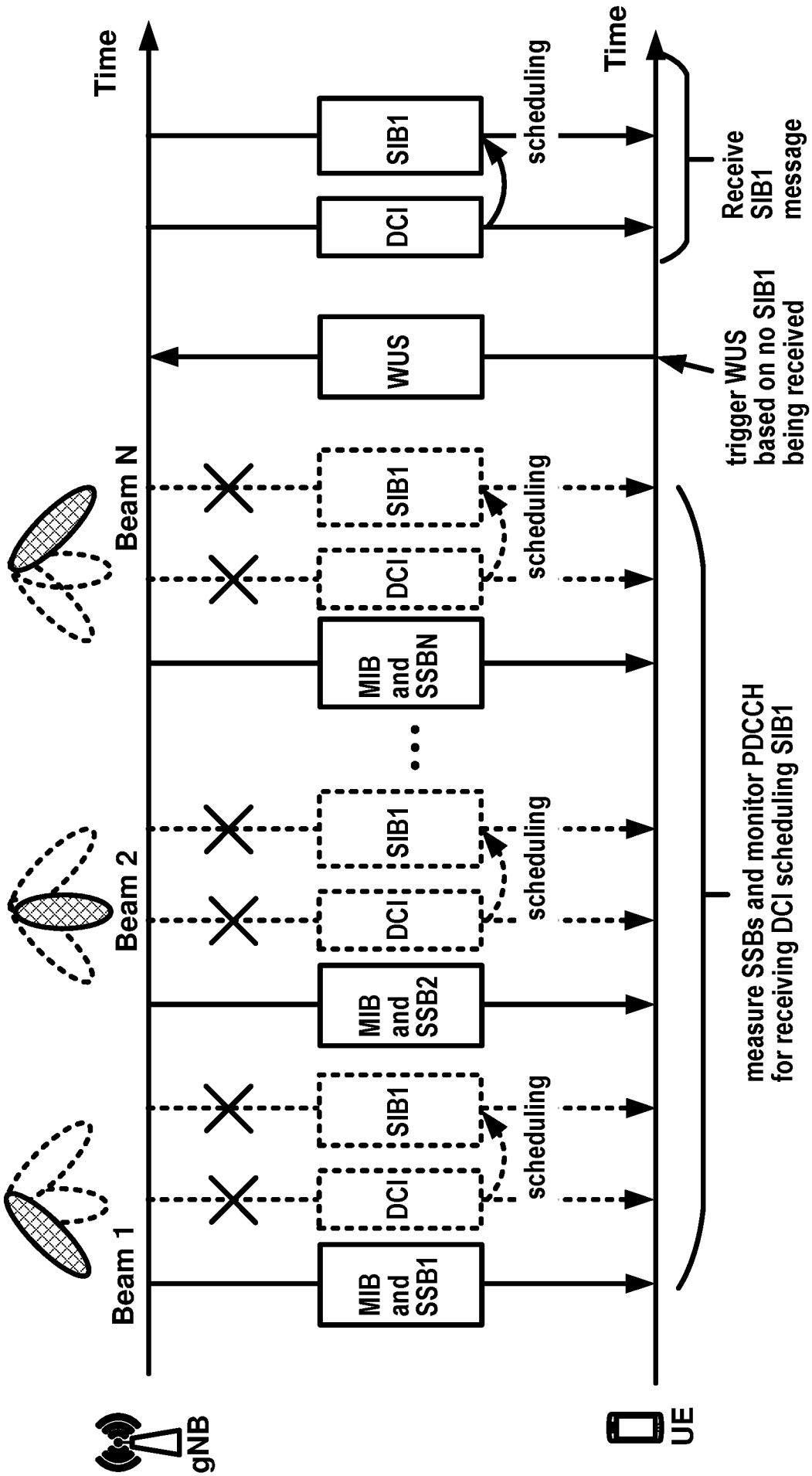

gNB
UE
Time
Time
Beam 1
Beam 2
Beam N
MIB and SSB1
MIB and SSB2
MIB and SSBN
DCI
SIB1
scheduling
WUS
trigger WUS based on no SIB1 being received
Receive SIB1 message
measure SSBs and monitor PDCCH for receiving DCI scheduling SIB1

