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(71) Applicant: **OFINNO, LLC** [US/US]; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US).

(72) Inventors: **LIN, Huifa**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US). **JEON, Hyoungsuk**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US). **DINAN, Esmael Hejazi**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US). **HUI, Bing**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US). **ZHOU, Hua**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US). **CIRIK, Ali Cagatay**; 1950 Opportunity Way, Suite 1200, Reston, Virginia 20190 (US).

(74) Agent: **GARDNER, Brett K.** et al.; 11091 Sunset Hills Rd. Ste 510, Reston, Virginia 20190 (US).

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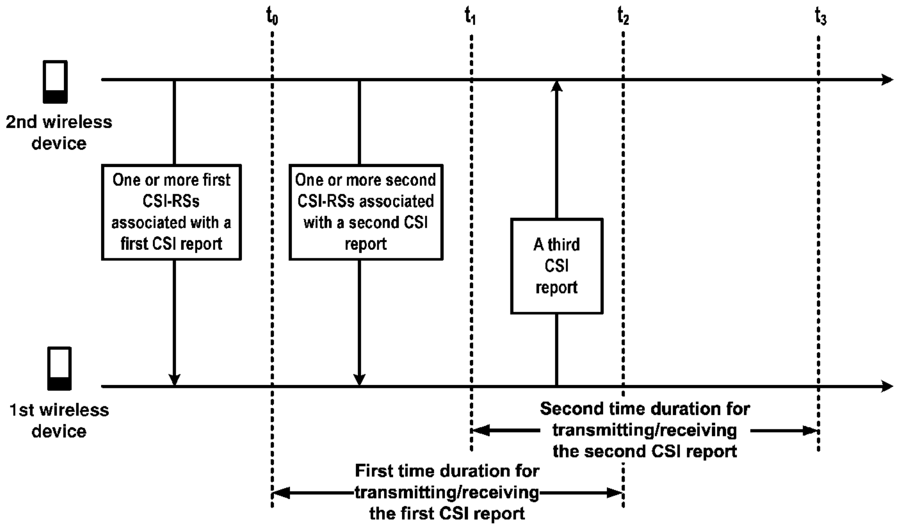

FIG. 35

(57) Abstract: A first wireless device receives, from a second wireless device, one or more first channel state information reference signals (CSI-RSs) via a first slot and one or more second CSI-RSs via a second slot. The first wireless device transmits a channel state information (CSI) report, having a first measurement on the one or more first CSI-RSs and a second measurement on the one or more second CSI-RSs. The CSI report is transmitted based on a first time duration overlapping a second time duration. The first time duration starts based on the first slot, and the second time duration starts based on the second slot.

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TITLE

Sidelink Beam Management

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/434,758, filed December 22, 2022, which is hereby incorporated by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[0023] FIG. 17 illustrates examples of device-to-device (D2D) communication as per an aspect of an example embodiment of the present disclosure.

[0024] FIG. 18 illustrates an example of a resource pool for sidelink operations as per an aspect of an example embodiment of the present disclosure.

[0025] FIG. 19 illustrates an example of sidelink symbols in a slot as per an aspect of an example embodiment of the present disclosure.

[0026] FIG. 20 illustrates an example of resource indication for a first TB (e.g., a first data packet) and resource reservation for a second TB (e.g., a second data packet) as per an aspect of an example embodiment of the present disclosure.

[0027] FIG. 21 illustrates an example of configuration information for sidelink communication as per an aspect of an example embodiment of the present disclosure.

[0028] FIG. 22 illustrates an example of configuration information for sidelink communication as per an aspect of an example embodiment of the present disclosure.

[0029] FIG. 23 illustrates an example format of a MAC subheader for sidelink shared channel (SL-SCH) an aspect of an example embodiment of the present disclosure.

[0030] FIG. 24 illustrates an example time of a resource selection procedure as per an aspect of an example embodiment of the present disclosure.

[0031] FIG. 25 illustrates an example timing of a resource selection procedure as per an aspect of an example embodiment of the present disclosure.

[0032] FIG. 26 illustrates an example flowchart of a resource selection procedure by a wireless device for transmitting a TB via sidelink as per an aspect of an example embodiment of the present disclosure.

[0033] FIG. 27 illustrates an example diagram of the resource selection procedure among layers of the wireless device as per an aspect of an example embodiment of the present disclosure.

[0034] FIG. 28 an example of a resource selection procedure (e.g., periodic partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink as per an aspect of an example embodiment of the present disclosure.

[0035] FIG. 29 illustrates an example of a resource selection procedure (e.g., contiguous partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink as per an aspect of an example embodiment of the present disclosure.

[0036] FIG. 30 illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 1).

[0037] FIG. 31 illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 2).

[0038] FIG. 32 illustrates an example of sidelink CSI-RS transmission and a sidelink CSI reporting procedure.

[0039] FIG. 33 illustrates an example of CS-RS resource set.

[0040] FIG. 34 illustrates an example of CSI reporting for multiple CSI-RSs.

[0041] FIG. 35 illustrates an example of CSI reporting for multiple CSI-RSs as per an aspect of an example embodiment of the present disclosure.

[0042] FIG. 36 illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure.

[0043] FIG. 37 illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0044] 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.

[0045] Embodiments may be configured to operate as desired. 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.

[0046] 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 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.

[0047] 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.

[0048] 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.

[0049] 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 settings in a device that effect the operational characteristics of the device whether the device is in an operational or non-operational state. In other words, the hardware, software, firmware, registers, memory values, and/or the like may be “configured” within a device, whether the device is in an operational or nonoperational state, to provide the device with 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 characteristics or may be used to implement certain actions in the device, whether the device is in an operational or non-operational state.

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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.

[0055] 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.

[0056] 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 desired or usable. For example, a wireless device may be a telephone, smart phone, tablet, computer, laptop, sensor, meter, wearable device, Internet of Things (IoT) device, vehicle road side unit (RSU), relay node, automobile, and/or any combination thereof. The term wireless device encompasses other terminology, including user equipment (UE), user terminal (UT), access terminal (AT), mobile station, handset, wireless transmit and receive unit (WTRU), and/or wireless communication device.

[0057] The RAN 104 may include one or more base stations (not shown). The term base station may be used throughout this disclosure to refer to and encompass a Node B (associated with UMTS and/or 3G standards), an Evolved Node B (eNB, associated with E-UTRA and/or 4G standards), a remote radio head (RRH), a baseband processing unit coupled to one or more RRHs, a repeater node or relay node used to extend the coverage area of a donor node, a Next Generation Evolved Node B (ng-eNB), a Generation Node B (gNB, associated with NR and/or 5G standards), an access point (AP, associated with, for example, WiFi or any other suitable wireless communication standard), and/or any combination thereof. A base station may comprise at least one gNB Central Unit (gNB-CU) and at least one a gNB Distributed Unit (gNB-DU).

[0058] 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.

[0059] 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.

[0060] 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.

[0061] 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.

[0062] 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.

[0063] 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).

[0064] 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.

[0065] 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.

[0066] 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).

[0067] 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.

[0068] 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.

[0069] 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.

[0070] 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.

[0071] 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.

[0072] 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.

[0073] 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.

[0074] 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.

[0075] 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 constraints (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.

[0076] The PDCPs 214 and 224 may perform header compression/decompression to reduce the amount of data 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 use high reliability.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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.

[0082] 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.

[0083] 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.

[0084] 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.

[0085] FIG. 4B further illustrates MAC control elements (CEs) inserted into the MAC PDU by a MAC, such as MAC 212 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.

[0086] 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.

[0087] 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 UE or as a common logical channel that may be used by more than one UE. A logical channel may also be defined by the type of information it carries. The set of logical channels defined by NR include, for example:

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

- a dedicated control channel (DCCH) for carrying control messages to/from a UE to configure the UE; and
- a dedicated traffic channel (DTCH) for carrying user data to/from a UE.

[0088] Transport channels are used between the MAC and PHY layers and may be defined by how the information they carry is transmitted over the air interface. The set of transport channels defined by NR include, for example:

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

[0089] The PHY may use physical channels to pass information between processing levels of the PHY. A physical channel may have an associated set of time-frequency resources for carrying the information of one or more transport channels. The PHY may generate control information to support the low-level operation of the PHY and provide the control information to the lower levels of the PHY via physical control channels, known as L1/L2 control channels. The set of physical channels and physical control channels defined by NR include, for example:

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

[0090] 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.

[0091] 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.

[0092] 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.

[0093] 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.

[0094] 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).

[0095] 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.

[0096] 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.

[0097] 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.

[0098] 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).

[0099] 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.

[0100] 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.

[0101] 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.

[0102] A gNB, such as gNBs 160 in FIG. 1B, may be split in two parts: a central unit (gNB-CU), and one or more distributed units (gNB-DU). A gNB-CU may be coupled to one or more gNB-DUs using an F1 interface. The gNB-CU may comprise the RRC, the PDCP, and the SDAP. A gNB-DU may comprise the RLC, the MAC, and the PHY.

[0103] 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.

[0104] 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.

[0105] 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.

[0106] 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 provided for a transmission. These partial slot transmissions may be referred to as mini-slot or subslot transmissions.

[0107] 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.

[0108] 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.

[0109] 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.

[0110] 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.

[0111] 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.

[0112] 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.

[0113] 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).

[0114] 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.

[0115] 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.

[0116] 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.

[0117] 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).

[0118] 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.

[0119] FIG. 9 illustrates an example of bandwidth adaptation using three configured BWPs for an NR carrier. A UE configured with the three BWPs may switch from one BWP to another BWP at a switching point. In the example illustrated in FIG. 9, the BWPs include: a BWP 902 with a bandwidth of 40 MHz and a subcarrier spacing of 15 kHz; a BWP 904 with a bandwidth of 10 MHz and a subcarrier spacing of 15 kHz; and a BWP 906 with a bandwidth of 20 MHz and a subcarrier spacing of 60 kHz. The BWP 902 may be an initial active BWP, and the BWP 904 may be a default BWP. The UE may switch between BWPs at switching points. In the example of FIG. 9, the UE may switch from the BWP 902 to the BWP 904 at a switching point 908. The switching at the switching point 908 may occur for any suitable reason, for example, in response to an expiry of a BWP inactivity timer (indicating switching to the default BWP) and/or in response to receiving a DCI indicating BWP 904 as the active BWP. The UE may switch at a switching point 910 from active BWP 904 to BWP 906 in response receiving a DCI indicating BWP 906 as the active BWP. The UE may switch at a switching point 912 from active BWP 906 to BWP 904 in response to an expiry of a BWP inactivity timer and/or in response receiving a DCI indicating BWP 904 as the active BWP. The UE may switch at a switching point 914 from active BWP 904 to BWP 902 in response receiving a DCI indicating BWP 902 as the active BWP.

[0120] 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.

[0121] 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.

[0122] 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).

[0123] 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.

[0124] 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).

[0125] 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).

[0126] 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.

[0127] 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.

[0128] 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.

[0129] 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.

[0130] 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.

[0131] 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.

[0132] 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.

[0133] 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.

[0134] 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.

[0135] 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 configured for 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.

[0136] 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.

[0137] 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.

[0138] 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.

[0139] 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.

[0140] 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.

[0141] 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.

[0142] 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.

[0143] 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.

[0144] 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).

[0145] 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.

[0146] 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.

[0147] 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.

[0148] 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.

[0149] 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.

[0150] 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.

[0151] 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.

[0152] 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.

[0153] Channels that use beamforming may use 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.

[0154] 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.

[0155] 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.

[0156] 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.

[0157] 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).

[0158] FIG. 12A illustrates examples of three downlink beam management procedures: P1, P2, and P3. Procedure P1 may enable a UE measurement on transmit (Tx) beams of a transmission reception point (TRP) (or multiple TRPs), e.g., to support a selection of one or more base station Tx beams and/or UE Rx beams (shown as ovals in the top row and bottom row, respectively, of P1). Beamforming at a TRP may comprise a Tx beam sweep for a set of beams (shown, in the top rows of P1 and P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Beamforming at a UE may comprise an Rx beam sweep for a set of beams (shown, in the bottom rows of P1 and P3, as ovals rotated in a clockwise direction indicated by the dashed arrow). Procedure P2 may be used to enable a UE measurement on Tx beams of a TRP (shown, in the top row of P2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). The UE and/or the base station may perform procedure P2 using a smaller set of beams than is used in procedure P1, or using narrower beams than the beams used in procedure P1. This may be referred to as beam refinement. The UE may perform procedure P3 for Rx beam determination by using the same Tx beam at the base station and sweeping an Rx beam at the UE.

[0159] FIG. 12B illustrates examples of three uplink beam management procedures: U1, U2, and U3. Procedure U1 may be used to enable a base station to perform a measurement on Tx beams of a UE, e.g., to support a selection of one or more UE Tx beams and/or base station Rx beams (shown as ovals in the top row and bottom row, respectively, of U1). Beamforming at the UE may include, e.g., a Tx beam sweep from a set of beams (shown in the bottom rows of U1 and U3 as ovals rotated in a clockwise direction indicated by the dashed arrow). Beamforming at the base station may include, e.g., an Rx beam sweep from a set of beams (shown, in the top rows of U1 and U2, as ovals rotated in a counter-clockwise direction indicated by the dashed arrow). Procedure U2 may be used to enable the base station to adjust its Rx beam when the UE uses a fixed Tx beam. The UE and/or the base station may perform procedure U2 using a smaller set of beams than is used in procedure U1, or using narrower beams than the beams used in procedure U1. 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.

[0160] 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).

[0161] 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 or DM-RSs). 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.

[0162] 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.

[0163] 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).

[0164] 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.

[0165] 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.

[0166] 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).

[0167] 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.

[0168] 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.

[0169] 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).

[0170] 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:

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 ≤ s_id < 14), t_id may be an index of a first slot of the PRACH occasion in a system frame (e.g., 0 ≤ t_id < 80), f_id may be an index of the PRACH occasion in the frequency domain (e.g., 0 ≤ 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).

[0171] 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).

[0172] 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.

[0173] 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).

[0174] 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.

[0175] 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).

[0176] 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.

[0177] 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.

[0178] 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.

[0179] 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.

[0180] 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.

[0181] 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).

[0182] 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.

[0183] 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.

[0184] 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).

[0185] 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.

[0186] 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.

[0187] 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).

[0188] 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.

[0189] 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.

[0190] 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).

[0191] 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).

[0192] 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.

[0193] 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.

[0194] 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”.

[0195] 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.

[0196] 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.

[0197] 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.

[0198] 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.

[0199] 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.

[0200] 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.

[0201] 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.

[0202] 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.

[0203] 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.

[0204] 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.

[0205] FIG. 16A illustrates an example structure for uplink transmission. A baseband signal representing a physical uplink shared channel may perform one or more functions. The one or more functions may comprise at least one of: scrambling; modulation of scrambled bits to generate complex-valued symbols; mapping of the complex-valued modulation symbols onto one or several transmission layers; transform precoding to generate complex-valued symbols; precoding of the complex-valued symbols; mapping of precoded complex-valued symbols to resource elements; generation of complex-valued time-domain Single Carrier-Frequency Division Multiple Access (SC-FDMA) or CP-OFDM signal for an antenna port; and/or the like. In an example, when transform precoding is enabled, a SC-FDMA signal for uplink transmission may be generated. In an example, when transform precoding is not enabled, an CP-OFDM signal for uplink transmission may be generated by FIG. 16A. These functions are illustrated as examples and it is anticipated that other mechanisms may be implemented in various embodiments.

[0206] 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.

[0207] 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.

[0208] 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.

[0209] 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.

[0210] 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. FIG. 17 illustrates examples of device-to-device (D2D) communication, in which there is a direct communication between wireless devices. In an example, D2D communication may be performed via a sidelink (SL). The wireless devices may exchange sidelink communications via a sidelink interface (e.g., a PC5 interface). Sidelink differs from uplink (in which a wireless device communicates to a base station) and downlink (in which a base station communicates to a wireless device). A wireless device and a base station may exchange uplink and/or downlink communications via a user plane interface (e.g., a Uu interface).

[0211] As shown in the figure, wireless device #1 and wireless device #2 may be in a coverage area of base station #1. For example, both wireless device #1 and wireless device #2 may communicate with the base station #1 via a Uu interface. Wireless device #3 may be in a coverage area of base station #2. Base station #1 and base station #2 may share a network and may jointly provide a network coverage area. Wireless device #4 and wireless device #5 may be outside of the network coverage area.

[0212] In-coverage D2D communication may be performed when two wireless devices share a network coverage area. Wireless device #1 and wireless device #2 are both in the coverage area of base station #1. Accordingly, they may perform an in-coverage intra-cell D2D communication, labeled as sidelink A. Wireless device #2 and wireless device #3 are in the coverage areas of different base stations, but share the same network coverage area. Accordingly, they may perform an in-coverage inter-cell D2D communication, labeled as sidelink B. Partial-coverage D2D communications may be performed when one wireless device is within the network coverage area and the other wireless device is outside the network coverage area. Wireless device #3 and wireless device #4 may perform a partial-coverage D2D communication, labeled as sidelink C. Out-of-coverage D2D communications may be performed when both wireless devices are outside of the network coverage area. Wireless device #4 and wireless device #5 may perform an out-of-coverage D2D communication, labeled as sidelink D.

[0213] Sidelink communications may be configured using physical channels, for example, a physical sidelink broadcast channel (PSBCH), a physical sidelink feedback channel (PSFCH), a physical sidelink discovery channel (PSDCH), a physical sidelink control channel (PSCCH), and/or a physical sidelink shared channel (PSSCH). PSBCH may be used by a first wireless device to send broadcast information to a second wireless device. PSBCH may be similar in some respects to PBCH. The broadcast information may comprise, for example, a slot format indication, resource pool information, a sidelink system frame number, or any other suitable broadcast information. PSFCH may be used by a first wireless device to send feedback information to a second wireless device. The feedback information may comprise, for example, HARQ feedback information. PSDCH may be used by a first wireless device to send discovery information to a second wireless device. The discovery information may be used by a wireless device to signal its presence and/or the availability of services to other wireless devices in the area. PSCCH may be used by a first wireless device to send sidelink control information (SCI) to a second wireless device. PSCCH may be similar in some respects to PDCCH and/or PUCCH. The control information may comprise, for example, time/frequency resource allocation information (RB size, a number of retransmissions, etc.), demodulation related information (DMRS, MCS, RV, etc.), identifying information for a transmitting wireless device and/or a receiving wireless device, a process identifier (HARQ, etc.), or any other suitable control information. The PSCCH may be used to allocate, prioritize, and/or reserve sidelink resources for sidelink transmissions. PSSCH may be used by a first wireless device to send and/or relay data and/or network information to a second wireless device. PSSCH may be similar in some respects to PDSCH and/or PUSCH. Each of the sidelink channels may be associated with one or more demodulation reference signals. Sidelink operations may utilize sidelink synchronization signals to establish a timing of sidelink operations. Wireless devices configured for sidelink operations may send sidelink synchronization signals, for example, with the PSBCH. The sidelink synchronization signals may include primary sidelink synchronization signals (PSSS) and secondary sidelink synchronization signals (SSSS).

[0214] Sidelink resources may be configured to a wireless device in any suitable manner. A wireless device may be pre-configured for sidelink, for example, pre-configured with sidelink resource information. Additionally, or alternatively, a network may broadcast system information relating to a resource pool for sidelink. Additionally, or alternatively, a network may configure a particular wireless device with a dedicated sidelink configuration. The configuration may identify sidelink resources to be used for sidelink operation (e.g., configure a sidelink band combination).

[0215] The wireless device may operate in different modes, for example, an assisted mode (which may be referred to as mode 1) or an autonomous mode (which may be referred to as mode 2). Mode selection may be based on a coverage status of the wireless device, a radio resource control status of the wireless device, information and/or instructions from the network, and/or any other suitable factors. For example, if the wireless device is idle or inactive, or if the wireless device is outside of network coverage, the wireless device may select to operate in autonomous mode. For example, if the wireless device is in a connected mode (e.g., connected to a base station), the wireless device may select to operate (or be instructed by the base station to operate) in assisted mode. For example, the network (e.g., a base station) may instruct a connected wireless device to operate in a particular mode.

[0216] In an assisted mode, the wireless device may request scheduling from the network. For example, the wireless device may send a scheduling request to the network and the network may allocate sidelink resources to the wireless device. Assisted mode may be referred to as network-assisted mode, gNB-assisted mode, or base station-assisted mode. In an autonomous mode, the wireless device may select sidelink resources based on measurements within one or more resource pools (for example, pre-configure or network-assigned resource pools), sidelink resource selections made by other wireless devices, and/or sidelink resource usage of other wireless devices.

[0217] To select sidelink resources, a wireless device may observe a sensing window and a selection window. During the sensing window, the wireless device may observe SCI transmitted by other wireless devices using the sidelink resource pool. The SCIs may identify resources that may be used and/or reserved for sidelink transmissions. Based on the resources identified in the SCIs, the wireless device may select resources within the selection window (for example, resource that are different from the resources identified in the SCIs). The wireless device may transmit using the selected sidelink resources.

[0218] FIG. 18 illustrates an example of a resource pool for sidelink operations. A wireless device may operate using one or more sidelink cells. A sidelink cell may include one or more resource pools. Each resource pool may be configured to operate in accordance with a particular mode (for example, assisted or autonomous). The resource pool may be divided into resource units. In the frequency domain, each resource unit may comprise, for example, one or more resource blocks which may be referred to as a sub-channel. In the time domain, each resource unit may comprise, for example, one or more slots, one or more subframes, and/or one or more OFDM symbols. The resource pool may be continuous or non-continuous in the frequency domain and/or the time domain (for example, comprising contiguous resource units or non-contiguous resource units). The resource pool may be divided into repeating resource pool portions. The resource pool may be shared among one or more wireless devices. Each wireless device may attempt to transmit using different resource units, for example, to avoid collisions.

[0219] Sidelink resource pools may be arranged in any suitable manner. In the figure, the example resource pool is non-contiguous in the time domain and confined to a single sidelink BWP. In the example resource pool, frequency resources are divided into a Nf resource units per unit of time, numbered from zero to Nf-1. The example resource pool may comprise a plurality of portions (non-contiguous in this example) that repeat every k units of time. In the figure, time resources are numbered as n, n+1... n+k, n+k+1..., etc.

[0220] A wireless device may select for transmission one or more resource units from the resource pool. In the example resource pool, the wireless device selects resource unit (n,0) for sidelink transmission. The wireless device may further select periodic resource units in later portions of the resource pool, for example, resource unit (n+k,0), resource unit (n+2k,0), resource unit (n+3k,0), etc. The selection may be based on, for example, a determination that a transmission using resource unit (n,0) will not (or is not likely) to collide with a sidelink transmission of a wireless device that shares the sidelink resource pool. The determination may be based on, for example, behavior of other wireless devices that share the resource pool. For example, if no sidelink transmissions are detected in resource unit (n-k,0), then the wireless device may select resource unit (n,0), resource (n+k,0), etc. For example, if a sidelink transmission from another wireless device is detected in resource unit (n-k,1), then the wireless device may avoid selection of resource unit (n,1), resource (n+k,1), etc.

[0221] Different sidelink physical channels may use different resource pools. For example, PSCCH may use a first resource pool and PSSCH may use a second resource pool. Different resource priorities may be associated with different resource pools. For example, data associated with a first QoS, service, priority, and/or other characteristic may use a first resource pool and data associated with a second QoS, service, priority, and/or other characteristic may use a second resource pool. For example, a network (e.g., a base station) may configure a priority level for each resource pool, a service to be supported for each resource pool, etc. For example, a network (e.g., a base station) may configure a first resource pool for use by unicast UEs, a second resource pool for use by groupcast UEs, etc. For example, a network (e.g., a base station) may configure a first resource pool for transmission of sidelink data, a second resource pool for transmission of discovery messages, etc.

[0222] In an example of vehicle-to-everything (V2X) communications via a Uu interface and/or a PC5 interface, the V2X communications may be vehicle-to-vehicle (V2V) communications. A wireless device in the V2V communications may be a vehicle. In an example, the V2X communications may be vehicle-to-pedestrian (V2P) communications. A wireless device in the V2P communications may be a pedestrian equipped with a mobile phone/handset. In an example, the V2X communications may be vehicle-to-infrastructure (V2I) communications.

The infrastructure in the V2I communications may be a base station/access point/node/roadside unit. A wireless device in the V2X communications may be a transmitting wireless device performing one or more sidelink transmissions to a receiving wireless device. The wireless device in the V2X communications may be a receiving wireless device receiving one or more sidelink transmissions from a transmitting wireless device.

[0223] FIG. 19 illustrates an example of sidelink symbols in a slot. In an example, a sidelink transmission may be transmitted in a slot in the time domain. In an example, a wireless device may have data to transmit via sidelink. The wireless device may segment the data into one or more transport blocks (TBs). The one or more TBs may comprise different pieces of the data. A TB of the one or more TBs may be a data packet of the data. The wireless device may transmit a TB of the one or more TBs (e.g., a data packet) via one or more sidelink transmissions (e.g., via PSCCH/PSSCH in one or more slots). In an example, a sidelink transmission (e.g., in a slot) may comprise SCI. The sidelink transmission may further comprise a TB. The SCI may comprise a 1st-stage SCI and a 2nd-stage SCI. A PSCCH of the sidelink transmission may comprise the 1st-stage SCI for scheduling a PSSCH (e.g., the TB). The PSSCH of the sidelink transmission may comprise the 2nd-stage SCI. The PSSCH of the sidelink transmission may further comprise the TB. In an example, sidelink symbols in a slot may or may not start from the first symbol of the slot. The sidelink symbols in the slot may or may not end at the last symbol of the slot. In an example of FIG. 19, sidelink symbols in a slot start from the second symbol of the slot. The sidelink symbols in the slot end at the twelfth symbol of the slot. A first sidelink transmission may comprise a first automatic gain control (AGC) symbol (e.g., the second symbol in the slot), a PSCCH (e.g., in the third, fourth and the fifth symbols in a sub-channel in the slot), a PSSCH (e.g., from the third symbol to the eighth symbol in the slot), and/or a first guard symbol (e.g., the ninth symbol in the slot). A second sidelink transmission may comprise a second AGC symbol (e.g., the tenth symbol in the slot), a PSFCH (e.g., the eleventh symbol in the slot), and/or a second guard symbol for the second sidelink transmission (e.g., the twelfth symbol in the slot). In an example, one or more HARQ feedbacks (e.g., positive acknowledgement or ACK and/or negative acknowledgement or NACK) may be transmitted via the PSFCH. In an example, the PSCCH, the PSSCH, and the PSFCH may have different number of sub-channels (e.g., a different number of frequency resources) in the frequency domain.

[0224] In an example, a set of slots that may belong to a sidelink resource pool is denoted by $(t_0^{SL}, t_1^{SL}, \cdots, t_{T_{max}-1}^{SL})$ where

- $0 \le t_i^{SL} < 10240 \times 2^{\mu}, 0 \le i < T_{max}$,
- the slot index is relative to slot #0 of the radio frame corresponding to SFN 0 of the serving cell or DFN 0,
- the set includes all the slots except the following slots (e.g., from a set of slots consecutively located in the radio frame),
  - N_{S_SSB} slots in which S-SS/PSBCH block (S-SSB) is configured,
  - N_{nonSL} slots in each of which at least one of *Y-th, (Y+1)-th, ..., (Y+X-1)-th* OFDM symbols are not semi-statically configured as uplink as per the higher layer parameter *tdd-UL-DL-*

ConfigurationCommon of the serving cell if provided or *sl-TDD-Configuration* if provided or *sl-TDD-Config* of the received PSBCH if provided, where *Y* and *X* are set by the higher layer parameters *sl-StartSymbol* and *sl-LengthSymbols*, respectively.

- The reserved slots which are determined by the following steps.
  1) the remaining slots excluding N_{S_SSB} slots and N_{nonSL} slots from the set of all the slots are denoted by $(l_0, l_1, \cdots, l_{(10240\times 2^{\mu}-N_{S_{SSB}}-N_{nonSL}-1)})$ arranged in increasing order of slot index.
  2) a slot l_r $(0 \le r < 10240 \times 2^{\mu} - N_{S_{SSB}} - N_{nonSL})$ belongs to the reserved slots if $r = \left\lfloor \frac{m\cdot(10240\times 2^{\mu}-N_{S_{SSB}}-N_{nonSL})}{N_{reserved}} \right\rfloor$, here $m = 0,1,\cdots,N_{reserved}-1$ and $N_{reserved} = (10240 \times 2^{\mu} - N_{S_{SSB}} - N_{nonSL})\ mod\ L_{bitmap}$ where L_{bitmap} denotes the length of bitmap configured by higher layers.
- The slots in the set are arranged in increasing order of slot index.

[0225] In an example, a wireless device may determine the set of slots assigned to a sidelink resource pool as follows:

- a bitmap $\left(b_0, b_1, \ldots, b_{L_{bitmap}-1}\right)$ associated with the resource pool is used where L_{bitmap} the length of the bitmap is configured by higher layers.
- a slot t_k^{SL} $(0 \le k < 10240 \times 2^{\mu} - N_{S_{SSB}} - N_{nonSL} - N_{reserved})$ belongs to the set if $b_{k'} = 1$ where $k' = k\ mod\ L_{bitmap}$.
- The slots in the set are re-indexed such that the subscripts *i* of the remaining slots t'^{SL}_i are successive {0, 1, ..., $T'_{max} - 1$} where T'_{max} is the number of the slots remaining in the set.

[0226] In an example, a slot of the set of slots assigned to a sidelink resource pool (e.g., after excluding the S-SSB slots, the non-sidelink slots, and the reserved slots, mapping according to the bitmap, and re-indexing the slot index) may be referred to as a logical slot. A slot of the set of slots consecutively located in the radio frame may be referred to as physical slot. For example, the set of slots consecutively located in the radio frame may comprise slot #0, slot #1, ..., slot #$10240 \times 2^{\mu} - 1$. The set of slots assigned to a sidelink resource pool may be mapped/associated to a subset of slots in the set of slots consecutively located in the radio frame. The set of slots assigned to a sidelink resource pool may be consecutively indexed. The set of slots assigned to a sidelink resource pool may be not consecutively located in the radio frame.

[0227] In an example, a wireless device may receive, from a second wireless device, an SCI (e.g., SCI format). The SCI may schedule to receive a PSSCH from the second wireless device and/or may schedule a transmission of a PSFCH, to the second wireless device, with HARQ-ACK information corresponding to the reception of the PSSCH. The wireless device may transmit HARQ-ACK information that comprises ACK or NACK on the reception of the PSSCH. For example, the wireless device may transmit a PSFCH indicating an ACK via a PSFCH transmission occasion resource if the reception and/or decoding of the PSCCH is successful. For example, the wireless device may transmit a NACK via a PSFCH transmission occasion resource if the reception and/or decoding of the PSCCH is not successful.

[0228] In an example, a wireless device may receive a message (e.g., RRC message and/or SIB) from a base station and/or a second wireless device. The message may comprise a configuration parameter, e.g., *sl-PSFCH-Period*, indicating a periodicity of a slot comprising a PSFCH transmission occasion resource. For example, the configuration parameter may indicate a number of slots in a sidelink resource pool for a period of PSFCH transmission occasion resources. If the number of slots is *X* (e.g., 1, 2, or 4), the PSFCH period may be *X* slots indicating that a slot comprising a PSFCH transmission occasion resource is configured in every *X* slots in the sidelink resource pool. If the number of slots is zero, no PSFCH transmission occasions resource is configured in the sidelink resource pool.

[0229] In an example, a wireless device may determine that a slot t'^{SL}_k $(0 \leq k < T'_{max})$ comprising a PSFCH transmission occasion resource, e.g., if $k \bmod N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}} = 0$. For example, t'^{SL}_k is a slot, of a sidelink resource pool, comprising PSSCH, PSCCH, PSBCH, and/or PSFCH. For example, T'_{max} may be a number of slots that belong to the resource pool within a reference time duration (e.g., 10240 msec). For example, $N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}$ may be a periodicity (e.g., *sl-PSFCH-Period*) of a slot comprising a PSFCH transmission occasion resource.

[0230] In an example, a wireless device may receive, via a PSCCH, a first-stage SCI (e.g., SCI format 1-A) that schedule a second stage SCI (e.g., SCI format 2-A, SCI format 2-B, and/or SCI format 2-C) and a PSCCH associated with the first-stage SCI and the second stage SCI. The wireless device may receive, via a PSSCH indicated by the first-stage SCI, the second stage SCI (e.g., SCI format 2-A, SCI format 2-B, and/or SCI format 2-C) and the PSCCH associated with the first-stage SCI and the second stage SCI. The wireless device may transmit the HARQ-ACK feedback via a PSFCH transmission occasion resource in a sidelink resource pool, e.g., if the wireless device receives the PSSCH in the sidelink resource pool and/or if the HARQ feedback enabled/disabled indicator field in the second-stage SCI indicates the HARQ feedback is enabled. The wireless device may transmit the PSFCH in a first slot that comprise PSFCH resources and is at least a number of slots, provided by *sl-MinTimeGapPSFCH*, of the resource pool after a last slot of the PSSCH reception.

[0231] In an example, a wireless device is provided by *sl-PSFCH-RB-Set* a set of $M^{\mathrm{PSFCH}}_{\mathrm{PRB,\,set}}$ PRBs in a resource pool for PSFCH transmission with HARQ-ACK information in a PRB of the resource pool. A wireless device can be provided by *sl-PSFCH-Conflict-RB-Set* a set of $M^{\mathrm{PSFCH}}_{\mathrm{PRB,\,set}}$ PRBs in a resource pool for PSFCH transmission with conflict information in a PRB of the resource pool. For a number of N_{subch} sub-channels for the resource pool, provided by *sl-NumSubchannel*, and a number of PSSCH slots associated with a PSFCH slot that is less than or equal to $N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}$, the wireless device allocates the $\left[\left(i + j \cdot N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}\right) \cdot M^{\mathrm{PSFCH}}_{\mathrm{subch,\,slot}}, \left(i + 1 + j \cdot N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}\right) \cdot M^{\mathrm{PSFCH}}_{\mathrm{subch,\,slot}} - 1\right]$ PRBs from the $M^{\mathrm{PSFCH}}_{\mathrm{PRB,\,set}}$ PRBs to slot i among the PSSCH slots associated with the PSFCH slot and sub-channel j, where $M^{\mathrm{PSFCH}}_{\mathrm{subch,\,slot}} = M^{\mathrm{PSFCH}}_{\mathrm{PRB,\,set}} / \left(N_{\mathrm{subch}} \cdot N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}\right)$, $0 \leq i < N^{\mathrm{PSFCH}}_{\mathrm{PSSCH}}$, $0 \leq j < N_{\mathrm{subch}}$, and the allocation starts in an ascending order of i and continues in an ascending order of j. The wireless device expects that $M_{\text{PRB, set}}^{\text{PSFCH}}$ is a multiple of $N_{\text{subch}} \cdot N_{\text{PSSCH}}^{\text{PSFCH}}$.

[0232] In an example, a wireless device that transmitted a PSSCH scheduled by a SCI format 2-A or a SCI format 2-B that indicates HARQ feedback enabled, may attempt to receive associated PSFCHs with HARQ-ACK information according to determined PSFCH resources. The wireless device may determine an ACK or a NACK value for HARQ-ACK information provided in each PSFCH resource. The wireless device does not determine both an ACK value and a NACK value at a same time for a PSFCH resource.

[0233] The 1st-stage SCI may be a SCI format 1-A. The SCI format 1-A may comprise a plurality of fields used for scheduling of the first TB on the PSSCH and the 2nd-stage SCI on the PSSCH. The following information may be transmitted by means of the SCI format 1-A.

- *A priority* of the sidelink transmission. For example, the priority may be a physical layer (e.g., layer 1) priority of the sidelink transmission. For example, the priority may be determined based on logical channel priorities of the sidelink transmission;
- *Frequency resource assignment* of the PSSCH;
- *Time resource assignment* of the PSSCH;
- *Resource reservation period/interval* for a second TB;
- *Demodulation reference signal (DMRS) pattern*;
- *A format of the 2nd-stage SCI*;
- *Beta_offset indicator*;
- *Number of DMRS port*;
- *Modulation and coding scheme* of the PSSCH;
- *Additional MCS table indicator*;
- *PSFCH overhead indication*;
- *Reserved bits*.

[0234] The 2nd-stage SCI may be a SCI format 2-A. The SCI format 2-A may be used for the decoding of the PSSCH, with HARQ operation when HARQ-ACK information includes ACK or NACK, or when there is no feedback of HARQ-ACK information. The SCI format 2-A may comprise a plurality of fields indicating the following information.

- *HARQ process number*;
- *New data indicator*;
- *Redundancy version*;
- *Source ID of a transmitter* (e.g., a transmitting wireless device) of the sidelink transmission;
- *Destination ID of a receiver* (e.g., a receiving wireless device) of the sidelink transmission;
- *HARQ feedback enabled/disabled indicator*;
- *Cast type indicator* indicating that the sidelink transmission is a broadcast, a groupcast and/or a unicast;
- *CSI request*.

[0235] The 2nd-stage SCI may be a SCI format 2-B. The SCI format 2-B may be used for the decoding of the PSSCH, with HARQ operation when HARQ-ACK information includes only NACK, or when there is no feedback of HARQ-ACK information. The SCI format 2-B may comprise a plurality of fields indicating the following information.

- *HARQ process number*;
- *New data indicator*;
- *Redundancy version*;
- *Source ID of a transmitter* (e.g., a transmitting wireless device) of the sidelink transmission;
- *Destination ID of a receiver* (e.g., a receiving wireless device) of the sidelink transmission;
- *HARQ feedback enabled/disabled indicator*;
- *Zone ID* indicating a zone in which a transmitter (e.g., a transmitting wireless device) of the sidelink transmission is geographic located;
- *Communication range requirement* indicating a communication range of the sidelink transmission.

[0236] FIG. 20 illustrates an example of resource indication for a first TB (e.g., a first data packet) and resource reservation for a second TB (e.g., a second data packet). SCI of an initial transmission (e.g., a first transmission) and/or retransmission of the first TB may comprise one or more first parameters (e.g., *Frequency resource assignment* and *Time resource assignment*) indicating one or more first time and frequency (T/F) resources for transmission and/or retransmission of the first TB. The SCI may further comprise one or more second parameters (e.g., *Resource reservation period*) indicating a reservation period/interval of one or more second T/F resources for initial transmission and/or retransmission of the second TB.

[0237] In an example, in response to triggering a resource selection procedure, a wireless device may select one or more first T/F resources for initial transmission and/or retransmission of a first TB. As shown in FIG. 20, the wireless device may select three resources for transmitting the first TB. The wireless device may transmit an initial transmission (initial Tx of a first TB in FIG. 20) of the first TB via a first resource of the three resources. The wireless device may transmit a first retransmission (1st re-Tx in FIG. 20) of the first TB via a second resource of the three resources. The wireless device may transmit a second retransmission (2nd re-Tx in FIG. 20) of the first TB via a third resource of the three resources. A time duration between a starting time of the initial transmission of the first TB and the second retransmission of the first TB may be smaller than or equal to 32 sidelink slots (e.g., $T \leq 32$ slots in FIG. 20). A first SCI may associate with the initial transmission of the first TB. The first SCI may indicate a first T/F resource indication for the initial transmission of the first TB, the first retransmission of the first TB and the second retransmission of the first TB. The first SCI may further indicate a reservation period/interval of resource reservation for a second TB. A second SCI may associate with the first retransmission of the first TB. The second SCI may indicate a second T/F resource indication for the first retransmission of the first TB and the second retransmission of the first TB. The second SCI may further indicate the reservation period/interval of resource reservation for the second TB. A third SCI may associate with the second retransmission of the first TB. The third

SCI may indicate a third T/F resource indication for the second retransmission of the first TB. The third SCI may further indicate the reservation period/interval of resource reservation for the second TB.

[0238] FIG. 21 and FIG. 22 illustrate examples of configuration information for sidelink communication. In an example, a base station may transmit one or more radio resource control (RRC) messages to a wireless device for delivering the configuration information for the sidelink communication. The configuration information may comprise a field of *sl-UE-SelectedConfigRP*. A parameter *sl-ThresPSSCH-RSRP-List* in the field may indicate a list of 64 thresholds. In an example, a wireless device may receive first sidelink control information (SCI) indicating a first priority. The wireless device may have second SCI to be transmitted. The second SCI may indicate a second priority. The wireless device may select a threshold from the list based on the first priority in the first SCI and the second priority in the second SCI. Referring to second exclusion in FIG. 26, the wireless device may exclude resources from candidate resource set based on the threshold. A parameter *sl-MaxNumPerReserve* in the field may indicate a maximum number of reserved PSCCH/PSSCH resources indicated in an SCI. A parameter *sl-MultiReserveResource* in the field may indicate if it is allowed to reserve a sidelink resource for an initial transmission of a TB by an SCI associated with a different TB, based on sensing and resource selection procedure. A parameter *sl-ResourceReservePeriodList* may indicate a set of possible resource reservation periods/intervals (e.g., *SL-ResourceReservedPeriod*) allowed in a resource pool. Up to 16 values may be configured per resource pool. A parameter *sl-RS-ForSensing* may indicate whether DMRS of PSCCH or PSSCH is used for layer 1 (e.g., physical layer) RSRP measurement in sensing operation. A parameter *sl-SensingWindow* may indicate a start of a sensing window. A parameter *sl-SelectionWindowList* may indicate an end of a selection window in resource selection procedure for a TB with respect to priority indicated in SCI. Value $n1$ may correspond to $1 * 2\mu$, value $n5$ corresponds to $5 * 2\mu$, and so on, where $\mu = 0,1,2,3$ for subcarrier spacing (SCS) of 15, 30, 60, and 120 kHz respectively. A parameter *SL-SelectionWindowConfig* may indicate a mapping between a sidelink priority (e.g., *sl-Priority*) and the end of the selection window (e.g., *sl-SelectionWindow*).

[0239] The configuration information may comprise a parameter *sl-PreemptionEnable* indicating whether sidelink pre-emption is disabled or enabled in a resource pool. For example, a priority level *p_preemption* may be configured if the sidelink pre-emption is enabled. For example, if the sidelink pre-emption is enabled but the *p_preemption* is not configured, the sidelink pre-emption may be applicable to all priority levels.

[0240] The configuration information may comprise a parameter *sl-TxPercentageList* indicating a portion of candidate single-slot PSSCH resources over total resources. For example, value p20 may correspond to 20%, and so on. A parameter *SL-TxPercentageConfig* may indicate a mapping between a sidelink priority (e.g., *sl-Priority*) and the portion of candidate single-slot PSSCH resources over total resources (e.g., *sl-TxPercentage*).

[0241] FIG. 23 illustrates an example format of a MAC subheader for sidelink shared channel (SL-SCH). The MAC subheader for SL-SCH may comprise seven header fields V/R/R/R/R/SCR/DST. The MAC subheader is octet aligned. For example, the V field may be a MAC protocol data units (PDU) format version number field indicating which version of the SL-SCH subheader is used. For example, the SRC field may carry 16 bits of a Source Layer-2 identifier (ID) field set to a first identifier provided by upper layers. For example, the DST field may carry 8 bits of the Destination Layer-2 ID set to a second identifier provided by upper layers. In an example, if the V field is set to "1", the second identifier may be a unicast identifier. In an example, if the V field is set to "2", the second identifier may be a groupcast identifier. In an example, if the V field is set to "3", the second identifier may be a broadcast identifier. For example, the R field may indicate reserved bit.

[0242] FIG. 24 illustrates an example of a resource selection procedure. A wireless device may perform the resource selection procedure to select resources for one or more sidelink transmissions. As shown in FIG. 24, a sensing window of the resource selection procedure may start at time $(n - T0)$ (e.g., parameter *sl-SensingWindow*). The sensing window may end at time $(n - T_{proc,0})$. New data of the one or more sidelink transmissions may arrive at the wireless device at time $(n - T_{proc,0})$. The time period $T_{proc,0}$ may be a processing delay of the wireless device to determine to trigger the resource selection procedure. The wireless device may determine to trigger the resource selection procedure at time n to select the resources for the new data arrived at time $(n - T_{proc,0})$. The wireless device may complete the resource selection procedure at time $(n + T1)$. The wireless device may determine the parameter $T1$ based on a capability of the wireless device. The capability of the wireless device may be a processing delay of a processor of the wireless device. A selection window of the resource selection procedure may start at time $(n + T1)$. The selection window may end at time $(n + T2)$ indicating the ending of the selection window. The wireless device may determine the parameter $T2$ based on a parameter $T2min$ (e.g., *sl-SelectionWindow*). In an example, the wireless device may determine the parameter $T2$ subject to $T2min \leq T2 \leq PDB$, where the PDB (packet delay budget) may be the maximum allowable delay (e.g., a delay budget) for successfully transmitting the new data via the one or more sidelink transmissions. The wireless device may determine the parameter $T2min$ to a corresponding value for a priority of the one or more sidelink transmissions (e.g., based on a parameter *SL-SelectionWindowConfig* indicating a mapping between a sidelink priority *sl-Priority* and the end of the selection window *sl-SelectionWindow*). In an example, the wireless device may set the parameter $T2 = PDB$ if the parameter $T2min > PDB$.

[0243] FIG. 25 illustrates an example timing of a resource selection procedure. A wireless device may perform the resource selection procedure for selecting resources for one or more sidelink transmissions. Referring to FIG. 24, a sensing window of initial selection may start at time $(n - T0)$. The sensing window of initial selection may end at time $(n - T_{proc,0})$. New data of the one or more sidelink transmissions may arrive at the wireless device at the time $(n - T_{proc,0})$. The time period $T_{proc,0}$ may be a processing delay for the wireless device to determine to trigger the initial selection of the resources. The wireless device may determine to trigger the initial selection at time n for selecting the resources for the new data arrived at the time $(n - T_{proc,0})$. The wireless device may complete the resource selection procedure at time $(n + T1)$. The time $(n + T_{proc,1})$ may be the maximum allowable processing latency for completing the resource selection procedure being triggered at the time n, where $0 < T1 \leq T_{proc,1}$. A selection window of initial selection may start at time $(n + T1)$. The selection window of initial selection may end at time $(n + T2)$. The parameter $T2$ may be configured, preconfigured, or determined at the wireless device.

[0244] The wireless device may determine first resources (e.g., selected resources in FIG. 25) for the one or more sidelink transmissions based on the completion of the resource selection procedure at the time $(n + T1)$. The wireless device may select the first resources from candidate resources in the selection window of initial selection based on measurements in the sensing window for initial selection. The wireless device may determine a resource collision between the first resources and other resources reserved by another wireless device. The wireless device may determine to drop the first resources for avoiding interference. The wireless device may trigger a resource reselection procedure (e.g., a second resource selection procedure) at time $(m - T3)$ and/or before time $(m - T3)$. The time period $T3$ may be a processing delay for the wireless device to complete the resource reselection procedure (e.g., a second resource selection procedure). The wireless device may determine second resources (e.g., reselected resource in FIG. 25) via the resource reselection procedure (e.g., a second resource selection procedure). The start time of the first resources may be time m (e.g., the first resources may be in slot m).

[0245] In an example, at least one of time parameters $T0$, $T_{proc,0}$, $T_{proc,1}$, $T2$, and PDB may be configured by a base station to the wireless device. In an example, the at least one of the time parameters $T0$, $T_{proc,0}$, $T_{proc,1}$, $T2$, and PDB may be preconfigured to the wireless device. The at least one of the time parameters $T0$, $T_{proc,0}$, $T_{proc,1}$, $T2$, and PDB may be stored in a memory of the wireless device. In an example, the memory may be a Subscriber Identity Module (SIM) card. In an example of FIG. 24 and FIG. 25, the time n, m, $T0$, $T1$, $T_{proc,0}$, $T_{proc,1}$, $T2$, $T2min$, $T3$, and PDB may be in terms of slots and/or slot index.

[0246] FIG. 26 illustrates an example flowchart of a resource selection procedure by a wireless device for transmitting a TB (e.g., a data packet) via sidelink.

[0247] FIG. 27 illustrates an example diagram of the resource selection procedure among layers of the wireless device.

[0248] Referring to FIG. 26 and FIG. 27, the wireless device may transmit one or more sidelink transmissions (e.g., a first transmission of the TB and one or more retransmissions of the TB) for the transmitting of the TB. Referring to FIG. 19, a sidelink transmission of the one or more sidelink transmission may comprise a PSCCH. The sidelink transmission may comprise a PSSCH. The sidelink transmission may comprise a PSFCH. The wireless device may trigger the resource selection procedure for the transmitting of the TB. The resource selection procedure may comprise two actions. The first action of the two actions may be a resource evaluation action. Physical layer (e.g., layer 1) of the wireless device may perform the first action. The physical layer may determine a subset of resources based on the first action and report the subset of resources to higher layer (e.g., RRC layer and/or MAC layer) of the wireless device. The second action of the two actions may be a resource selection action. The higher layer (e.g., RRC layer and/or MAC layer) of the wireless device may perform the second action based on the reported the subset of resources from the physical layer.

[0249] In an example, higher layer (e.g., RRC layer and/or MAC layer) of a wireless device may trigger a resource selection procedure for requesting the wireless device to determine a subset of resources. The higher layer may select resources from the subset of resources for PSSCH and/or PSCCH transmission. To trigger the resource selection procedure, e.g., in slot n, the higher layer may provide the following parameters for the PSSCH and/or PSCCH transmission:

- a resource pool, from which the wireless device may determine the subset of resources;
- layer 1 priority, $prio_{TX}$ (e.g., *sl-Priority* referring to FIG. 21 and FIG. 22), of the PSSCH/PSCCH transmission;
- remaining packet delay budget (PDB) of the PSSCH and/or PSCCH transmission;
- a number of sub-channels, L_{subCH}, for the PSSCH and/or PSCCH transmission in a slot;
- a resource reservation period/interval, $P_{\text{rsvp\_TX}}$, in units of millisecond (ms).

[0250] In an example, if the higher layer requests the wireless device to determine a subset of resources from which the higher layer will select the resources for the PSSCH and/or PSCCH transmission for re-evaluation and/or pre-emption, the higher layer may provide a set of resources $(r_0, r_1, r_2, ...)$ which may be subject to the re-evaluation and a set of resources $(r'_0, r'_1, r'_2, ...)$ which may be subject to the pre-emption.

[0251] In an example, a base station (e.g., network) may transmit a message comprising one or more parameters to the wireless device for performing the resource selection procedure. The message may be an RRC/SIB message, a MAC CE, and/or a DCI. In an example, a second wireless device may transmit a message comprising one or more parameters to the wireless device for performing the resource selection procedure. The message may be an RRC message, a MAC CE, and/or a SCI. The one or more parameters may indicate following information.

- *sl-SelectionWindowList* (e.g., *sl-SelectionWindow* referring to FIG. 21 and FIG. 22): an internal parameter $T2min$ (e.g., $T2min$ referring to FIG. 24) may be set to a corresponding value from the parameter *sl-SelectionWindowList* for a given value of $prio_{TX}$ (e.g., based on *SL-SelectionWindowConfig* referring to FIG. 21 and FIG. 22).
- *sl-ThresPSSCH-RSRP-List* (e.g., *sl-ThresPSSCH-RSRP-List* referring to FIG. 21 and FIG. 22): a parameter may indicate an RSRP threshold for each combination $(p_i,\ p_j)$, where p_i is a value of a priority field in a received SCI format 1-A and p_{j} is a priority of a sidelink transmission (e.g., the PSSCH/PSCCH transmission) of the wireless device; In an example of the resource selection procedure, an invocation of p_{j} may be $p_{\text{j}} = prio_{TX}$.
- *sl-RS-ForSensing* (e.g., *sl-RS-ForSensing* referring to FIG. 21 and FIG. 22): a parameter may indicate whether DMRS of a PSCCH or a PSSCH is used, by the wireless device, for layer 1 (e.g., physical layer) RSRP measurement in sensing operation.
- *sl-ResourceReservePeriodList* (e.g., *sl-ResourceReservePeriodList* referring to FIG. 21 and FIG. 22)

- *sl-SensingWindow* (e.g., *sl-SensingWindow* referring to FIG. 21 and FIG. 22): an internal parameter T_0 may be defined as a number of slots corresponding to *t0_SensingWindow* ms.
- *sl-TxPercentageList* (e.g., based on *SL-TxPercentageConfig* referring to FIG. 21 and FIG. 22): an internal parameter X (e.g., *sl-TxPercentage* referring to FIG. 21 and FIG. 22) for a given $prio_{TX}$ (e.g., *sl-Priority* referring to FIG. 21 and FIG. 22) may be defined as *sl-xPercentage*($prio_{TX}$) converted from percentage to ratio.
- *sl-PreemptionEnable* (e.g., *p_preemption* referring to FIG. 21 and FIG. 22): an internal parameter $prio_{pre}$ may be set to a higher layer provided parameter *sl-PreemptionEnable.*

[0252] The resource reservation period/interval, $P_{\text{rsvp\_TX}}$, if provided, may be converted from units of ms to units of logical slots, resulting in $P'_{\text{rsvp\_TX}}$.

[0253] Notation: $(t_0^{SL}, t_1^{SL}, t_2^{SL}, \ldots)$ may denote a set of slots of a sidelink resource pool.

[0254] In the resource evaluation action (e.g., the first action in FIG. 26), the wireless device may determine a sensing window (e.g., the sensing window shown in FIG. 24 and FIG. 25 based on *sl-SensingWindow*) based on the triggering the resource selection procedure. The wireless device may determine a selection window (e.g., the selection window shown in FIG. 24 and FIG. 25 based on *sl-SelectionWindowList*) based on the triggering the resource selection procedure. The wireless device may determine one or more reservation periods/intervals (e.g., parameter *sl-ResourceReservePeriodList*) for resource reservation. In an example, a candidate single-slot resource for transmission $R_{x,y}$ may be defined as a set of L_{subCH} contiguous sub-channels with sub-channel $x + j$ in slot t_y^{SL} where $j = 0, \ldots, L_{\text{subCH}} - 1$. The wireless device may assume that a set of L_{subCH} contiguous sub-channels in the resource pool within a time interval $[n + T_1, n + T_2]$ correspond to one candidate single-slot resource (e.g., referring to FIG. 24 and FIG. 25). A total number of candidate single-slot resources may be denoted by M_{total}. In an example, referring to FIG. 24 and FIG. 25, the sensing window may be defined by a number of slots in a time duration of $[n - T_0, n - T_{proc,0})$. The wireless device may monitor a first subset of the slots, of a sidelink resource pool, within the sensing window. The wireless device may not monitor a second subset of the slots than the first subset of the slots due to half duplex. The wireless device may perform the following actions based on PSCCH decoded and RSRP measured in the first subset of the slots. In an example, an internal parameter $Th(p_i, p_j)$ may be set to the corresponding value of RSRP threshold indicated by the i-th field in *sl-ThresPSSCH-RSRP-List,* where $i = p_i + (p_j - 1) * 8$.

[0255] Referring to FIG. 26 and FIG. 27, in the resource evaluation action (e.g., the first action in FIG. 26), the wireless device may initialize a candidate resource set (e.g., a set S_A) to be a set of candidate resources. In an example, the candidate resource set may be the union of candidate resources within the selection window. In an example, a candidate resource may be a candidate single-subframe resource. In an example, a candidate resource may be a candidate single-slot resource. In an example, the set S_A may be initialized to a set of all candidate single-slot resources.

[0256] The terminologies of "a set of candidate resource" and "a candidate resource set", and "S_A" may be used interchangeably.

[0257] Referring to FIG. 26 and FIG. 27, in the resource evaluation action (e.g., the first action in FIG. 26), the wireless device may perform a first exclusion for excluding second resources from the candidate resource set based on first resources and one or more reservation periods/intervals. In an example, the wireless device may not monitor the first resources within a sensing window. In an example, the one or more reservation periods/intervals may be configured/associated with a resource pool of the second resources. In an example, the wireless device may determine the second resources within a selection window which might be reserved by a transmission transmitted via the first resources based on the one or more reservation periods/intervals. In an example, the wireless device may exclude a candidate single-slot resource $R_{x,y}$ from the set S_A based on following conditions:

- the wireless device has not monitored slot t_m^{SL} in the sensing window.
- for any periodicity value allowed by the parameter *sl-ResourceReservePeriodList* and a hypothetical SCI format 1-A received in the slot t_m^{SL} with "Resource reservation period" field set to that periodicity value and indicating all sub-channels of the resource pool in this slot, $condition\ c$ of a second exclusion would be met.

[0258] Referring to FIG. 26 and FIG. 27, in the resource evaluation action (e.g., the first action in FIG. 26), the wireless device may perform a second exclusion for excluding third resources from the candidate resource set. In an example, a SCI may indicate a resource reservation of the third resources. The SCI may further indicate a priority value (e.g., indicated by a higher layer parameter *sl-Priority*). The wireless device may exclude the third resources from the candidate resource set based on a reference signal received power (RSRP) of the third resources being higher than an RSRP threshold (e.g., indicated by a higher layer parameter *sl-ThresPSSCH-RSRP-List*). The RSRP threshold may be related to the priority value based on a mapping list of RSRP thresholds to priority values configured and/or pre-configured to the wireless device. In an example, a base station may transmit a message to the wireless device for configuring the mapping list. The message may be a radio resource control (RRC) message. In an example, the mapping list may be pre-configured to the wireless device. A memory of the wireless device may store the mapping list. In an example, a priority indicated by the priority value may be a layer 1 priority (e.g., physical layer priority). In an example, a bigger priority value may indicate a higher priority of a sidelink transmission. A smaller priority value may indicate a lower priority of the sidelink transmission. In another example, a bigger priority value may indicate a lower priority of a sidelink transmission. A smaller priority value may indicate a higher priority of the sidelink transmission. In an example, the wireless device may exclude a candidate single-slot resource $R_{x,y}$ from the set S_A based on following conditions:

a) the wireless device receives an SCI format 1-A in slot t_m^{SL}, and "Resource reservation period" field, if present, and "Priority" field in the received SCI format 1-A indicate the values P_{rsvp_RX} and $prio_{RX}$;

b) the RSRP measurement performed, for the received SCI format 1-A, is higher than $Th(prio_{RX}, prio_{TX})$;

c) the SCI format received in slot t_m^{SL} or the same SCI format which, if and only if the "Resource reservation period" field is present in the received SCI format 1-A, is assumed to be received in slot(s) $t_{m+q\times P'_{rsvp\_RX}}^{SL}$ determines the set of resource blocks and slots which overlaps with $R_{x,y+j\times P'_{rsvp\_TX}}$ for $q = 1, 2, \ldots, Q$ and $j = 0, 1, \ldots, C_{resel} - 1$. Here, P'_{rsvp_RX} is P_{rsvp_RX} converted to units of logical slots, $Q = \left\lceil \frac{T_{scal}}{P_{rsvp\_RX}} \right\rceil$ if $P_{rsvp\_RX} < T_{scal}$ and $n' - m \leq P'_{rsvp\_RX}$, where $t_{n'}^{SL} = n$ if slot n belongs to the set $\left(t_0^{SL}, t_1^{SL}, \ldots, t_{T_{max}}^{SL}\right)$, otherwise slot $t_{n'}^{SL}$ is the first slot after slot n belonging to the set $\left(t_0^{SL}, t_1^{SL}, \ldots, t_{T_{max}}^{SL}\right)$; otherwise $Q = 1$. T_{scal} is set to selection window size $T2$ converted to units of ms.

[0259] Referring to FIG. 26 and FIG. 27, in the resource evaluation action (e.g., the first action in FIG. 26), the wireless device may determine whether remaining candidate resources in the candidate resource set are sufficient for selecting resources for the one or more sidelink transmissions of the TB based on a condition, after performing the first exclusion and the second exclusion. In an example, the condition may be the total amount of the remaining candidate resources in the candidate resource set being more than X percent (e.g., indicated by a higher layer parameter *sl-TxPercentageList*) of the candidate resources in the candidate resource set before performing the first exclusion and the second exclusion. If the condition is not met, the wireless device may increase the RSRP threshold used to exclude the third resources with a value Y and iteratively re-perform the initialization, first exclusion, and second exclusion until the condition being met. In an example, if the number of remaining candidate single-slot resources in the set S_A is smaller than $X \cdot M_{total}$, then $Th(p_i, p_j)$ may be increased by 3 dB and the procedure continues with re-performing of the initialization, first exclusion, and second exclusion until the condition being met. In an example, the wireless device may report the set S_A (e.g., the remaining candidate resources of the candidate resource set) to the higher layer of the wireless device. In an example, based on the wireless device determining that the number of remaining candidate single-slot resources in the set S_A are greater than or equal to $X \cdot M_{total}$, the wireless device may report the set S_A (e.g., the remaining candidate resources of the candidate resource set when the condition is met) to the higher layer of the wireless device.

[0260] Referring to FIG. 26 and FIG. 27, in the resource selection action (e.g., the second action in FIG. 26), the wireless device (e.g., the higher layer of the wireless device) may select fourth resources from the remaining candidate resources of the candidate resource set (e.g., the set S_A reported by the physical layer) for the one or more sidelink transmissions of the TB. In an example, the wireless device may randomly select the fourth resources from the remaining candidate resources of the candidate resource set.

[0261] Referring to FIG. 26 and FIG. 27, in an example, if a resource r_i from the set $(r_0, r_1, r_2, \ldots)$ is not a member of S_A (e.g., the remaining candidate resources of the candidate resource set when the condition is met), the wireless device may report re-evaluation of the resource r_i to the higher layers.

[0262] Referring to FIG. 26 and FIG. 27, in an example, if a resource r'_i from the set $(r'_0, r'_1, r'_2, \ldots)$ meets the conditions below, then the wireless device may report pre-emption of the resource r'_i to the higher layers.

[0263] - r_i' is not a member of S , and

[0264] - r_i' meets the conditions for the second exclusion, with $Th(prio_{RX}, prio_{TX})$ set to a final threshold for reaching $X \cdot M_{\text{total}}$, and

[0265] - the associated priority $prio_{RX}$, satisfies one of the following conditions:

- *sl-PreemptionEnable* is provided and is equal to 'enabled' and $prio_{TX} > prio_{RX}$
- *sl-PreemptionEnable* is provided and is not equal to 'enabled', and $prio_{RX} < prio_{pre}$ and $prio_{TX} > prio_{RX}$

[0266] In an example, if the resource r_i is indicated for re-evaluation by the wireless device (e.g., the physical layer of the wireless device), the higher layer of the wireless device may remove the resource r_i from the set $(r_0, r_1, r_2, \ldots)$. In an example, if the resource r_i' is indicated for pre-emption by the wireless device (e.g., the physical layer of the wireless device), the higher layer of the wireless device may remove the resource r_i' from the set $(r_0', r_1', r_2', \ldots)$. The higher layer of the wireless device may randomly select new time and frequency resources from the remaining candidate resources of the candidate resource set (e.g., the set S_A reported by the physical layer) for the removed resources r_i and/or r_i'. The higher layer of the wireless device may replace the removed resources r_i and/or r_i' by the new time and frequency resources. For example, the wireless device may remove the resources r_i and/or r_i' from the set $(r_0, r_1, r_2, \ldots)$ and/or the set $(r_0', r_1', r_2', \ldots)$ and add the new time and frequency resources to the set $(r_0, r_1, r_2, \ldots)$ and/or the set $(r_0', r_1', r_2', \ldots)$ based on the removing of the resources r_i and/or r_i'.

[0267] In an example, the MAC layer may trigger a resource evaluation, revaluation, or preemption procedure. The PHY layer may report to the MAC layer with a set of candidate resources after performing the resource evaluation, revaluation, or preemption procedure at the PHY layer.

[0268] Sidelink pre-emption may happen between a first wireless device and a second wireless device. The first wireless device may select first resources for a first sidelink transmission. The first sidelink transmission may have a first priority. The second wireless device may select second resources for a second sidelink transmission. The second sidelink transmission may have a second priority. The first resources may partially and/or fully overlap with the second resources. The first wireless device may determine a resource collision between the first resources and the second resources based on the first resources and the second resources being partially and/or fully overlapped. The resource collision may imply fully and/or partially overlapping between the first resources and the second resources in time, frequency, code, power, and/or spatial domain. Referring to an example of FIG. 18, the first resources may comprise one or more first sidelink resource units in a sidelink resource pool. The second resources may comprise one or more second sidelink resource units in the sidelink resource pool. A partial resource collision between the first resources and the second resources may indicate that the at least one sidelink resource unit of the one or more first sidelink resource units belongs to the one or more second sidelink resource units. A full resource collision between the first resources and the second resources may indicate that the one or more first sidelink resource units may be the same as or a subset of the one or more second sidelink resource units. In an example, a bigger priority value may indicate a lower priority of a sidelink transmission. A smaller priority value may indicate a higher priority of the sidelink transmission. In an example, the first wireless device may determine the sidelink pre-emption based on the resource collision and the second priority being higher than the first priority. That is, the first wireless device may determine the sidelink pre-emption based on the resource collision and a value of the second priority being smaller than a value of the first priority. In another example, the first wireless device may determine the sidelink pre-emption based on the resource collision, the value of the second priority being smaller than a priority threshold, and the value of the second priority being smaller than the value of the first priority.

[0269] Referring to FIG. 25, a first wireless device may trigger a first resource selection procedure for selecting first resources (e.g., selected resources after resource selection with collision in FIG. 25) for a first sidelink transmission. A second wireless device may transmit an SCI indicating resource reservation of the first resource for a second sidelink transmission. The first wireless device may determine a resource collision on the first resources between the first sidelink transmission and the second sidelink transmission. The first wireless device may trigger a resource re-evaluation (e.g., a resource evaluation action of a second resource selection procedure) at and/or before time $(m - T3)$ based on the resource collision. The first wireless device may trigger a resource reselection (e.g., a resource selection action of the second resource selection procedure) for selecting second resources (e.g., reselected resources after resource reselection in FIG. 25) based on the resource re-evaluation. The start time of the second resources may be time m.

[0270] FIG. 28 illustrates an example of a resource selection procedure (e.g., periodic partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink. Referring to FIG. 24, a wireless device may perform the resource selection procedure (e.g., periodic partial sensing) for selecting resources for one or more sidelink transmissions in a sidelink resource pool. A sensing window of the resource selection procedure may start at time $(n - T0)$. The sensing window may end at time $(n - T_{proc,0})$. The wireless device may determine to trigger the resource selection procedure at time n for selecting the resources for the new data arrived at the time $(n - T_{proc,0})$. The wireless device may complete the resource selection procedure at time $(n + T1)$. A selection window of the resource selection procedure may start at time $(n + T1)$. The selection window may end at time $(n + T2)$.

[0271] Referring to FIG. 28, the wireless device may select a selection duration comprising Y slots in the selection window as candidate slots for the resource selection procedure. The number of Y slots may be configured by a base station/RSU/second wireless device and/or pre-configured to the wireless device. In an example, the base station/RSU/second wireless device may send a message comprising a parameter/field, to the wireless device, for indicating the number of Y slots. The parameter/field may be a portion/percentage of resources in the selection window. The message may be an RRC/SIB, MAC CE, DCI and/or SCI. The selection duration may start from a time indicated by a slot t_y.

[0272] Referring to FIG. 28, the base station/RSU/second wireless device may send a message to the wireless device configuring one or more reservation intervals/periods (e.g., *sl-ThresPSSCH-RSRP-List* referring to FIG. 21 and FIG. 22) of the sidelink resource pool. Referring to FIG. 26 and FIG. 27, the wireless device may determine one or more sensing durations (e.g., periodic sensing occasions) in the sensing window based on the time t_y, the Y slots, and/or reservation intervals/periods P'_{rsvp_RX} in SCI. The wireless device may receive the SCI in the one or more sensing durations. In an example, the configured/pre-configured one or more reservation intervals/periods (e.g., *sl-ThresPSSCH-RSRP-List* referring to FIG. 21 and FIG. 22) of the sidelink resource pool may comprise the reservation intervals/periods P'_{rsvp_RX}. The one or more sensing durations in the sensing window may be $t_y - q \times P'_{rsvp\_RX}$, where q is a positive integer number. The wireless device may select resources from the selection duration based on sensing in the one or more sensing durations according to examples of FIG. 26 and FIG. 27. The wireless device may perform resource re-evaluation and/or pre-emption based on the resource selection procedure of FIG. 28 (e.g., periodic partial sensing) according to examples of FIG. 26 and FIG. 27.

[0273] FIG. 29 illustrates an example of a resource selection procedure (e.g., contiguous partial sensing) by a wireless device for transmitting a TB (e.g., a data packet) via sidelink. Referring to FIG. 20, an initial sidelink transmission may comprise SCI indicating resource indication of one or more resources for re-transmission(s) of the sidelink transmission. The initial sidelink transmission and the re-transmission(s) of a TB may be in a time duration of 32 slots. Referring to FIG. 28, a wireless device may select a selection duration comprising Y slots in the selection window as candidate slots for the resource selection procedure. The number of Y slots may be configured by a base station/RSU/second wireless device and/or pre-configured to the wireless device. In an example, the base station/RSU/second wireless device may send a message comprising a parameter/field, to the wireless device, for indicating the number of Y slots. The parameter/field may be a portion/percentage of resources in the selection window. The message may be an RRC/SIB, MAC CE, DCI and/or SCI. The selection duration may start from a time indicated by a slot t_y. The wireless device may determine a sensing duration of $[n + T_A, n + T_B]$ based on the time n and/or the time t_y, the Y slots, and/or reservation indication (e.g., *Time resource assignment* of a PSSCH) for re-transmissions of a TB in SCI. The wireless device may receive the SCI in the sensing duration (e.g., contiguous partial sensing duration). The wireless device may exclude one or more resources from the Y candidate slots based on the reservation indication in the SCI and/or a RSRP measurement based on SCI. The value of T_A and T_B may be a zero, positive and/or negative number. T_A may be larger than or equal to -32. T_B may be larger than or equal to T_A.

[0274] FIG. 30 illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 1). A first wireless device and a second wireless device may perform an inter-UE coordination. The first wireless device may be a requesting wireless device of the inter-UE coordination between the first wireless device and the second wireless device. The first wireless device may be a transmitter of one or more sidelink transmissions. The second wireless device may be a coordinating wireless device of the inter-UE coordination. The second wireless device may or may not be an intended receiver of the one or more sidelink transmissions by the first wireless device.

[0275] Referring to FIG. 19, a sidelink transmission may comprise a PSCCH, a PSSCH and/or a PSFCH. A SCI of the sidelink transmission may comprise a destination ID of the sidelink transmission. A wireless device may be an intended receiver of the sidelink transmission when the wireless device has a same ID as the destination ID in the SCI.

[0276] In an example, before transmitting the one or more sidelink transmissions, the first wireless device may request, from the second wireless device, coordination information (e.g., assistance information) for the one or more sidelink transmissions. The coordination information may comprise a first set of resources for transmitting the one or more sidelink transmissions. The first wireless device may send/transmit, to the second wireless device and via sidelink, a request message, for the requesting of the coordination information (e.g., the first set of resources), to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on the receiving of the request message from the first wireless device. In an example, the first wireless device may not transmit a request message to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on an event and/or condition.

[0277] In response to the triggering of the inter-UE coordination, the second wireless device may select the first set of resources for the inter-UE coordination. In an example, the second wireless device may trigger a first resource selection procedure for selecting the first set of resources. In an example, the second wireless device may not trigger a first resource selection procedure for selecting the first set of resources. The second wireless device may select the first set of resources based on resource reservation/allocation information at the second wireless device. For example, the second wireless device may select the first set of resources based on that the first set of resources are reserved for uplink transmissions of the intended receiver of the one or more sidelink transmissions. For example, the second wireless device may select the first set of resources based on that the intended receiver of the one or more sidelink transmissions would receive other sidelink transmissions via the first set of resources. In an example, the first set of resources may be a set of preferred resources by the first wireless device for the one or more sidelink transmissions. The first set of resources may be a set of preferred resources by an intended receiver of the one or more sidelink transmissions. In an example, the first set of resources may be a set of non-preferred resources by the first wireless device for the one or more sidelink transmissions. The first set of resources may be a set of non-preferred resources by the intended receiver of the one or more sidelink transmissions.

[0278] The second wireless device may transmit, to the first wireless device and via sidelink, a message (e.g., the coordination information) comprising/indicating the first set of resources. The message may comprise a RRC, MAC CE, and/or SCI. Referring to FIG. 19, the SCI may comprise a first stage and a second stage. In an example, the first stage of the SCI may comprise/indicate the first set of resources. In an example, the second stage of the SCI may comprise/indicate the first set of resources.

[0279] In response to receiving the message, the first wireless device may select a second set of resources based on the first set of resources. In an example, the first wireless device may trigger a second resource selection procedure for the selecting of the second set of resources. In an example, the first wireless device may not trigger a second resource selection procedure for the selecting of the second set of resources. The first wireless device may select the second set of resources based on (e.g., from) the first set of resources. For example, the first wireless device may randomly select a resource, from the first set of resources, for the second set of resources. For example, the first wireless device may select a resource, from the first set of resources, for the second set of resources, if the resource is in a selection window of the second resource selection procedure. For example, the first wireless device may select a resource, from the first set of resources, for the second set of resources, if the resource is before a PDB (e.g., no later than the PDB) of the one or more sidelink transmissions.

[0280] The example of the inter-UE coordination in FIG. 30 may be an inter-UE coordination scheme 1. In the inter-UE coordination scheme 1, a coordinating wireless device may select a set of preferred resources and/or a set of non-preferred resources for a requesting wireless device. The coordinating wireless device may transmit/send/provide/indicate the set of preferred resources and/or the set of non-preferred resources (e.g., coordination information/assistance information) to the requesting wireless device. The requesting wireless device may transmit one or more sidelink transmissions based on the set of preferred resources and/or the set of non-preferred resources.

[0281] In an example, a preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a RSRP (e.g., measured by the coordinating wireless device) being lower than a RSRP threshold. In an example, a preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a priority value being greater than a priority threshold.

[0282] In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a RSRP (e.g., measured by the coordinating wireless device) being higher than a RSRP threshold (e.g., hidden node problem with high interference level). In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource with a priority value being smaller than the priority threshold (e.g., resource collision problem with another sidelink transmission/reception, which has a high priority). In an example, a non-preferred resource, for transmitting (e.g., by a requesting wireless device of an inter-UE coordination) and/or receiving (e.g., by a coordinating wireless device of the inter-UE coordination) a sidelink transmission, may be a resource being reserved for a second sidelink and/or uplink transmission by the coordinating wireless device and/or an intended receiver (e.g., half-duplex problem). The coordinating wireless device may or may not perform a resource selection procedure for selecting a set of non-preferred resources. The coordinating wireless device may select the set of non-preferred resources based on sensing results of the coordinating wireless device.

[0283] In an example, a larger priority value may indicate a lower priority. A smaller priority value may indicate a higher priority. For example, a first sidelink transmission may have a first priority value. A second sidelink transmission may have a second priority value. The first priority value may be greater than the second priority value, while a first priority of the first sidelink transmission indicated by the first priority value is lower than a second priority of the second sidelink transmission indicated by the second priority value.

[0284] FIG. 31 illustrates an example of a sidelink inter-UE coordination (e.g., an inter-UE coordination scheme 2). A first wireless device and a second wireless device may perform an inter-UE coordination. The first wireless device may be a requesting wireless device of the inter-UE coordination between the first wireless device and the second wireless device. The first wireless device may be a transmitter of one or more first sidelink transmissions. The second wireless device may be a coordinating wireless device of the inter-UE coordination. The second wireless device may or may not be an intended receiver of the one or more first sidelink transmissions by the first wireless device.