FIG. 38

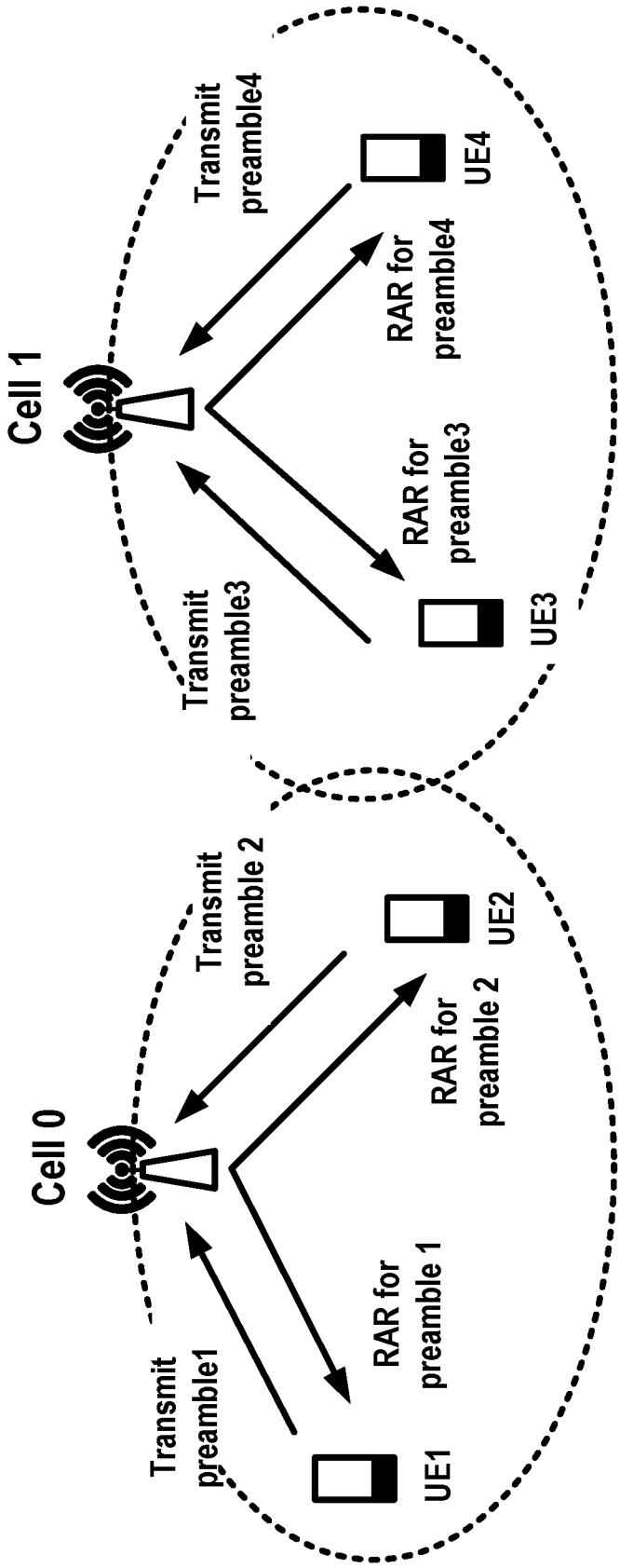

Cell 0
Cell 1
Transmit preamble1
RAR for preamble 1
Transmit preamble 2
RAR for preamble 2
Transmit preamble3
RAR for preamble3
Transmit preamble4
RAR for preamble4
UE1
UE2
UE3
UE4

FIG. 39

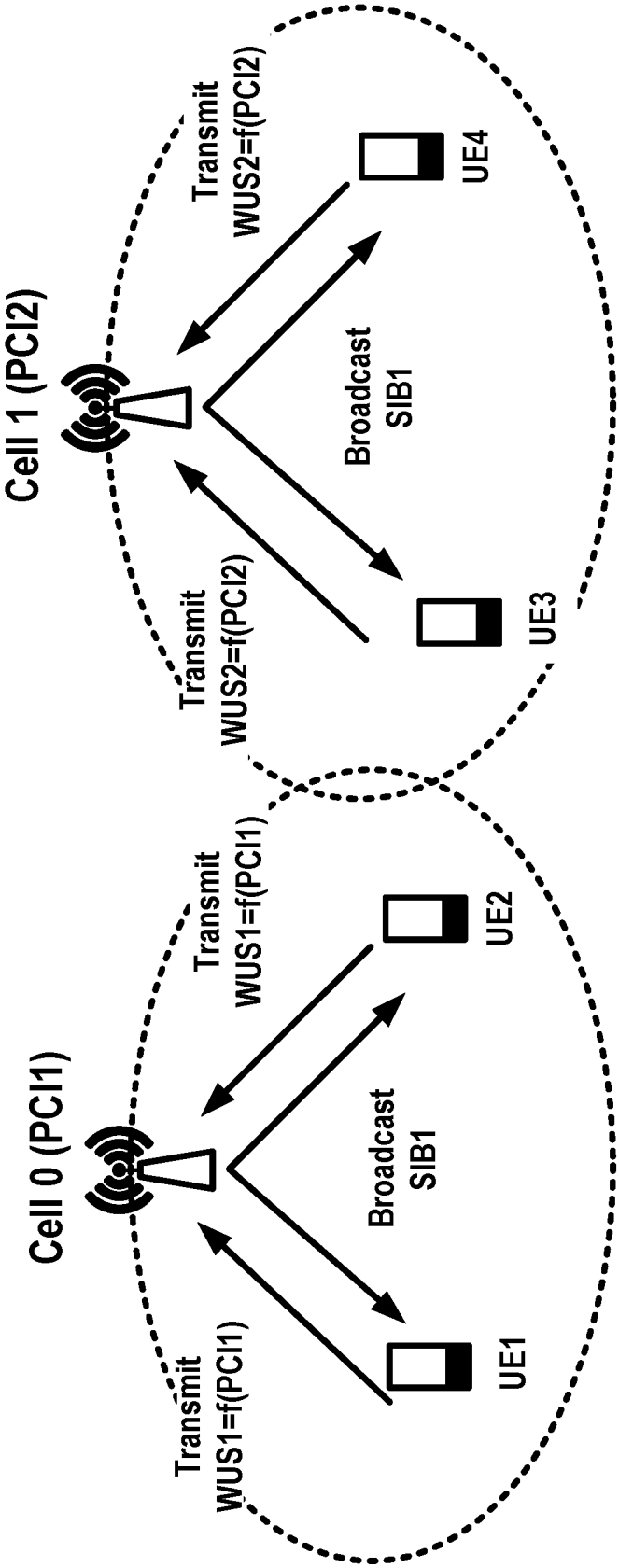

Cell 0 (PCI1)
Cell 1 (PCI2)
Transmit WUS1=f(PCI1)
Transmit WUS1=f(PCI1)
Broadcast SIB1
Transmit WUS2=f(PCI2)
Transmit WUS2=f(PCI2)
Broadcast SIB1
UE1
UE2
UE3
UE4