[0285] Referring to FIG. 19, a sidelink transmission may comprise a PSCCH, a PSSCH and/or a PSFCH. A SCI of the sidelink transmission may comprise a destination ID of the sidelink transmission. A wireless device may be an intended receiver of the sidelink transmission when the wireless device has a same ID as the destination ID in the SCI.

[0286] In an example, the first wireless device may request, from the second wireless device, coordination information (e.g., assistance information) for the one or more sidelink transmissions. The first wireless device may send/transmit, to the second wireless device and via sidelink, a request message, for the requesting of the coordination information, to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on the receiving of the request message from the first wireless device. In an example, the first wireless device may not transmit a request message to trigger the inter-UE coordination. The second wireless device may trigger the inter-UE coordination based on an event and/or condition.

[0287] In an example, the second wireless device may receive a first SCI from the first wireless device. The first SCI may reserve one or more first resources for the one or more sidelink transmissions. In an example, the request message may comprise the first SCI. In an example, the one or more sidelink transmissions may comprise the first SCI. In an example, the second wireless device may receive, from a third wireless device, one or more second sidelink transmissions. The one or more second sidelink transmissions may comprise a second SCI. The second SCI may reserve one or more second resources for the one or more second sidelink transmissions. The second wireless device may or may not be an intended receiver of the one or more second sidelink transmissions.

[0288] In response to the triggering of the inter-UE coordination, the second wireless device may determine the coordination information for the inter-UE coordination. In an example, the second wireless device may determine the coordination information based on the first SCI. The second wireless device may determine the one or more first resources comprising resources on which the second wireless device would not receive the one or more first sidelink transmissions, e.g., when the second wireless device is an intended receiver of the one or more first sidelink transmissions. The second wireless device may transmit via sidelink and/or uplink via the resources on which the second wireless device would not receive the one or more first sidelink transmissions. The second wireless device may experience half-duplex when transmitting via the resources (e.g., transmit via sidelink). The coordination information may comprise/indicate the resources on which the second wireless device would not receive the one or more first sidelink transmissions, e.g., when the second wireless device is an intended receiver of the one or more first sidelink transmissions. In an example, the second wireless device may determine the coordination information based on the first SCI and/or the second SCI. In an example, the second wireless device may determine the one or more first resources fully/partially overlapping with the one or more second resources. The second wireless device may determine the coordination information indicating overlapped resources of the one or more first resources and the one or more second resources. The overlapped resources may be expected/potential overlapped resources (e.g., future resources) and/or detected overlapped resources (e.g., past resources). The coordination information may comprise/indicate the overlapped resources between the one or more first resources and the one or more second resources. Referring to FIG. 18, fully overlapping between a first set of resources and a second set of resources may indicate that the first set of resources is the same as the second set of resources (e.g., the same as a subset of the second set of resources). Partially overlapping between a first set of resources and a second set of resources may indicate that the first set of resources and the second set of resources comprise overlapped (e.g., identical) one or more first sidelink resource units and/or non-overlapped (e.g., different) one or more second sidelink resource units.

[0289] In an example, the second wireless device may transmit, to the first wireless device and via sidelink, a message (e.g., coordination information/assistance information) comprising/indicating the coordination information, e.g., comprising indication of one or more resources based on example embodiments described above. The message may comprise a RRC, MAC CE, SCI and/or a PSFCH (e.g., a PSFCH format 0). A PSFCH format 0 may be a pseudo-random (PN) sequence defined by a length-31 Gold sequence. An index of a PN sequence of a PSFCH format 0 may indicate a resource collision on a resource, when the resource is associated with a PSFCH resource conveying the PSFCH format 0. Referring to FIG. 19, the SCI may comprise a first stage and a second stage. In an example, the first stage of the SCI may comprise/indicate the coordination information. In an example, the second stage of the SCI may comprise/indicate the coordination information.

[0290] In response to receiving the coordination message, the first wireless device may select and/or update a set of resources for the one or more first sidelink transmissions based on the coordination information. In an example, the first wireless device may trigger a resource selection procedure for the selecting/updating of the set of resources. In an example, the first wireless device may not trigger a resource selection procedure for the selecting/updating of the set of resources. In an example, the first wireless device may determine whether to retransmit the one or more first sidelink transmissions based on the coordination information.

[0291] The example of the inter-UE coordination in FIG. 31 may be an inter-UE coordination scheme 2. In the inter-UE coordination scheme 2, a coordinating wireless device may determine coordination information based on expected/potential overlapped/collided resources (e.g., future resources) and/or detected overlapped/collided resources (e.g., past resources) between a first set of resources reserved by a requesting wireless device and a second set of resources reserved by a third wireless device.

[0292] FIG. 32 illustrates an example of sidelink CSI-RS transmission and a sidelink CSI reporting procedure.

[0293] In an example, as illustrated in FIG. 32, a first wireless device (transmitter UE) may initiate (trigger, perform, run, and/or apply) a sidelink RRC reconfiguration procedure with a second wireless device (receiver UE). The first wireless device may initiate the sidelink RRC reconfiguration procedure on (e.g., for) a corresponding PC5-RRC connection (e.g., between the first the wireless device and the second wireless device). In an example, as illustrated in FIG. 32, the first wireless device may transmit a message (e.g., an RRC message, e.g., *RRCReconfigurationSidelink*) to the second wireless device. Purposes of the sidelink RRC reconfiguration procedure may comprise to indicate (e.g., configure or reconfigure) parameters on NR sidelink measurement and reporting, to indicate (e.g., configure or reconfigure) sidelink CSI reference signal resources, and/or to indicate (e.g., configure or reconfigure) a CSI reporting latency bound. For example, the message may comprise one or more parameters. The one or more parameters may comprise *sl-LatencyBoundCSI-Report* (e.g., latency bound in FIG. 32). *sl-LatencyBoundCSI-Report* (e.g., latency bound in FIG. 32) may indicate the CSI reporting latency bound. The one or more parameters included in the message may comprise, for CSI-RS transmission (and/or reception), *sl-CSI-RS-FirstSymbol* indicating the first OFDM symbol in a PRB used for SL CSI-RS; and/or *sl-CSI-RS-FreqAllocation* indicating the number of antenna ports and the frequency domain allocation for SL CSI-RS. The second wireless device may receive the message.

[0294] In an example, as illustrated in FIG. 32, the first wireless device may transmit sidelink CSI-RS within or via a PSSCH transmission. The PSSCH transmission may be a unicast PSSCH transmission. Conditions for transmitting the sidelink CSI-RS may comprise that 1) CSI reporting is enabled by a higher layer parameter (e.g., *sl-CSI-Acquisition*); and 2) a field (e.g., the '*CSI request*' field) in a corresponding SCI (e.g., SCI format 2-A) is set to 1. The corresponding SCI may schedule the PSSCH (e.g., be used for decoding of the PSSCH). The first wireless device may set value of the '*CSI request*' field as indicated by higher layers (e.g., to 1). When the first wireless device is configured with Q_p={1,2} CSI-RS port(s) in sidelink and the number of scheduled layers is n_{layer}^{PSSCH}, the CSI-RS scaling factor β_{CSIRS} is given by $\beta_{\mathrm{CSIRS}} = \beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}} \cdot \sqrt{\frac{n_{layer}^{PSSCH}}{Q_p}}$, where $\beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}}$ is the scaling factor for the corresponding PSSCH.

[0295] CSI may comprise CQI, RI, LI, CRI, PMI, L1-RSRP, and L1-SINR. The CQI and RI may be always reported together. The second wireless device may transmit, to the first wireless device, the CSI via a CSI report. A procedure of transmitting the CSI report (and generating the CSI) may be denoted as CSI reporting. The CSI reporting may be aperiodic or periodic. Configured CSI-RS may be aperiodic or periodic.

[0296] In an example, as illustrated in FIG. 32, aperiodic CSI reporting may be triggered by an SCI (SCI triggering a CSI report). An aperiodic CSI report (e.g., CSI report in FIG. 32) is triggered by the SCI (e.g., SCI format 2-A) with the 'CSI request' field set to 1. A CSI-triggering wireless device (e.g., the first wireless device) may be not allowed to trigger aperiodic CSI report for the same wireless device before the last slot of the expected reception (e.g., from t_0 to t_1 in FIG. 32) or completion of the ongoing aperiodic CSI report associated with the SCI (e.g., SCI format 2-A) with the 'CSI request' field set to 1 (e.g., from t_0 to t_2 in FIG. 32), where the last slot of the expected reception of the ongoing aperiodic CSI report may be given by a status of a timer for the CSI reporting (e.g., the timer expires). The second wireless device may be not expected to transmit a sidelink CSI-RS and a sidelink PT-RS which overlap.

[0297] In an example, as illustrated in FIG. 32, the second wireless device may be configured with one CSI-RS pattern as indicated by the higher layer parameters *sl-CSI-RS- FreqAllocation*, *sl-CSI-RS-FirstSymbol* in *SL-CSI-RS-Config*. The second wireless device may assume non-zero transmission power for CSI-RS. The second wireless device may not be expected to be configured such that a CSI-RS and the corresponding PSCCH can be mapped to the same resource element. The second wireless device may be not expected to receive sidelink CSI-RS and PSSCH DM-RS, nor CSI-RS and 2nd-stage SCI, on the same symbol. Sidelink CSI-RS may be transmitted in the resource blocks used for the PSSCH associated with the SCI format 2-A triggering a report. The second wireless device may be configured with one CSI reporting latency bound as indicated by the higher layer parameter *sl-LatencyBoundCSI-Report*.

[0298] In an example, as illustrated in FIG. 32, the CSI reporting (e.g., Sidelink Channel State Information (SL-CSI) reporting procedure) may be used to provide a peer wireless device (the first wireless device) with sidelink CSI. RRC (e.g., an RRC message) may configure the following parameters to control the SL-CSI reporting procedure:

[0299] - sl-LatencyBoundCSI-Report, which is maintained for each PC5-RRC connection.

[0300] A MAC entity (of the second wireless device) may maintain a timer (e.g., *sl-CSI-ReportTimer*) for each pair of the Source Layer-2 ID and the Destination Layer-2 ID corresponding to a PC5-RRC connection. The *sl-CSI-ReportTimer* may be used for an SL-CSI reporting wireless device (e.g., the second wireless device) to follow the latency requirement (e.g., *sl-LatencyBoundCSI-Report*) signalled from a CSI triggering wireless device (e.g., the first wireless device). The value (e.g., an initial value) of *sl-CSI-ReportTimer* may be the same as the latency requirement of the SL-CSI reporting in the *sl-LatencyBoundCSI-Report* configured by RRC. The MAC entity may for each pair of the Source Layer-2 ID and the Destination Layer-2 ID corresponding to the PC5-RRC connection which has been established by upper layers:

[0301] 1> if the *SL-CSI reporting* has been triggered by an SCI and not cancelled:

[0302] 2> if the *sl-CSI-ReportTimer* for the triggered SL-CSI reporting is not running:

[0303] 3> start the *sl-CSI-ReportTimer*. (e.g., t_0 in FIG. 32)

[0304] 2> if the *sl-CSI-ReportTimer* for the triggered SL-CSI reporting expires:

[0305] 3> cancel the triggered SL-CSI reporting. (e.g., t_2 in FIG. 32)

[0306] 2> else if the MAC entity has SL resources allocated for new transmission and the SL-SCH resources can accommodate the SL-CSI reporting MAC CE and its subheader as a result of logical channel prioritization:

[0307] 3> instruct the Multiplexing and Assembly procedure to generate a Sidelink CSI Reporting MAC CE;

[0308] 3> stop the *sl-CSI-ReportTimer* for the triggered SL-CSI reporting; (e.g., t_1 in FIG. 32)

[0309] 3> cancel the triggered SL-CSI reporting.

[0310] 2> else if the MAC entity has been configured with Sidelink resource allocation mode 1:

[0311] 3> trigger a Scheduling Request.

[0312] The MAC entity configured with Sidelink resource allocation mode 1 may trigger a Scheduling Request if transmission of a pending SL-CSI reporting with the sidelink grant(s) cannot fulfil the latency requirement associated to the SL-CSI reporting.

[0313] The following descriptions on a CSI framework comprising CSI-RS, CSI, and CSI reporting may be an example implementation of a SL CSI framework. For example, the terminology “CSI-RS” may be replaced by the terminology of “SL CSI-RS” (these two terminologies may be used interchangeably). For example, the terminology “CSI” may be replaced by the terminology of “SL CSI” (these two terminologies may be used interchangeably). For example, the terminology “CSI report” may be replaced by the terminology of “CSI report” (these two terminologies may be used interchangeably). For example, the terminology “CSI reporting” may be replaced by the terminology of “CSI reporting” (these two terminologies may be used interchangeably). In an example, in sidelink communications (e.g., CSI-RS transmission/reception and CSI reporting), a transmitter wireless device (e.g., a wireless device transmitting a CSI-RS and/or triggering a CSI report) may have or execute functions (actions, behaviors, a role, and/or the like) of a base station. For example, the terminology “base station” may be replaced by the terminology of “wireless device” (e.g., a transmitter wireless device, a first wireless device, a second wireless device, or the like). For example, the transmitter wireless device may transmit, to a receiver wireless device (e.g., a wireless device receiving the CSI-RS and/or transmitting the CSI report), a message comprising configuration(s) on CSI-RS resources and CSI reporting, one or more CSI-RSs, and/or the like. For example, the transmitter wireless device may receive, from the receiver wireless device, the CSI report. For example, the terminology “downlink channel” may be replaced by the terminology of “sidelink channel” (these two terminologies may be used interchangeably). For example, the terminology “uplink channel” may be replaced by the terminology of “sidelink channel” (these two terminologies may be used interchangeably).

[0314] A CSI-RS resource may be transmitted with a number of antenna ports, a CDM type, a density (in terms of REs/port/PRB for a CSI-RS resource). In an example, a base station may transmit one or more CSI-RSs to a wireless device (or a group of wireless devices). A CSI-RS may be based on a reference signal sequence. The wireless device may determine the reference signal sequence $r(m)$ as $r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j\frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1))$, where $c(i)$ is a pseudo-random sequence with a pseudo-random sequence generator being initialized with $c_{init} = \left(2^{10}\left(N_{symb}^{slot} n_{s,f}^{\mu} + l + 1\right)(2n_{ID} + 1) + n_{ID}\right) \bmod 2^{31}$ at the start of each

OFDM symbol where $n_{s,f}^{\mu}$ is the slot number within a radio frame, l is the OFDM symbol number within a slot, and n_{ID} equals the higher-layer parameter *scramblingID* or *sequenceGenerationConfig*.

[0315] In an example, for each CSI-RS configured, the wireless device may determine the sequence $r(m)$ being mapped to resources elements $(k,l)_{p,\mu}$ when the following conditions are fulfilled: the resource element $(k,l)_{p,\mu}$ is within the resource blocks occupied by the CSI-RS resource for which the wireless device is configured.

[0316] In an example, the wireless device is not expected to receive CSI-RS and DM-RS on the same resource elements.

[0317] In an example, a wireless device may assume (or determine) $\beta_{CSIRS} > 0$ for a non-zero-power CSI-RS where β_{CSIRS} is selected such that the power offset specified by the higher-layer parameter *powerControlOffsetSS* in the *NZP-CSI-RS-Resource* IE, if provided, is fulfilled. An NZP-CSI-RS is a CSI-RS with non-zero power transmission, which is contrast to ZP-CSI-RS which is a CSI-RS with zero power transmission.

[0318] In an example, a wireless device may determine that a CSI-RS is transmitted using antenna ports p numbered according to

[0319] $p = 3000 + s + jL;$

[0320] $j = 0, 1, \ldots, \frac{N}{L} - 1;$

[0321] $s = 0, 1, \ldots, L - 1;$

[0322] where s is a sequence index, $L \in \{1,2,4,8\}$ is the CDM group size, and N is the number of CSI-RS ports. The CDM group index j corresponds to the time/frequency locations $(\bar{k}, \bar{l})$ for a given row of the table. The CDM groups are numbered in order of increasing frequency domain allocation first and then increasing time domain allocation. For a CSI-RS resource configured as periodic or semi-persistent by the higher-layer parameter *resourceType* or configured by the higher-layer parameter *CSI-RS-CellMobility*, the wireless device may assume that the CSI-RS is transmitted in slots satisfying

[0323] $\left(N_{slot}^{frame,\mu} n_f + n_{s,f}^{\mu} - T_{offset}\right) \bmod T_{CSI\text{-}RS} = 0,$

[0324] where the periodicity $T_{CSI\text{-}RS}$ (in slots) and slot offset T_{offset} are obtained from the higher-layer parameter CSI-*ResourcePeriodicityAndOffset* or *slotConfig*.

[0325] In an example, a wireless device may assume that antenna ports within a CSI-RS resource are quasi co-located with QCL Type A, Type D (when applicable), and average gain.

[0326] In an example, a base station may transmit to a wireless device (or a group of wireless devices), one or more RRC messages comprising configuration parameters of CSI-RS resources. The one or more RRC messages may be cell specific RRC messages (which may be applied for all wireless devices), or wireless device specific RRC messages (which may be applied dedicatedly for the wireless device receiving the messages). The one or more RRC messages may comprise *CSI-RS-resourceMapping* IE to configure resource element mapping of a CSI-RS resource in time domain and frequency domain.

[0327] In an example, a *CSI-RS-ResourceMapping* IE may comprise, for each CSI-RS resource, a frequency domain allocation indication (by f*requencyDomainAllocation*), a number of antenna ports (by *nrofPorts*), a first time domain parameter (*firstOFDMSymbolInTimeDomain*), a second time domain parameter (*firstOFDMSymbolInTimeDomain2*), a CDM type indicator, a density indication, a frequency band indication. for a CSI-RS resource, the density indication may indicate 0.5, 1 or 3 RE/port/PRB for X=1, 0.5 or 1 for X=2, 16, 24 or 32, 1 for X=4, 8, 12.

[0328] In an example, a CSI-RS resource, e.g., a none-zero CSI-RS (NZP-CSI-RS), may be configured by the base station with RRC messages, e.g., *NZP-CSI-RS-Resource* IE. The *NZP-CSI-RS-Resource* IE may configure, for a CSI-RS resource, an NZP-CSI-RS resource ID (or index), a resource mapping indication (*CSI-RS-ResourceMapping*), one or more power control parameters (e.g., *powerControlOffset*, *powerControlOffsetSS*), a scrambling ID, a periodicity and offset indication, a QCL indication, and/or the like.

[0329] In an example, the base station may configure a plurality of CSI-RS resource sets, each CSI-RS resource set comprising a plurality of CSI-RS resources. A CSI-RS resource set may be configured by *NZP-CSI-RS-ResourceSet* IE. A CSI-RS resource set may be configured with parameters comprising a CSI-RS resource set ID (or index), a number of CSI-RS resource IDs, a repetition indication (indicating on or off), and/or the like.

[0330] In an example, the base station may configure a plurality of CSI resource configurations. A CSI resource configuration may be configured by the base station with RRC messages, e.g., *CSI-ResourceConfig* IE. A *CSI-ResourceConfig* IE may indicate, for a CSI resource configuration, a CSI resource configuration ID, a number of NZP-CSI-RS-Resource sets, a number of SSB resource sets, a BWP ID and a resource type indication (indicating whether the resource is aperiodic, semi-persistence, or periodic resource), and/or the like.

[0331] FIG. 33 illustrates an example of CS-RS resource set. A base station may transmit RRC messages comprising configuration parameters of a plurality of CSI-RS resource sets, each CSI-RS resource set comprising a plurality of CSI-RS resources. Configuration of CSI-RS resource set may enable the base station to transmit per CSI-RS resource set indication for saving signaling overhead.

[0332] As shown in FIG. 33, a base station may configure a plurality of CSI-RS resource sets (e.g., a CSI-RS resource set 1, a CSI-RS resource set 2, ..., a CSI-RS resource set *N*). Each CSI-RS resource set may comprise overlapping CSI-RS resources, or non-overlapping CSI-RS resources. In an example, the CSI-RS resource set 1 may comprise CSI-RS resource 0, CSI-RS resource 1, and CSI-RS resource 2. The CSI-RS resource set 2 may comprise CSI-RS resource 0 and CSI-RS resource 4. The CSI-RS resource set *N* may comprise CSI-RS resource 5, ..., and CSI-RS resource 191.

[0333] In an example, a CSI-RS resource set may be configured with a repetition indicator.

[0334] In an example, a base station may transmit, a CSI-RS resource, of the CSI-RS resource set, with different spatial domain filter (or transmission beam), in response to the repetition indicator, of the CSI-RS resource set, being set to 'off'. Based on transmitting each CSI-RS resource in different beam, a wireless device may perform downlink beam management (e.g., P2 in FIG. 12A, to identify a best transmission beam among the multiple beams of the multiple CSI-RS resources of the CSI-RS resource set). Downlink beam management may be implemented based on example embodiments described above with respect to FIG. 12A and/or FIG. 12B.

[0335] In an example, a base station may transmit, each CSI-RS resource, of the CSI-RS resource set, with the same spatial domain filter (or transmission beam), in response to the repetition indicator, of the CSI-RS resource set, being set to 'on'. Based on transmitting each CSI-RS resource in the same beam, a wireless device may perform downlink beam management (e.g., P3 in FIG. 12A, to identify a best receiving beam at the wireless device for receiving the CSI-RS resource set).

[0336] In the example of FIG. 33, CSI-RS resource set 1 may be associated with a repetition indicator being set to 'off', wherein the base station may transmit CSI-RS #0, CSI-RS #1 and CSI-RS #2 with different transmission beams. CSI-RS resource set 2 is associated with a repetition indicator being set to 'on', wherein the base station may transmit CSI-RS #0 and CSI-RS #4 with the same transmission beam. CSI-RS resource set *N* is associated with a repetition indicator being absent (e.g., not configured), wherein the base station may transmit CSI-RS #5 and CSI-RS #191 with different transmission beams.

[0337] A base station may flexibly configure CSI-RS resources and CSI-RS resource sets. With the configured CSI-RS resources and CSI-RS resource sets, a wireless device may perform beam management procedure, measure the channel quality, and/or transmit a CSI report to the base station.

[0338] In an example, a wireless device may transmit, to a base station, a periodic CSI report, an aperiodic CSI report, and/or a semi-persistent CSI report. The time and frequency resources used by the wireless device to report CSI may be controlled by the base station. CSI may comprise Channel Quality Indicator (CQI), precoding matrix indicator (PMI), CSI-RS resource indicator (CRI), SS/PBCH Block Resource indicator (SSBRI), layer indicator (LI), rank indicator (RI), layer 1 reference signal received power (L1-RSRP), and layer 1 signal-to-interference-plus-noise ratio (L1-SINR).

[0339] In an example, for CQI, PMI, CRI, SSBRI, LI, RI, L1-RSRP, and/or L1-SINR, a wireless device may be configured by higher layers with $N \geq 1$ *CSI-ReportConfig* Reporting Settings, $M \geq 1$ *CSI-ResourceConfig* Resource Settings, and one or two list(s) of trigger states (given by the higher layer parameters *CSI-AperiodicTriggerStateList* and *CSI-SemiPersistentOnPUSCH-TriggerStateList*). Each trigger state in *CSI-AperiodicTriggerStateList* may comprise (or contain) a list of associated *CSI-ReportConfigs* indicating the Resource Set IDs for channel and optionally for interference. Each trigger state in *CSI-SemiPersistentOnPUSCH-TriggerStateList* may comprise (or contain) one associated *CSI-ReportConfig*.

[0340] In an example, a Reporting Setting *CSI-ReportConfig* may be associated with a single downlink BWP (indicated by higher layer parameter *BWP-Id*) given in the associated *CSI-ResourceConfig* for channel measurement and may comprise (or contain) the parameter(s) for one CSI reporting band: codebook configuration including codebook subset restriction, time-domain behavior, frequency granularity for CQI and PMI, measurement restriction configurations, and the CSI-related quantities to be reported by the wireless device such as the layer indicator (LI), L1-RSRP, L1-SINR, CRI, and SSBRI (SSB Resource Indicator).

[0341] In an example, time domain behavior of the *CSI-ReportConfig* is indicated by the higher layer parameter *reportConfigType* and may be set to 'aperiodic', 'semiPersistentOnPUCCH', 'semiPersistentOnPUSCH', or 'periodic'. For 'periodic' and 'semiPersistentOnPUCCH'/'semiPersistentOnPUSCH' CSI reporting, the configured periodicity and slot offset applies in the numerology of the UL BWP in which the CSI report is configured to be transmitted on. The higher layer parameter *reportQuantity* indicates the CSI-related, L1-RSRP-related or L1-SINR-related quantities to report. The *reportFreqConfiguration* indicates the reporting granularity in the frequency domain, including the CSI reporting band and if PMI/CQI reporting is wideband or sub-band. The *timeRestrictionForChannelMeasurements* parameter in *CSI-ReportConfig* may be configured to enable time domain restriction for channel measurements and *timeRestrictionForInterferenceMeasurements* may be configured to enable time domain restriction for interference measurements. The *CSI-ReportConfig* may also contain *CodebookConfig*, which contains configuration parameters for Type-I, Type II, Enhanced Type II CSI, or Further Enhanced Type II Port Selection including codebook subset restriction when applicable, and configurations of group-based reporting.

[0342] In an example, a CSI Resource Setting *CSI-ResourceConfig* may comprise (or contain) a configuration of a list of $S \geq 1$ CSI Resource Sets (given by higher layer parameter *csi-RS-ResourceSetList*), where the list is comprised of references to either or both of NZP CSI-RS resource set(s) and SS/PBCH block set(s) or the list is comprised of references to CSI-IM resource set(s). A CSI Resource Setting may be located in the DL BWP identified by the higher layer parameter *BWP-id*, and all CSI Resource Settings linked to a CSI Report Setting may have the same DL BWP.

[0343] In an example, time domain behavior of the CSI-RS resources within a CSI Resource Setting are indicated by the higher layer parameter *resourceType* and may be set to aperiodic, periodic, or semi-persistent. For periodic and semi-persistent CSI Resource Settings, when the wireless device is configured with group based beam report, the number of CSI Resource Sets configured is $S = 2$; otherwise the number of CSI-RS Resource Sets configured is limited to $S = 1$.

[0344] In an example, for periodic and semi-persistent CSI Resource Settings, the configured periodicity and slot offset is given in the numerology of its associated DL BWP, as given by *BWP-id*. When a wireless device is configured with multiple *CSI-ResourceConfig*s including the same NZP CSI-RS resource ID, the same time domain behavior may be configured for the *CSI-ResourceConfig*s. When a wireless device is configured with multiple *CSI-ResourceConfig*s including the same CSI-IM resource ID, the same time-domain behavior may be configured for the *CSI-ResourceConfig*s. All CSI Resource Settings linked to a CSI Report Setting may have the same time domain behavior.

[0345] In an example, for L1-SINR measurement, when one Resource Setting is configured, the Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel and interference measurement on NZP CSI-RS for L1-SINR computation. A wireless device may assume that same one port NZP CSI-RS resource(s) with density 3 REs/RB is used for both channel and interference measurements.

[0346] In an example, for L1-SINR measurement, when two Resource Settings are configured, the first one Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement on SSB or NZP CSI-RS and the second one (given by either higher layer parameter *csi-IM-ResourcesForInterference* or higher layer parameter *nzp-CSI-RS-ResourcesForInterference*) is for interference measurement performed on CSI-IM or on one port NZP CSI-RS with density 3 REs/RB, where each SSB or NZP CSI-RS resource for channel measurement is associated with one CSI-IM resource or one NZP CSI-RS resource for interference measurement by the ordering of the SSB or NZP CSI-RS resource for channel measurement and CSI-IM resource or NZP CSI-RS resource for interference measurement in the corresponding resource sets. The number of SSB(s) or CSI-RS resources for channel measurement equals to the number of CSI-IM resources or the number of NZP CSI-RS resource for interference measurement. In this case, a wireless device may apply the SSB, or 'typeD' RS configured with qcl-Type set to 'typeD' to the NZP CSI-RS resource for channel measurement, as the reference RS for determining 'typeD' assumption for the corresponding CSI-IM resource or the corresponding NZP CSI-RS resource for interference measurement configured for one CSI reporting. A wireless device may expect that the NZP CSI-RS resource set for channel measurement and the NZP-CSI-RS resource set for interference measurement, if any, are configured with the higher layer parameter repetition.

[0347] In an example, for semi-persistent or periodic CSI, a *CSI-ReportConfig* is linked to periodic or semi-persistent Resource Setting(s). When one Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is configured, the Resource Setting is for channel measurement for L1-RSRP or for channel and interference measurement for L1-SINR computation. When two Resource Settings are configured, the first Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement and the second Resource Setting (e.g., by *csi-IM-ResourcesForInterference*) is used for interference measurement performed on CSI-IM. For L1-SINR computation, the second Resource Setting (given by higher layer parameter *csi-IM-ResourcesForInterference* or higher layer parameter *nzp-CSI-RS-ResourceForInterference*) is used for interference measurement performed on CSI-IM or on NZP CSI-RS.

[0348] In an example, for L1-RSRP computation, a wireless device may be configured with CSI-RS resources, SS/PBCH Block resources or both CSI-RS and SS/PBCH block resources, when resource-wise quasi co-located with 'type C' and 'typeD' when applicable. The wireless device may be configured with CSI-RS resource setting up to 16 CSI-RS resource sets having up to 64 resources within each set. The total number of different CSI-RS resources over all resource sets is no more than 128.

[0349] In an example, for L1-RSRP reporting, if the higher layer parameter *nrofReportedRS* in *CSI-ReportConfig* is configured to be one, the reported L1-RSRP value is defined by a 7-bit value in the range [-140, -44] dBm with 1dB step size. If the higher layer parameter *nrofReportedRS* is configured to be larger than one, or if the higher layer parameter *groupBasedBeamReporting* is configured as 'enabled', or if the higher layer parameter *groupBasedBeamReporting-r17* is configured, the wireless device may use differential L1-RSRP based reporting, where the largest measured value of L1-RSRP is quantized to a 7-bit value in the range [-140, -44] dBm with 1dB step size, and the differential L1-RSRP is quantized to a 4-bit value. The differential L1-RSRP value is computed with 2 dB step size with a reference to the largest measured L1-RSRP value which is part of the same L1-RSRP reporting instance.

[0350] In an example, when the higher layer parameter *groupBasedBeamReporting-r17* in *CSI-ReportConfig* is configured, the wireless device may indicate the CSI Resource Set associated with the largest measured value of L1-RSRP, and for each group, CRI or SSBRI of the indicated CSI Resource Set is present first.

[0351] In an example, if the higher layer parameter *timeRestrictionForChannelMeasurements* in *CSI-ReportConfig* is set to 'notConfigured', the wireless device may derive the channel measurements for computing L1-RSRP value reported in uplink slot *n* based on only the SS/PBCH or NZP CSI-RS, no later than the CSI reference resource, associated with the CSI resource setting.

[0352] In an example, if the higher layer parameter *timeRestrictionForChannelMeasurements* in *CSI-ReportConfig* is set to 'Configured', the wireless device may derive the channel measurements for computing L1-RSRP reported in uplink slot *n* based on only the most recent, no later than the CSI reference resource, occasion of SS/PBCH or NZP CSI-RS associated with the CSI resource setting.

[0353] In an example, for L1-SINR computation, for channel measurement the wireless device may be configured with NZP CSI-RS resources and/or SS/PBCH Block resources, for interference measurement the wireless device may be configured with NZP CSI-RS or CSI-IM resources. For channel measurement, the wireless device may be configured with CSI-RS resource setting with up to 16 resource sets, with a total of up to 64 CSI-RS resources or up to 64 SS/PBCH Block resources.

[0354] In an example, for L1-SINR reporting, if the higher layer parameter *nrofReportedRS* in *CSI-ReportConfig* is configured to be one, the reported L1-SINR value is defined by a 7-bit value in the range [-23, 40] dB with 0.5 dB step size. If the higher layer parameter *nrofReportedRS* is configured to be larger than one, or if the higher layer parameter g*roupBasedBeamReporting* is configured as 'enabled', the wireless device may use differential L1-SINR based reporting, where the largest measured value of L1-SINR is quantized to a 7-bit value in the range [-23, 40] dB with 0.5 dB step size, and the differential L1-SINR is quantized to a 4-bit value. The differential L1-SINR is computed with 1 dB step size with a reference to the largest measured L1-SINR value which is part of the same L1-SINR reporting instance. When NZP CSI-RS is configured for channel measurement and/or interference measurement, the reported L1-SINR values should not be compensated by the power offset(s) given by higher layer parameter *powerControOffsetSS* or *powerControlOffset*.

[0355] In an example, when one or two resource settings are configured for L1-SINR measurement, if the higher layer parameter *timeRestrictionForChannelMeasurements* in *CSI-ReportConfig* is set to 'notConfigured', the wireless device may derive the channel measurements for computing L1-SINR reported in uplink slot n based on only the SSB or NZP CSI-RS, no later than the CSI reference resource, associated with the CSI resource setting. If the higher layer parameter *timeRestrictionForChannelMeasurements* in CSI-*ReportConfig* is set to 'configured', the wireless device may derive the channel measurements for computing L1-SINR reported in uplink slot *n* based on only the most recent, no later than the CSI reference resource, occasion of SSB or NZP CSI-RS associated with the CSI resource setting. If the higher layer parameter *timeRestrictionForInterferenceMeasurements* in *CSI-ReportConfig* is set to 'notConfigured', the wireless device may derive the interference measurements for computing L1-SINR reported in uplink slot *n* based on only the CSI-IM or NZP CSI-RS for interference measurement or NZP CSI-RS for channel and interference measurement no later than the CSI reference resource associated with the CSI resource setting. If the higher layer parameter *timeRestrictionForInterferenceMeasurements* in *CSI-ReportConfig* is set to 'configured', the wireless device may derive the interference measurements for computing the L1-SINR reported in uplink slot n based on the most recent, no later than the CSI reference resource, occasion of CSI-IM or NZP CSI-RS for interference measurement or NZP CSI-RS for channel and interference measurement associated with the CSI resource setting.

[0356] In an example, a base station may transmit to a wireless device one or more RRC messages (e.g., *ServingCellConfig* IE) comprising configuration parameters of a cell. The *ServingCellConfig* IE may be used to configure (add or modify) the wireless device with a serving cell, which may be a SpCell or an SCell of an MCG or SCG. The configuration parameters may be mostly wireless device specific but partly also cell specific (e.g., in additionally configured bandwidth parts). Reconfiguration between a PUCCH and PUCCHless SCell may be supported using an SCell release and add. The configuration parameters may indicate a plurality of BWPs configured on the cell, PDCCH configuration, PDSCH configuration, CSI measurement configuration (e.g., *CSI-MeasConfig* IE), and/or the like. CSI measurement configuration may be associated with parameters indicating a plurality of NZP-CSI-RS resources, a plurality of NZP-CSI-RS resource sets, a plurality of CSI-IM resources, a plurality of CSI-IM resource sets, a plurality of CSI-SSB resource sets, a plurality of CSI resource configurations, a plurality of CSI report configurations, and/or the like.

[0357] In an example, a wireless device may derive CSI report based on SS/PBCH block and/or CSI-RSs. The wireless device may measure SS-RSRP (L1-RSRP) within a SMTC occasion based on the SS-RSRP being defined as the linear average over the power contributions (in [W]) of the REs that carry SSSs. For SS-RSRP determination based on DM-RS for PBCH and, if indicated by higher layers, the wireless device may use CSI-RSs in addition to SSSs for SS-RSRP measurement. The wireless device may measure SS-RSRP using DM-RS for PBCH or CSI-RSs by linearly averaging over the power contributions of the REs that carry corresponding RSs taking into account power scaling for the RSs. If SS-RSRP is not used for L1-RSRP, the additional use of CSI-RS for SS-RSRP determination is not applicable. The wireless device may measure SS-RSRP only among the reference signals corresponding to SS/PBCH blocks with the same SS/PBCH block index and the same physical-layer cell identity. The wireless device may measure SS-RSRP only from an indicated set of SS/PBCH block(s) if SS-RSRP is not used for L1-RSRP and higher-layers indicate the set of SS/PBCH blocks for performing SS-RSRP measurements. The wireless device may determine, for frequency range 1, a reference point for the SS-RSRP measurement as an antenna connector of the wireless device. The wireless device may, for frequency range 2, measure SS-RSRP based on a combined signal from antenna elements corresponding to a given receiver branch.

For frequency range 1 and 2, if receiver diversity is in use by the wireless device, the wireless device may report SS-RSRP with a value not lower than the corresponding SS-RSRP of any of the individual receiver branches.

[0358] In an example, the wireless device may measure CSI-RSRP (L1-RSRP) based on the CSI-RSRP being defined as the linear average over the power contributions (in [W]) of the resource elements of the antenna port(s) that carry CSI reference signals configured for RSRP measurements within the considered measurement frequency bandwidth in the configured CSI-RS occasions. For CSI-RSRP determination, CSI reference signals transmitted on an antenna port may be used. If CSI-RSRP is used for L1-RSRP, CSI reference signals transmitted on antenna ports may be used for CSI-RSRP determination. For intra-frequency CSI-RSRP measurements, if the measurement gap is not configured, wireless device is not expected to measure the CSI-RS resource(s) outside of the active downlink bandwidth part. For frequency range 1, the reference point for the CSI-RSRP may be the antenna connector of the UE. For frequency range 2, CSI-RSRP may be measured based on the combined signal from antenna elements corresponding to a given receiver branch. For frequency range 1 and 2, if receiver diversity is in use by the UE, the reported CSI-RSRP value may not be lower than the corresponding CSI-RSRP of any of the individual receiver branches.

[0359] In an example, the wireless device may measure SS-RSRQ (L1-RSRQ) based on SS-RSRQ being defined as the ratio of $N \times$ SS-RSRP / NR carrier RSSI, where N is the number of resource blocks in the NR carrier RSSI measurement bandwidth. The measurements in the numerator and denominator may be made over the same set of resource blocks. NR carrier Received Signal Strength Indicator (NR carrier RSSI) may comprise the linear average of the total received power (in [W]) observed only in certain OFDM symbols of measurement time resource(s), in the measurement bandwidth, over N number of resource blocks from all sources, including (or comprising) co-channel serving and non-serving cells, adjacent channel interference, thermal noise. For cell selection, the measurement time resources(s) for NR Carrier RSSI may be not constrained. Otherwise (for a purpose other than the cell selection), the measurement time resource(s) for NR Carrier RSSI may be confined within SMTC window duration. If indicated by higher layers, if measurement gap is not used, the NR Carrier RSSI may be measured in slots within the SMTC window duration that are indicated by the higher layer parameter *measurementSlots* and in predefined OFDM symbols. If measurement gap is used, the NR Carrier RSSI is measured in slots within the SMTC window duration that are indicated by the higher layer parameter *measurementSlots* and in the predefined OFDM symbols that are overlapped with the measurement gap. For intra-frequency measurements, NR Carrier RSSI is measured with timing reference corresponding to the serving cell in the frequency layer. For inter-frequency measurements, NR Carrier RSSI is measured with timing reference corresponding to any cell in the target frequency layer. Otherwise not indicated by the higher layers, if measurement gap is not used, NR Carrier RSSI is measured from OFDM symbols within SMTC window duration. If measurement gap is used, NR Carrier RSSI is measured from OFDM symbols corresponding to overlapped time span between SMTC window duration and the measurement gap. If the higher layers indicate certain SS/PBCH blocks for performing SS-RSRQ measurements, SS-RSRP may be measured only from the indicated set of

SS/PBCH block(s). For frequency range 1, the reference point for the SS-RSRQ may be the antenna connector of the UE. For frequency range 2, NR Carrier RSSI may be measured based on the combined signal from antenna elements corresponding to a given receiver branch, where the combining for NR Carrier RSSI may be the same as the one used for SS-RSRP measurements. For frequency range 1 and 2, if receiver diversity is in use by the UE, the reported SS-RSRQ value may not be lower than the corresponding SS-RSRQ of any of the individual receiver branches.

[0360] In an example, the wireless device may measure CSI-RSRQ (L1-RSRQ) based on CSI-RSRQ being defined as the ratio of N × CSI-RSRP to CSI-RSSI, where N is the number of resource blocks in the CSI-RSSI measurement bandwidth. The measurements in the numerator and denominator may be made over the same set of resource blocks. CSI Received Signal Strength Indicator (CSI-RSSI), comprises the linear average of the total received power (in [W]) observed only in OFDM symbols of measurement time resource(s), in the measurement bandwidth, over N number of resource blocks from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc. The measurement time resource(s) for CSI-RSSI corresponds to OFDM symbols containing configured CSI-RS occasions. For CSI-RSRQ determination CSI reference signals transmitted on an antenna port may be used. For intra-frequency CSI-RSRQ measurements, if the measurement gap is not configured, wireless device is not expected to measure the CSI-RS resource(s) outside of the active downlink bandwidth part. For frequency range 1, the reference point for the CSI-RSRQ may be the antenna connector of the UE. For frequency range 2, CSI-RSSI may be measured based on the combined signal from antenna elements corresponding to a given receiver branch, where the combining for CSI-RSSI may be the same as the one used for CSI-RSRP measurements. For frequency range 1 and 2, if receiver diversity is in use by the UE, the reported CSI-RSRQ value may not be lower than the corresponding CSI-RSRQ of any of the individual receiver branches.

[0361] In an example, the wireless device may measure SS-SINR (L1-SINR) based on SS-SINR being defined as the linear average over the power contribution (in [W]) of the resource elements carrying SS signals divided by the linear average of the noise and interference power contribution (in [W]). If SS-SINR is used for L1-SINR reporting with dedicated interference measurement resources, the interference and noise is measured over resource(s) indicated by higher layers. Otherwise, the interference and noise are measured over the resource elements carrying SS signals within the same frequency bandwidth. The measurement time resource(s) for SS-SINR are confined within SMTC window duration. If SS-SINR is used for L1-SINR as configured by reporting configurations, the measurement time resources(s) restriction by SMTC window duration is not applicable. For SS-SINR determination demodulation reference signals for physical broadcast channel (PBCH) in addition to secondary synchronization signals may be used. If SS-SINR is not used for L1-SINR and higher-layers indicate certain SS/PBCH blocks for performing SS-SINR measurements, then SS-SINR is measured only from the indicated set of SS/PBCH block(s). For frequency range 1, the reference point for the SS-SINR may be the antenna connector of the UE. For frequency range 2, SS-SINR may be measured based on the combined signal from antenna elements corresponding to a given receiver branch. For frequency range 1 and 2, if receiver diversity is in use by the UE, the reported SS-SINR value may not be lower than the corresponding SS-SINR of any of the individual receiver branches.

[0362] In an example, the wireless device may measure CSI-SINR (L1-SINR) based on CSI-SINR being defined as the linear average over the power contribution (in [W]) of the resource elements carrying CSI reference signals divided by the linear average of the noise and interference power contribution (in [W]). If CSI-SINR is used for L1-SINR reporting with dedicated interference measurement resources, the interference and noise is measured over resource(s) indicated by higher layers. Otherwise, the interference and noise are measured over the resource elements carrying CSI reference signals within the same frequency bandwidth. For CSI-SINR determination CSI reference signals transmitted on an antenna port may be used. If CSI-SINR is used for L1-SINR, CSI reference signals transmitted on antenna ports may be used for CSI-SINR determination. For intra-frequency CSI-SINR measurements not used for L1-SINR reporting, if the measurement gap is not configured, wireless device is not expected to measure the CSI-RS resource(s) outside of the active downlink bandwidth part. For frequency range 1, the reference point for the CSI-SINR may be the antenna connector of the UE. For frequency range 2, CSI-SINR may be measured based on the combined signal from antenna elements corresponding to a given receiver branch. For frequency range 1 and 2, if receiver diversity is in use by the UE, the reported CSI-SINR value may not be lower than the corresponding CSI-SINR of any of the individual receiver branches.

[0363] In an example, a wireless device may obtain CSI-RS configuration parameters and measure CSI (and/or beam). The wireless device may transmit CSI report to a base station. For example, base station (gNB) may transmit, and/or a wireless device (UE) may receive, one or more RRC messages indicating first configuration parameter of a plurality of periodic CSI-RS (P-CSI-RS) resources. A P-CSI-RS may be an NZP-CSI-RS which is a periodic CSI-RS transmitted with a non-zero power. The one or more RRC messages may be a cell specific RRC message, or a wireless device specific RRC message. The configuration parameters may indicate a first number of P-CSI-RS resources in a CSI-RS resource set. The CSI-RS resource set may comprise the first number of P-CSI-RS resources. The configuration parameters may indicate a first transmission density, a first transmission bandwidth, a first transmission periodicity for a P-CSI-RS resource of the first number of P-CSI-RS resources in the CSI-RS resource set. The configuration parameters may indicate a number of CSI-RS resource sets. Different CSI-RS resource sets may be used for the wireless device for measuring different CSI quantities (e.g., CQI, PMI, CRI, SSBRI, LI, RI, L1-RSRP, L1-SINR, and/or the like).

[0364] In an example, based on the one or more RRC messages, the base station may transmit the P-CSI-RSs in the configured resources.

[0365] In an example, the wireless device, based on periodically transmitted P-CSI-RSs (the first number of CSI-RSs) configured in the one or more RRC messages, may determine that the P-CSI-RSs are transmitted in configured locations (time domain and frequency domain) with a configured periodicity, with a configured number of beams, and/or with a configured transmission power. Based on the determining, the wireless device may obtain a first periodic CSI/beam measurements (e.g., CSI, L1-RSRP, and/or L1-SINR). The wireless device may measure the CSI/beam quantities.

[0366] In an example, the wireless device may further measure CSI quantities based on periodic transmitted SSBs. The wireless device may transmit CSI report based on measurements on SSBs and P-CSI-RSs according to configuration parameters of the CSI report. The CSI report, measured based on SSBs and P-CSI-RSs, may comprise a SSB index of a SSB (e.g., with the best RSRP value among RSRP values of SSBs), a CSI-R resource index of a P-CSI-RS (e.g., with the best RSRP value among RSRP values of the P-CSI-RSs), a RSRP value and/or a differential RSRP value.

[0367] In an example (e.g., in high frequency deployment), the base station may transmit SSBs with wider beams than the P-CSI-RSs. The base station transmits SSBs with wider beams to achieve sufficient coverage for multiple wireless devices in a cell. The base station transmits P-CSI-RSs with narrower beams to facilitate a specific wireless device to identify a good beam pair between the wireless device and the base station, e.g., for actual data/control information transmissions.

[0368] In an example, the wireless device, based on the measured CSI report, may transmit a first periodic CSI report via uplink channel (e.g., PUCCH/PUSCH). The first periodic CSI report may comprise a plurality of CSI quantities (e.g., CQI, PMI, CRI, SSBRI, LI, RI, L1-RSRP, L1-SINR, and/or the like), based on configuration parameters of the CSI report. In an example, the wireless device may transmit the first periodic CSI report via a PUCCH resource configured for the periodic CSI report.

[0369] In an example, the base station, based on receiving the CSI report, may determine a scheduling strategy (e.g., determining a transmission beam, bandwidth, MCS, antenna ports, layers, ranks, and/or the like). The base station may determine to perform beam, TRP change (or switch), and/or cell change (or switch) for the wireless device.

[0370] A first wireless device (receiver wireless device) may receive, from a second wireless device (transmitter wireless device), a CSI-RS within a PSSCH in a first slot scheduled by an SCI. The SCI may trigger (or request) a CSI report (CSI reporting procedure) associated with the CSI-RS. The first wireless device may start, based on the CSI reporting procedure being triggered, a timer with a value that is the same as a configured latency bound for CSI reporting. The first wireless device may receive one or more first CSI-RSs associated with a first CSI report. The first wireless device may receive, after the end of a first latency bound for transmitting the first CSI report, one or more second CSI-RSs associated with a second CSI report. For example, the one or more CSI-RSs and the CSI report may be used for sidelink beam management.

[0371] A problem arises when receiving the one or more second CSI-RSs after the end of the first latency bound for transmitting the first CSI report. The second wireless device may need to wait for a long time to transmit the one or more second CSI-RSs and trigger the second CSI report. The first wireless device may receive the one or more second CSI-RSs after the end of the first latency bound. The problem causes inflexible CSI reporting, increased latency of CSI-RS transmission and CSI reporting, and increased power consumption.

[0372] Example embodiment(s) of present disclosure enhance sidelink CSI reporting. In a solution for the problem, the first wireless device may receive the one or more second CSI-RSs before the end of the first latency bound. The second wireless device may transmit the one or more second CSI-RSs and trigger the second CSI report before the end of the first latency bound. The solution prevents the first wireless device from receiving the one or more second CSI-RSs only after the end of the first latency bound and thus prevents inflexible CSI reporting, increased latency of CSI-RS transmission and CSI reporting, and increased power consumption.

[0373] When the second wireless device is allowed to transmit the one or more second CSI-RSs (and trigger the second CSI report) before the end of the first latency bound, the first wireless device may transmit a CSI report within an overlapped period of the first latency bound and a second latency bound for transmitting the second CSI report.

[0374] A problem arises when receiving the one or more second CSI-RSs before the end of the first latency bound for transmitting the first CSI report (e.g., the first latency bound and the second latency bound for transmitting the second CSI report overlap in time domain). The first wireless device may transmit, during the overlapped period of the first latency bound and the second latency bound, the CSI report (either the first CSI report or the second CSI report). When receiving the CSI report during the overlapped period, the second wireless device may not correctly determine which CSI report (the first CSI report or the second CSI report) is included. The problem causes inefficient CSI reporting, inefficient beam management, and increased power consumption.

[0375] Example embodiment(s) of present disclosure enhance sidelink CSI reporting. In a solution for the problem, the second wireless device may indicate a first identification associated with the first CSI report and a second identification associated with the second CSI report. The first wireless device may indicate one or more identifications (e.g., the first identification and/or the second identification) in the CSI report or via a SCI scheduling a PSSCH within which the CSI report is transmitted. The solution prevents the second wireless device from incorrectly determining which CSI report is included and thus prevents inefficient CSI reporting, inefficient beam management, and increased power consumption.

[0376] When the first wireless device may transmit the CSI report within the overlapped period of the first latency bound and the second latency bound, the first wireless device may include one of the first CSI report and the second CSI report in the CSI report.

[0377] A problem arises when transmitting the CSI report including one of the first CSI report and the second CSI report via a PSSCH. The first wireless device may transmit another PSSCH for the other one of the first CSI report and the second CSI report. The problem causes inefficient CSI reporting, inefficient use of resources, increased latency of CSI reporting, and increased power consumption.

[0378] Example embodiment(s) of present disclosure enhance sidelink CSI reporting. In a solution for the problem, the second wireless device may multiplex, in the CSI report, the first CSI report and the second CSI report. The solution prevents the second wireless device from transmitting the CSI report including one of the first CSI report and the second CSI report and thus prevents inefficient CSI reporting, inefficient use of resources, increased latency of CSI reporting, and increased power consumption.

[0379] FIG. 34 illustrates an example of CSI reporting for multiple CSI-RSs.

[0380] In an example of FIG. 34, a first wireless device may receive (e.g., a wireless device as illustrated in FIG. 17), from a second wireless device (e.g., a wireless device as illustrated in FIG. 17), a trigger of a first CSI report. The first wireless device may transmit, within a first time duration (e.g., a latency bound of the first CSI report) for transmitting the first CSI report (e.g., associated with one or more first CSI-RSs), the first CSI report. The first wireless device may receive, after the first time duration for transmitting the first CSI report, a trigger of a second CSI report. For example, the second wireless device may not be allowed to transmit the trigger of the second CSI report (e.g., request the second CSI report) before the end of the first time duration for transmitting the first CSI report. The first wireless device may transmit within a second time duration for transmitting the second CSI report (e.g., associated with one or more second CSI-RSs), the second CSI report. CSI reporting for multiple CSI-RSs (e.g., transmission/reception of the multiple CSI-RSs and reception/transmission of CSI report(s)) may be inflexible. There may be extra latency of the CSI reporting.

[0381] FIG. 35 illustrates an example of CSI reporting for multiple CSI-RSs as per an aspect of an example embodiment of the present disclosure.

[0382] In an example as illustrated in FIG. 35, a first wireless device (e.g., a wireless device as illustrated in FIG. 17) may receive from a second wireless device (e.g., a wireless device as illustrated in FIG. 17), one or more first channel state information reference signals (CSI-RSs) associated with a first channel state information (CSI) report. The first wireless device may receive, before an end (e.g., the last slot or symbol) of a first time duration (e.g., a first latency bound; e.g., from t_0 to t_2 as illustrated in FIG. 35) for transmitting the first CSI report, one or more second CSI-RSs associated with a second CSI report. The first wireless device may transmit (e.g., to the second wireless device) a third CSI report. The first wireless device may transmit, based on absence of (e.g., not receiving) the one or more second CSI-RSs, transmit the first CSI report.

[0383] In an example as illustrated in FIG. 35, a first identification associated with the first CSI report may be: a first group index (e.g., where CSI-RS(s) or PSSCH(s) carrying the CSI-RS(s) with the same first group index belong to a first group); indexes of the one or more first CSI-RSs (e.g., in the first group); or a first one or more beam indexes of the one or more first CSI-RSs (e.g., in the first group).

[0384] In an example as illustrated in FIG. 35, the first wireless device may receive a first sidelink control information (SCI) comprising one or more fields indicating a first physical sidelink shared channel (PSSCH), wherein a first CSI-RS of the one or more first CSI-RSs is within the first PSSCH.

[0385] In an example as illustrated in FIG. 35, the first SCI may indicate the first identification of the first CSI report.

[0386] In an example as illustrated in FIG. 35, the first CSI report may comprise the first identification.

[0387] In an example as illustrated in FIG. 35, a second identification associated with the second CSI report may be: a second group index (e.g., where CSI-RS(s) or PSSCH(s) carrying the CSI-RS(s) with the same second group index belong to a second group); indexes of the one or more second CSI-RSs (e.g., in the second group); or a second one or more beam indexes of the one or more second CSI-RSs (e.g., in the second group).

[0388] In an example as illustrated in FIG. 35, the first wireless device may receive a second SCI comprising one or more fields indicating (e.g., scheduling) a second PSSCH, wherein a second CSI-RS of the one or more second CSI-RSs may be within the second PSSCH.

[0389] In an example as illustrated in FIG. 35, the second SCI may indicate (e.g., via a field of the second SCI) the second identification of the second CSI report.

[0390] In an example as illustrated in FIG. 35, the second CSI report may comprise the second identification (e.g., by multiplexing the second identification in a MAC CE or PSSCH carrying the second CSI report).

[0391] In an example as illustrated in FIG. 35, the message may comprise one or more parameters indicating a pattern of a CSI-RS of the one or more first CSI-RSs or the one or more second CSI-RSs. For example, transmission and/or reception of the CSI-RS may be based on the pattern.

[0392] In an example as illustrated in FIG. 35, the pattern may comprise: a frequency domain position of the CSI-RS; and a position of starting symbol (and/or a number of symbols) of the CSI-RS. For example, the frequency domain position may be within a resource pool. For example, the position may be within a sidelink slot.

[0393] In an example as illustrated in FIG. 35, the first wireless device may receive a message comprising a parameter indicating whether selecting one CSI report or multiplexing multiple reports.

[0394] In an example as illustrated in FIG. 35, the first wireless device may transmit, to the second wireless device, a third SCI comprising one or more fields indicating (e.g., scheduling) a third PSSCH for the transmitting the third CSI report.

[0395] In an example as illustrated in FIG. 35, the first wireless device may transmit the third CSI report via (or within) the third PSSCH.

[0396] In an example as illustrated in FIG. 35, the third SCI may indicate (e.g., via a field of the third SCI; e.g., via a bitmap) the first identification and/or the second identification.

[0397] In an example as illustrated in FIG. 35, the first wireless device may transmit the third CSI report within an overlapped time duration between the first time duration for transmitting the first CSI report and a second time duration (e.g., a second latency bound; e.g., from t_1 to t_3 as illustrated in FIG. 35) for transmitting the second CSI report.

[0398] In an example as illustrated in FIG. 35, an end of a time duration may be a last (an end) slot (or symbol) of the time duration.

[0399] In an example as illustrated in FIG. 35, the second wireless device may receive a message comprising a parameter indicating a value of the time duration. For example, the value may be a latency bound of CSI reporting. For example, the value may be a value of a timer of the CSI reporting.

[0400] In an example as illustrated in FIG. 35, the value of the time duration may be in terms of: number of slots; number of symbols; and combination of number of slots and number of symbols.

[0401] In an example as illustrated in FIG. 35, the time duration may comprise the first time duration and the second time duration.

[0402] In an example as illustrated in FIG. 35, the first wireless device may transmit the third CSI report within the first time duration for transmitting the first CSI report.

[0403] In an example as illustrated in FIG. 35, the first wireless device may transmit the third CSI report within the second time duration for transmitting the second CSI report.

[0404] In an example as illustrated in FIG. 35, the third SCI may be a first stage SCI or a second stage SCI.

[0405] In an example as illustrated in FIG. 35, the third CSI report may comprise the first CSI report and the second CSI report.

[0406] In an example as illustrated in FIG. 35, the first wireless device may select one of the first CSI report and the second CSI report as the third CSI report, e.g., based on the parameter indicating selecting one CSI report; and/or capability of the first wireless device indicating selecting one CSI report.

[0407] In an example as illustrated in FIG. 35, the first wireless device (e.g., a MAC entity of the first wireless device) may multiplex, in the third CSI report, the first CSI report and the second CSI report, e.g., based on: the parameter indicating multiplexing multiple reports; and/or the capability of the first wireless device indicating multiplexing multiple reports.

[0408] In an example as illustrated in FIG. 35, the first wireless device may transmit the third CSI report via a media access control control element (MAC CE) multiplexed in (e.g., via) the third PSSCH.

[0409] In an example as illustrated in FIG. 35, the MAC CE may comprise only one of the first CSI report and the second CSI report.

[0410] In an example as illustrated in FIG. 35, a size of the MAC CE may be fixed.

[0411] In an example as illustrated in FIG. 35, the MAC CE may comprise one or more CSI reports of the first CSI report and the second CSI report.

[0412] In an example as illustrated in FIG. 35, the size of the MAC CE may be variable.

[0413] In an example as illustrated in FIG. 35, the first wireless device may order the first CSI report and the second CSI report, e.g., based on: the first identification and the second identification; and/or reception timings of the one or more first CSI-RSs and the one or more second CSI-RSs.

[0414] In an example as illustrated in FIG. 35, the first wireless device may receive a fourth SCI requesting or triggering the second CSI report.

[0415] In an example as illustrated in FIG. 35, the first wireless device may set a CSI request field in the fourth SCI to 1.

[0416] In an example as illustrated in FIG. 35, the fourth SCI may be (e.g., be the same as) the second SCI.

[0417] In an example as illustrated in FIG. 35, the fourth SCI may be different from the second SCI.

[0418] In an example as illustrated in FIG. 35, the second wireless device may transmit to the first wireless device, one or more first CSI-RSs associated with a first CSI report. The second wireless device may transmit one or more second CSI-RSs associated with a second CSI report. The second wireless device may trigger, before an end of a first time duration for receiving the first CSI report, the second CSI report.

[0419] In an example as illustrated in FIG. 35, a first identification associated with the first CSI report may be: a first group index; indexes of the one or more first CSI-RSs; or a first one or more beam indexes of the one or more first CSI-RSs.

[0420] In an example as illustrated in FIG. 35, the second wireless device may transmit a first SCI comprising one or more fields indicating a first PSSCH, wherein a first CSI-RS of the one or more first CSI-RSs may be within the first PSSCH.

[0421] In an example as illustrated in FIG. 35, the first SCI may indicate the first identification of the first CSI report.

[0422] In an example as illustrated in FIG. 35, the first CSI report may comprise the first identification.

[0423] In an example as illustrated in FIG. 35, a second identification associated with the second CSI report may be: a second group index; indexes of the one or more second CSI-RSs; or a second one or more beam indexes of the one or more second CSI-RSs.

[0424] In an example as illustrated in FIG. 35, the second wireless device may transmit a second SCI comprising one or more fields indicating a second PSSCH, wherein a second CSI-RS of the one or more second CSI-RSs may be within the second PSSCH.

[0425] In an example as illustrated in FIG. 35, the second SCI may indicate the second identification of the second CSI report.

[0426] In an example as illustrated in FIG. 35, the second CSI report may comprise the second identification.

[0427] In an example as illustrated in FIG. 35, receiving the third CSI report comprising the first CSI report and the second CSI report.

[0428] In an example as illustrated in FIG. 35, the second wireless device may receive the third CSI report within an overlapped time duration between the time duration for receiving the first CSI report and a second time duration for receiving the second CSI report.

[0429] In an example as illustrated in FIG. 35, the second wireless device may receive the third CSI report within the first time duration for receiving the first CSI report.

[0430] In an example as illustrated in FIG. 35, the second wireless device may receive the third CSI report within the second time duration for receiving the second CSI report.

[0431] In an example as illustrated in FIG. 35, the second wireless device may receive, from the first wireless device, a third SCI comprising one or more fields indicating a third PSSCH for the receiving the third CSI report.

[0432] In an example as illustrated in FIG. 35, the second wireless device may receive the third CSI report via the third PSSCH.

[0433] In an example as illustrated in FIG. 35, the third SCI may indicate the first identification and/or the second identification.

[0434] In an example as illustrated in FIG. 35, the third SCI may be a first stage SCI or a second stage SCI.

[0435] The method of claim 55, wherein the third CSI report may be one of the first CSI report and the second CSI report.

[0436] In an example as illustrated in FIG. 35, the second wireless device may decode (detect), based on receiving the first identification, the third CSI report that is the same as the first CSI report.

[0437] In an example as illustrated in FIG. 35, the third CSI report may be a combination of the first CSI report and the second CSI report.

[0438] In an example as illustrated in FIG. 35, the second wireless device may decode (detect), based on receiving the first identification and the second identification, the third CSI report that is the combination of the first CSI report and the second CSI report.

[0439] In an example as illustrated in FIG. 35, the third CSI report may be via a MAC CE multiplexed in the third PSSCH.

[0440] In an example as illustrated in FIG. 35, the MAC CE may comprise only one of the first CSI report and the second CSI report.

[0441] In an example as illustrated in FIG. 35, a size of the MAC CE may be fixed.

[0442] In an example as illustrated in FIG. 35, the MAC CE may comprise one or more CSI reports of the first CSI report and the second CSI report.

[0443] In an example as illustrated in FIG. 35, the size of the MAC CE may be variable.

[0444] In an example as illustrated in FIG. 35, the second wireless device may transmit a fourth SCI indicating the triggering the second CSI report.

[0445] In an example as illustrated in FIG. 35, the second wireless device may set a CSI request field in the fourth SCI to 1.

[0446] In an example as illustrated in FIG. 35, the fourth SCI may be the second SCI.

[0447] In an example as illustrated in FIG. 35, the fourth SCI may be different from the second SCI.

[0448] In an example as illustrated in FIG. 35, the fourth SCI may be after the second SCI.

[0449] In an example, a second wireless device (e.g., a wireless device as illustrated in FIG. 17) may transmit to a first wireless device (e.g., a wireless device as illustrated in FIG. 17), a first CSI-RS via a first PSSCH and a first SCI comprising one or more fields indicating the first PSSCH, wherein: the first SCI may indicate a first identification. A first time window may be associated with the first identification. The second wireless device may transmit a second CSI-RS via a second PSSCH and a second SCI comprising one or more fields indicating the second PSSCH, wherein: the second SCI may indicate a second identification. A second time window may be associated with the second identification. The second wireless device may receive, via a third PSSCH in an overlapped duration between the first time window and the second time window, a CSI report associated with the first PSSCH, where the third PSSCH may comprise the first identification; or a third SCI comprising one or more fields indicating the third PSSCH may indicate the first identification.

[0450] FIG. 36 illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure. At 3601, the first wireless device may receive one or more first channel state information reference signals (CSI-RSs) associated with a first channel state information (CSI) report. At 3602, the first wireless device may receive, before an end of a first time duration for transmitting the first CSI report, one or more second CSI-RSs associated with a second CSI report. At 3603, the first wireless device may transmit a third CSI report.

[0451] FIG. 37 illustrates an example of flow diagram as per an aspect of an embodiment of the present disclosure. At 3701, the first wireless device may transmit one or more first channel state information reference signals (CSI-RSs) associated with a first channel state information (CSI) report; and one or more second CSI-RSs associated with a second CSI report. At 3702, the first wireless device may trigger, before an end of a first time duration for receiving the first CSI report, the second CSI report.

CLAIMS

What is claimed is:

1. A method comprising:

receiving, by a first wireless device from a second wireless device, one or more first channel state information reference signals (CSI-RSs) via a first slot;

receiving one or more second CSI-RSs via a second slot; and

transmitting a channel state information (CSI) report, comprising a first measurement on the one or more first CSI-RSs and a second measurement on the one or more second CSI-RSs, based on a first time duration overlapping a second time duration, wherein:

the first time duration starts based on the first slot; and

the second time duration starts based on the second slot.

2. A method comprising:

transmitting, by a first wireless device, a sidelink (SL) channel state information (CSI) report indicating a first CSI and a second CSI, based on:

a first time duration associated with the first CSI; and

a second time duration associated with the second CSI.

3. The method of claim 2, wherein the transmitting is further based on the first time duration overlapping the second time duration.

4. The method of any one of claims 2-3, wherein the first time duration starts based on a first slot.

5. The method of any one of claims 2-4, further comprising receiving one or more first SL CSI-reference signals (CSI-RSs) via a first slot.

6. The method of any one of claims 2-5, wherein the second time duration starts based on a second slot.

7. The method of any one of claims 2-6, further comprising receiving one or more second SL CSI-RSs via a second slot.

8. The method of any one of claims 2-7, wherein the CSI report comprises at least one of:

a first measurement on one or more first CSI-RSs; or

a second measurement on one or more second CSI-RSs.

9. The method of any one of claims 1-8, wherein the transmitting the CSI report is within a time duration starting from a beginning of the second time duration.

10. The method of any one of claims 1-9, wherein the transmitting the CSI report is within an overlapped time duration between the first time duration and the second time duration.

11. The method of any one of claims 1-10, further comprising receiving a first sidelink control information (SCI) comprising one or more fields indicating a first physical sidelink shared channel (PSSCH), wherein a first CSI-RS of the one or more first CSI-RSs is within the first PSSCH.

12. The method of any one of claims 1-11, further comprising receiving a second SCI comprising one or more fields indicating a second PSSCH, wherein a second CSI-RS of the one or more second CSI-RSs is within the second PSSCH.

13. A method comprising:

transmitting, by a second wireless device from a first wireless device, one or more first channel state information reference signals (CSI-RSs) via a first slot;

transmitting one or more second CSI-RSs via a second slot; and

receiving a channel state information (CSI) report, comprising a first measurement on the one or more first CSI-RSs and a second measurement on the one or more second CSI-RSs, based on a first time duration overlapping a second time duration, wherein:

the first time duration starts based on the first slot; and

the second time duration starts based on the second slot.

14. A method comprising:

receiving, by a second wireless device, a sidelink (SL) channel state information (CSI) report indicating a first CSI and a second CSI, based on:

a first time duration associated with the first CSI; and

a second time duration associated with the second CSI.

15. The method of claim 14, wherein the receiving is further based on the first time duration overlapping the second time duration.

16. The method of any one of claims 14-15, wherein the first time duration starts based on a first slot.

17. The method of any one of claims 14-16, further comprising transmitting one or more first SL CSI-reference signals (CSI-RSs) via a first slot.

18. The method of any one of claims 14-17, wherein the second time duration starts based on a second slot.

19. The method of any one of claims 14-18, further comprising transmitting one or more second SL CSI-RSs via a second slot.

20. The method of any one of claims 14-19, wherein the CSI report comprises at least one of:

a first measurement on one or more first SL CSI-RSs; or

a second measurement on one or more second SL CSI-RSs.

21. The method of any one of claims 13-20, wherein the receiving the CSI report is within a time duration starting from a beginning of the second time duration.

22. The method of any one of claims 13-21, wherein the receiving the CSI report is within an overlapped time duration between the first time duration and the second time duration.

23. The method of any one of claims 13-22, further comprising transmitting a first sidelink control information (SCI) comprising one or more fields indicating a first physical sidelink shared channel (PSSCH), wherein a first CSI-RS of the one or more first CSI-RSs is within the first PSSCH.

24. The method of any one of claims 13-23, further comprising transmitting a second SCI comprising one or more fields indicating a second PSSCH, wherein a second CSI-RS of the one or more second CSI-RSs is within the second PSSCH.

25. A wireless device comprising:

one or more processors; and

memory storing instructions that, when executed by the one or more processors, cause the wireless device to perform the method of any one of claims 1-24.

26. A non-transitory computer-readable medium comprising instructions that, when executed by one or more processors of a wireless device, cause the wireless device to perform the method of any one of claims 1-24.

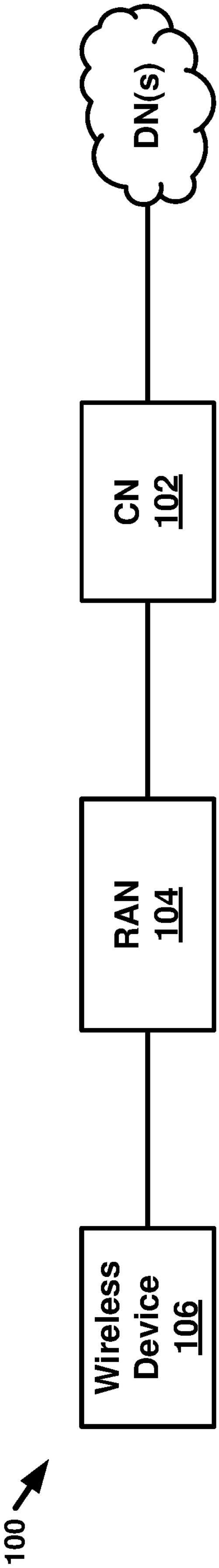
100
Wireless Device 106
RAN 104
CN 102
DN(s)

FIG. 1A

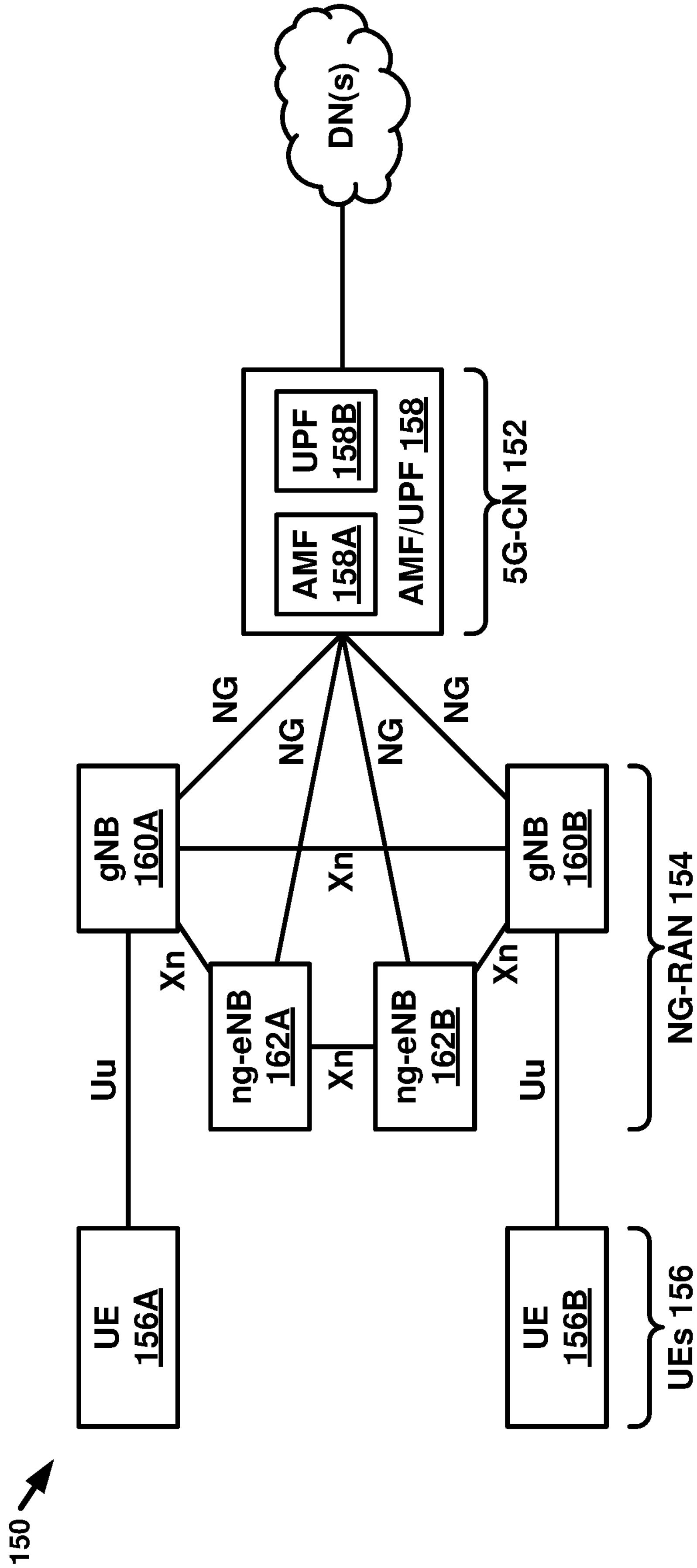
150
UE 156A
UE 156B
UEs 156
Uu
Uu
gNB 160A
gNB 160B
ng-eNB 162A
ng-eNB 162B
Xn
Xn
Xn
Xn
NG-RAN 154
NG
NG
NG
NG
AMF 158A
UPF 158B
AMF/UPF 158
5G-CN 152
DN(s)

FIG. 1B

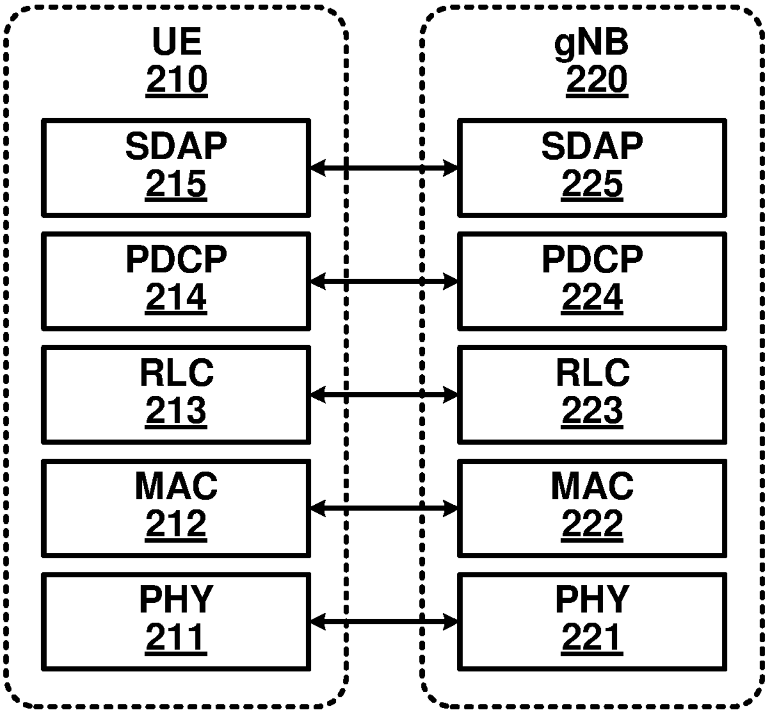
UE
210
SDAP
215
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
SDAP
225
PDCP
224
RLC
223
MAC
222
PHY
221