FIG. 40

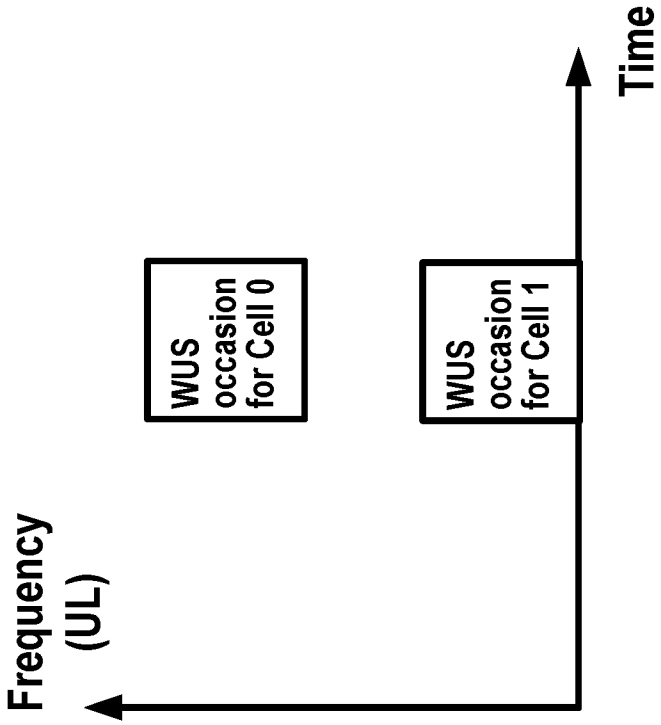


FIG. 41B

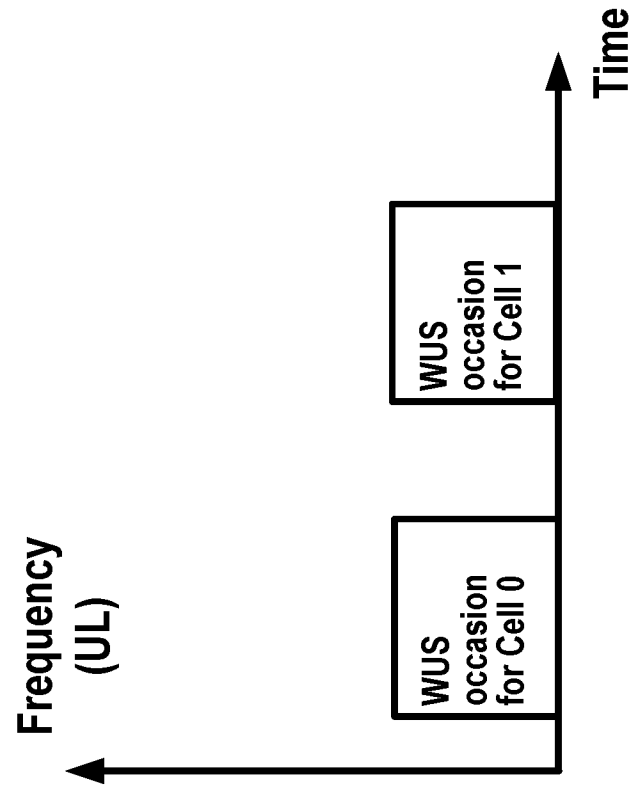


FIG. 41A

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/056368

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/23 H04W48/10 H04W76/28
ADD.

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

B. FIELDS SEARCHED

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FEI WANG ET AL: "Discussion on network energy saving techniques", 3GPP DRAFT; R1-2211692; TYPE DISCUSSION; FS_NETW_ENERGY_NR, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Toulouse, FR; 20221114 - 20221118 7 November 2022 (2022-11-07), XP052222257, Retrieved from the Internet: URL:https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_111/Docs/R1-2211692.zip R1-2211692Â DiscussionÂ onÂ networkÂ energyÂ savingÃ techniques-clean.docx [retrieved on 2022-11-07] section 3.3 -/--	1-56

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2025	24/02/2025

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	Vercauteren, Steven

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/056368

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	RESEARCH IN MOTION ET AL: "TDD UL/DL reconfiguration signalling methods", 3GPP DRAFT; R1-131353 RIM TDD EIMTA SIGNALLING METHODS, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Chicago, USA; 20130415 - 20130419 6 April 2013 (2013-04-06), XP050697208, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_72b/Docs/ [retrieved on 2013-04-06] section 2.3	1-56