FIG. 2A

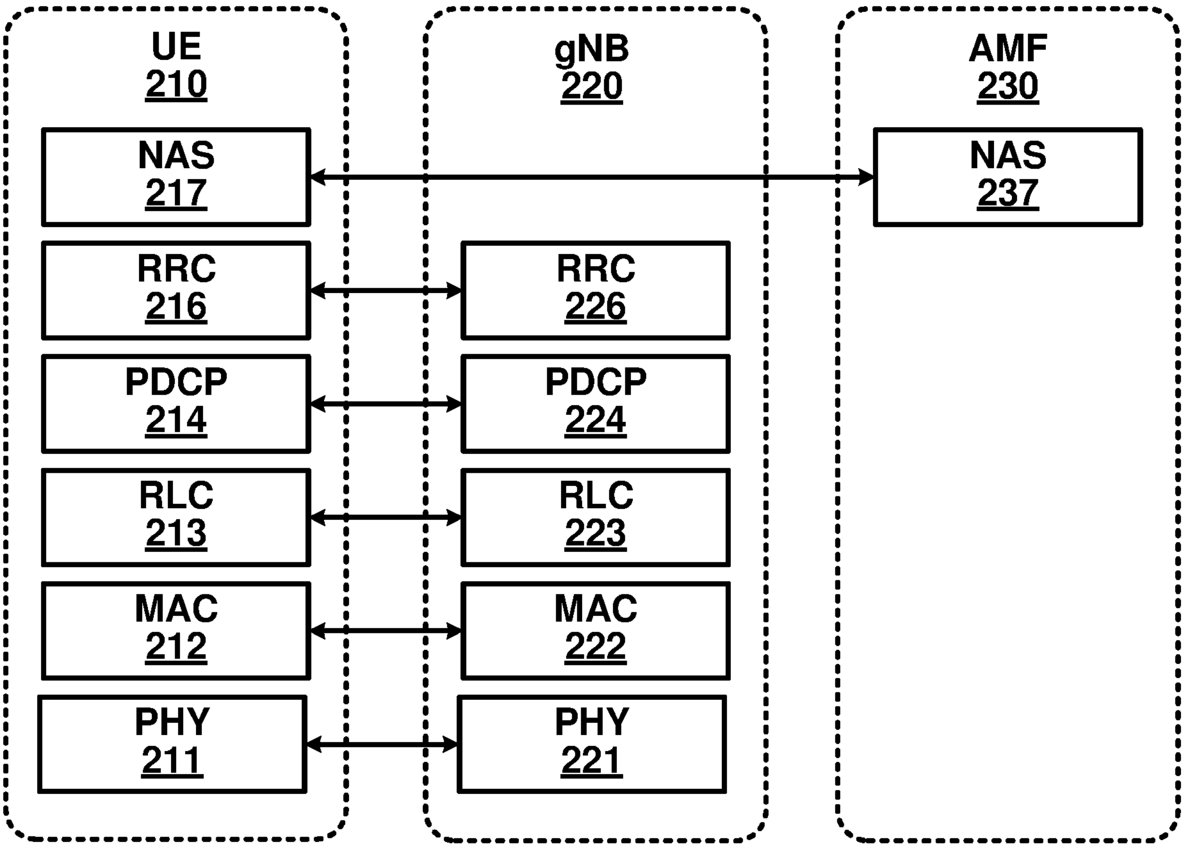
UE
210
NAS
217
RRC
216
PDCP
214
RLC
213
MAC
212
PHY
211
gNB
220
RRC
226
PDCP
224
RLC
223
MAC
222
PHY
221
AMF
230
NAS
237

FIG. 2B

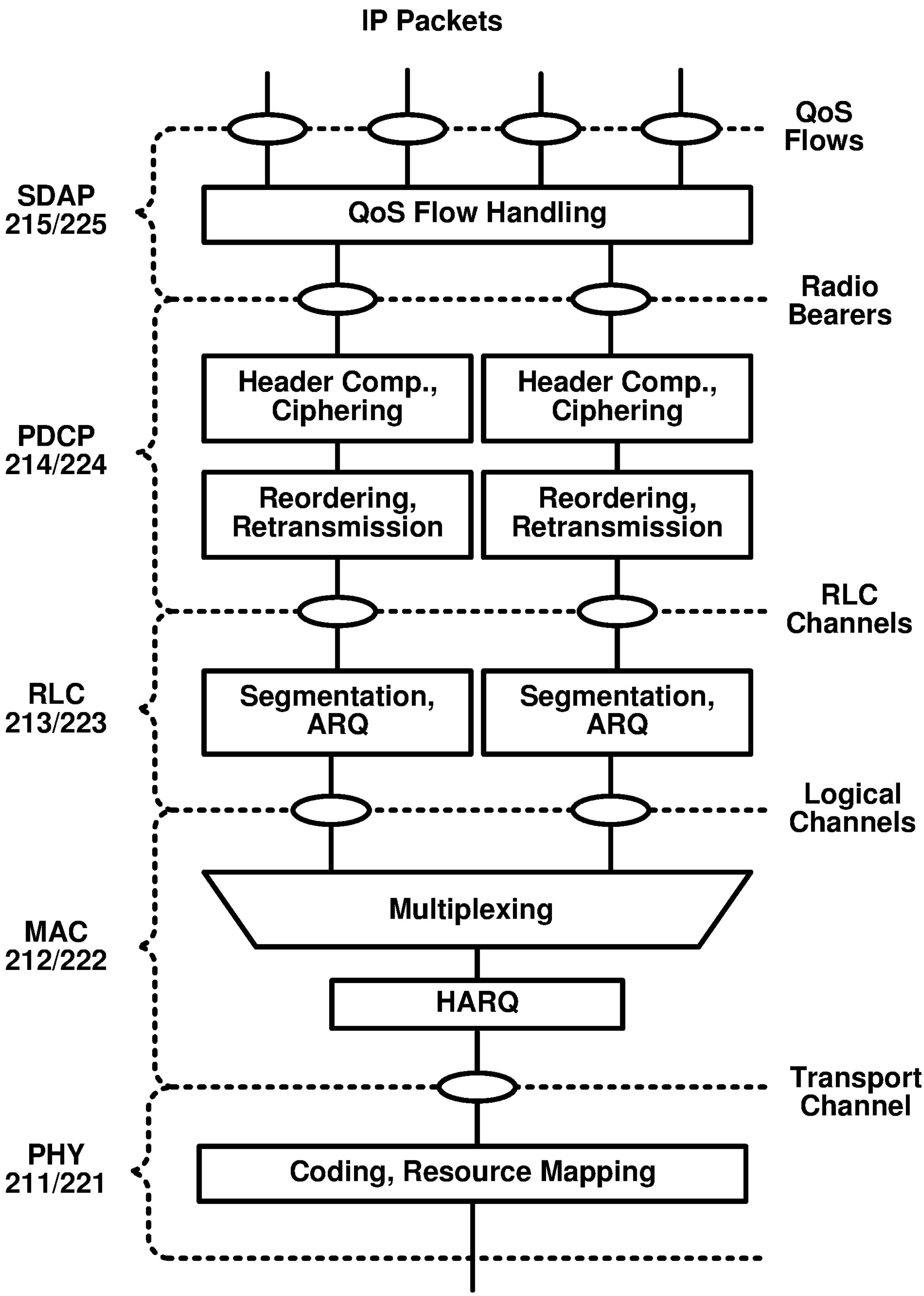
IP Packets
QoS Flows
SDAP 215/225
QoS Flow Handling
Radio Bearers
Header Comp., Ciphering
Header Comp., Ciphering
PDCP 214/224
Reordering, Retransmission
Reordering, Retransmission
RLC Channels
RLC 213/223
Segmentation, ARQ
Segmentation, ARQ
Logical Channels
Multiplexing
MAC 212/222
HARQ
Transport Channel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

FIG. 3

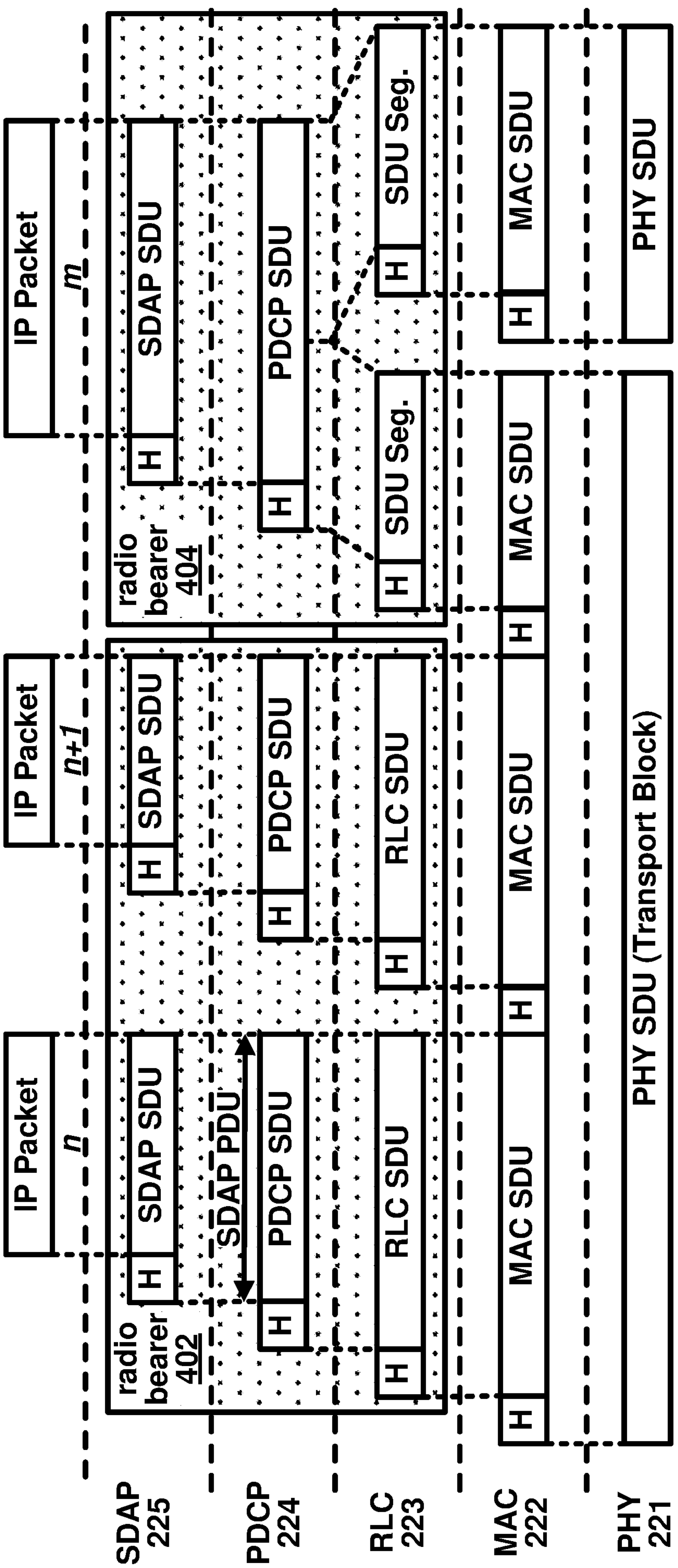
SDAP 225
PDCP 224
RLC 223
MAC 222
PHY 221
IP Packet n
IP Packet n+1
IP Packet m
radio bearer 402
radio bearer 404
H
SDAP SDU
SDAP PDU
PDCP SDU
RLC SDU
SDU Seg.
MAC SDU
PHY SDU (Transport Block)
PHY SDU

FIG. 4A

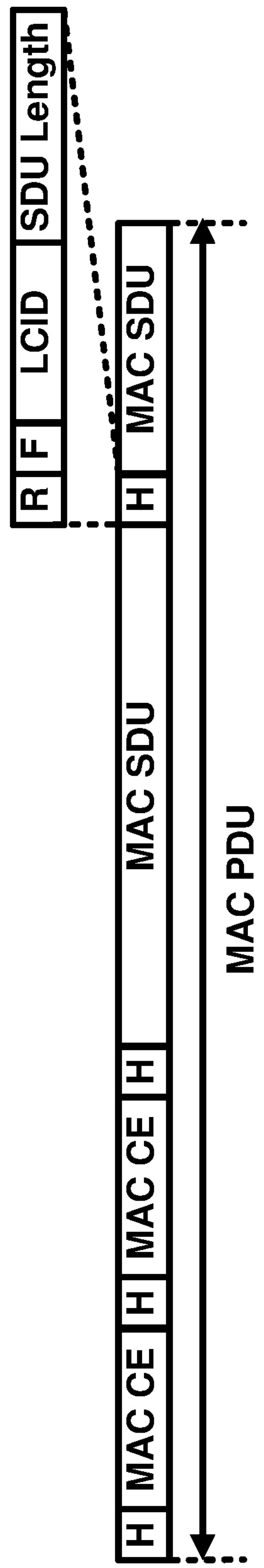
R
F
LCID
SDU Length
H
MAC CE
MAC SDU
MAC PDU

FIG. 4B

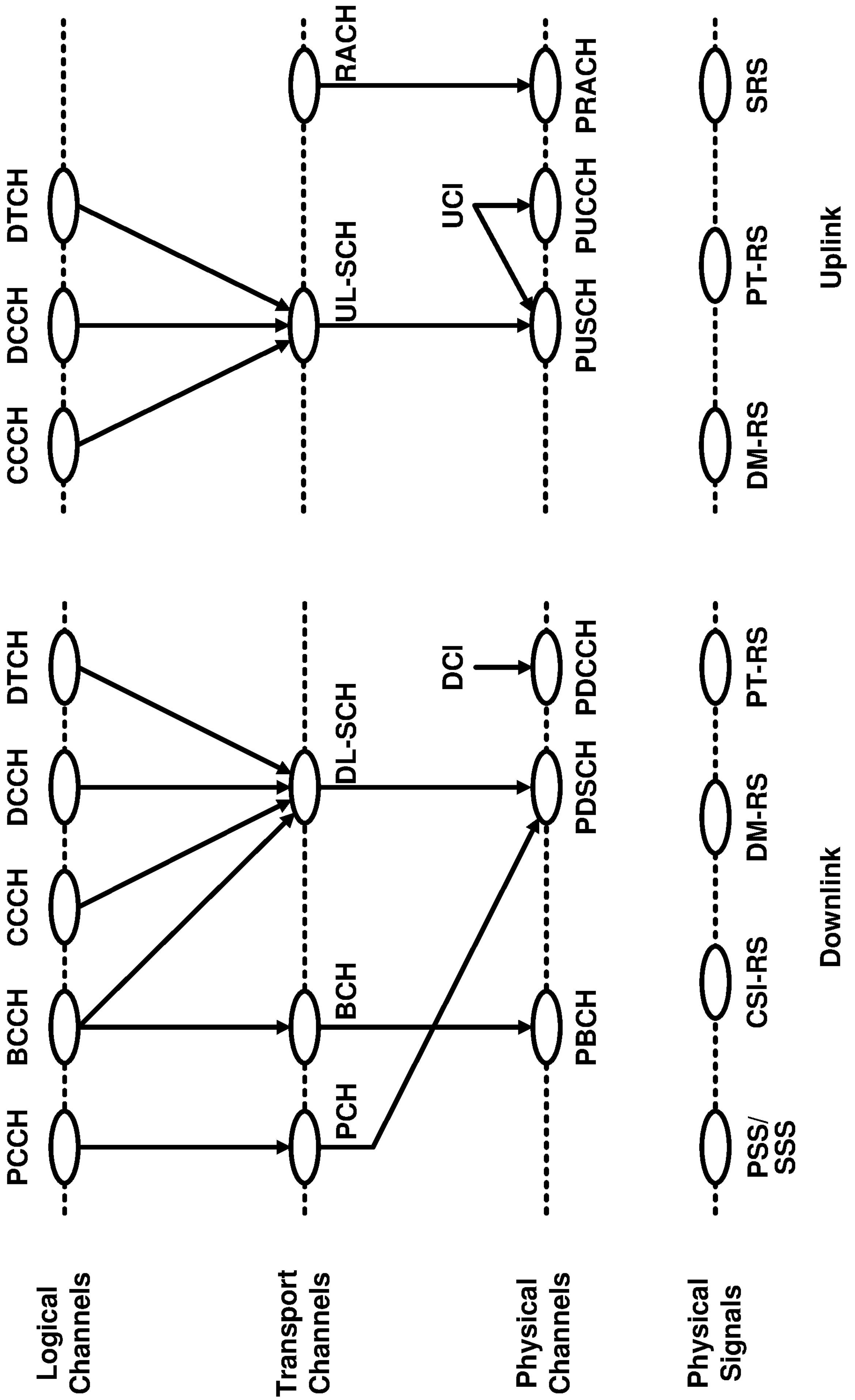
Logical Channels
Transport Channels
Physical Channels
Physical Signals
PCCH
BCCH
CCCH
DCCH
DTCH
PCH
BCH
DL-SCH
PBCH
PDSCH
PDCCH
DCI
PSS/ SSS
CSI-RS
DM-RS
PT-RS
Downlink
CCCH
DCCH
DTCH
UL-SCH
RACH
PUSCH
PUCCH
PRACH
UCI
DM-RS
PT-RS
SRS
Uplink

FIG. 5A

FIG. 5B

6/37

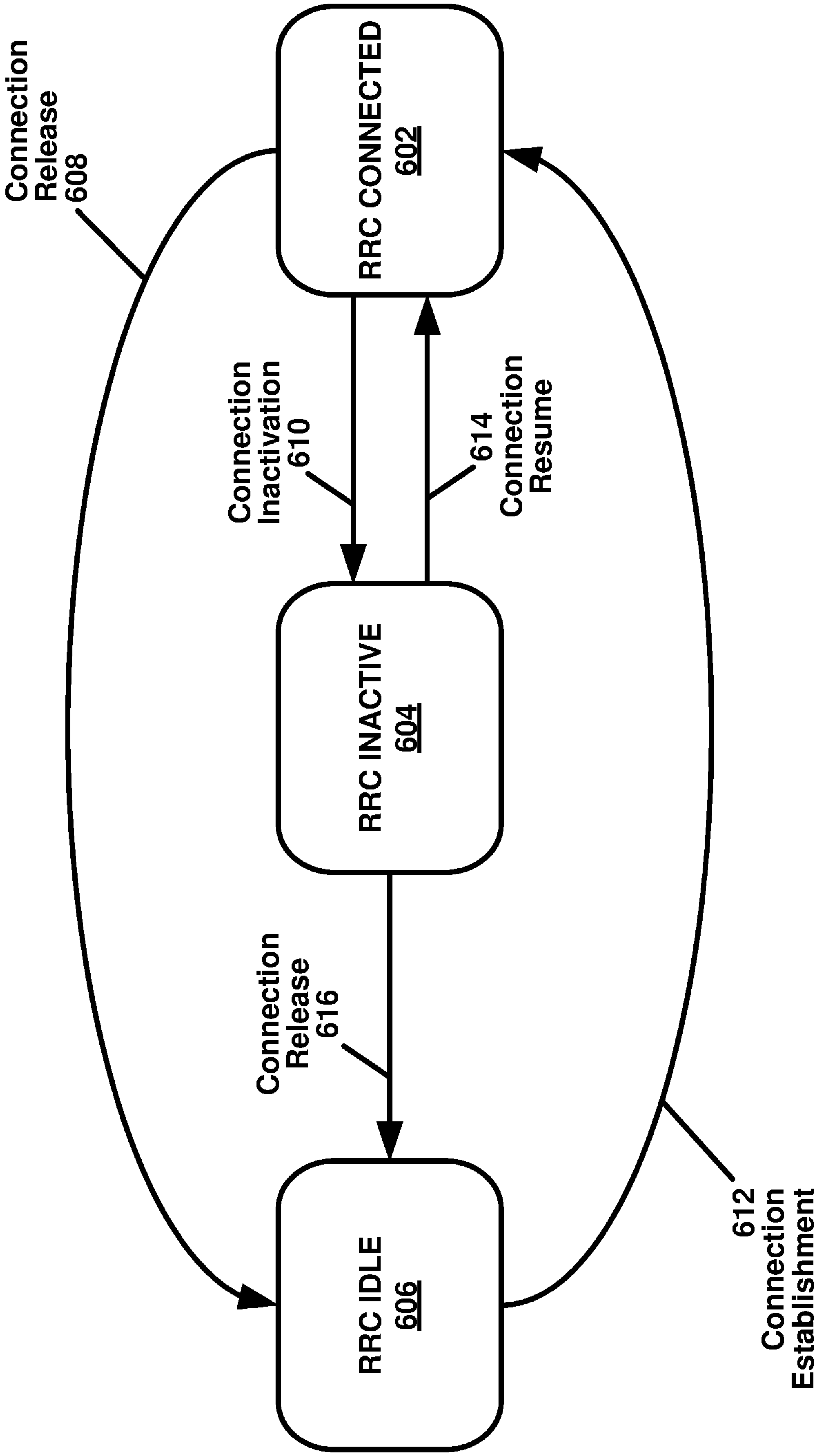
RRC CONNECTED
602
RRC INACTIVE
604
RRC IDLE
606
Connection Release 608
Connection Inactivation 610
612 Connection Establishment
614 Connection Resume
Connection Release 616

FIG. 6

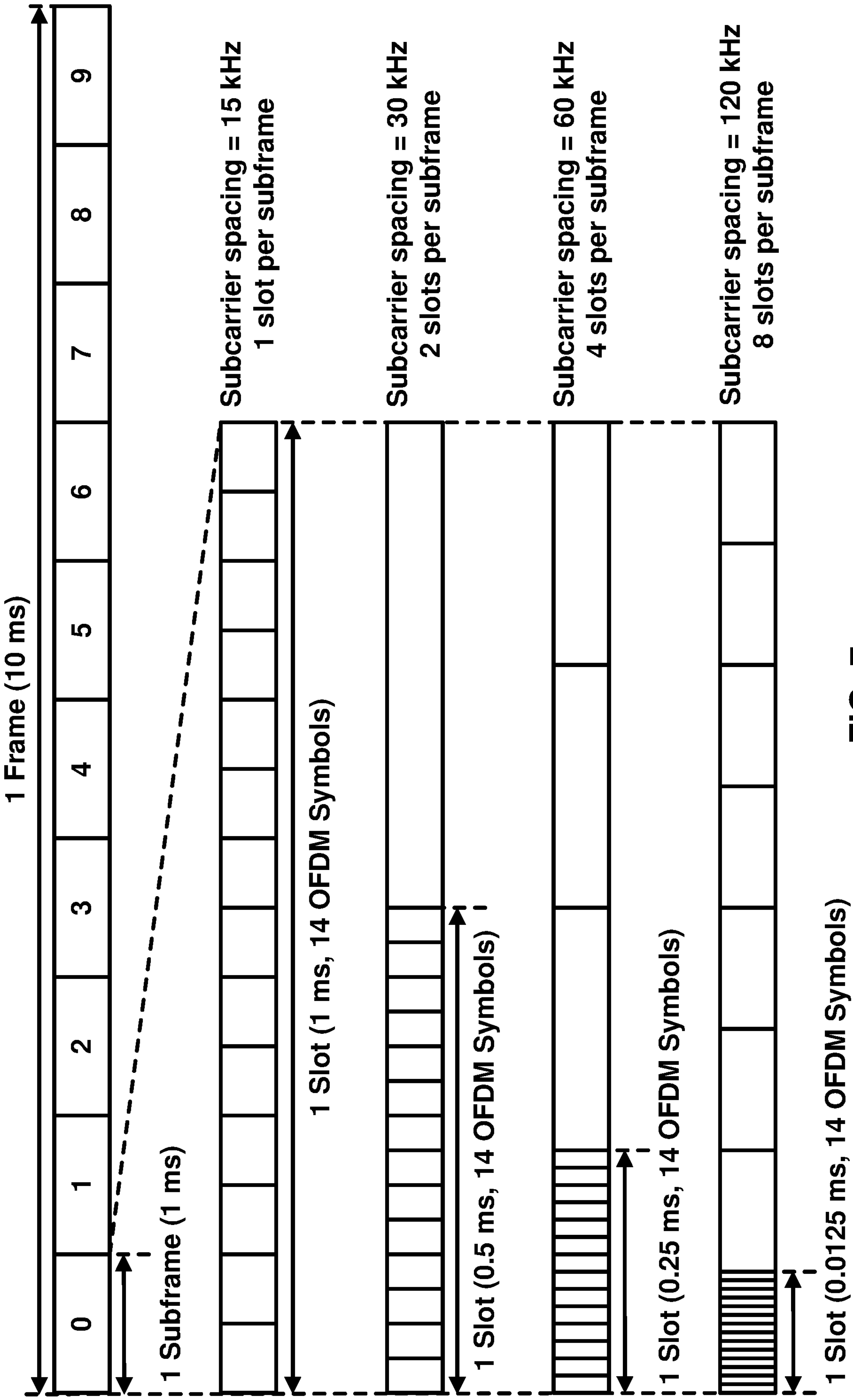
1 Frame (10 ms)
0
1
2
3
4
5
6
7
8
9
1 Subframe (1 ms)
Subcarrier spacing = 15 kHz
1 slot per subframe
1 Slot (1 ms, 14 OFDM Symbols)
Subcarrier spacing = 30 kHz
2 slots per subframe
1 Slot (0.5 ms, 14 OFDM Symbols)
Subcarrier spacing = 60 kHz
4 slots per subframe
1 Slot (0.25 ms, 14 OFDM Symbols)
Subcarrier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

FIG. 7

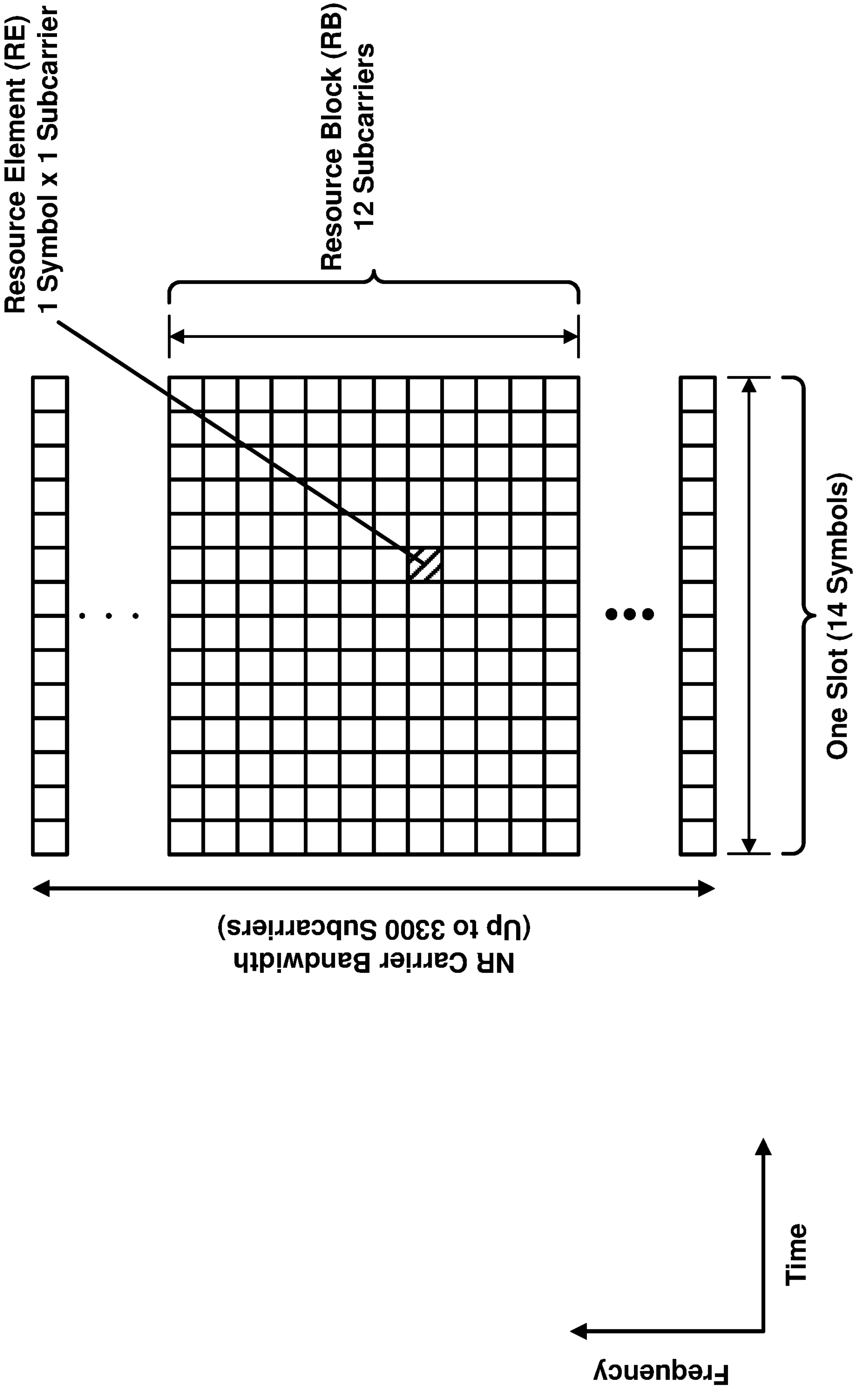
Resource Element (RE)
1 Symbol x 1 Subcarrier
Resource Block (RB)
12 Subcarriers
One Slot (14 Symbols)
NR Carrier Bandwidth
(Up to 3300 Subcarriers)
Time
Frequency

FIG. 8

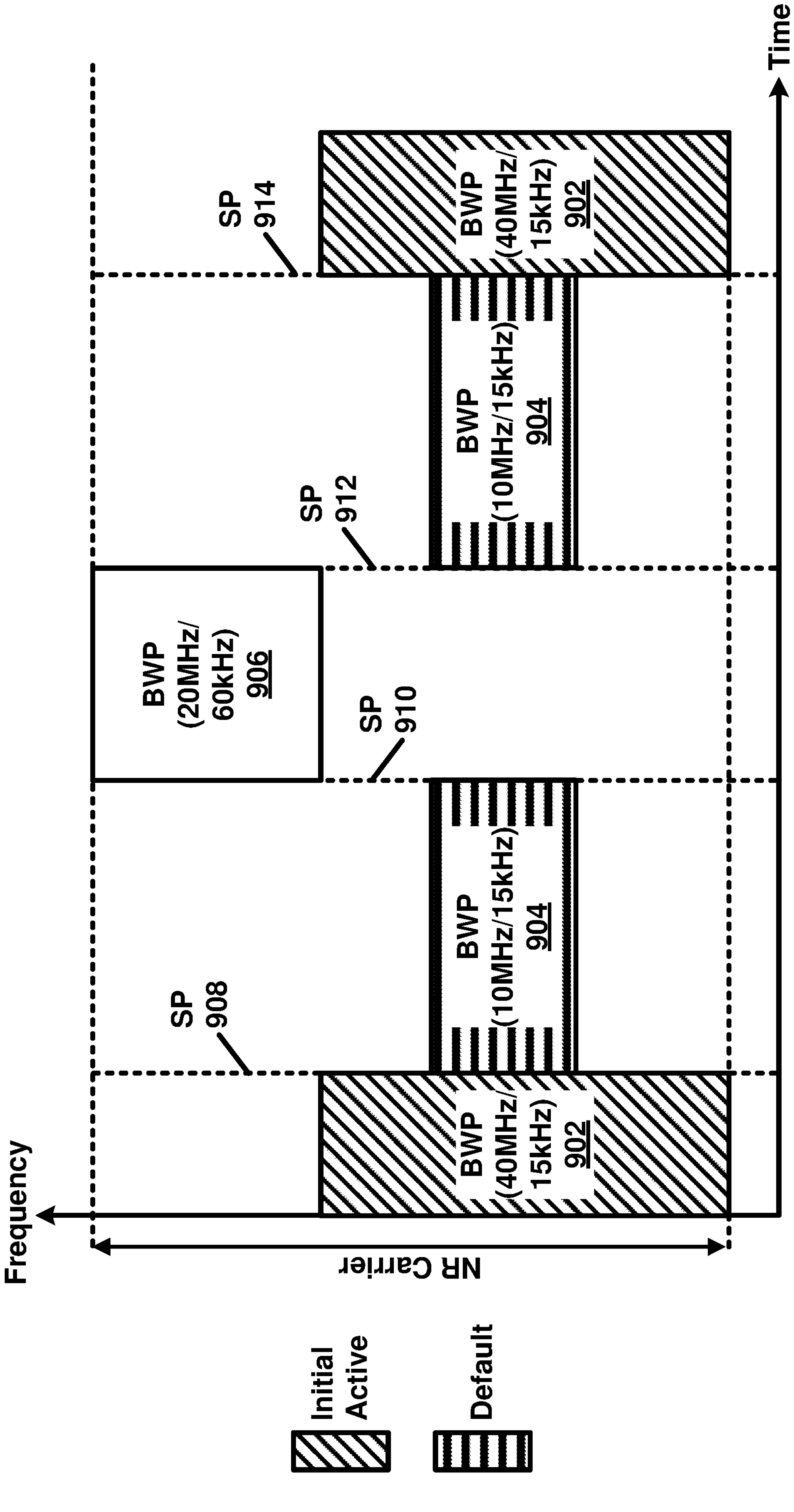
Time
Frequency
NR Carrier
SP 908
SP 910
SP 912
SP 914
BWP (40MHz/ 15kHz) 902
BWP (10MHz/15kHz) 904
BWP (20MHz/ 60kHz) 906
BWP (10MHz/15kHz) 904
BWP (40MHz/ 15kHz) 902
Initial Active
Default

FIG. 9

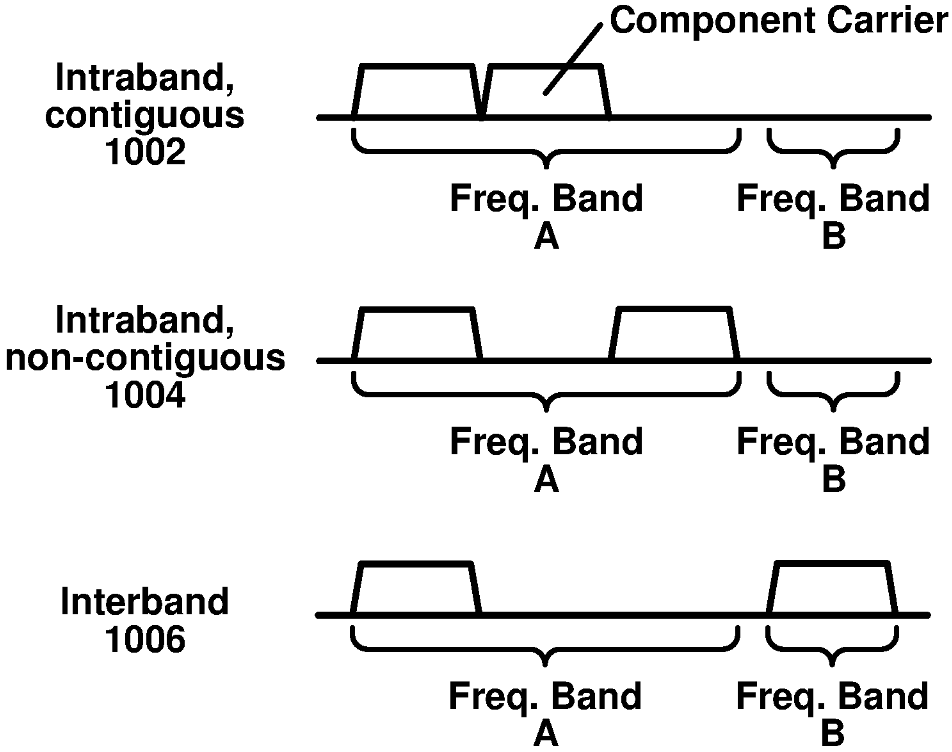

FIG. 10A

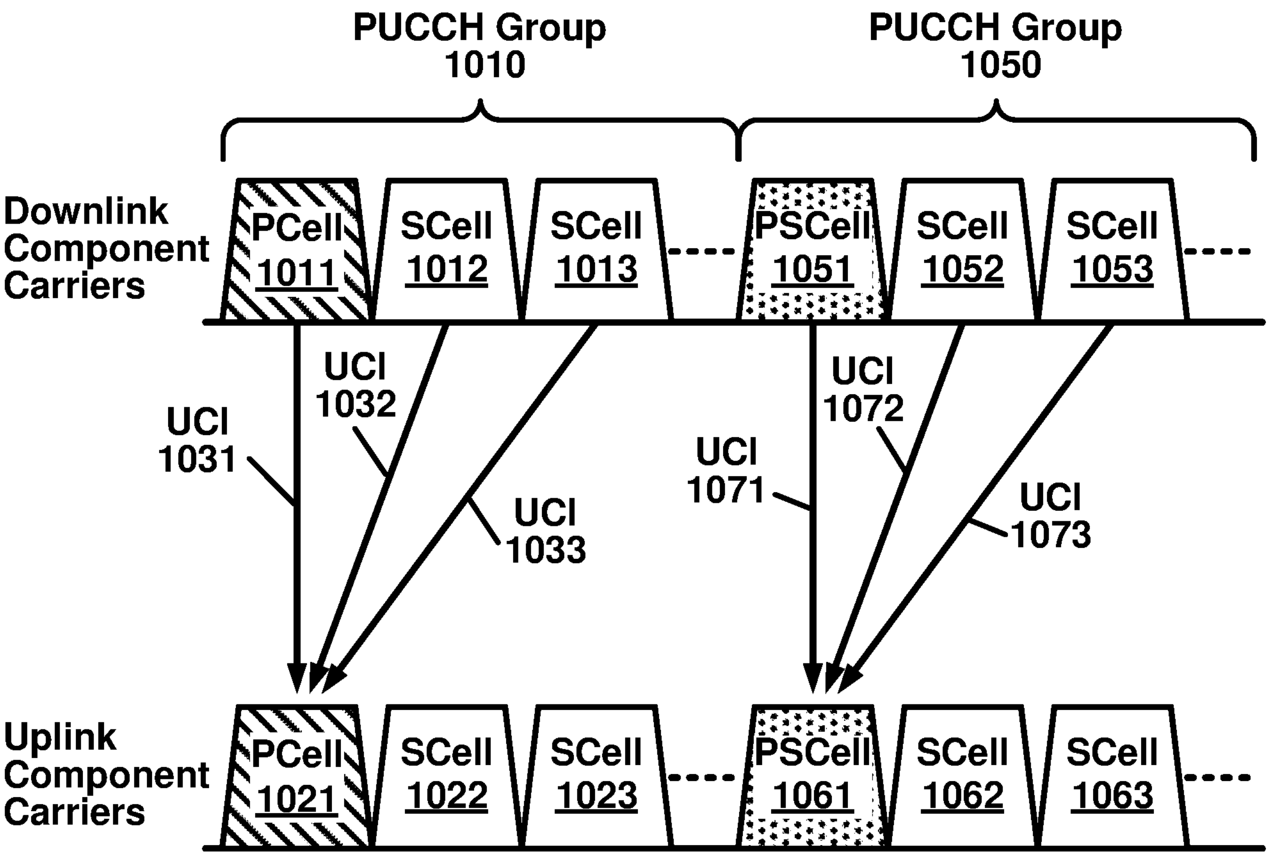

FIG. 10B

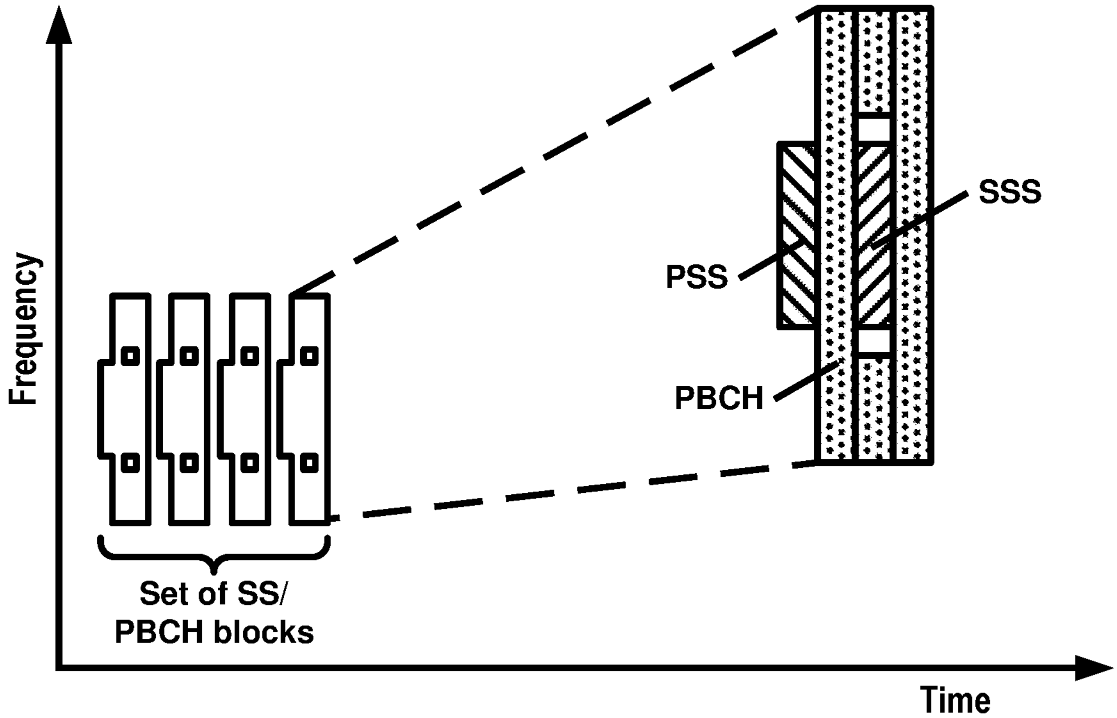

FIG. 11A

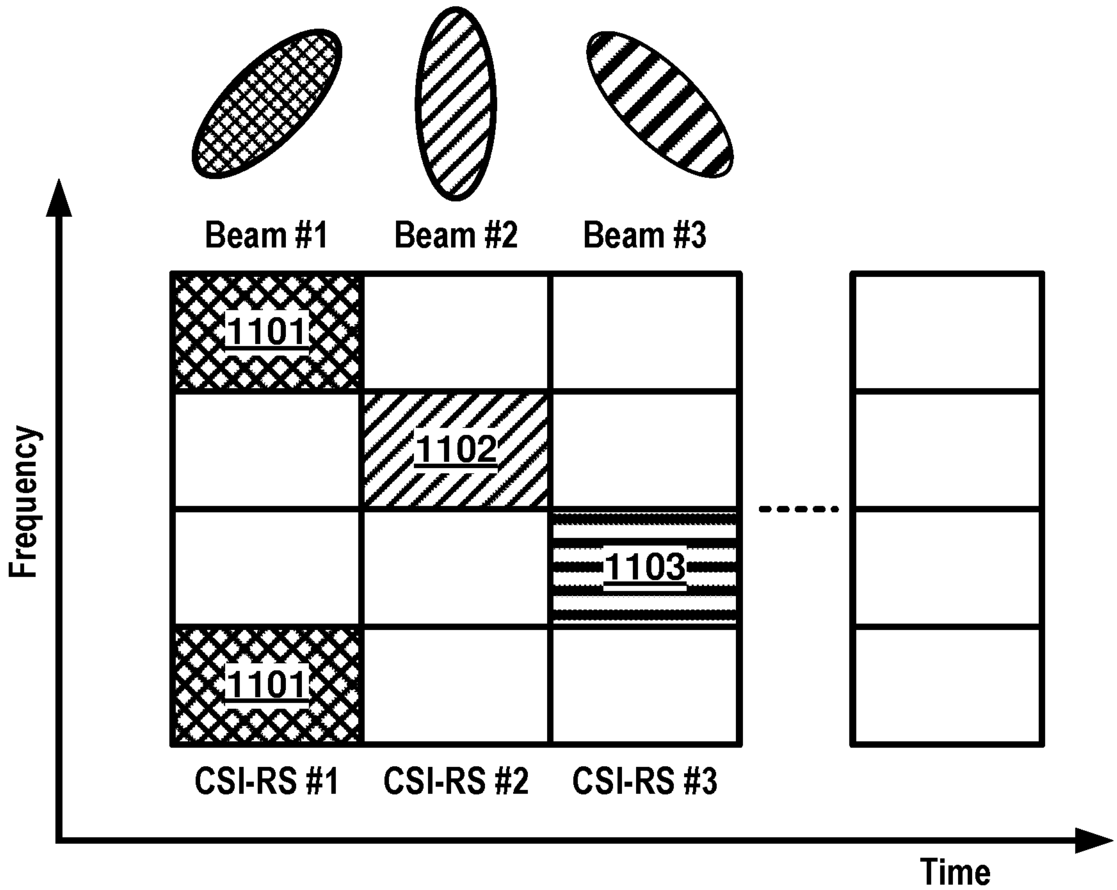

FIG. 11B

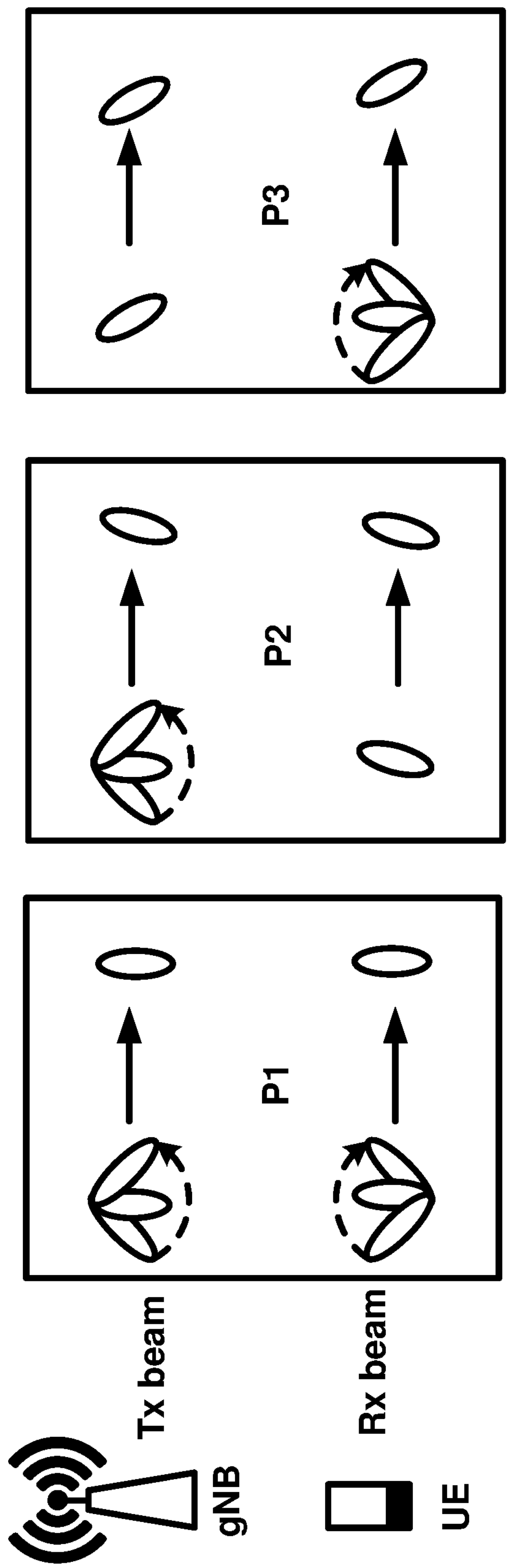

FIG. 12A

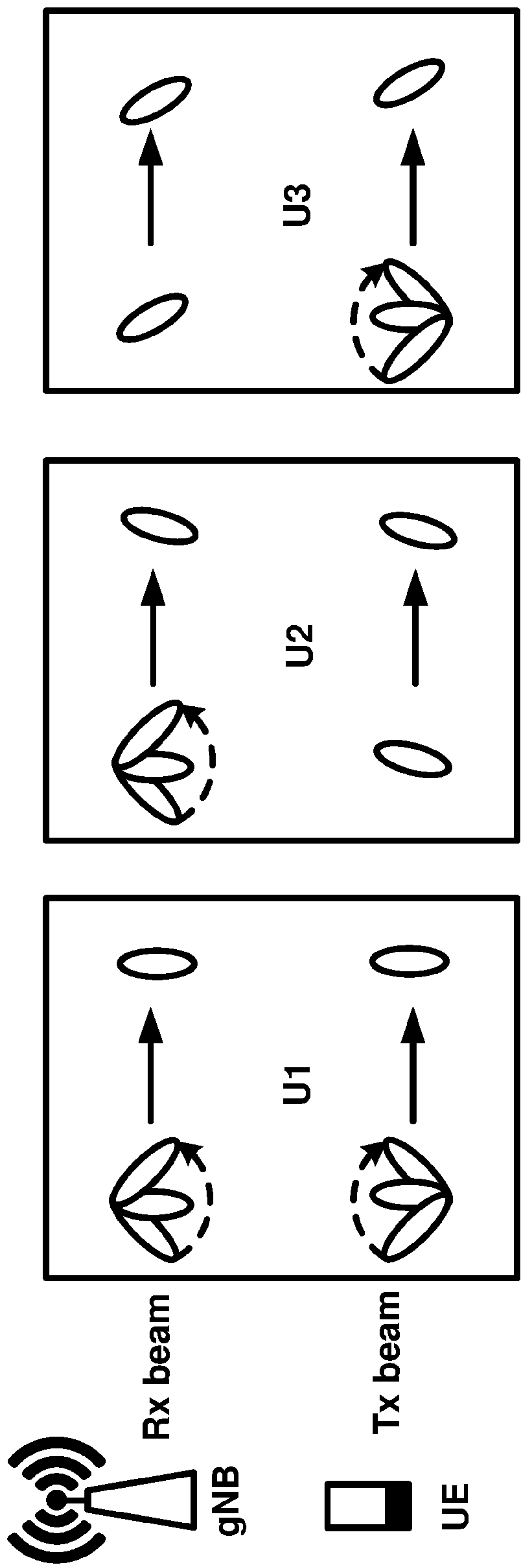

FIG. 12B

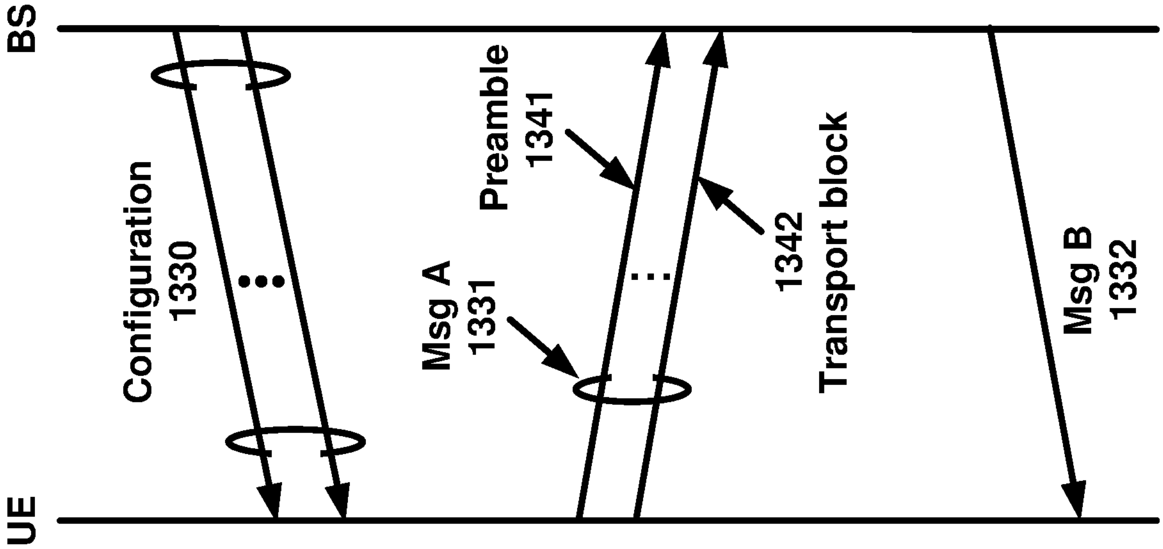

FIG. 13C

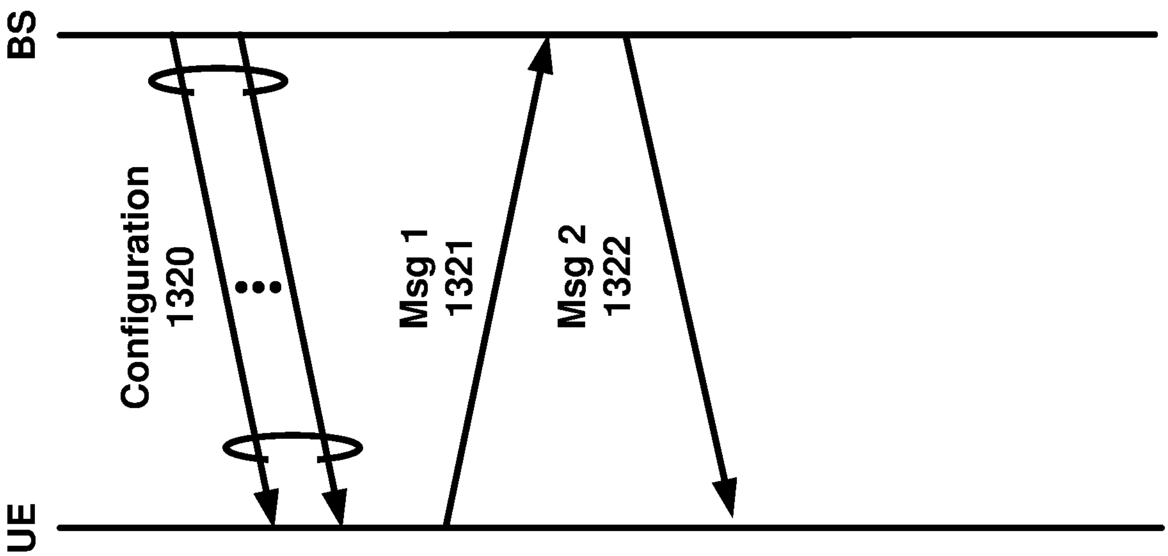

FIG. 13B

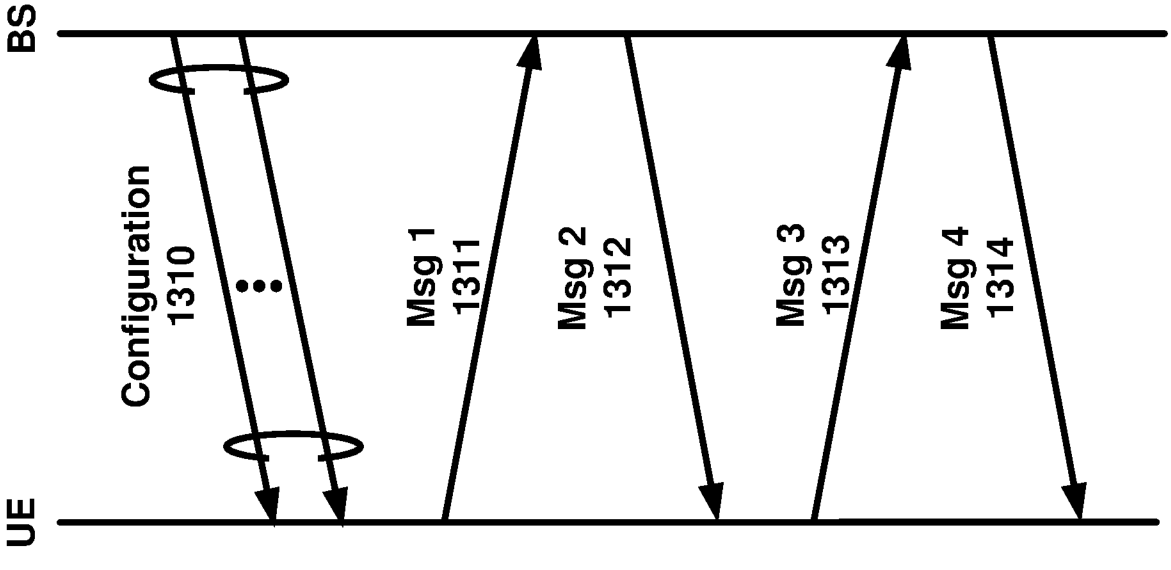

FIG. 13A

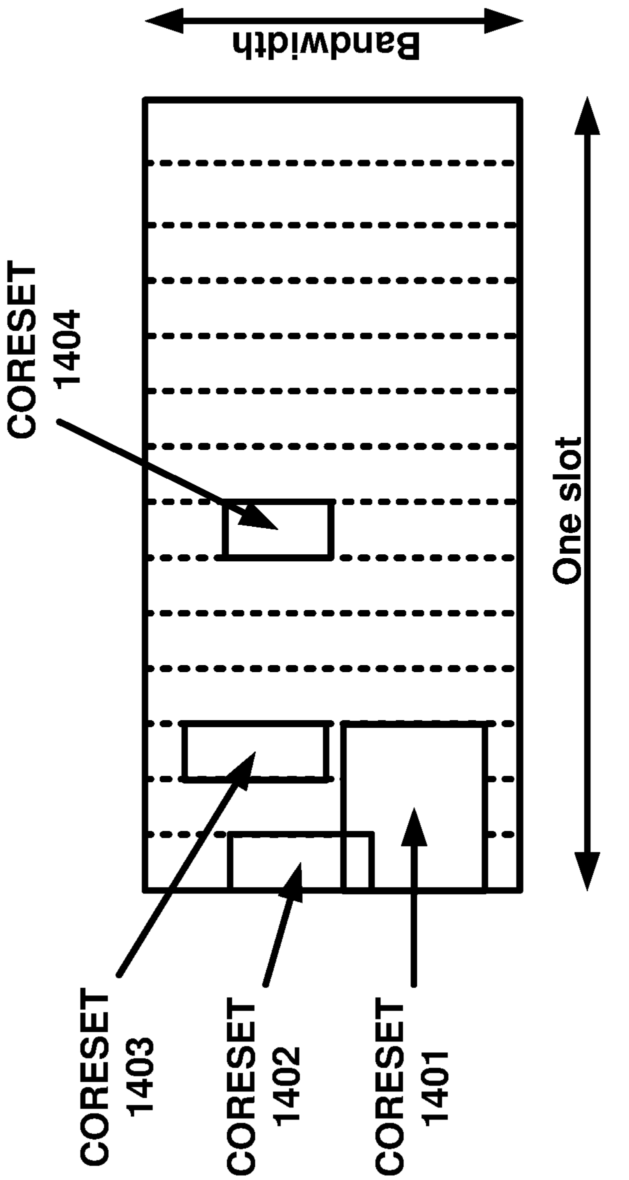

FIG. 14A

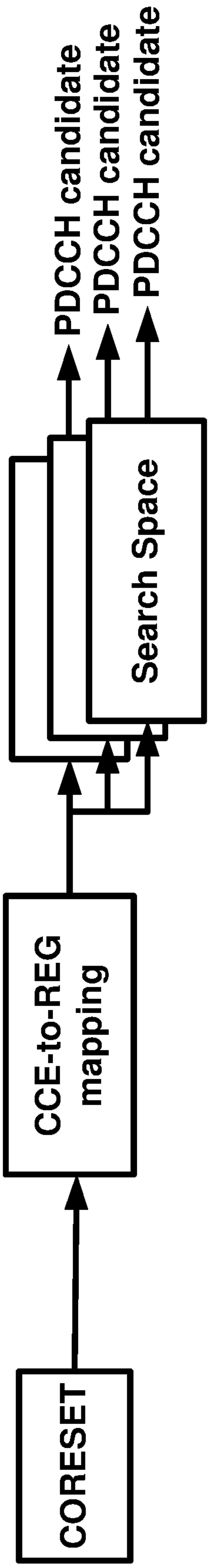

FIG. 14B

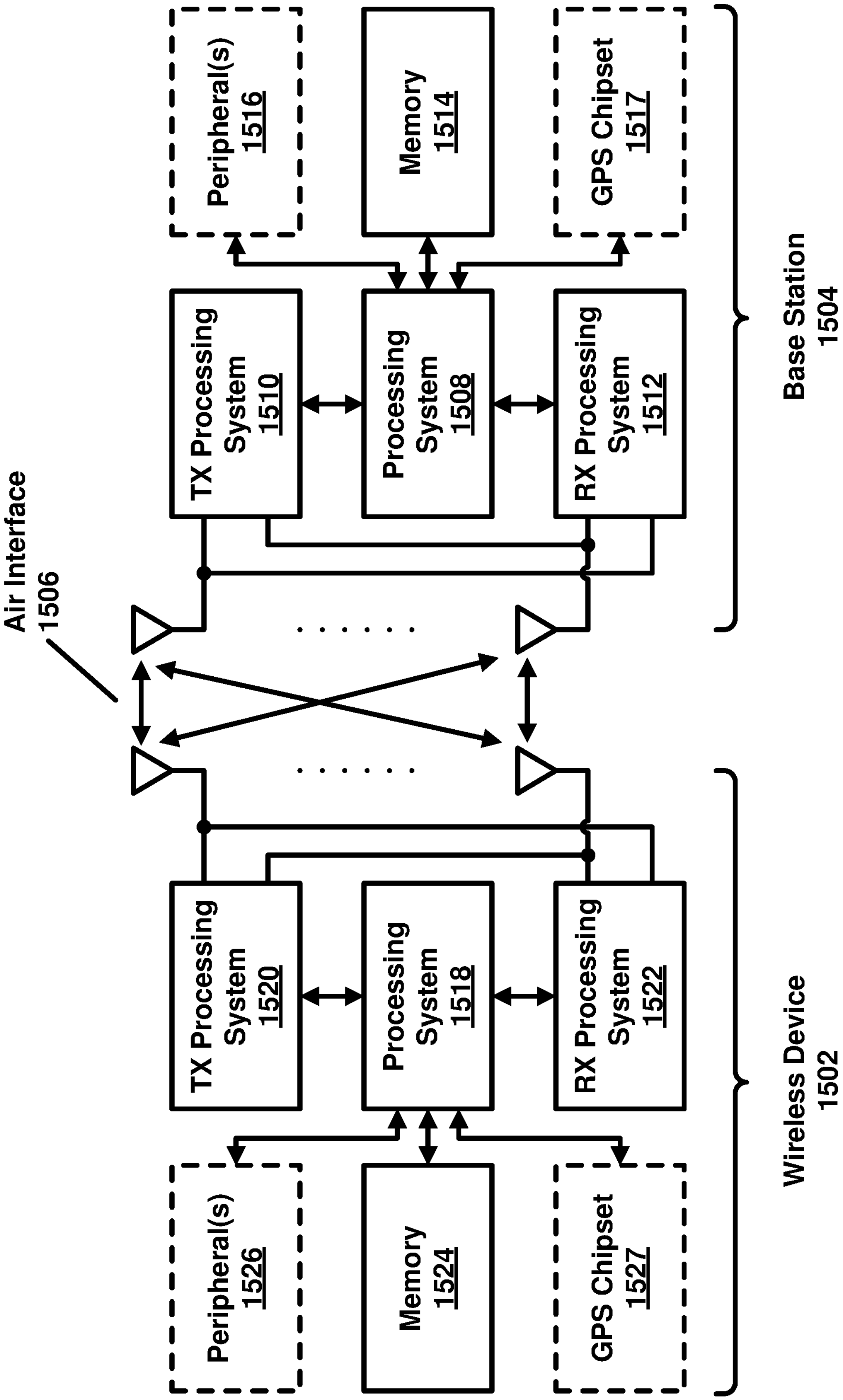
Air Interface
1506
Base Station
1504
Peripheral(s)
1516
Memory
1514
GPS Chipset
1517
TX Processing
System
1510
Processing
System
1508
RX Processing
System
1512
Wireless Device
1502
TX Processing
System
1520
Processing
System
1518
RX Processing
System
1522
Peripheral(s)
1526
Memory
1524
GPS Chipset
1527

FIG. 15

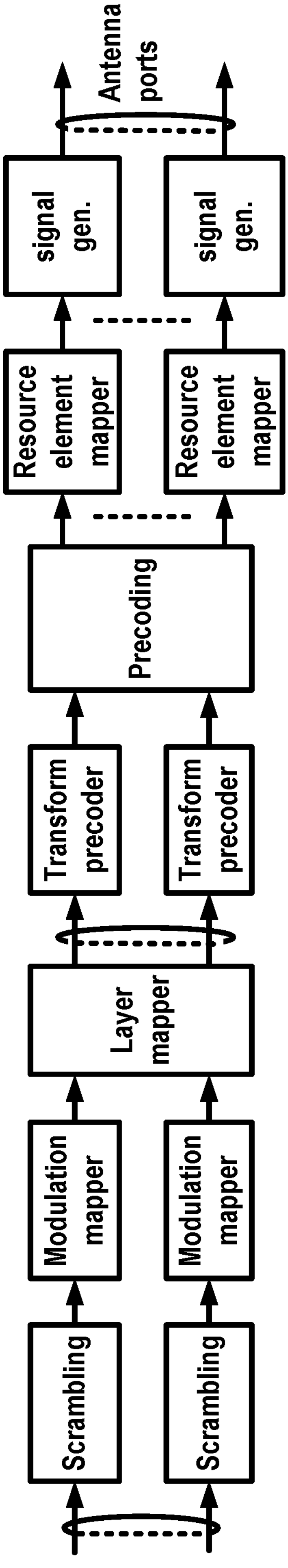

FIG. 16A

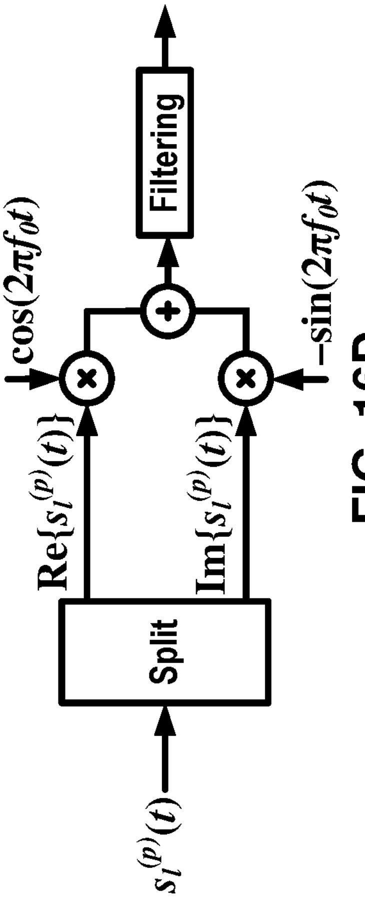

FIG. 16D

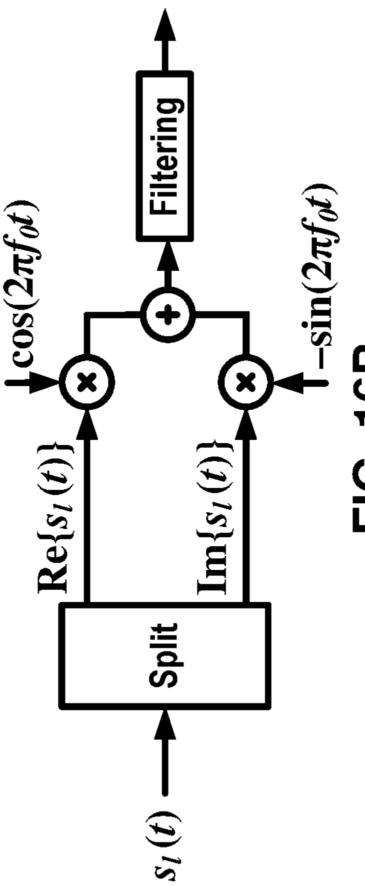

FIG. 16B

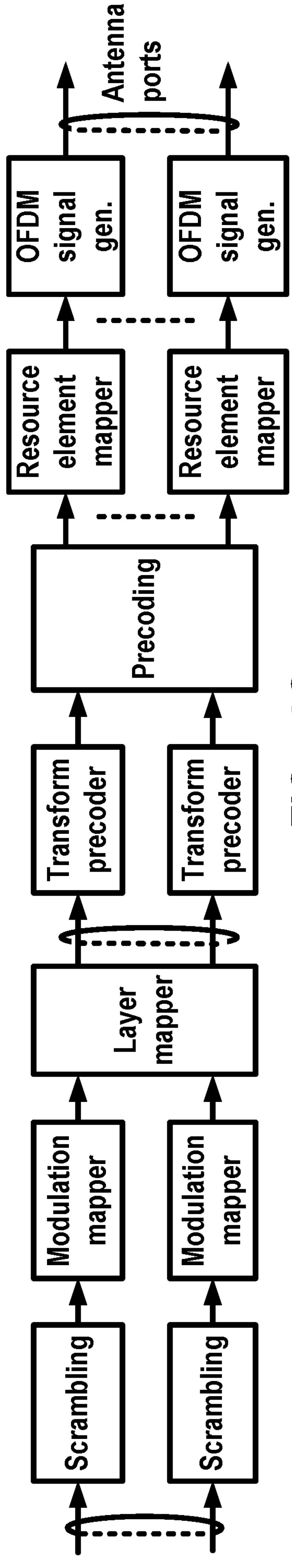

FIG. 16C

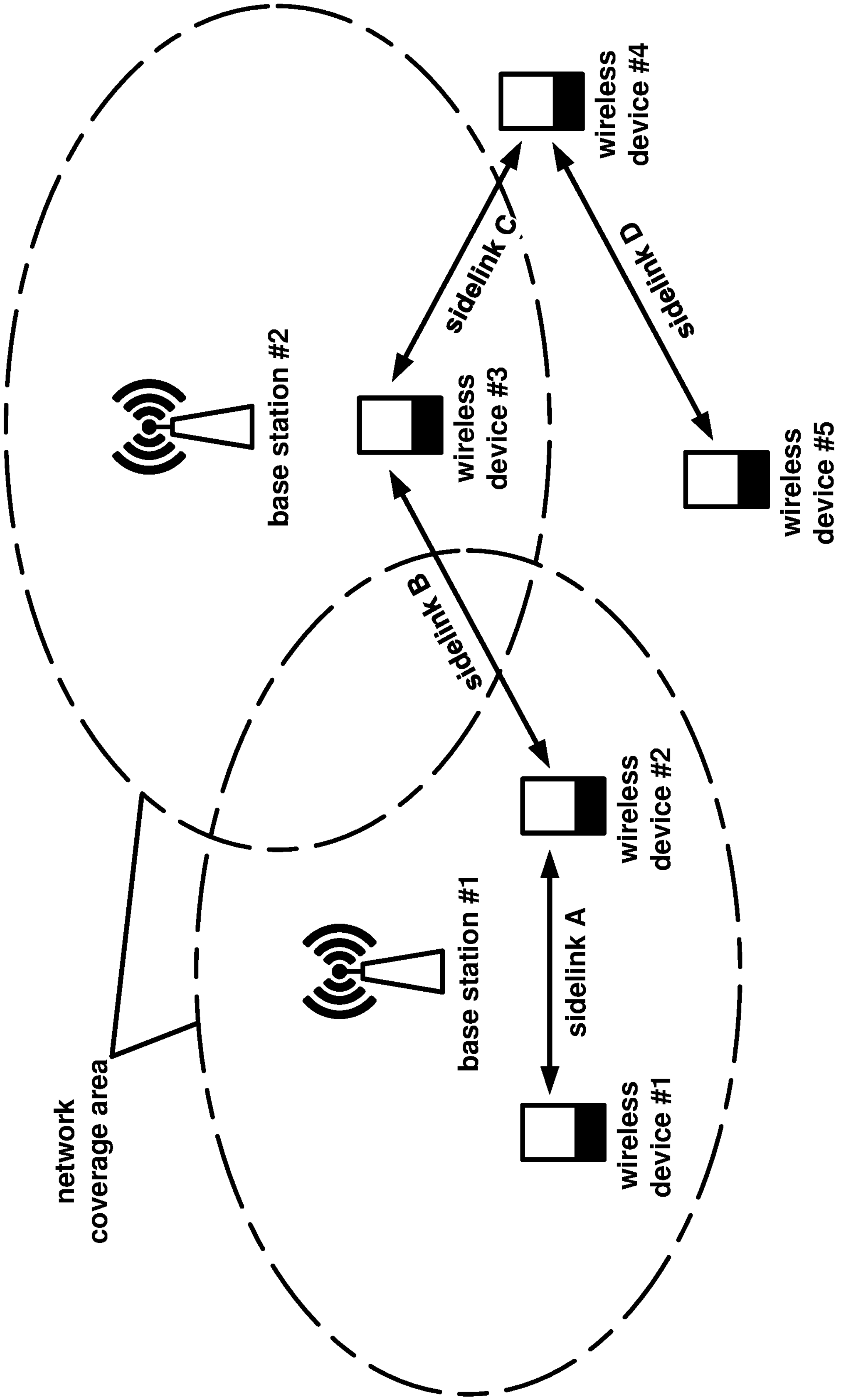
base station #2
wireless device #3
wireless device #4
sidelink C
sidelink D
wireless device #5
sidelink B
wireless device #2
base station #1
sidelink A
wireless device #1
network coverage area

FIG. 17

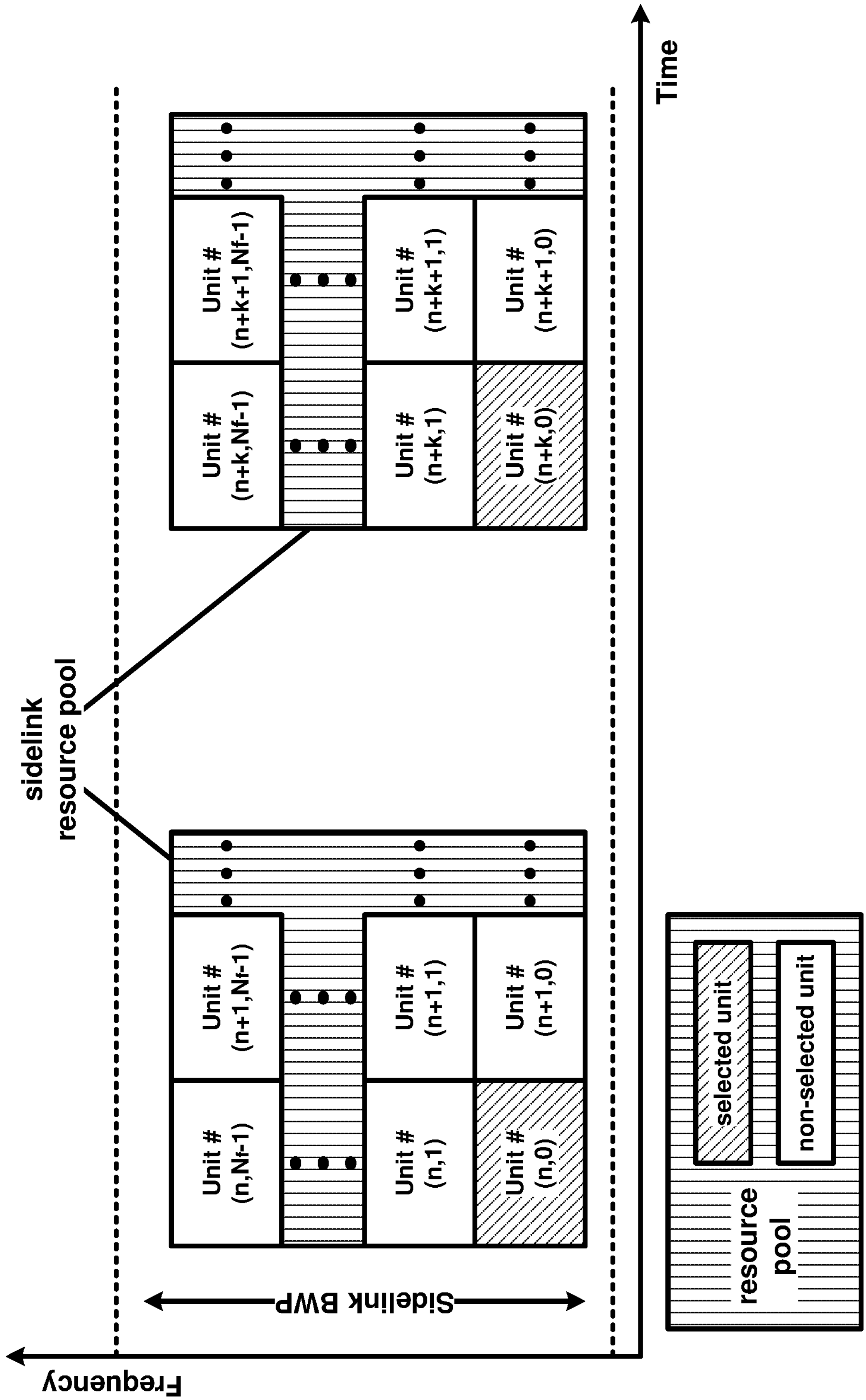
Time
Frequency
Sidelink BWP
sidelink
resource pool
Unit #
(n,Nf-1)
Unit #
(n,1)
Unit #
(n,0)
Unit #
(n+1,Nf-1)
Unit #
(n+1,1)
Unit #
(n+1,0)
Unit #
(n+k,Nf-1)
Unit #
(n+k,1)
Unit #
(n+k,0)
Unit #
(n+k+1,Nf-1)
Unit #
(n+k+1,1)
Unit #
(n+k+1,0)
resource
pool
selected unit
non-selected unit

FIG. 18

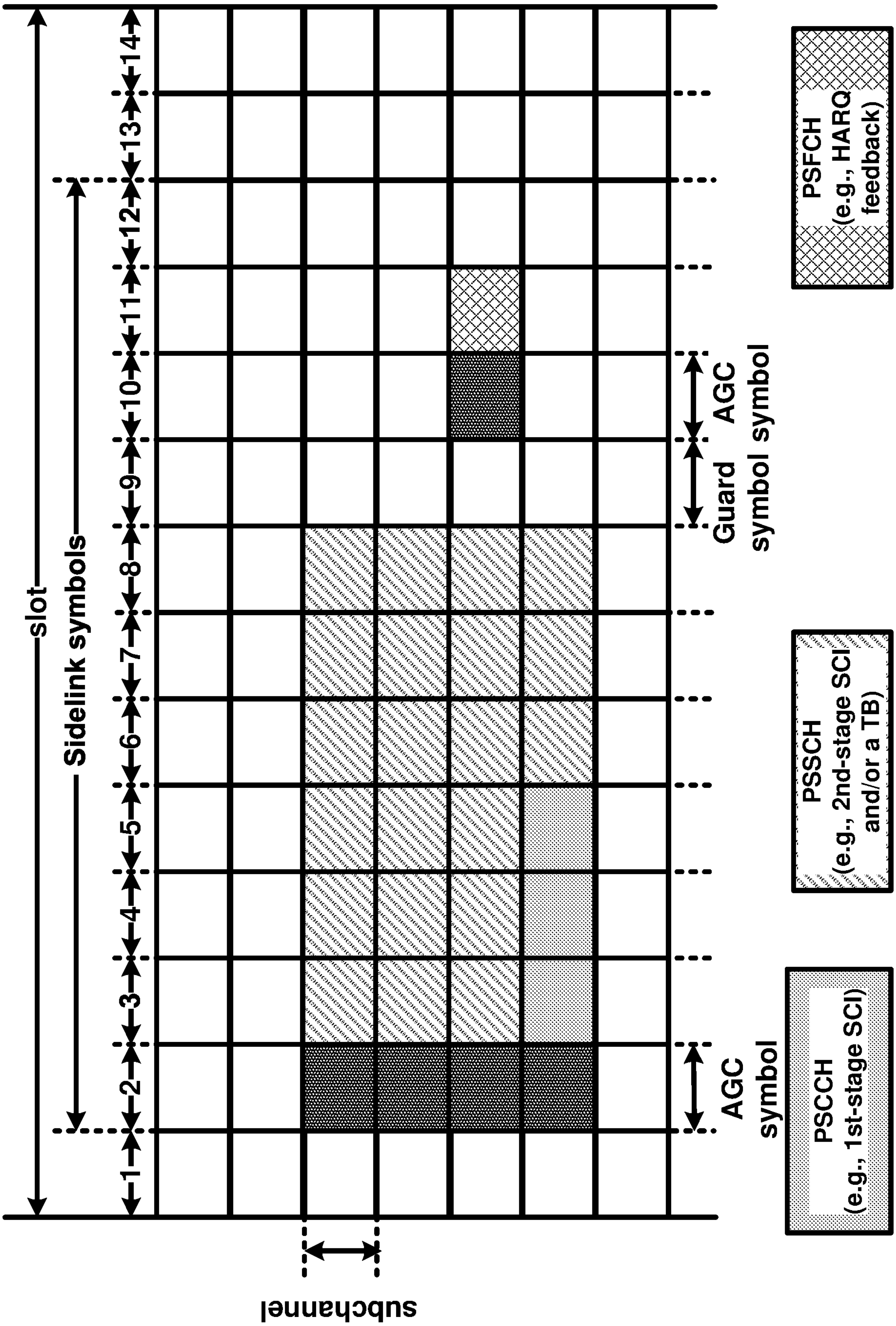
slot
Sidelink symbols
1
2
3
4
5
6
7
8
9
10
11
12
13
14
subchannel
AGC symbol
Guard symbol
AGC symbol
PSCCH (e.g., 1st-stage SCI)
PSSCH (e.g., 2nd-stage SCI and/or a TB)
PSFCH (e.g., HARQ feedback)

FIG. 19

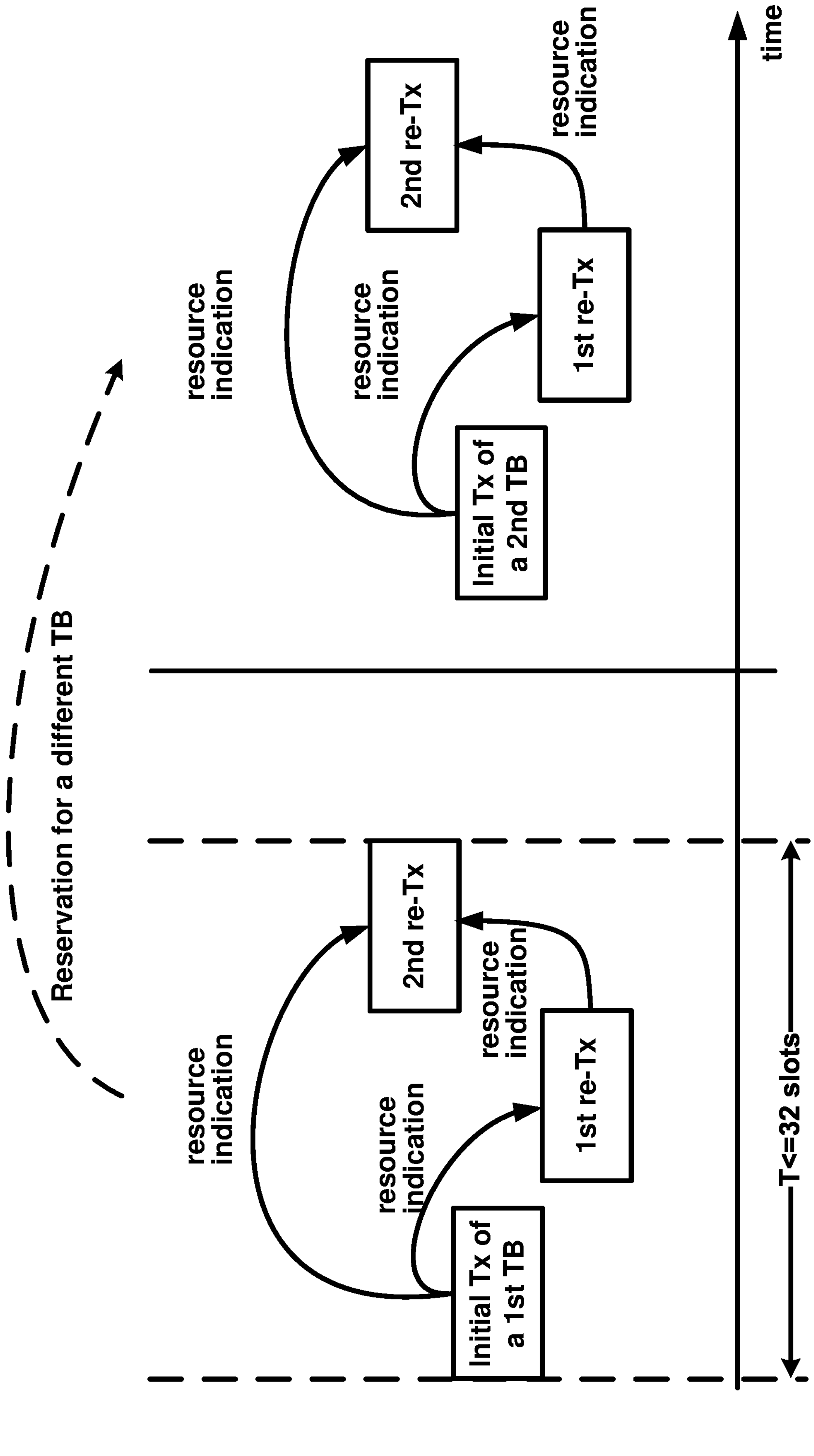
Reservation for a different TB
resource indication
resource indication
Initial Tx of a 1st TB
1st re-Tx
resource indication
2nd re-Tx
T<=32 slots
resource indication
resource indication
Initial Tx of a 2nd TB
1st re-Tx
resource indication
2nd re-Tx
time

FIG. 20

```
SL-ResourcePool::=              SEQUENCE {
...
    sl-UE-SelectedConfigRP              SL-UE-SelectedConfigRP
...
    sl-PreemptionEnable                 ENUMERATED {enabled, pl1, pl2, pl3, pl4,
pl5, pl6, pl7, pl8}
...
    sl-TxPercentageList                 SL-TxPercentageList
...
}

sl-UE-SelectedConfigRP ::=          SEQUENCE {
...
    sl-ThresPSSCH-RSRP-List             SL-ThresPSSCH-RSRP-List
    sl-MultiReserveResource             ENUMERATED {enabled}
    sl-MaxNumPerReserve                 ENUMERATED {n2, n3}
    sl-SensingWindow                    ENUMERATED {ms100, ms1100}
    sl-SelectionWindowList              SL-SelectionWindowList
    sl-ResourceReservePeriodList     SEQUENCE (SIZE (1..16)) OF SL-
ResourceReservePeriod
    sl-RS-ForSensing                    ENUMERATED {pscch, pssch},
    ...
}
```

FIG. 21

```
SL-ResourceReservePeriod ::=        CHOICE {
    sl-ResourceReservePeriod1           ENUMERATED {ms0, ms100, ms200,
ms300, ms400, ms500, ms600, ms700, ms800, ms900, ms1000},
    sl-ResourceReservePeriod2           INTEGER (1..99)
}

SL-SelectionWindowList ::=          SEQUENCE (SIZE (8)) OF SL-
SelectionWindowConfig

SL-SelectionWindowConfig ::=        SEQUENCE {
    sl-Priority                         INTEGER (1..8),
    sl-SelectionWindow                  ENUMERATED {n1, n5, n10, n20}
}

SL-TxPercentageList ::=             SEQUENCE (SIZE (8)) OF SL-
TxPercentageConfig

SL-TxPercentageConfig ::=           SEQUENCE {
    sl-Priority                         INTEGER (1..8),
    sl-TxPercentage                     ENUMERATED {p20, p35, p50}
}
```

FIG. 22

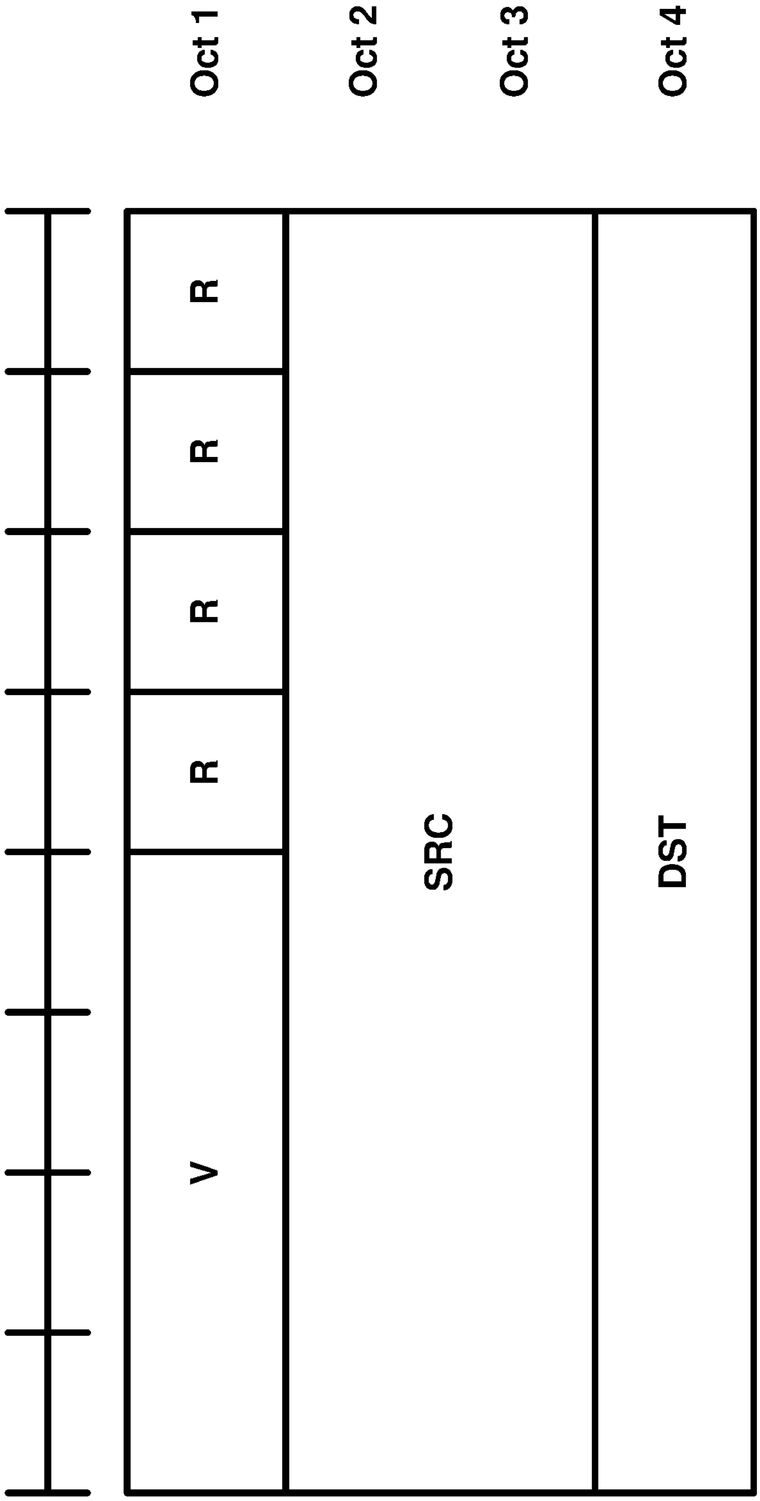

FIG. 23

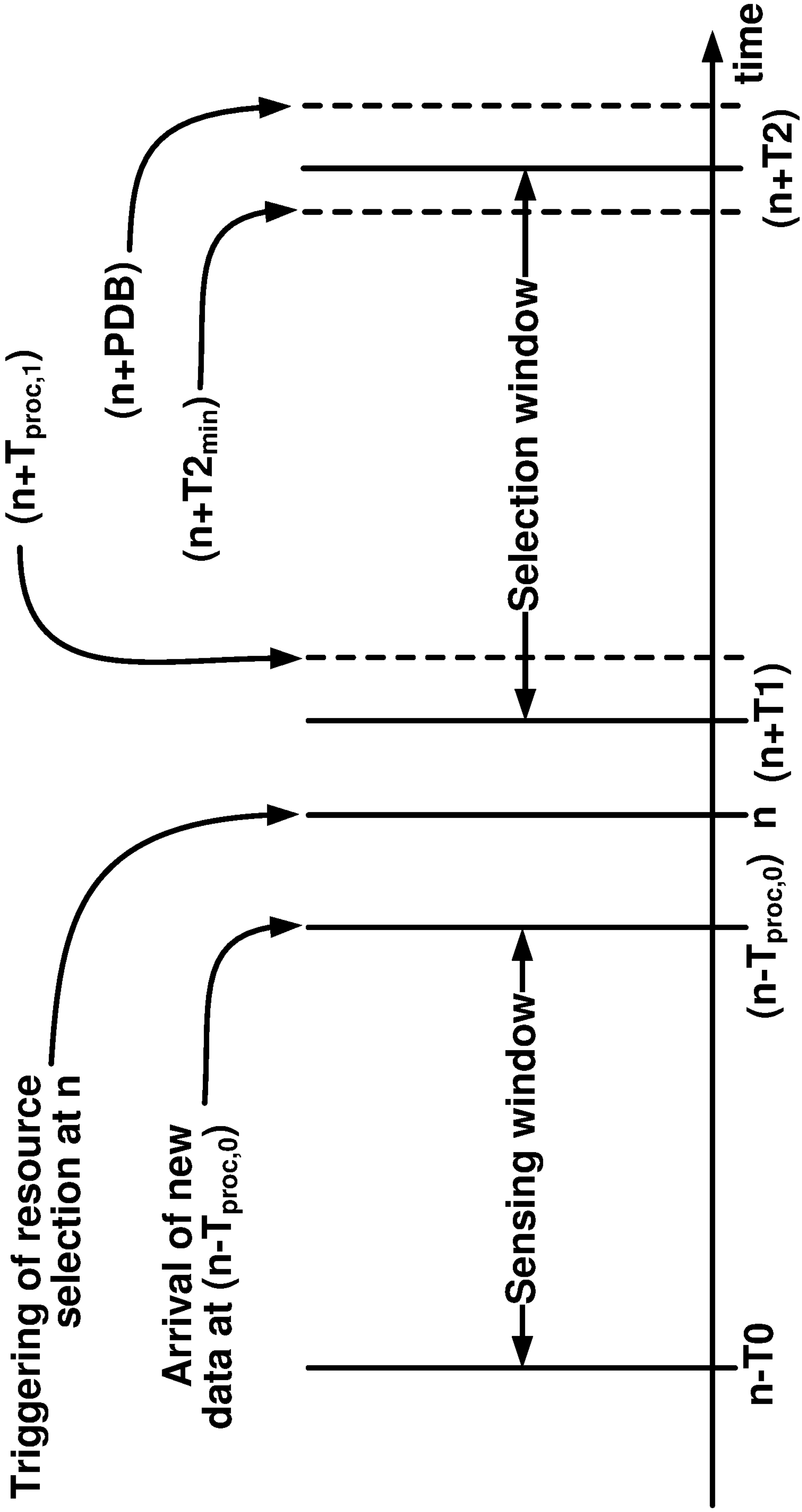
Triggering of resource selection at n
Arrival of new data at (n-$T_{proc,0}$)
Sensing window
Selection window
(n+$T_{proc,1}$)
(n+PDB)
(n+$T2_{min}$)
n-T0
(n-$T_{proc,0}$)
n
(n+T1)
(n+T2)
time

FIG. 24

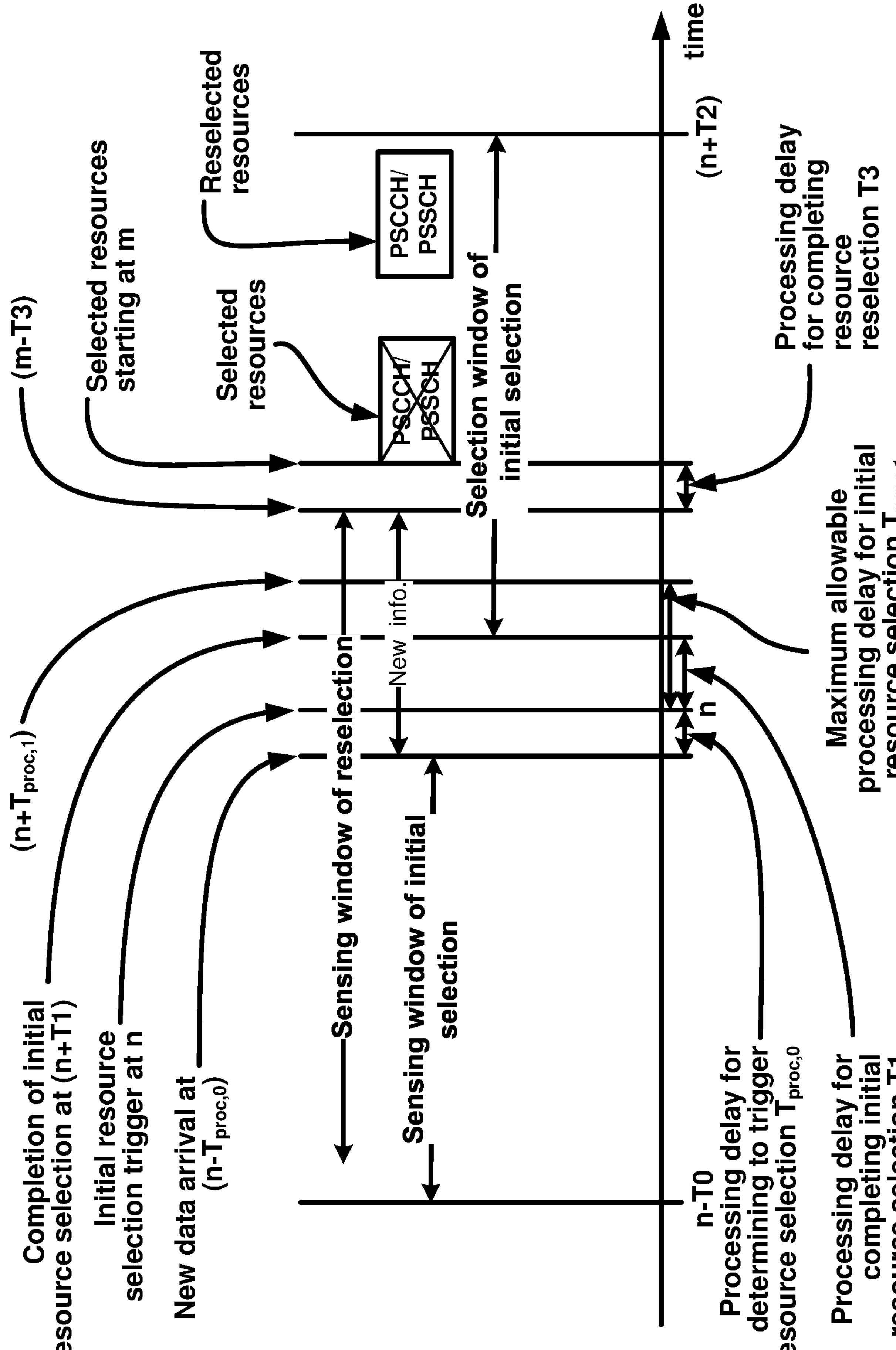
Completion of initial resource selection at (n+T1)
Initial resource selection trigger at n
New data arrival at ($n-T_{proc,0}$)
($n+T_{proc,1}$)
(m-T3)
Selected resources starting at m
Selected resources
Reselected resources
PSCCH/ PSSCH
PSCCH/ PSSCH
Sensing window of reselection
New info.
Sensing window of initial selection
Selection window of initial selection
n-T0
n
(n+T2)
time
Processing delay for determining to trigger resource selection $T_{proc,0}$
Processing delay for completing initial resource selection T1
Maximum allowable processing delay for initial resource selection $T_{proc,1}$
Processing delay for completing resource reselection T3

FIG. 25

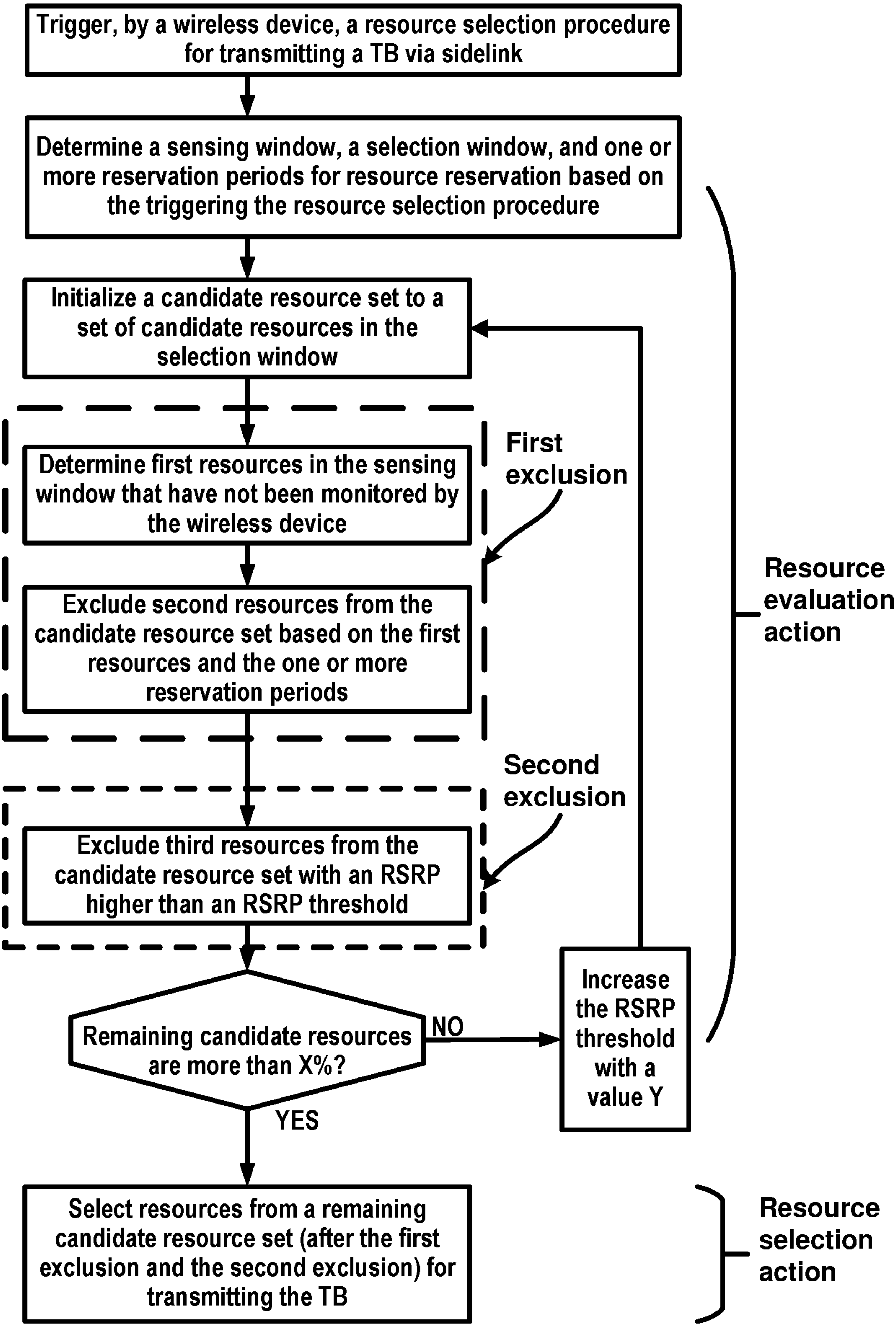
Trigger, by a wireless device, a resource selection procedure for transmitting a TB via sidelink
Determine a sensing window, a selection window, and one or more reservation periods for resource reservation based on the triggering the resource selection procedure
Initialize a candidate resource set to a set of candidate resources in the selection window
Determine first resources in the sensing window that have not been monitored by the wireless device
First exclusion
Exclude second resources from the candidate resource set based on the first resources and the one or more reservation periods
Second exclusion
Exclude third resources from the candidate resource set with an RSRP higher than an RSRP threshold
Remaining candidate resources are more than X%?
NO
Increase the RSRP threshold with a value Y
YES
Resource evaluation action
Select resources from a remaining candidate resource set (after the first exclusion and the second exclusion) for transmitting the TB
Resource selection action

FIG. 26

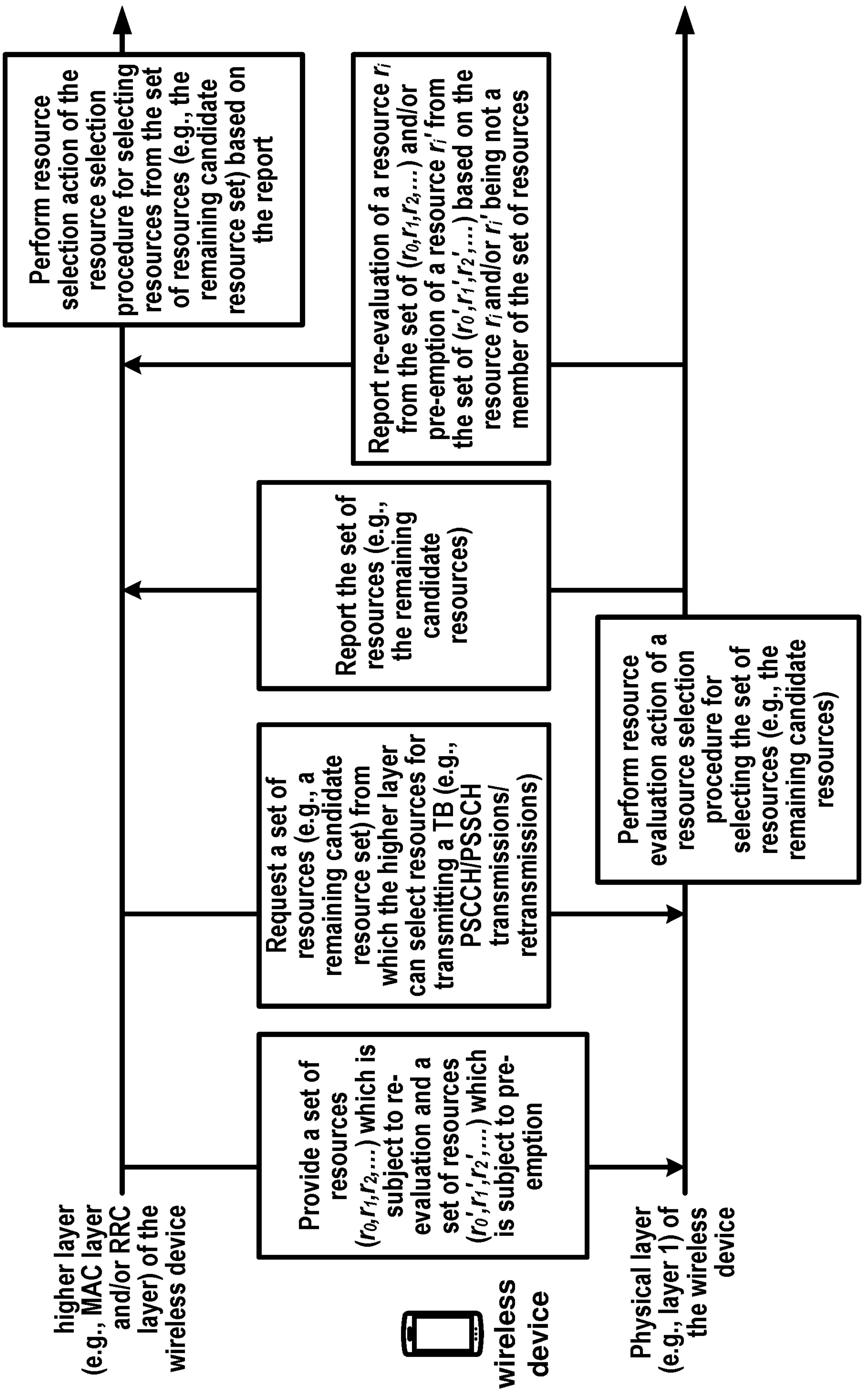
wireless device
higher layer (e.g., MAC layer and/or RRC layer) of the wireless device
Physical layer (e.g., layer 1) of the wireless device
Provide a set of resources ($r_0,r_1,r_2,\ldots$) which is subject to re-evaluation and a set of resources ($r_0',r_1',r_2',\ldots$) which is subject to pre-emption
Request a set of resources (e.g., a remaining candidate resource set) from which the higher layer can select resources for transmitting a TB (e.g., PSCCH/PSSCH transmissions/ retransmissions)
Perform resource evaluation action of a resource selection procedure for selecting the set of resources (e.g., the remaining candidate resources)
Report the set of resources (e.g., the remaining candidate resources)
Report re-evaluation of a resource r_i from the set of ($r_0,r_1,r_2,\ldots$) and/or pre-emption of a resource r_i' from the set of ($r_0',r_1',r_2',\ldots$) based on the resource r_i and/or r_i' being not a member of the set of resources
Perform resource selection action of the resource selection procedure for selecting resources from the set of resources (e.g., the remaining candidate resource set) based on the report

FIG. 27

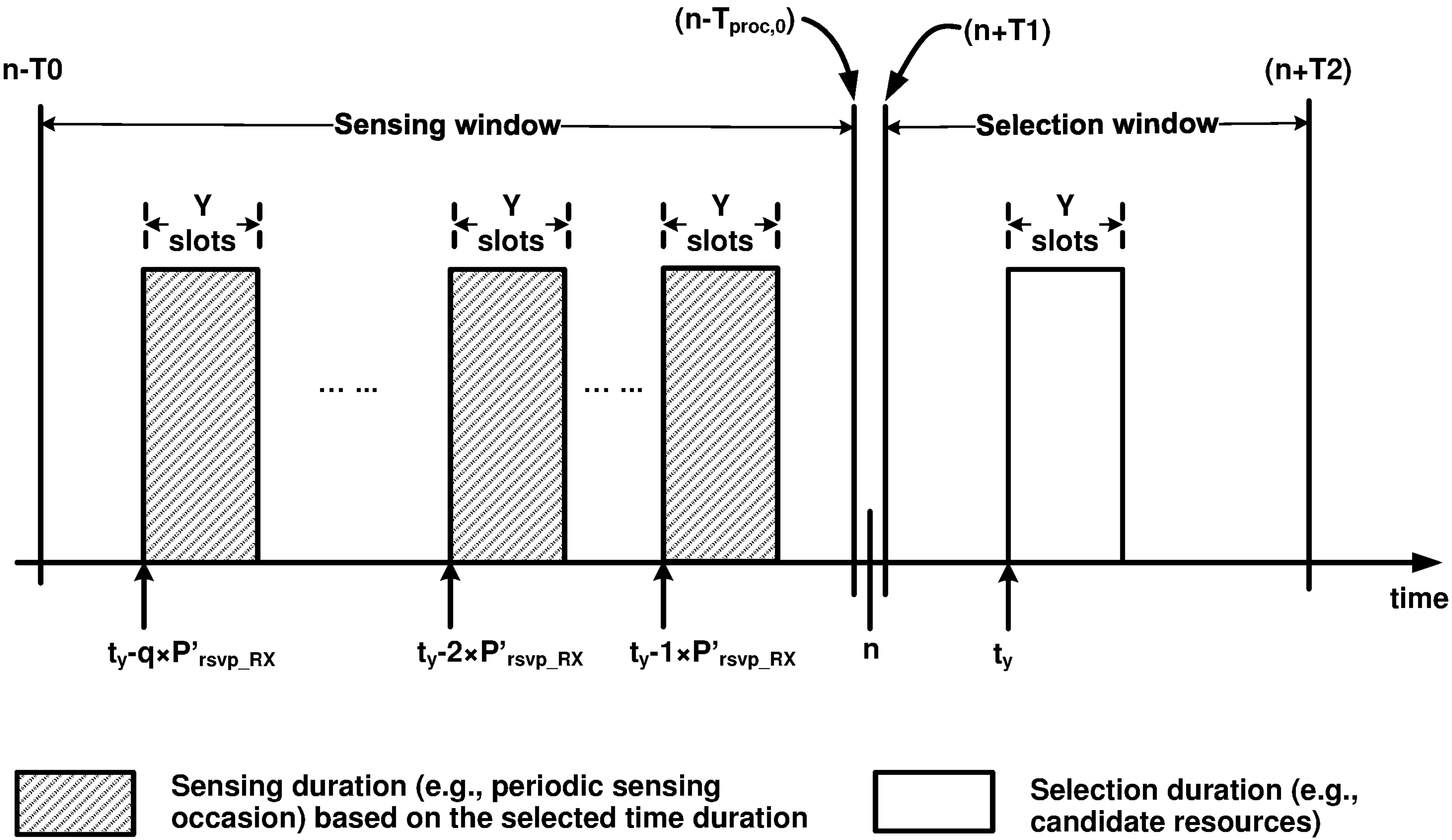
n-T0
(n-$T_{proc,0}$)
(n+T1)
(n+T2)
Sensing window
Selection window
Y slots
t_y-q×P'_{rsvp_RX}
t_y-2×P'_{rsvp_RX}
t_y-1×P'_{rsvp_RX}
n
t_y
time
Sensing duration (e.g., periodic sensing occasion) based on the selected time duration
Selection duration (e.g., candidate resources)

FIG. 28

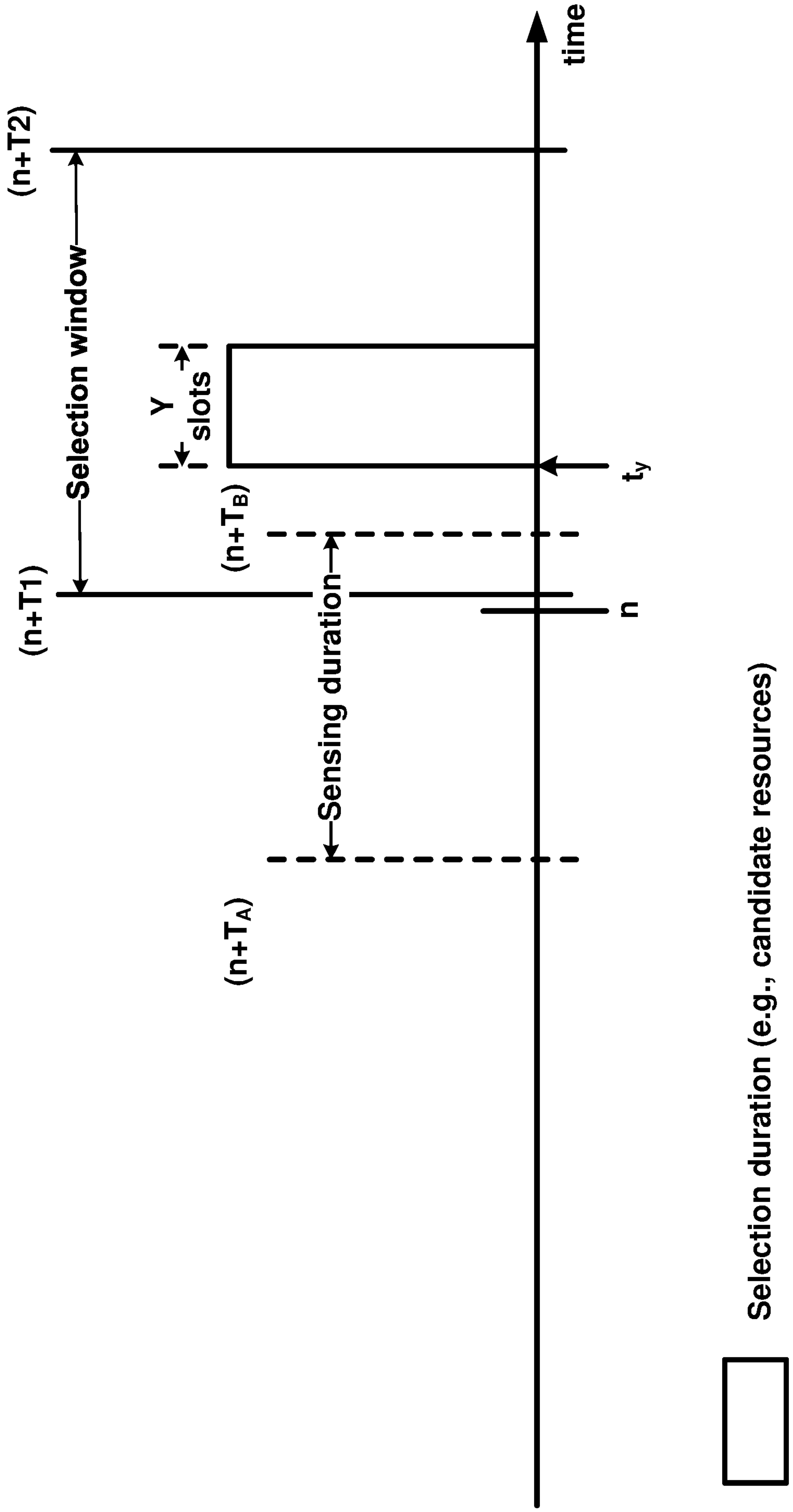
time
(n+T2)
Selection window
(n+T1)
Y slots
t_y
$(n+T_B)$
Sensing duration
$(n+T_A)$
n
Selection duration (e.g., candidate resources)

FIG. 29

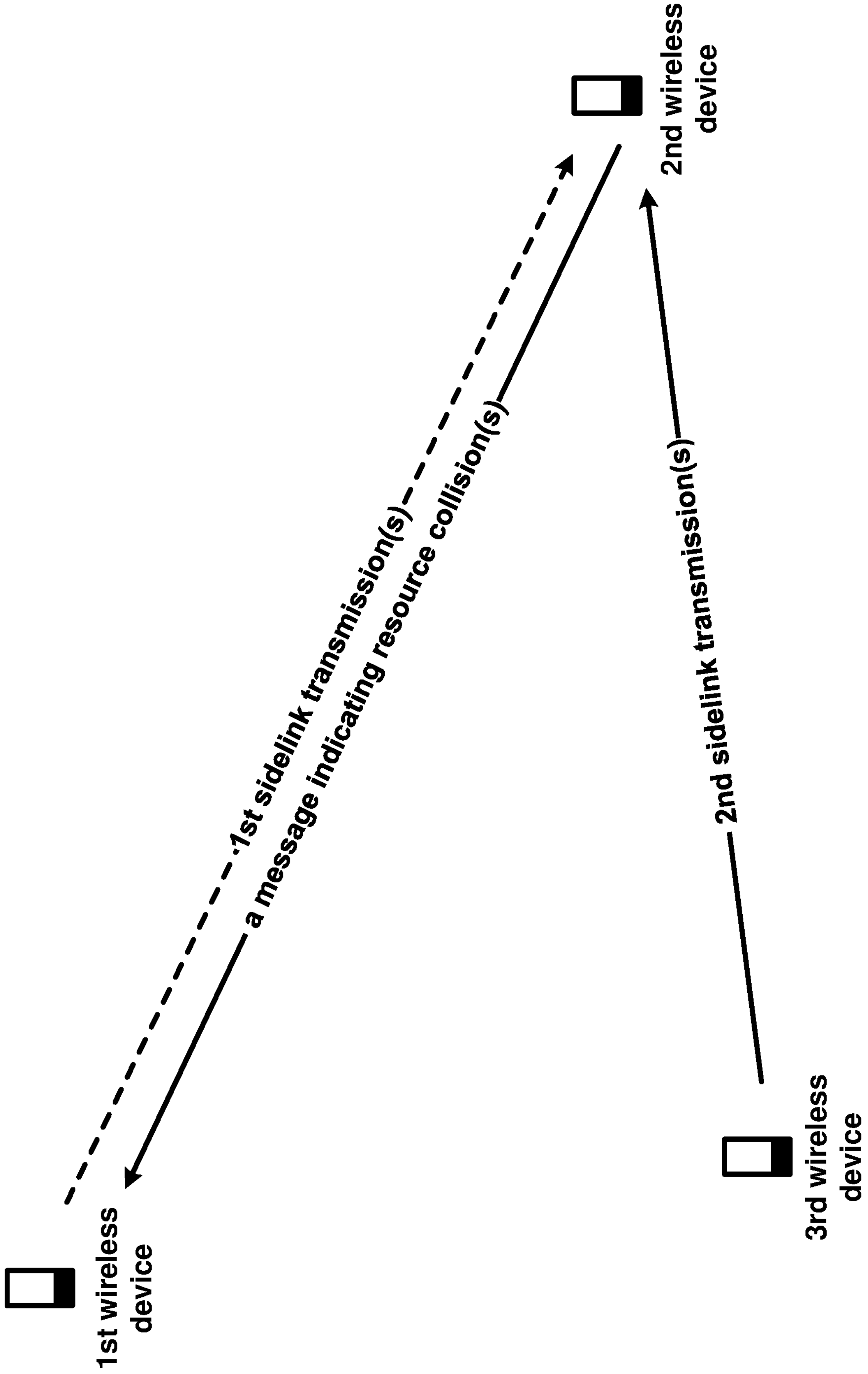
2nd wireless device
1st sidelink transmission(s)
a message indicating resource collision(s)
2nd sidelink transmission(s)
1st wireless device
3rd wireless device

FIG. 30

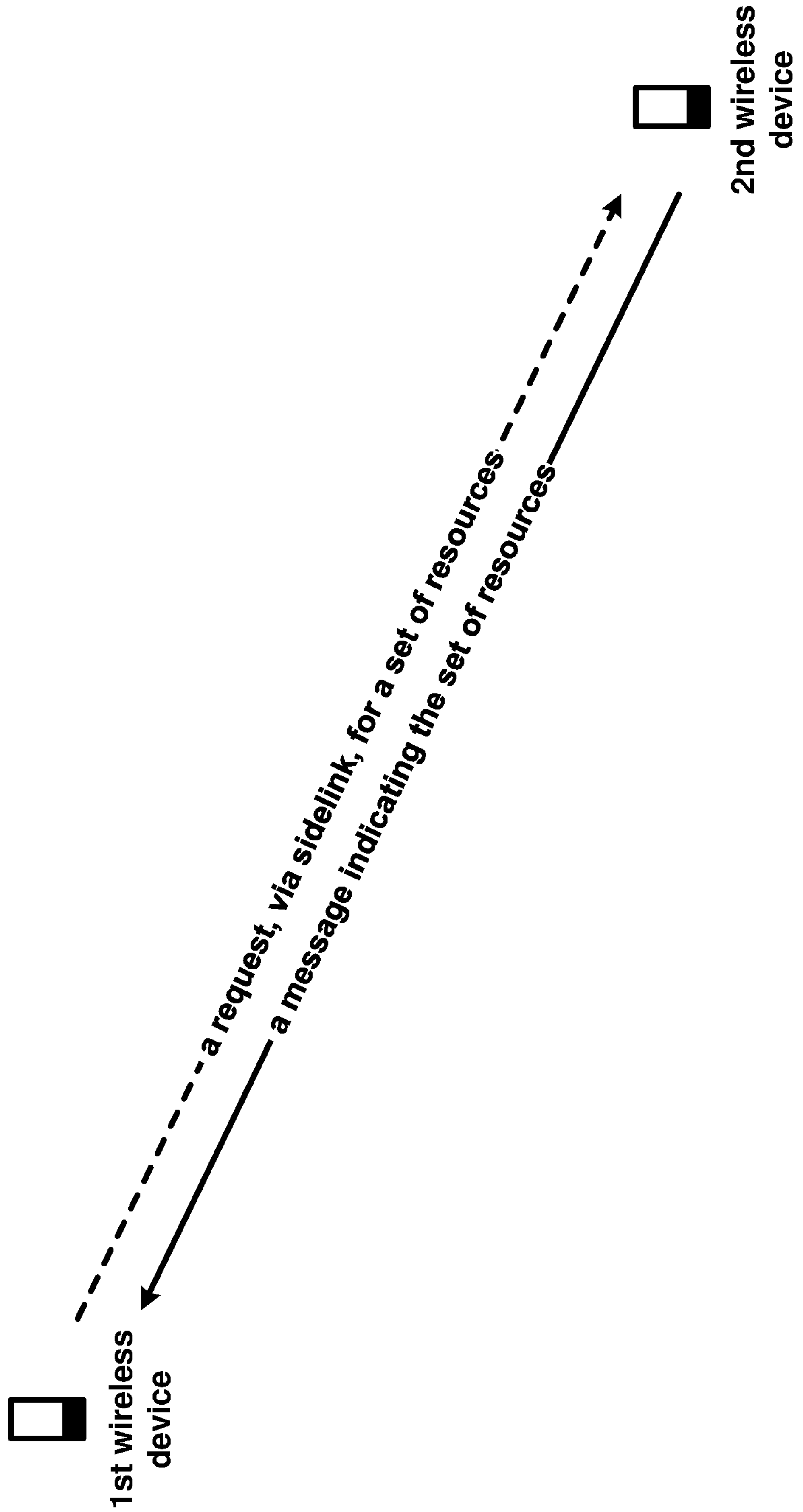
2nd wireless device
a request, via sidelink, for a set of resources
a message indicating the set of resources
1st wireless device

FIG. 31

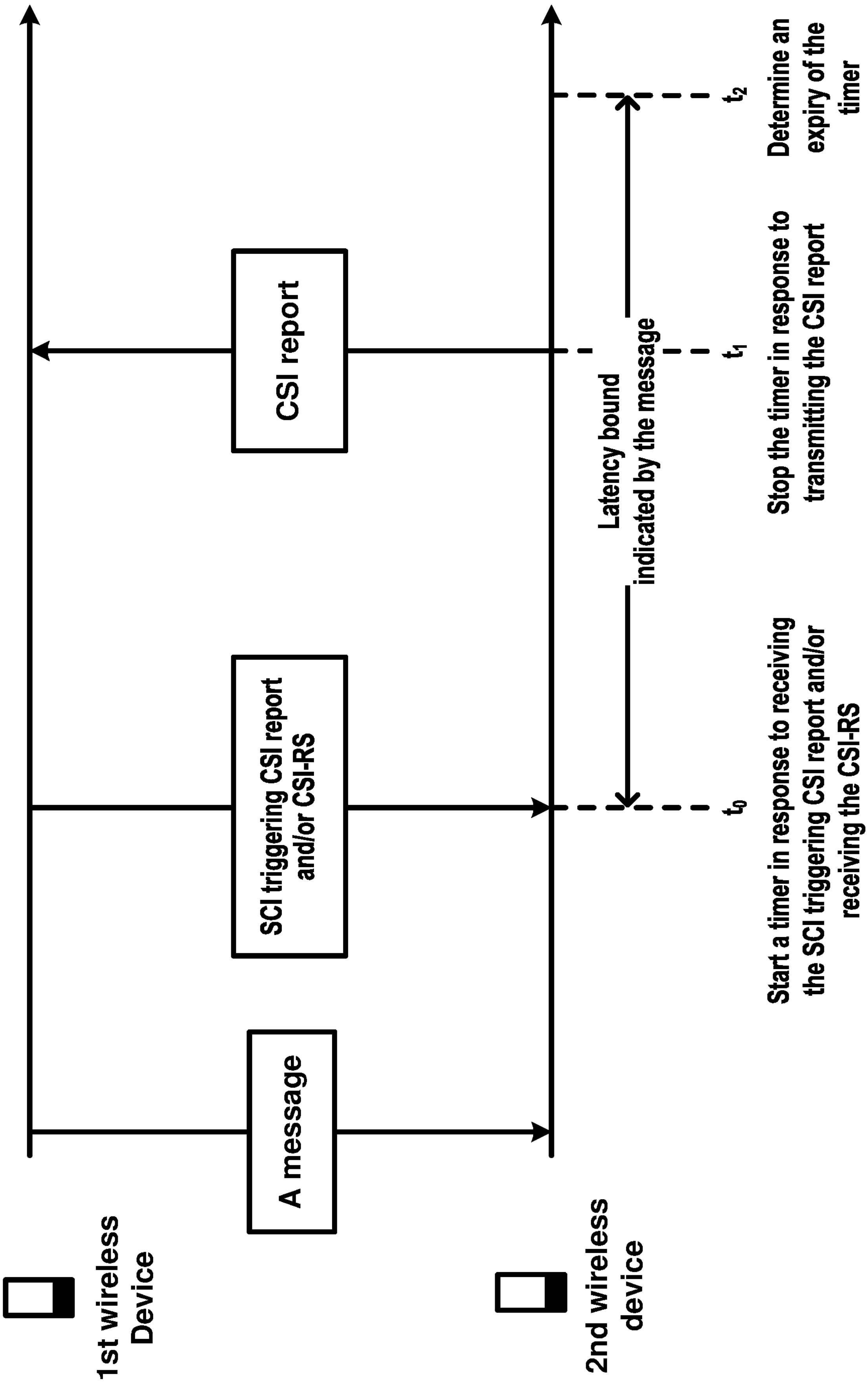
1st wireless Device
2nd wireless device
A message
SCI triggering CSI report and/or CSI-RS
CSI report
Latency bound indicated by the message
t0
t1
t2
Start a timer in response to receiving the SCI triggering CSI report and/or receiving the CSI-RS
Stop the timer in response to transmitting the CSI report
Determine an expiry of the timer

FIG. 32

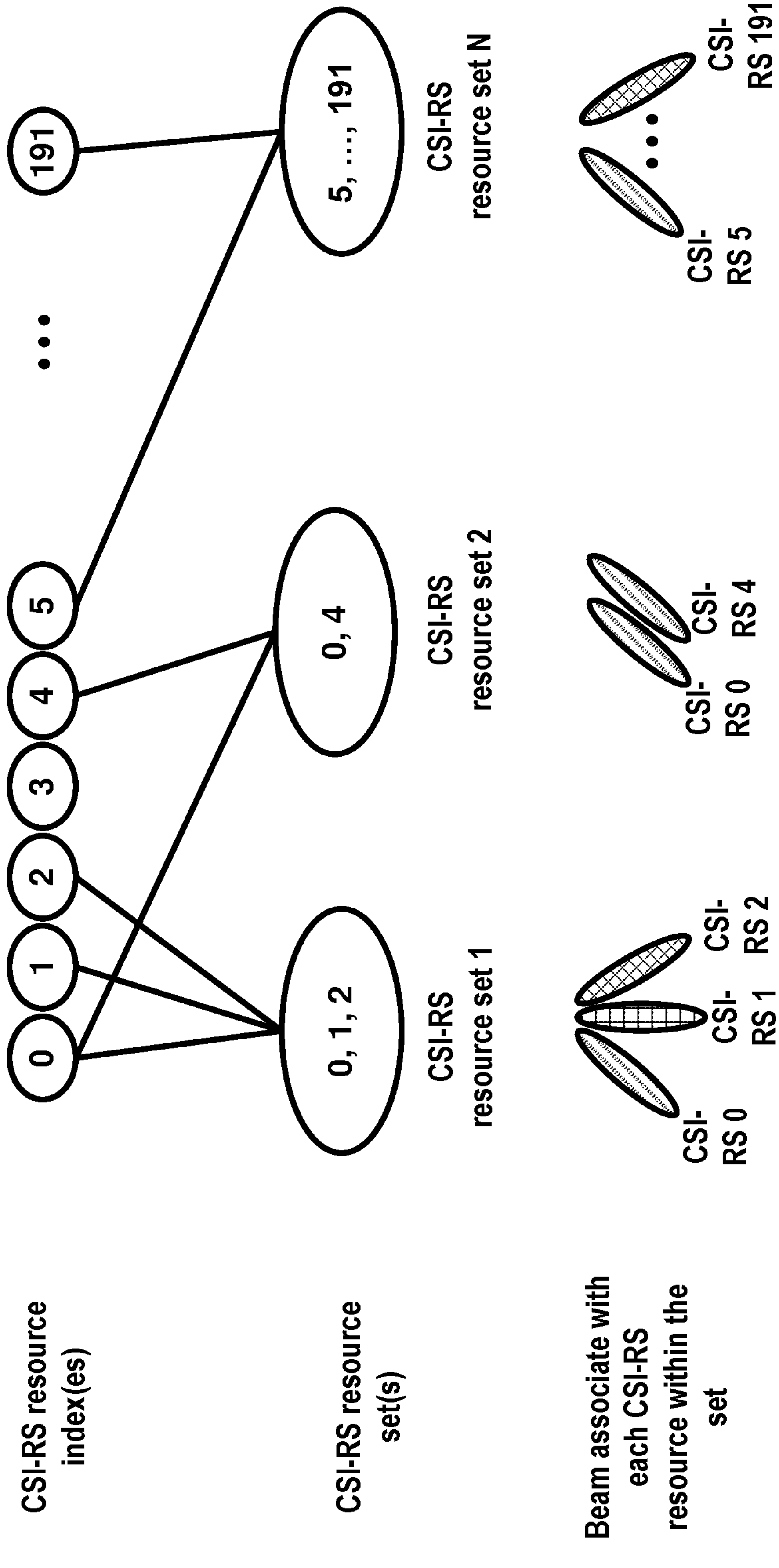
CSI-RS resource index(es)
CSI-RS resource set(s)
Beam associate with each CSI-RS resource within the set
0
1
2
3
4
5
191
0, 1, 2
CSI-RS resource set 1
0, 4
CSI-RS resource set 2
5, ..., 191
CSI-RS resource set N
CSI-RS 0
CSI-RS 1
CSI-RS 2
CSI-RS 0
CSI-RS 4
CSI-RS 5
CSI-RS 191

FIG. 33

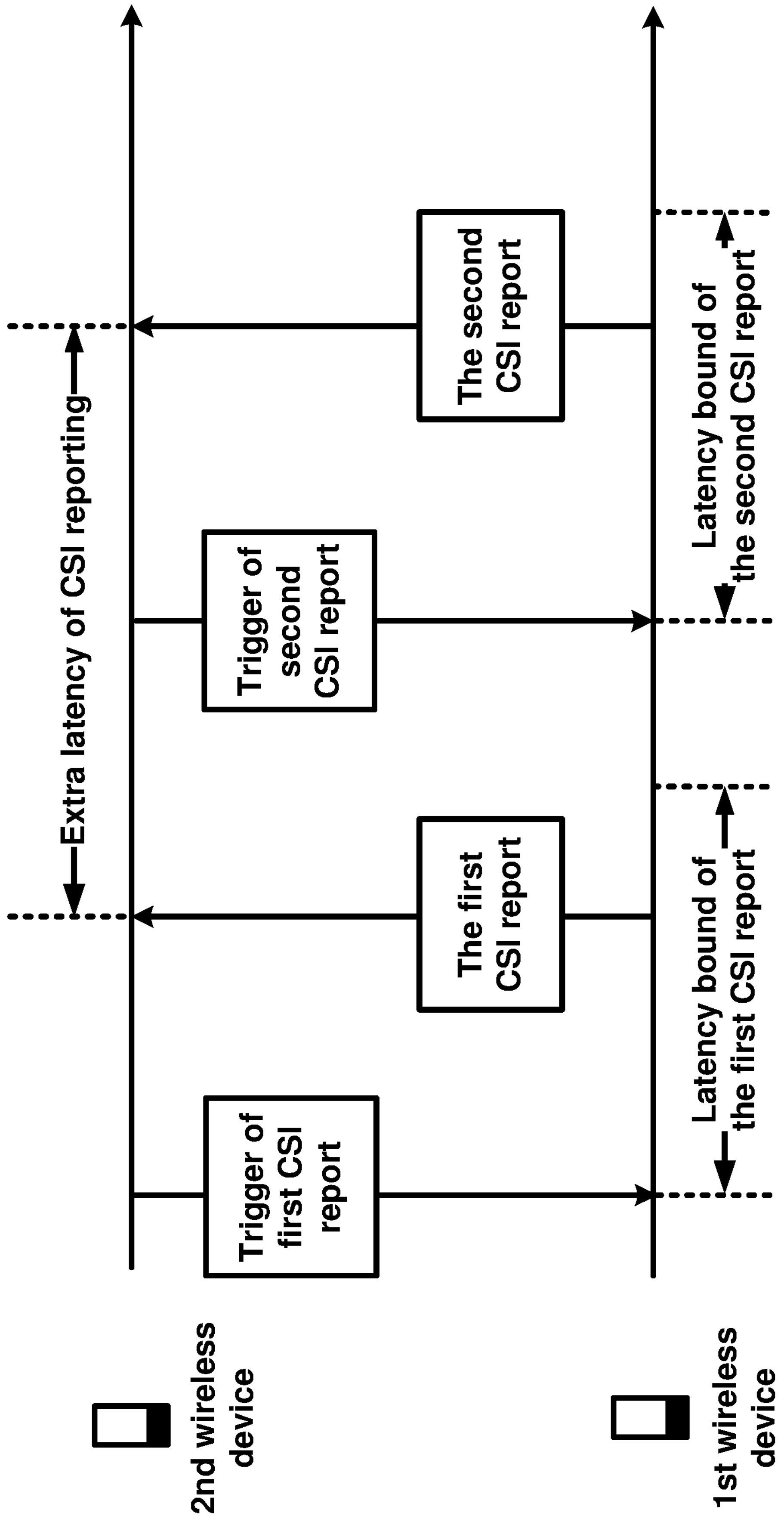
2nd wireless device
1st wireless device
Trigger of first CSI report
The first CSI report
Trigger of second CSI report
The second CSI report
Extra latency of CSI reporting
Latency bound of the first CSI report
Latency bound of the second CSI report

FIG. 34

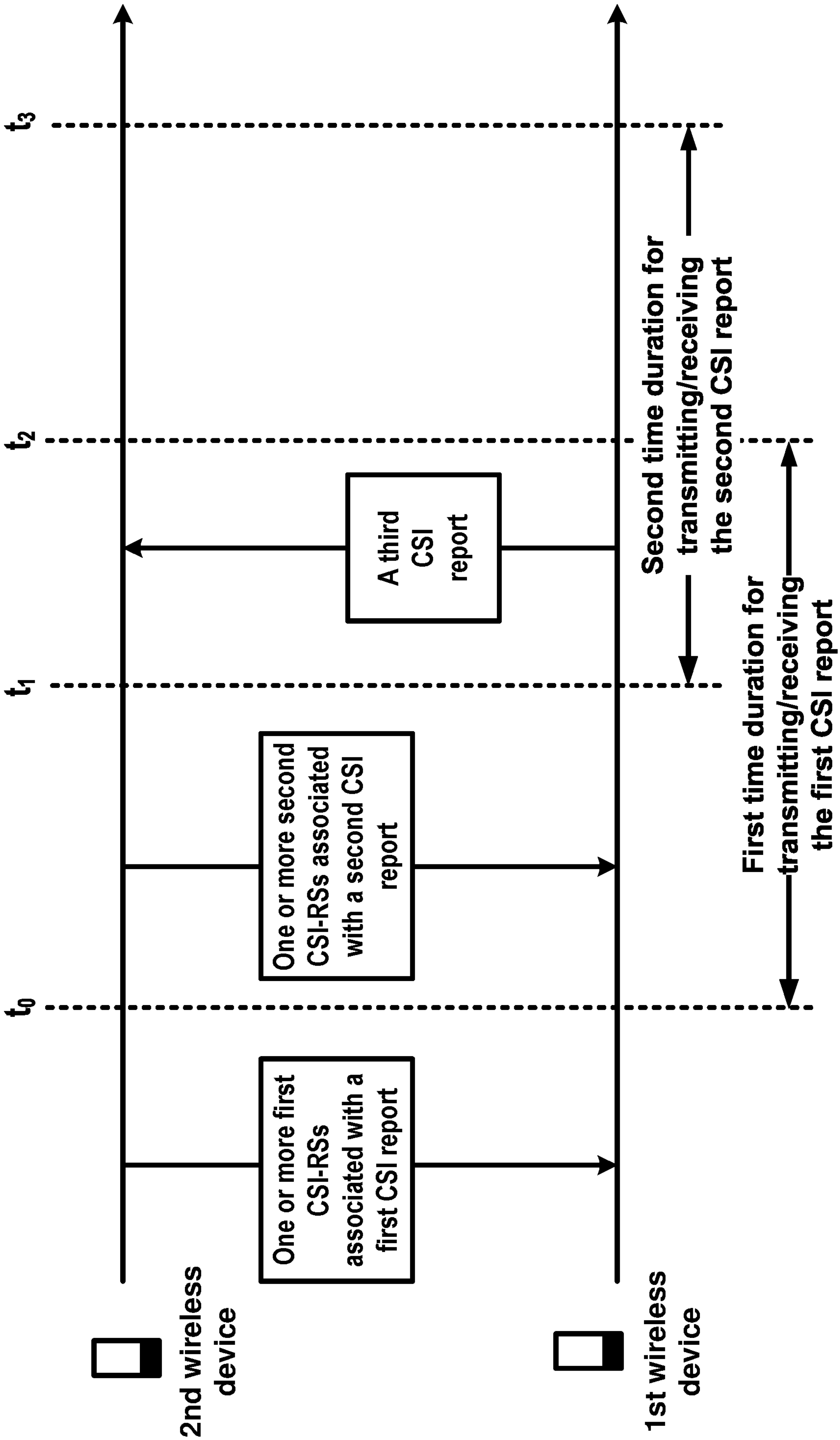
2nd wireless device
1st wireless device
t0
t1
t2
t3
One or more first CSI-RSs associated with a first CSI report
One or more second CSI-RSs associated with a second CSI report
A third CSI report
First time duration for transmitting/receiving the first CSI report
Second time duration for transmitting/receiving the second CSI report

FIG. 35

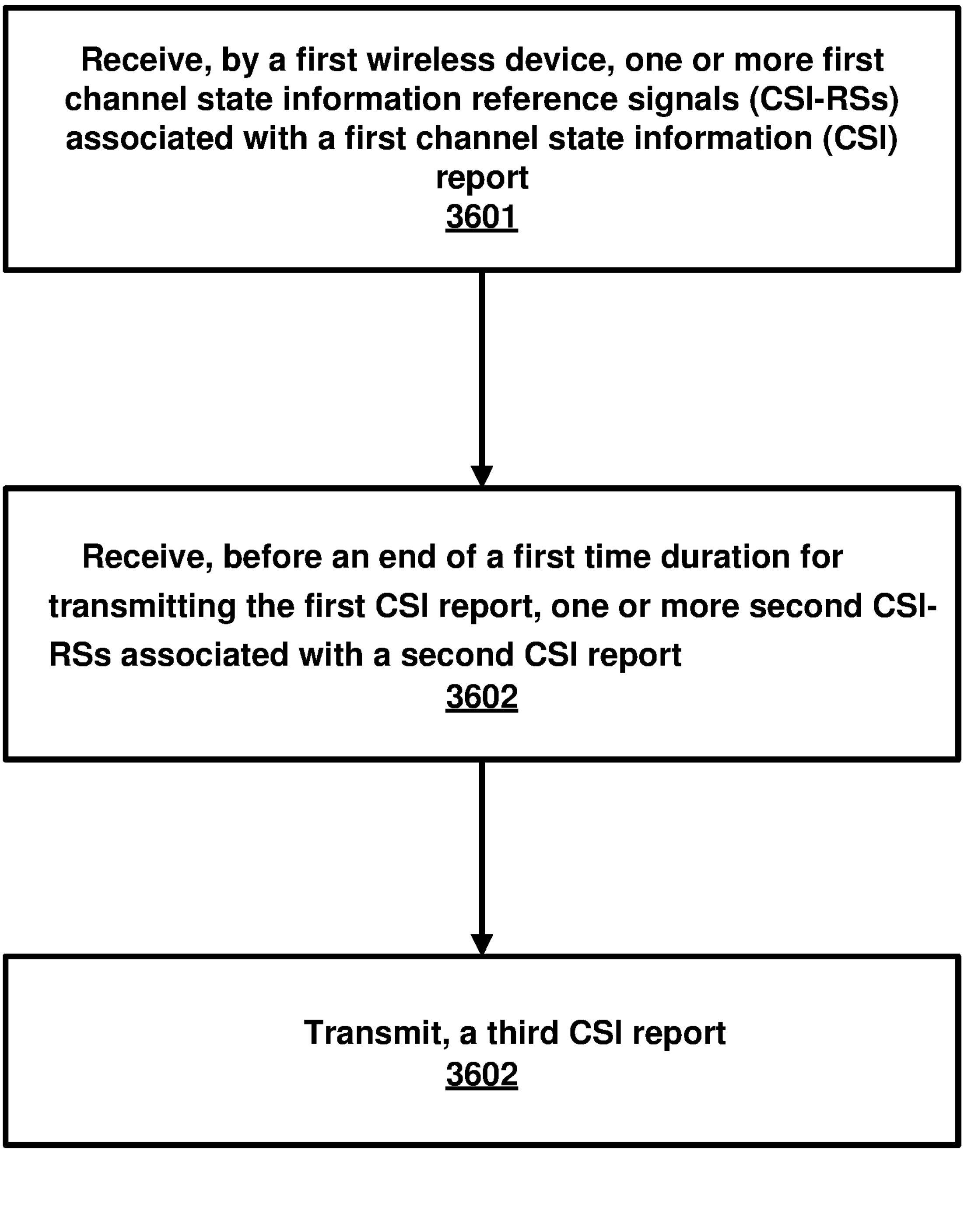
Receive, by a first wireless device, one or more first channel state information reference signals (CSI-RSs) associated with a first channel state information (CSI) report
3601
Receive, before an end of a first time duration for transmitting the first CSI report, one or more second CSI-RSs associated with a second CSI report
3602
Transmit, a third CSI report
3602

FIG. 36

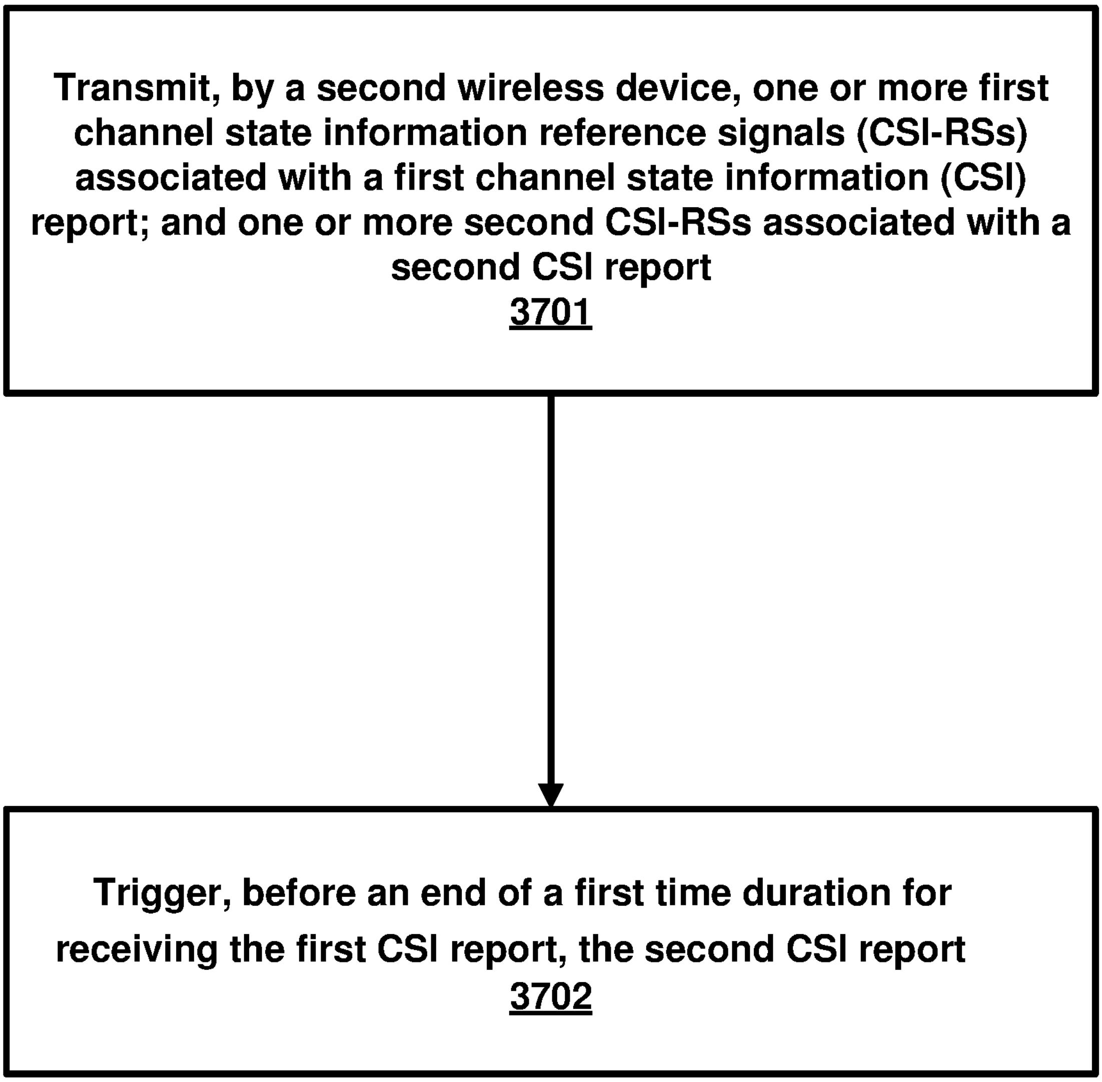
Transmit, by a second wireless device, one or more first channel state information reference signals (CSI-RSs) associated with a first channel state information (CSI) report; and one or more second CSI-RSs associated with a second CSI report
3701
Trigger, before an end of a first time duration for receiving the first CSI report, the second CSI report
3702

FIG. 37

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/085539

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L5/00
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)
H04L

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2022/345347 A1 (PAPASAKELLARIOU ARIS [US]) 27 October 2022 (2022-10-27) paragraphs [0037] - [0041], [0073] - [0087], [0238] - [0322] -----	1,9,10, 13,21, 22,25,26
X	US 2021/067205 A1 (MANOLAKOS ALEXANDROS [US] ET AL) 4 March 2021 (2021-03-04) paragraphs [0243] - [0284] -----	1,9,10, 13,21, 22,25,26

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
27 March 2024	04/06/2024

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/085539

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

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

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

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

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

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

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

see additional sheet

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

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

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

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1, 9, 10, 13, 21, 22, 25, 26

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1, 9, 10, 13, 21, 22, 25, 26

   Slot-based Channel State Information, SCI, reporting

   ---

2. claims: 2-8, 11, 12, 14-20, 23, 24

   Sidelink Channel State Information, SCI, reporting

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2023/085539

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2022345347 A1	27-10-2022	AU 2018216588 A1	29-08-2019
		AU 2022204668 A1	21-07-2022
		CA 3052762 A1	09-08-2018
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		US 2021091988 A1	25-03-2021
		US 2022345347 A1	27-10-2022
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		EP 4022820 A1	06-07-2022
		US 2021067205 A1	04-03-2021
		WO 2021040908 A1	04-03-2021